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# Proposal of Block Bidding for Large-Scale Wind Power Energy

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**Abstract:** It is necessary for power systems to provide flexible power to balance the fluctuation and intermittency of wind power. For the large-scale and central-integrated wind generation (such as that in China), the required flexible power may be very significant and expensive. In market environment, it is important to design a proper market mechanism and price signal which can promote conventional power and load demand to integrate wind power and gain corresponding profit. Firstly, the paper analyzes the current economy and dispatch policy for wind power in China. Then, a Block Bidding mode for wind power is presented. Unlike Timely Bidding mode that power is auctioned hourly by hourly, for Block Bidding the wind power energy is divided into different energy block. And these blocks are auctioned by conventional power resources and load demands. The Block Bidding mode has some advantages: 1) subdivides wind power by energy quality, and then the value of different parts can be revealed; 2) provides incentive for conventional power resource and load demand to integrate wind power; 3) is convenient for trading and dispatching wind power. Finally, a simple numerical case is given to illustrate the validity of Block Bidding mode.

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## 1. INTRODUCTION

Renewable energy has received more and more attention with the increasing consumption of fossil fuel resources and the strength of public's environment consciousness. Wind power, as a kind of renewable clean energy that can be large-scale developed and utilized, has been developing rapidly worldwide in recent years. However, because of the fluctuation and intermittency of wind power, it is necessary to provide flexible power to balance its fluctuation and intermittency in power system operation. From the perspective of economy, when integrating wind power, other conventional resources (such as coal-thermal, gas, oil generation) should be paid because valuable contribution has been given by them to compensate the fluctuation of wind power. The more wind power is integrated, the more flexible capacity and compensatory cost are required.

The compensatory cost of wind power has been concerned by many studies. Based on the large amount of real data in UK market, the influence of wind power "balancing cost" in power systems is analyzed by Swinand and Godel (2012), results show that the balancing cost is increasing with the increasing capacity of wind power integration. Hannele et al. (2011) presents the opinion that high penetration of wind power would bring considerable integrating costs, including cost of operation balance and cost of grid strengthen. Andrianesis and Liberopoulos (2012) studies the "hidden cost" from the perspective of optimal dispatch, but it only gives a preliminary result with a simple numerical example without systematic analyses. Milligan et al. (2011) and Milligan and Kirby (2009) analyzes the problem of "integrating cost" of wind power systematically and discusses some problems in current research. Mills et al. (2009) focus on the "extra cost" of wind power integration in the sense of transmission cost. And Mount et al. (2011) analyzes the hidden cost in term of power market, but the electricity price is ignored. Makarov et al (2009) evaluates the impacts of wind power on the balance of power grid. Ummels (2006) presents the influence of integration of wind power on the Dutch power system. Holttinen (2005) concludes that the reserve demands would greatly increase with the increase of wind power penetration.

As a large-scale and rapid developed wind power country, China has constructed 75.3 GW wind power in 2012, which is shown in Fig.1. In the future ten years, the wind power of China will be continually increased in 3-5 times. Therefore, the required flexible power to balance wind power fluctuation may be significant. Especially for China power system that has few flexible powers (over 70% coal-fired powers), the required flexible power may be very expensive. Even currently, in some regions of China, the balance has become very difficult, which results expensive compensatory cost. For example, in Inner Mongolia, North China, North-east China, all of the coal-thermal generators should usually operate in their minimum output level.

As renewable energy, wind power should be sufficiently utilized. Many countries have made economy policies to encourage wind power development. For instance, in China 1) wind power should be fully dispatched in priority; 2) wind power is paid for high price that is the same as that for thermal power (Besides these policies, wind power can also get investment allowance and the profit of international carbon emissions). However, these policies do not give effectively incentive to conventional power, and then bring some problems (as shown in Table 1).

