Research on Mechanism and Model of Centralized Bidding for Pumped Storage Power in Shanghai

ZHONG Hua1, YING Zhiwei1, LV Zhengyu2, YANG Jianlin2, HUANG Yupeng2 and DONG Li3

1. Shanghai Electric Power Trading Center Limited Company, Pudong New District 200122, Shanghai, China;
2. State Grid Shanghai Municipal Electric Power Company Economic and Technical Research Institute, Pudong New District 200122, Shanghai, China;
3. Jiangsu Provincial Key Laboratory of Smart Grid Technology and Equipment (Southeast University), Nanjing 210096, Jiangsu Province, China

Zhong Hua, Email:keeprock@163.com.

Abstract. China is now in the transition stage toward power market and in some specific area, market approach has already been adopted to improve the overall efficiency. In this paper, bidding and trading modes of pumped storage energy in various regions of China are analysed. Based on the constraints of bidding price and electricity, as well as the system power flow, the trading model is established to collect the capacity cost of pumped storage energy in Shanghai. With the trading model proposed, that the generators who actively undertake the capacity cost of pumped storage energy and bid enough electricity with lower price can be rewarded, while those attempts to conspire and manipulate the market will be penalized. Finally, using seven generators in Shanghai as examples to simulate the market operation, the effectiveness of the proposed model is verified.

1. Introduction
Because of the great gap between peak load and valley load in Shanghai, a certain percentage of capacity of the pumped storage power station in eastern China is needed for peak regulation. The pumped storage power station implements the two-part tariff according to the requirements of the government, in which the capacity price is determined by the fixed cost and permitted income of the pumped storage power station. In principle, the grid companies needs to cover 50 per cent of the pumped storage power station rental fees, and power generation companies and users undertake 25% respectively.

At present, the tendering works of the pumped storage energy in various regions of China are actively carried out. Take the trading modes in Anhui and Yixing, Jiangsu for example, the two regions both provide declared electricity quantity only. As for clearance rules, when the total amount of declared electricity quantity is greater than the total amount of the tender, the final clearing price is determined by the proportion of the tender transaction power and the transaction power share in Anhui, while in Yixing, Jiangsu, the price is shared according to the proportion of all declared power plant installed capacity. But in the transaction model which allows power generators to declare electricity only, the declared price is fixed and the enthusiasm of market is not high. Also the comprehensive benefits of pumped storage power station are not ensured.
There are two main types of bidding mechanism: unified price bidding mechanism and declared price settling account mechanism [1]. Uniform price bidding mechanism dispatches power load, according to the power generator declaration from low to high order, with certain constraints. All transactions are settled at a uniform system marginal price. Declared price settling account mechanism dispatches power load, according to the generator quotation from low to high order, until meet the system load. All transactions are settled at the actual price settlement. The impacts of conspiring and manipulating the market are researched under the unified price bidding mechanism and declared price settling account mechanism in paper [2-3]. The operation mode and the price mechanism of the pumped storage power station abroad are analysed in paper [4-6]. The way of covering the costs of pumped storage power stations is discussed in paper [7-9]. The method how to achieve the investment recovery of the pumped storage power station is proposed in paper [10]. However, these papers do not propose a suitable trading model to guide the generators to undertake the capacity of electricity, and effectively suppress the behaviour to conspire and manipulate the market. In order to standardize market trading behaviour, contribute to the comprehensive benefits of pumped storage power station, and promote the marketization and normalization of pumped storage energy trading, this paper puts forward a new trading mode.

The amount of electricity is decided by the balance of the annual power supply and demand of Shanghai Power Grid, as well as the annual start-up mode of the pumped storage power station, at the meantime, the capacity price that the generators need to undertake is considered. The trading electricity is not included in the annual generation plan and regarded as the extra power generation of power plants, except for the planned on-grid electricity. All market members adopt a centralized trading model in which the electricity and price are declared simultaneously and participate in the trade voluntarily. On the basic of declared price, the clearing price is decided by the incentive mechanism for active participation in the transaction and engagement in the bidding, as well as the punishment mechanism for conspiring and manipulating the market.

2. Transaction mode

2.1. Transaction flow

The Participants in the centralized bidding power transactions include power grid enterprises, market members and market operators. The competent authorities shall, in conjunction with the energy regulatory authorities, regulate the entry and exit of market members and supervise the power grid enterprises and market operators, according to relevant rules of the market.

