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Intelligent Mode Design for the Electricity Market Based on Compound Bidding Matchmaking

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As the driving force of social progress, the use of electric power is increasing. The electricity trading market is developing vigorously, and the volume, amount and subject of electricity trading are constantly increasing. The problems of low transaction efficiency, low competition, incomplete transaction, transaction security and openness are becoming more and more serious. However, the traditional electricity market cannot effectively solve the problems of the electricity market by adopting a single transaction mode. On the other hand, while the existing transaction mode addresses the issue of lower efficiency, intelligent management is receiving less attention although it has a greater number of problems. Through the analysis of both the characteristics of electricity market transactions and the law of transaction development, the use of a multistage intelligent bidding trading model can effectively solve the problems associated with electricity market transactions. In the first stage, in particular, the centralized bidding model solves the problems of large volumes and numerous trading entities. In the second stage, a method of listing and bidding is adopted to increase the volume of market transactions and the competitiveness, and gives full play to the role of the market in resource allocation. The whole process is open and transparent, real-time publication in the form of data, which reflects the fairness of the transaction, and increases the market participants' willingness to participate in market behavior.

Keywords: Electricity trading market; Double bidding; Electricity trading characteristics, Intelligent mode design

1. INTRODUCTION

China has implemented the second round of power reforms since 2002, following similar reforms implemented by foreign powers. This reform breaks the ice of the power industry system, solves the original system problems, government and enterprise problems, etc., and implements bidding on the Internet to achieve a reasonable allocation of production factors through competition, producing diversified competitiveness in the power market that continues to this day [1].

With the implementation of more reforms, the electricity trading market is facing several problems that need to be resolved. Reference [2] pointed out that there is no mechanism for market transactions, and the utilization of resources is inefficient. In particular, there is insufficient competition in the electricity sales market to increase productivity and promote the survival of the fittest. The transactions between power producers and electricity purchasers are limited; hence, the electricity trading market needs to be improved. Therefore, the establishment of a perfect market competition mechanism has a key role in the current power market. References [3–6] detailed the foreign power market trading mechanism in Japan and the European Union, and also pointed out that it is necessary to learn from the experiences in other countries in order to promote the development of the domestic power market. China is also actively exploring ways to find a path suitable for the country's reform. References [7–9] proposed a centralized bidding model and carried out appropriate simulation experiments. This model considered

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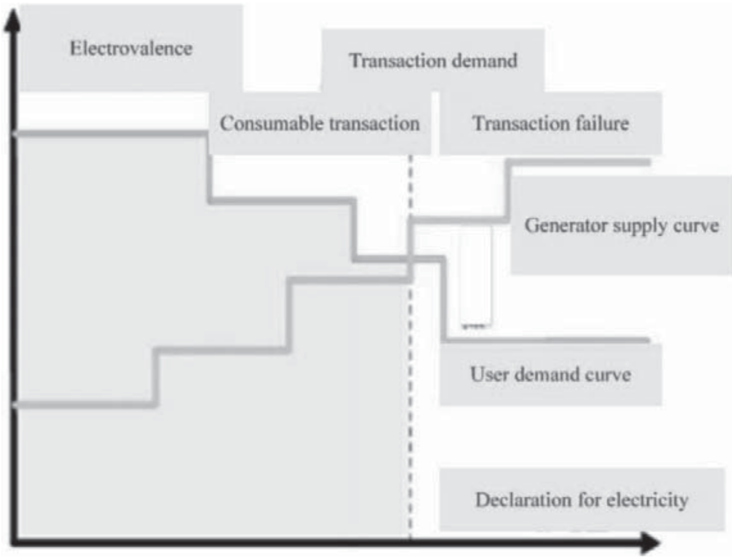

Figure 1 Bidding Matching Trading Chart.

fully the factors of price and queuing time, and used this data as a starting point to propose a benchmark price trading model. The centralized bidding model can effectively reduce transaction risks, protect the interests of both parties to the transaction, and promote fairness. References [10–11] proposed a two-way listing bidding model for electricity sellers and electricity purchasers. This bidding model relies on electricity trading centers to issue transaction information in a centralized manner, issue two-way delisting, and clear transactions based on delisted electricity prices. This type of electricity trading mode enables the issuer and the buyer to make quotations according to their own strength, increases the competition between the issuer and the multi-directional electricity entity, reduces transaction risks, and increases volume of the transactions. However, this mode requires a longer transaction time and has lower transaction efficiency. Reference [12] proposed a model and method of centralized matching transaction, which considers network constraints. This method is based on the fact that security constraints are not met in current actual matching transactions, and the transaction results are not realistic.