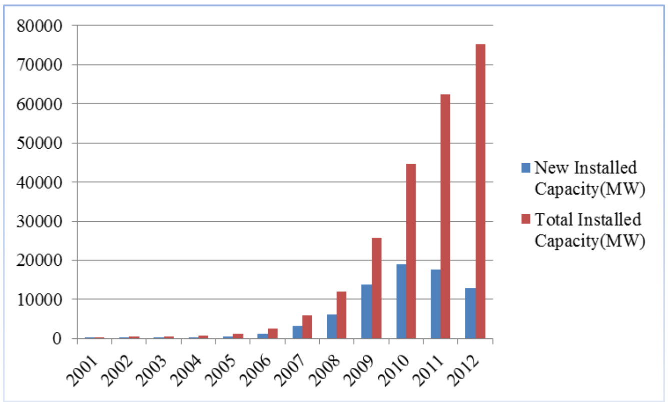

Fig.1. The installed capacity of wind power in China

Table 1. The problems of the wind power participants facing

| Market Participants | Problems |
|---|---|
| Conventional power | should modify unit commitment and power schedule to balance the fluctuation and intermittency of wind power, but without any reward. |
| Wind power | without price and product option rights, either be accepted or to be abandoned. |
| Load demand | would prefer stable controllable hydro or thermal power with the same market price. |

The key reason of above problems is that these policies do not deeply consider the following characters of wind power: 1) In power system dispatch, wind power is not an individual resource, it requires other resources' help to balance its fluctuation and intermittency; 2) The quality of wind power is different from that of other controllable generation resource. And in the sense of market, market price should be different according to the different products' quality.

In order to overcome above problems, a novel bidding mode of wind power, or Block Bidding mode, will be proposed in this paper. Firstly, the paper analyzes the quality of large-scale wind power. Then the block bidding mode is presented. Furthermore, a simple numerical example is provided to illustrate the validity of block bidding mode. Finally some discussions of block bidding are given.

## 2. THE COMPENSATORY COST AND VALUE OF WIND POWER IN A BLOCK VIEW

It is well-known that if wind power is dispatch in power system, its fluctuation and intermittency should be balanced by other generation resource to guarantee load balance and frequency stability of power systems. Therefore, extra cost (called compensatory cost in this paper) would arise to balance wind power fluctuation and intermittency. From the viewpoint of power systems or market, the total cost of integrating wind power includes not only its generation cost but also the compensatory cost:

$$IC_w = GC_w + CC_w \qquad (1)$$

where, $IC_w$ is the integration cost of wind power, $GC_w$ is the generating cost of wind power, $CC_w$ is the compensatory cost of wind power.

Generally, without fuel cost, the generating cost of wind power is very low. While, the compensatory cost may be high or low, which is determined by many factors, including the resource structure of system, penetration of wind power, flexible adjustment capacity of conventional power, etc. How to evaluate the compensatory cost is an interesting and challenging problem. Some calculation methods have been given to analyze this cost (Augustine et al 2012; Meibom et al. 2009). Here, the key idea is to find a proxy wind power generation and compare the differences.

(1) Although the compensatory cost can be calculated, this cost cannot be easily and correctly applied in timely power market that is the most popular market mechanism around the world and power is auctioned hourly by hourly because of the following reasons:

(2) The compensatory cost is relevant with unit commitment and ramp rate cost of other conventional generators. In other words, it is an optimization in a continuous time horizon with coupled and multiple time-interval constraints. And hourly by hourly bidding mode is unsuitable for the compensatory cost analysis.

In hourly by hourly bidding mode, the wind power of each hour is deemed as fluctuation power and requires to be balanced. This mode may underestimate wind power quality. In fact, some parts of wind energy quality are very good, especially for large-scale and centralized integrated wind power.

For example, Fig.2 gives an actual daily wind power output of Yumen area in northwest China. Large amount of wind generators form a complementary character in time and space intervals. The intermittency and fluctuation of total wind power output decrease. It can be found that at the bottom of output curves there is a continual and stable wind power output, and this output can be controllable dispatched without other generator's balance and compensatory cost.