The power generation enterprises that meet the market access conditions bid centrally for the electricity on a voluntary basis and undertake the capacity costs of the pumped storage power stations by a marketization way. In the process of centralized price bidding, all market members centrally declare and unilaterally bid for the electricity. The competent authority determines the frequency and time of the centralized bid for pumped storage electricity of the year, timely trigger the trade. Then, the market transaction announcement is released to all market members by the electricity trading institutions through the power trading platform. The contents include, but are not limited to: centralized bidding transaction power (on-grid electricity, the same below), the market participants, the range of declared electricity quantity and declared price, the trading cycle, the transaction flow and the time, etc.. Market participants take part in the transaction on the principle of equal participation, voluntary declaration, strict rules and win-win cooperation.

The market members declare electricity quantity and price in the approved declaration range on the principle of the priority of price and energy-saving emission reduction, and make transactions according to sort. The electricity is obtained by centrally declaring and unilaterally bidding. Market members enter the transaction according to the declared electricity quantity price. However, the clearing price is not equal to the declared price, which is determined by the declared price, the regulation-up factor, the regulation-down factor and the market-force-reduction factor. Through the
three regulatory factors of the clearing price, market members who declare electricity price reasonably are encouraged, and those who negatively trade, conspire and manipulate the market will be penalized.

Specific transaction flow is shown in Figure 1.

![Figure 1. Transaction flow](image)

### 2.2. Declaring limits

The declared electricity quantity and prices of market members must be within the range of approved electricity quantity and price respectively, otherwise the declaration will be regarded as invalid declaration.

#### 2.2.1. Limits of electricity declaration

The proportion of the actual electricity consumption of the market member to all the market members in the previous year is $R_i$. The proportion of the coal consumption and environmental incentive of the market member is $E_i$. (Determined by the competent authorities in accordance with the unit power consumption and environmental emissions, the minimum scale is 1%, and $0 \ll E_i \ll 5\%$). The upper limit of declared electricity quantity is $S_i$. Concentrated bidding electricity is $Q$. The amplification factor of declared electricity quantity is $K$.

(Determined by the competent authorities, the value range is 2-3, tentatively 2.).

Calculate the upper limit of declared electricity quantity of each market member:

$$S_i = Q \times K \times (R_i + E_i) \quad (1)$$

The market members’ upper limit of the declared power is examined by power dispatching agency safety check. If the safety check is failed, the market members shall make corresponding adjustments.

The minimum of market members’ declared electricity quantity is 0.

#### 2.2.2. Limits of price declaration

The market members are required to declare within the limits of the price. The maximum of the declared price is the approved price determined by the government (Including tax, without environmental protection electricity price and other government additional electricity price, the same below). The minimum of declared electricity quantity price is 0.

### 2.3. Transaction sort

After declaration, the declared electricity quantity and prices of market members are checked. If the declared electricity quantity data is missing, or exceeds the limits, they will be regarded as invalid declaration and removed from the trading sequence.

Sorting rules:
Sort the market members’ declared electricity quantity in accordance with the declared data from low to high.

- If the declared price is the same, sort the members in accordance with the capacity level from high to low.
- If the capacity level is the same, sort the members in accordance with the installed capacity from large to small.
- If the installed capacity is the same, sort the members in accordance with the award proportion of coal consumption and environmental protection from large to small.

After the introduction of the market members’ credit scoring mechanism by Shanghai Public Credit Information Service Centre, the market members can also refer to the credit score to sort.

2.4. Transaction clearing
When the transaction sort completes, market members trade by the declared electricity quantity order until the transaction electricity is equal to the sum of the centralized trading power amount, or all members’ declared electricity quantity is cleared, that is the end of the centralized bidding transaction.

2.4.1. Capacity of the pumped storage power station. The regulation-up factor $P_{\text{up}}$ for adjusting market price, the regulation-down factor $P_{\text{down}}$ and the market-force-reduction factor $P_{\text{market}}$ are set for encouraging market members to actively undertake the cost of the capacity price and declare reasonably in accordance with the actual cost of power plants and preventing market members from conspiring and manipulating the market.