The aforementioned researchers have conducted in-depth studies on the current power market and offered unique insights and solutions based on a particular research problem. However, power trading is a dynamic model with real-time changes and variability. Often it is difficult for a single market bidding model to have a practical effect on the market. The centralized bidding mode can effectively improve transaction efficiency when the transaction information is not clear and the transaction volume is large. The listing mode can effectively reduce the risk of poor transactions, increase the transaction volume, and allow the market resources to be fully and reasonably allocated. This paper analyzes the characteristics of the game trading between the issuing and receiving parties, comprehensively compares the advantages and disadvantages of various power trading mechanisms, adopts different methods for the principal contradictions at different stages, and adopts the double bidding mode to improve efficiency.

2. COMPOUND BIDDING

Although the electricity market is part of the socialist market, it has its own uniqueness. As a component of the socialist market, the electric power market inherits most of the characteristics of the socialist market. Compared with the trading of other products, power trading is more risky since a slight deviation can produce irreversible results. In the initial stage of power market transactions, market participants engage in a large number of sales and purchase activities, where both sides need to trade more commodities and might grasp less transaction information. When adopting the traditional trading method, most traders seek the maximization of insurance and profit. However, they often choose to sit on the sidelines, participation is not high, market competitiveness is small, and there is less enthusiasm in this market. In regard to this issue, centralized bidding can effectively solve the problem of low participation. It adopts the method of centralized bidding to carry out the transaction, and the system carries out the matching transaction. The transaction efficiency is high, and the transaction time is greatly reduced. Since it is a system that matches transactions, the transaction information held by each subject can be equally distributed, and the willingness to participate in the transaction is strong. Because the buyer knows that there are other competitors, when buying the goods, the buyer will not accept the quoted price but will offer a price close to the bottom line. The same situation is true for the seller, who will take all factors into account when making the transaction. The transaction matching involved in centralized bidding is depicted in Figure 1.

It can be seen from the Figure 1 that under the centralized trading mode, both parties to the transaction actively declare the electricity price and engage in market trading behavior. Different transaction subjects provide different electricity prices and electricity price information when participating in the competition, so as to meet the transaction requirements. Not all transaction subjects can conclude a transaction. The transaction subject on the left side of the transaction demand curve can complete the transaction (the price difference is greater than 0), while the subject on the right side of the curve cannot complete the transaction. In order to allocate the market resources fairly and promote the transaction maximization, transaction demand should be considered. For the right side of the curve to take the second phase of trading transactions. In the second stage, subjects intending to trade adopt the trading method of listing. At this point, both parties submit to the electric power trading system any information regarding electricity quantity and price relevant to the transaction, which is publicized after the data has been verified. Those who are willing to trade then do so face to face.

3. CENTRALIZED COMPETITIVE BIDDING

Centralized bidding refers to a bidding model in which two or more buyers and sellers declare expected price and expected quantity in the trading system, check and match them through the system, meet relevant constraints and security verification, and finally engage in the transaction.

3.1 Centralized Bidding Trading Model

It is assumed that trader i has strategy function $q_i(p, \eta_i)$, which means that under different power market, the main market players are willing to put into market power, and $q_i(p, \eta_i)$ on electricity price p within each piecewise function continuously differentiable. In addition, η_i=θ_i-r$\sigma^2 I$ (including θ_i is exclusive information for market players, r is risk factor, and I is the resources for market entities) said traders i transaction type. Quotation type is a buyer when $\frac{\partial q}{\partial p} < 0$, seller is $\frac{\partial q}{\partial p} > 0$.

3.1.1 Analyze the Buyer *i* Strategy

According to the previous trading experience, purchase e-commerce i determined the unique price probability density function and assumed that the market-clearing price probability density function of purchase e-commerce i summarized based on the experience was $f_i^B(\hat{p})$, probability distribution function is $F_i^B(\hat{p})$, $\hat{p} \in (\underline{P}, \overline{P})$, the total number of q coming from buyer i concludes the marginal value, i.e., $V_i^B(q, \eta_i)$. Then buyer i profit can be expressed as

$$\pi_i^B(q(\hat{p})) = \int_0^{q(\hat{p})} V_i^B(q, \eta_i)dx - \hat{p}q(\hat{p}) \tag{1}$$

To see whether the transaction can be successfully concluded, mainly based on whether the purchase price is greater than the market-clearing price, the probability of whether the transaction can be concluded is $Pr(p(q) \geqq \hat{p}) = F_i^B(\hat{p})$. The fundamental purpose of market participants engaging in market transactions is to maximize their profits as follows:

$$\begin{aligned} MAXE\pi_i^B(q(\hat{p})) = MAX \int_{\underline{P}}^{\overline{P}} \int_p^{q(\hat{p})} V_i^B(q, \eta_i)dx \\ - \hat{p}q(\hat{p})dF_i^B(p) \end{aligned} \tag{2}$$

Integration by parts computes the buyer i quote is $p = V_i^B(q, \eta_i)$.