Based on above analysis, we divide daily wind power into 3 horizontal blocks according to its continuity and stability, which is shown in Fig.2.

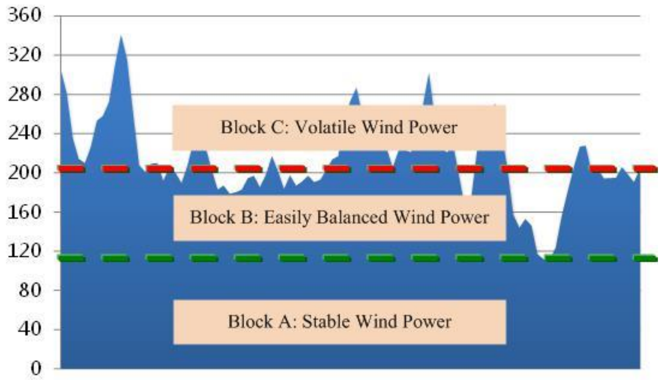

Fig.2. Typical daily wind power output of Yumen

The different block in Fig.2 has different wind power compensatory cost, as well as the quality or values:

- For Block A, the power quality is sustained and stable that does not need other conventional power to balance. Therefore, Block A is the energy that with the highest value and requires no compensatory cost. Here, it should be mentioned that the energy of Block A usually occupies about 50% of the total daily energy.
- For Block B, the power has a little fluctuation and is easy to be balanced. So the Block B is the energy with the higher value and requires a little compensatory cost.
- For Block C, the wind power fluctuates violently. So the Block C is the energy with the lowest value and requires large compensatory cost (even cannot be fully balanced in power system operation).

To a summary, when wind power is dispatched in power system, it needs other generation resources to balance its fluctuation and intermittency. In block view, not all wind power energy is fluctuation and intermittency, different block has different quality and value.

## 3. BLOCK BIDDING OF WIND POWER

Nowadays, timely bidding is the most popular market mechanism around the world. Timely Bidding divides the daily load into time intervals by hour or half hour. The power is auctioned by every time interval with a uniform market clearing price for each time interval. This bidding mode stimulates the development of power enterprises and improves the efficiency of power industry. However, Timely Bidding cannot distinguish quality and value for different component of wind power energy. And in current market, conventional power has not gained any distinct payment for balancing wind power (except conventional auxiliary reserve).

Unlike Timely Bidding that power is auctioned hourly by hourly, Block Bidding is a new mode that divides load demand into some load blocks according to continual hours, and the auction is carried out in the load blocks (Wang et al. 2002). Base on the idea of Block Bidding, a new Block Bidding mode for wind power is proposed in this paper.

In the proposed mode, wind power is divided into some horizontal blocks. And each block can submit different price and takes part in market auction. In economic theory, the wind power is authorized for option right of product subdivision with different price. At the same time, wind power should submit stable power output. Therefore, wind power should take compensatory cost into it bidding price.

For example, the specific steps and rules of bidding are described in Fig.3.

Firstly, the forecasting wind power curve is divided into some blocks, such as 3 blocks, indexed by $l_1$, $l_2$ and $l_3$ in Fig. 3.

Secondly, each block can bid separately. For each block, the bidding power output should be stable, such as a simple horizontal output curve in Fig.3. And the output of each block is denoted as $pl_1$, $pl_2$, $pl_3$ respectively.

$$pl_1 = P_1 \tag{2}$$

$$pl_2 = \mathrm{P}_2 - \mathrm{P}_1 \tag{3}$$

$$pl_3 = \mathrm{P}_3 - \mathrm{P}_2 \tag{4}$$

If the bid wins the auction, the stable power output should be provided. Therefore, wind farm should consider offer price high enough to pay for other conventional generator to balance the fluctuations of wind power.