As is showed in figure 2(a), the capacity price $C_i$ of pumped storage power stations that each member declare to undertake is determined by the government’ approved electricity price and power generation companies’ declared electricity quantity:

$$C_i = (P_{\text{up}} - P_i) \times Q_i$$  \hspace{1cm} (2)

Where $P_{\text{up}}$, $P_i$ and $Q_i$ separately denote the electricity price approved by government, declared price and declared electricity quantity.

2.4.2. The vacancy proportion of capacity price. Comparing the sum of the pumped storage power stations declaring capacity costs $\sum C_i$ and the total capacity $C_{\text{sum}}$, the vacancy proportion of capacity price $R_{\text{va}}$ can be calculated.

$$R_{\text{va}} = 1 - \frac{\sum C_i}{C_{\text{sum}}} \hspace{1cm} (0 \leq R_{\text{va}} \leq 1)$$  \hspace{1cm} (3)

2.4.3. The regulation-up factor. The regulation-up factor $P_{\text{up}}$ is set for encouraging market members to actively cover the cost of the capacity price and reasonably declare the unit maximum output and the actual cost of power plants, which is benefit for promoting the healthy and orderly operation of the market. According to the proportion of the declared capacity cost of each member, the regulation-up factor can be calculated.

$$P_{\text{up}} = (\text{Max}(P_i) - P_i) \times \frac{C_i}{C_{\text{sum}}}$$  \hspace{1cm} (4)

2.4.4. The regulation-down factor. The penalty mechanism is introduced to adjust the final clearing price of each market member by setting the regulation-down factor $P_{\text{down}}$ and prevent market members from the following behaviours: 1) participating in the transaction negatively; 2) appearing the loss of the total capacity cost; 3) the total declared electricity quantity less than the maximum output; 4) the declared price similar to each other and close to the approved price. The regulation-down factor can be calculated according to the vacancy of capacity cost and electricity quantity, expressed as
\[ P_{\text{down}} = \max \left( C_{\text{sum}} \times \left( \frac{S_i}{S_{\text{va}}} \right) \times \left( R_{\text{va}} + k \frac{S_i - Q_i}{Q} \right) \right) \] (5)

where \( k \) is constant.

2.4.5. Market-force-reduction factor. The market-reduction factor is set for preventing market members from conspiring and manipulating the market. Those whose declared price is similar or close to the approved price will be punished. Those who participate in the bidding actively and competitively are encouraged. The factor can be calculated according to the absolute value of the difference between declared market price of each market member and the average value, as well as the minimum difference between the declared price and the electricity price approved by government.

\[ P_{\text{down}} = P_{\text{off}} \times \frac{C_{\text{sum}}}{\sum Q_{\text{clear}}} \times \frac{\sum (Q_{\text{clear}} - P_i)}{\sum Q_{\text{clear}} + \min (P_{\text{ig}} - P_i)} \] (6)

where the value of the uniform offset price \( P_{\text{off}} \) is constant. The transaction clearing electricity: \( Q_{\text{clear}} \). The transaction clearing price: \( P_{\text{clear}} \).

2.4.6. The transaction clearing electricity. Finally, the clearing price of each market member is determined by the declared price, the regulation-up factor, the regulation-down factor and the market-force-reduction factor.

\[ P_{\text{clear}} = P_i + P_{\text{up}} - P_{\text{down}} - P_{\text{market}}, \quad 0 \leq P_{\text{clear}} \leq P_{\text{ig}} \] (7)

![Figure 2. Market Collusion and Market Forces Intervention Diagram](image)

3. The inhibition mechanism of market collusion and manipulation

3.1. The declared electricity prices of market members are similar, and close to the approved price.

As is shown in figure 2(b), it is considered that each power plant conspires and intends to manipulate the market with market forces. When the declarations are close to the approved price, on the one hand, the regulation-down factor \( P_{\text{down}} \) is proportional to the vacancy proportion of capacity price \( R_{\text{va}} \), so \( R_{\text{va}} \) and \( P_{\text{down}} \) are large. On the other hand, the difference between the declared maximum price and the approved price is very small. According to the formula of the market-force-reduction factor, this value is large. Generators will be penalized by the two aspects, and ultimately reflected in the reduction of clearing price, as well as the reduction of economic benefits.

3.2. All power plants are involved in the transaction by conspiring

As is shown in Figure 2(c), all the power plants are involved in the transaction by declaring different prices. In the case of a certain total power, the declared electricity quantity of each plant is accordingly less. The regulation-down factor is inversely proportional to the declared electricity quantity. So the less quantity power market members declare, the greater the punishment is.