3.1.2 Analyze The Seller *j* Strategy

Power retailer j determines his unique market-clearing price probability density function based on previous trading experience. Assume that power retailer j determines the market-clearing price probability density function based on experience as $f_j^B(\hat{p})$ and probability distribution function $F_j^B(\hat{p})$, $\hat{p} \in (\underline{P}, \overline{P})$. The marginal value of the quantity q purchased by the electricity purchaser is $V_j^s(q, \eta_j)$. Then the profit obtained by the electricity supplier j can be expressed as

$$\pi_j^s(q(\hat{p})) = \int_0^{q(\hat{p})} V_j^s(x, \eta_j)dx - \hat{p}q(\hat{p}) \tag{3}$$

Whether the market transaction can be completed is determined by whether the selling price is less than the market-clearing price. As market participants, the ultimate goal of e-commerce sellers participating in market behavior is to obtain maximum profit, which can be described as:

$$\begin{aligned} MAXE\pi_j^s(q(p)) = MAX \int_{\underline{P}}^{\overline{P}} [pq(p) \\ - \int_p^{q(\hat{p})} V_j^s(x, \eta_j)dx]dF_j^s(p) \end{aligned} \tag{4}$$

Integration by parts can calculate the price of seller j as $p = V_j^B(q, \eta_j)$.

Assume that all e-commerce buyers and sellers involved in market transactions take the same risk. In the bidding mode of the first stage, there are m e-commerce buyers participating in the bidding, and finally, there are n combinations of trading subjects that can reach the transaction success condition; when the transaction behavior of the n combination subjects is completed, the clearing price function and trading volume function of the market are Eqs. (5) and (6), respectively

$$\hat{p} = \frac{1}{m+n}\left(\sum_{i=1}^{m}\eta_i + \sum_{i=1}^{n}\eta_j\right) \tag{5}$$

$$\hat{Q} = \frac{1}{r\sigma^2(m+n)}\left(n\sum_{i=1}^{m}\eta_i + m\sum_{i=1}^{n}\eta_j\right) \tag{6}$$

At the beginning of the market transaction, e-commerce sellers i cannot obtain effective information and data to establish mathematical models of other e-commerce sellers. In order to build the mathematical model of other similar competitors, e-commerce sellers need to use fake methods. My means of various possible decisions, a functional model is established, and then the next step in the competitor's behavior is predicted according to this model. Suppose that the error between the mathematical cost model function and the actual mathematical cost function model predicted by the re-seller i satisfies the Gaussian distribution model. That is, the cost function predicted by the e-commerce seller i for its competitor j is:

$$C0st_j^i(q_j^i) = a_j^i (q_j^i)^2 + b_j^i q_j^i + c_j^i + \xi_j^i \tag{7}$$

where, $i, j = 1, 2, \ldots, n; i \neq j$, there be $\xi_j^i \in N[0, S^2(C0st_j^i)]$. $N[0, S^2(C0st_j^i)]$ is the Gaussian distribution model. It is assumed that the standard deviation in this Gaussian distribution model takes the following form $S^2(C0st_j^i) = gq_j^i$. Therefore, the expected revenue can be calculated as follows.

$$\overline{R_j^i}(q_j^i) = q_j^i f(Q^i) - a_j^i (q_j^i)^2 - b_j^i q_j^i - c_j^i \tag{8}$$

where, Q^i is electric power seller i forecasting the total demand in the electricity trading market, a standard deviation of the revenue is $\sigma[R_j^i(q_j^i)] = gq_j^i$. As producers of the electricity market, the purpose of participating in the market is to increase revenue. If this is maximized, the expectation in this model should have the maximum value and the minimum standard deviation. Therefore, the mathematical revenue function model of e-commerce seller j is as follows:

$$\begin{aligned} \psi_j^i(q_j^i) &= \overline{R_j^i}(q_j^i) - \alpha_j^i \sigma[R_j^i(q_j^i)] \\ &= q_j^i \left(P_{MAX} - \gamma \sum_{i.j=1}^{n} q_j^i - \gamma q_j^i \right) - a_j^i (q_j^i)^2 \\ &\quad - b_j^i q_j^i - c_j^i - a_j^i g q_j^i \end{aligned} \tag{9}$$

In order to maximize profits in the market competition, e-commerce seller i needs to satisfy $\frac{\partial R_i(q_i)}{\partial q_i} = 0$. And, the production decision function can be calculated as follows.

$$q_i = \left[-\gamma \sum_{i.j=1}^{n} q_j^i - \gamma q_j^i + P_{MAX} - b_j^i - a_j^i g \right] / (2\gamma + 2a_j^i) \tag{10}$$

E-commerce seller i predicts that e-commerce seller j meets the following conditions $\frac{\partial \psi_j^i(q_j^i)}{\partial q_j^i} = 0$ for-profit maximization.