In detail, the compensatory cost of each block is denoted as $CC_{w_1}$, $CC_{w_2}$, $CC_{w_3}$, respectively. And according to the fluctuation of each block, we can obtain:

$$CC_{w_1} = 0 \tag{5}$$

$$CC_{w_1} < CC_{w_2} < CC_{w_3} \tag{6}$$

Equation (5) means that for the block $l_1$, the wind power output is stable, and then it is unnecessary for other generator to balance fluctuation. So the compensatory cost is zero. Equation (6) means that with the increase of block index, the wind power energy decreases, and the required balance power increases more and more. So the compensatory cost increases.

Substitute (5) and (6) into (1):

$$IC_{w_1} < IC_{w_2} < IC_{w_3} \tag{7}$$

Where $IC_{w_1}$, $IC_{w_2}$, $\mathrm{I}C_{w_3}$ is the offer price for each block, respectively.

Equation (7) indicates that in Block Bidding mode, the wind power would submit an incremental price for the blocks. The more necessary compensatory cost is required; the more expensive energy is sold.

Finally, based on the wind power block bids, the whole market can be auctioned as usual. The system marginal price is set as clearing price, and the wined wind power block can gain excess profit.

In addition, to make incentive for balancing wind fluctuation, the excess profit is designed to be distributed among wind power and conventional power that provides balance. There may be many distribution methods, and a method based on cost-ratio is provided in this paper (shown in Fig. 4).

We may suppose the wind power's trading quantity of three blocks are $Q_1$, $Q_2$, $Q_3$, respectively and then the market clearing price is $\rho$.

For block $l_1$, as the wind power is steady and continuous, its compensatory cost is zero. The total excess profit belongs to wind power.

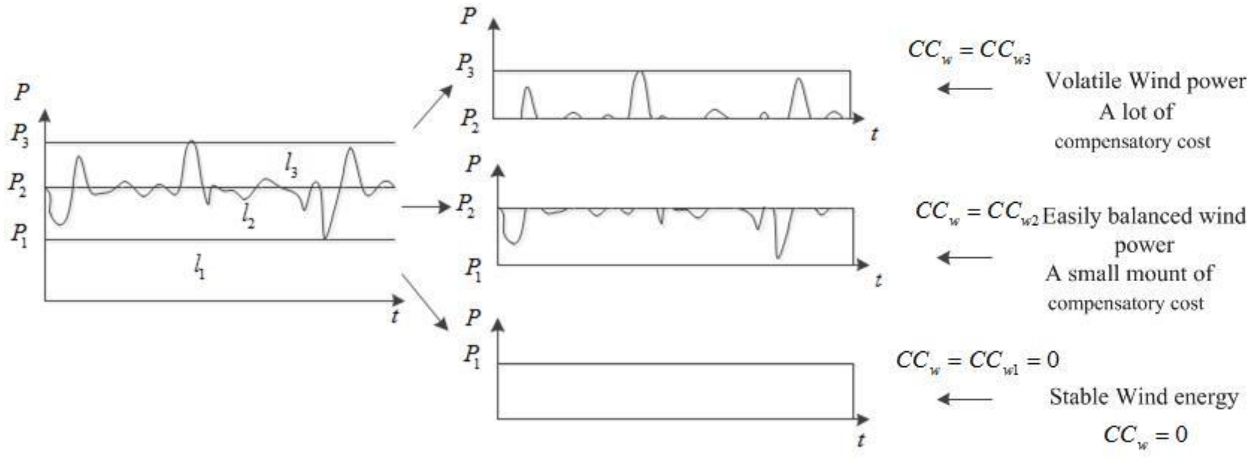

Fig. 3. Blocks bidding for wind power

For block $l_2$, the distribution ratio $\lambda_2$ between conventional power and wind power is:

$$\lambda_2 = \frac{(IC_{w2} - IC_{w1})Q_2}{IC_{w1}Q_2} = \frac{IC_{w2} - IC_{w1}}{IC_{w1}} \tag{8}$$