3.3. The declared price is too high or too low
As is shown in Figure 2(d), the power plant Q4 declares too high and the plant will be moved from the market members at the beginning of the transaction, because of the limitation of the declaration.

The declared price of power plant Q1 is too low, and the final clearing price is not entirely equal to the declared price. It is influenced by various factors, such as regulation-up factor, regulation-down factor, and market-force-reduction factor. Seen in Figure 2(d), the capacity price is great and the regulation-down factor is proportional to the declared capacity cost that power plants should undertake. Thus, the greater the amount of capacity price, the greater the regulation-down factor is. The declared price of each market member can be determined according to the actual cost, unit output and its expect-benefits in the market. The bidding strategy for generation companies participating in the market will be studied in the future study.

If the centralized bidding electricity is not trade or not completely trade, or the declaration of some market members is invalid, or some conspire and manipulate the market, the clearing results are cancelled depending upon the situation, and a second round of transaction will re-start. It will need to expand the scope of the transaction, adjust the trading rules as well as the limits of declare electricity quantity and price. If the above situations still occur, the competent departments and the energy regulatory authority will make additional arrangement.

4. Transaction Clearing Examples

Seven power plants are selected in Shanghai area (set up seven power plants as A-G), and the effectiveness of the transaction model is verified by the examples of the transaction model proposed in this paper. The related parameters are set in Table 1.

| Name | Generation proportion | Environmental reward factor | Si (Billion kwh) |
|------|-----------------------|-----------------------------|-----------------|
| A    | 0.0294                | 0.01                        | 2.5993          |
| B    | 0.1112                | 0.01                        | 7.9985          |
| C    | 0.1171                | 0.02                        | 9.0463          |
| D    | 0.1756                | 0.04                        | 14.2295         |
| E    | 0.2186                | 0.05                        | 17.7287         |
| F    | 0.1347                | 0.03                        | 10.8699         |
| G    | 0.2134                | 0.04                        | 16.7274         |

Parameters setting: (1) The amplification factor of declared electricity quantity: K =2. (2) Constant: k=10. (3) Uniform offset price: $P_{off} =-10$ yuan / MW. (4) The total capacity price of the pumped storage power stations: $C_{sum} = ¥180$ million. (5) Bidding electricity: 3.3 billion kWh.

4.1. The clearing example 1

The declaration of power plants is close to approved price (0.41 RMB / kWh), the clearing information is showed in Table 2.

| Market Member | Declared Electricity | Declared Price | Clearing Electricity | Clearing Price (RMB / kWh) | Declared Capacity Cost (Billion) |
|---------------|----------------------|----------------|----------------------|-----------------------------|----------------------------------|
| F             | 10.87                | 0.397          | 10.869               | 0.3249                      | 0.1413                           |
| E             | 17.7288              | 0.398          | 17.728               | 0.324                       | 0.2127                           |
| G             | 16.7274              | 0.3985         | 4.403                | 0.3264                      | 0.1924                           |

Total Capacity Cost 2.8176 (Billion)

Vacancy Proportion R 0.6964

The analyses are as follows:
(1) At this point, the vacancy proportion of capacity price is relatively large \( R_{\text{va}} = 0.6964 \), we can conclude that market members conspire with each other. According to the formula of \( P_{\text{down}} \), the greater the vacancy proportion of capacity price, the greater the \( P_{\text{down}} \) and punishment are.

(2) In addition, if the price of each market member is similar and close to the approved price, according to the formula of \( P_{\text{down}} \), the values of \( \min \left( p_i - p_l \right) \) in the molecule are relatively small. Therefore, \( P_{\text{down}} \) and market punishment are relatively large.

(3) Comparing the clearing price and the declared price of each market member, we can see that all the three power plants are punished.