Therefore, e-commerce seller i predicts that the production electricity of e-commerce seller j can be defined as

$$q_j^i = \left[-\gamma \sum_{i.j=1}^{n} q_j^i - \gamma q_i + P_{MAX} - b_j^i - a_j^i g \right] / (2\gamma + 2a_j^i) \tag{11}$$

3.2 Second Stage Game

According to the valuable information obtained in the game in the previous stage, the seller of e-commerce modifies the behavior rules. When the prediction accuracy of the revised model is higher than that of the previous model, the electricity seller will adopt a more accurate model for the second stage game.. Suppose the cost of selling electricity traders i predict j function is:

$$C0st_j^i(q_j^i) = a_j^i (q_j^i)^2 + b_j^i q_j^i + c_j^i \tag{12}$$

where, a_j^i, b_j^i, c_j^i is E-commerce i predicting the cost function coefficient of e-commerce j. After each game, e-commerce seller i modifies its cost prediction function model according to the actual declared electric quantity of e-commerce seller j:

$$C0st_j^i(q_{j,\ t-1}^i) = (1 + r_{j,a}^i) a_j^i (q_{j,t-1}^i)^2 + (1 + r_{j,b}^i) b_j^i q_j^i + c_j^i \tag{13}$$

The revenue function of e-commerce i is $R_i(q_i) = q_j^i f(Q^i) - Cost_i(q_i)$, where Q^i is the forecast of the total market demand of e-commerce seller i, that is, the supply quantity when the market clears. Therefore, $R_i(q_i) = (P_{MAX} - \gamma Q^i) q_i - [a_i (q_j^i)^2 + b_i q_i + c_i]$ can be met. In order to maximize the benefits, the following conditions should be met the condition

$$\frac{\partial R_i(q_i)}{\partial q_i} = -2(\gamma + a_i) q_i - \gamma \sum_{i.j=1}^{n} q_j + P_{MAX} - b_i = 0 \tag{14}$$

Then the production decision function of power generation enterprise i is:

$$q_i = (-\gamma \sum_{i.j=1}^{n} q_j + P_{MAX} - b_i)/2\gamma + 2a_i \tag{15}$$

E-commerce seller i predicts that e-commerce seller j needs to meet the following requirements in order to maximize profits: $\frac{\partial R_j^i(q_j^i)}{\partial q_j^i} = -2\left[\gamma + (1 + r_{j,b}^i) a_j^i\right] q_j^i - \gamma \sum_{i.j=1}^{n} q_j - \gamma q_j + P_{MAX} - (1 + r_{j,b}^i) b_j^i = 0$. Then the production decision function of power generation enterprise j can be defined as

$$q_j^i = \frac{\left[\gamma \sum_{i.j=1}^{n} q_j^i - \gamma q_i + P_{MAX} - (1 + r_{j,b}^i) b_j^i\right]}{2\left[\gamma + (1 + r_{j,b}^i) a_j^i\right]} \tag{16}$$

4. DOUBLE BIDDING RULE IMPLEMENTATION

The double-bidding fitting is implemented, and the transaction data volume is tracked over a year, as shown in Figure 2. The abscissa represents the month, and the ordinate represents the transaction success rate of the centralized bidding mode. There is a compound bidding mode during the period between January and April as the main body of trading information is limited, and cannot accurately forecast the main body of price and quantity. This was caused by the centralized price bidding mode where there is low transaction success rate, at this stage the trading success rate of the proposed model is higher; in aggregate, at this stage the efficiency is low and therefore cannot achieve the desired effect. In the compound bidding mode, the transaction subjects are more familiar with the workings of the model, so the amount of reliable information is gradually increased. In the centralized competitive bidding mode, the transaction success rate increases linearly because the centralized competitive trading success rate increases; the trading volume will gradually decrease as will the exchange rate. When the proportion of successful transactions in the centralized bidding mode reaches 70%, the double-bidding

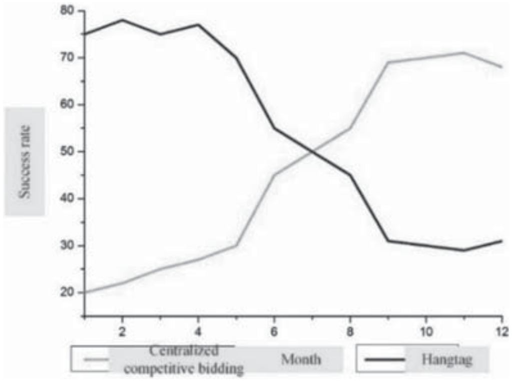

Figure 2 Transaction Ratio Diagram.