For block $l_3$, the distribution ratio $\lambda_3$ between conventional power and wind power is

$$\lambda_3 = \frac{(IC_{w3} - IC_{w1})Q_3}{IC_{w1}Q_3} = \frac{IC_{w3} - IC_{w1}}{IC_{w1}} \tag{9}$$

So the payment for wind power is:

$$P_w = \rho Q_1 + \rho Q_2 \frac{1}{1+\lambda_2} + \rho Q_3 \frac{1}{1+\lambda_3} \tag{10}$$

And the payment for conventional power which balances the fluctuation and intermittency of wind power is:

$$P_c = \rho Q_2 \frac{\lambda_2}{1+\lambda_2} + \rho Q_3 \frac{\lambda_3}{1+\lambda_3} \tag{11}$$

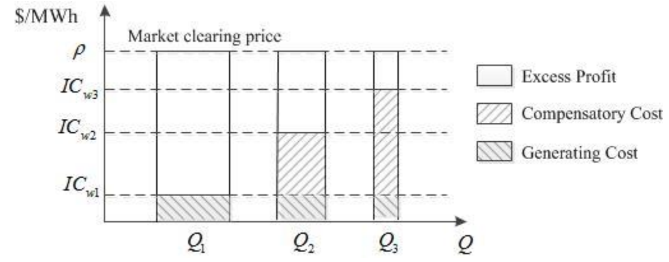

Fig. 4. The diagram of profit distribution for wind power block bidding mode

## 4. CASE STUDY

Here, a power system is chosen as an example to demonstrate the validity of the proposed block bidding mode. The system consists of the following components: one wind farm with 200MW capacity, two 50MW thermal power plants, and a load of 150MW. Firstly, the following assumptions are supposed:

(1) Wind power should be dispatched firstly as it is the clean energy. As shown in Fig. 5, when quoting, wind power is in the means of block mode and considers the compensatory cost. Here, the compensatory cost is determined according to the proportion of compensatory cost and generating cost.

(2) Conventional power (thermal power) is only used to complement the fluctuation of wind power, and does not directly participate in the bidding. Then, only three types of energy participate in the bidding: the high quality wind power, the wind power with a little compensatory cost and the wind power with massive compensatory cost.

(3) The daily output of wind power is divided into 24 time intervals and cleared by hourly and hourly. The power is auctioned by every time interval with a uniform market clearing price. The transaction price is determined by the marginal cost of the whole power systems.

(4) For the sake of simplification, the offer curve of wind power is supposed to be a straight line, as shown in Fig. 5.

As the generation cost of wind power is quite low, the major factor of integration cost is the compensatory cost. Then, the generation cost of different blocks can be supposed as the same. In period $t$, the marginal generating cost of wind power can be supposed as 10$/MWh. From Fig. 5, it can be seen that the market clearing price is 70$/MWh and the earning ratio of conventional power and wind power is

$$\lambda_2 = (\int_B^O pl_2 dp - \int_B^E pl_1 dp) / \int_B^E pl_1 dp = \frac{(70-10)\times 70/2}{10\times 70} = 3 .$$

So, in period $t$, the earning of wind power is

$$P_w = 70\times 80 + 70\times 70\times \frac{1}{3+1} = 6825$$

and the earning of conventional power which balances the fluctuation and intermittency of wind power is

$$P_c = 70\times 70\times \frac{3}{3+1} = 3675 .$$

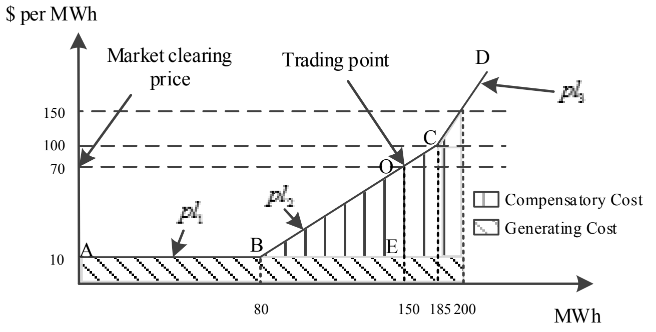

Fig. 5. The diagram of wind power clearing in period $t$

For the different load in the period $t$, the earnings of wind power and the conventional power are shown in Table 2. From the table, it can be seen that:

(1) When the volume of integrated wind power is less, the market clearing price is cheap because of the low generating cost of wind power. With the increase of the volume of integrated wind power, the second-block wind power is used and the quality of whole integrated wind power decreases. Then, the market clearing price increases. When the integrated volume of wind power reaches a certain level, the marginal value of wind power will be zero due to the massive compensatory cost.

(2) If the market clearing price is limited in 70$ per MWh, the volume of wind power integrated into grid is only 150MW which is located in the bottom of the output curve and has less compensatory cost due to their high quality and stability. The other valueless wind power can be abandoned.

Table 2. The earning distribution for different loads in period $t$

| Load (MW) | Market clearing price ($ per MWh) | Earning of the first-block wind power ($) | Earning of the second-block wind power ($) | Earning ratio of conventional power and wind power ( $\lambda_2$ ) | Total earning of wind power ($) | Total earning of conventional power ($) |
|---|---|---|---|---|---|---|
| 60 | 10 | 600 | 0 | 0 | 600 | 0 |
| 80 | 10 | 800 | 0 | 0 | 800 | 0 |
| 100 | 27.1 | 2168 | 292.3 | 0.855 | 2460.2 | 250.2 |
| 120 | 44. | 3544 | 652.7 | 1.715 | 4196.7 | 1119.3 |
| 140 | 61.4 | 4912 | 1031.9 | 2.57 | 5943.9 | 2652.1 |
| 150 | 70 | 5600 | 1225 | 3 | 6825 | 3675 |
| 160 | 78.6 | 6288 | 1419.4 | 3.43 | 7707.4 | 4868.6 |
| 170 | 87.1 | 6968 | 1614.6 | 3.855 | 8582.6 | 6224.4 |
| 180 | 95.7 | 7656 | 1810.8 | 4.285 | 9466.8 | 7759.2 |

## 5. DISCUSSION

In this paper, a novel bidding mode of wind power, or the Block Bidding mode, is proposed. This mode provides wind power the right to subdivide its energy product according to the different energy quality of its different blocks, and then the wind power suppliers can submit different bids for different energy block with the complement of conventional power suppliers.

It should be mentioned that many problems still need to be deeply investigated in the future, especially corresponding bidding mechanisms should be established. For example:

(1) The fluctuation and intermittency of wind power should be complemented by conventional power. Therefore, a sub-market should be established for wind power and conventional power to deal. In fact, some generation unions with both wind power and coal-thermal power have tried to coordinate the operation of wind and thermal power plants in China.

(2) How to evaluate the compensatory cost in market environment? By the mode of centralized optimization dispatching, or by the mode of negotiation? This is a question worthy of study.

(3) How to integrate Blocking Bidding and current Timely Bidding? This is also necessary to be investigated in detail.

(4) There are many methods to divide wind power into blocks. Which one is reasonable? If load-demand takes part in, the division of block and compensatory cost need to be analyzed again.

## 6. CONCLUSIONS

In order to accurately measure the cost of conventional power used to balance the fluctuation and intermittency of wind power, the concept of compensatory cost is proposed in the paper. By dividing the wind power into several blocks horizontally, the different compensatory cost of different blocks can be revealed clearly. Meanwhile, a block bidding mode for wind power energy is presented in the paper, which has the following advantages:

(1) In block bidding mode, wind power can be subdivided by energy quality. Then, different blocks can be set different prices according to their qualities.

(2) The scale of compensatory cost can be recognized clearly in the model of Block Bidding. Then, the benefit distribution of wind power plants and conventional power plants can be determined reasonably.

(3) Power grid can be guided to integrate the wind power

with high quality.

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