4.2. The clearing example _2
All market members appear in the clearing sequence and declare differently. The clearing information is shown in Table 3.

| Market Member | Declared Electricity Quantity | Declared Electricity Price | Clearing Electricity | Clearing Price (RMB/kWh) | Declared Capacity Cost (Billion) |
|---------------|-------------------------------|---------------------------|----------------------|--------------------------|-------------------------------|
| E             | 8.5                           | 0.34                      | 8.5                  | 0.2139                   | 0.595                         |
| D             | 7.5                           | 0.34                      | 7.5                  | 0.2127                   | 0.525                         |
| G             | 3.5                           | 0.36                      | 3.5                  | 0.2233                   | 0.175                         |
| F             | 2                             | 0.36                      | 2                    | 0.2229                   | 0.1                            |
| C             | 6.5                           | 0.37                      | 6.5                  | 0.2344                   | 0.26                          |
| A             | 4.5                           | 0.37                      | 4.5                  | 0.2434                   | 0.18                          |
| B             | 1                             | 0.37                      | 0.5                  | 0.2344                   | 0.04                          |
| **Total Capacity Cost** | **6.1931 (Billion)** |                                    |                      |                          |                               |
| **Vacancy Proportion R** | **0**                        |                                    |                      |                          |                               |

Although the declared prices of market members are different, some members declare negatively, such as B and F in Table 3. From the formula of \( P_{\text{down}} \), the value of \( 10(S_1 - Q_i)/Q \) is relatively large, so is the \( P_{\text{down}} \). The final clearing price will reflect the punishment.

4.3. The clearing example _3
Through declaring electricity quantity and price reasonably, the total capacity cost can be exactly 180 million RMB. The clearing information is shown in Table 4.

| Market Member | Declared Electricity Quantity | Declared Electricity Price | Clearing Electricity | Clearing Price (RMB/kWh) | Declared Capacity Cost (Billion) |
|---------------|-------------------------------|---------------------------|----------------------|--------------------------|-------------------------------|
| E             | 17.7288                       | 0.3519                    | 16.8699              | 0.3524                   | 0.9795                        |
| A             | 2.5994                        | 0.3676                    | 2.5870               | 0.3497                   | 0.1097                        |
| C             | 9.0464                        | 0.3704                    | 8.6036               | 0.3552                   | 0.3411                        |
| G             | 16.7274                       | 0.3827                    | 4.9395               | 0.3693                   | 0.4501                        |
| **Total Capacity Cost** | **1.8 (Billion)** |                                    |                      |                          |                               |
| **Vacancy Proportion R** | **0**                        |                                    |                      |                          |                               |
4.4. The clearing example
The clearing information of optimal bidding strategy for all market members is shown in Table 5.

| Market Member | Declared Electricity Quantity | Declared Electricity Price | Clearing Electricity Quantity | Clearing Electricity Price (RMB/kWh) | Declared Capacity Cost (Billion) |
|---------------|-------------------------------|----------------------------|---------------------------------|--------------------------------------|---------------------------------|
| D             | 14.2296                       | 0.3500                     | 14.2296                         | 0.3537                               | 0.8538                          |
| C             | 9.0464                        | 0.3827                     | 9.0464                          | 0.3695                               | 0.2462                          |
| B             | 7.9985                        | 0.3828                     | 7.9985                          | 0.3696                               | 0.2177                          |
| E             | 17.7288                       | 0.3829                     | 1.7256                          | 0.3697                               | 0.4814                          |
| **Total Capacity Cost** | **1.5607 (Billion)** |                                           |                                |                                      |
| **Vacancy Proportion R**  | **0.0005**                      |                                           |                                |                                      |

5. Conclusion
At present, the electricity industry deregulation in China is aimed at breaking the monopoly, introducing competition, improving efficiency, reducing costs, improving the electricity price mechanism, optimizing the allocation of resources, promoting the development of electric power, building fair competitive and ordered power market system under the government regulation. In order to introduce the competition into the power generation mechanism, the target of "separation of plant and network" has to be realized firstly.

During the marketization process, the design of power market bidding mechanism is significantly important. The effective bidding mechanism can restrict the market force, prohibit the market members from collusion and conspiracy, as well as guide the generators to compete with the actual cost, to finally realize rational allocation of power resource.

The current trading modes of pumped storage energy in various regions of China and the relevant data of local power plants in Shanghai are analysed in this paper. Besides, a new trading mode that allows declaring both electricity quantity and price is studied. The market members who are negative to participate the market, or intend to conspire and manipulate the market will be penalized though the regulation-down factor and market-force-reduction factor. By introducing the regulation-up factor, this trading mechanism can lead the market members to actively participate in market competition, and focus on environmental protection.

In the early stage of marketization, only the single-segment declaration of market members will be taken into consideration in the bidding transaction. When the market becomes mature, the transaction considering multi-segment declaration will be further studied, which is more flexible and efficient.

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