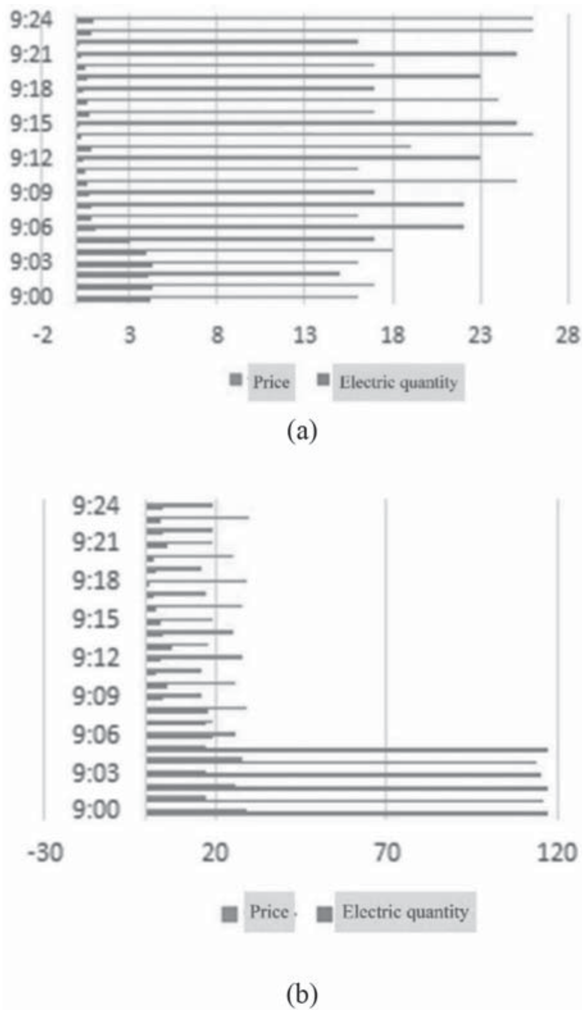

Figure 3 Data Diagram of User Declaration (a) and Power Generator Declaration (b).

mode tends to be stable, the trading ratio of the two bidding modes shows a stable value, and the trading efficiency reaches a stable period. Further exploration is needed to further improve efficiency.

It can be seen from Figure 3, that during the centralized bidding stage, both sides actively participate in the quotation. In the initial phase, power producers will sell enough electricity, buyers will choose lower prices and buy as much electricity as possible, and power producers will continue to adjust prices in response to power buyers. With the passage of time, after the electricity producers sell most of the electricity, they no longer provide more electricity to the electricity market, and the application volume of electricity drops sharply. The electricity buyers will actively raise the electricity purchase price to obtain electricity. Finally, the electricity and price stabilize to a certain value, and then the market reaches a small range of stability. In the later period of power trading, a small proportion of e-commerce buyers failed to obtain power, and these buyers will raise the purchase price again, but the power is limited. Despite the price increase, the amount of electricity available to the market will not increase. After receiving this signal, power producers will increase their capacity in the next electricity transaction to meet market demand.

5. CONCLUSIONS

Each bidding mode has its own value, and a single bidding mode has both advantages and disadvantages. Double bidding is not a simple combination of superposition. By analyzing the characteristics of the market and adopting different means for different anomalies, the disadvantages of the two bidding methods can be effectively avoided and the advantages can be maximized:

1) in the initial stage of market transactions, centralized bidding is adopted to replace the original decentralized bilateral negotiated transactions, and systematic matching is adopted to give both parties more choices to participate in market transactions so that the participants need to make decisions more quickly given the short time of system transactions;

2) the system is used to publicize the data and information on electricity and electricity prices of e-commerce and power generation companies, so that the transaction subjects can grasp the market transaction information more quickly and comprehensively, effectively solve the problem of insufficient information and information monopoly, and make the transaction fairer;

3) trading is more transparent, and all trading processes are presented to the public in the form of quantitative data;

4) wider competition, a more intense competition process, and more accurate power value positioning, can increase the enthusiasm for production, and encourage the development of production technology.

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