Supervision mechanism of virtual bidding in electricity market: a review

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Abstract. In the reform of China’s electricity market, most provinces adopt the centralized mode based on nodal pricing, thus the price convergence problem between day-ahead market and real-time market needs to be promoted. As a common practice in America, virtual bidding mechanism can promote price convergence, control market power and improve market efficiency. However, due to the financial nature of virtual bidding, virtual bidders may disrupt the market and obtain improper profits, thus damaging market efficiency and the interests of other participants. This paper summarizes the key characteristics of virtual bidding mechanisms in America, and analyzes the potential problems that by introducing virtual bidding into China. Then this paper summarizes the pre and post regulatory measures as well as credit mechanisms of virtual bidding in different electricity markets. In view of the cross-product manipulation through virtual bidding, this paper analyzes its principle and summarizes the regulation methods. Finally, considering the specific situation of China’s electricity market reform, this paper puts forward regulatory suggestions on implementing the virtual bidding mechanism in China.

1. Introduction

The ‘Several Opinions on Further Deepening the Reform of the Power System (Zhongfa [2015] No. 9)’ [1] clearly stated that China’s power market model is ‘mainly divided into two models: decentralized and centralized.’ According to the current work arrangements for the construction of the spot market in the southern region of China, the power spot market adopts the centralized mode. Under this mode, promoting the convergence of day-ahead and real-time prices is essential to stabilize market prices, promote price discovery, and improve market efficiency.

Under the virtual bidding mechanism, the arbitrage behavior of market participants can effectively promote price convergence. Literature [2-4] detailed the benefits of the virtual bidding mechanism: increasing market liquidity, mitigating market power, improving market efficiency, promoting price discovery, reducing price fluctuations, etc., while providing market participants with opportunities for risk hedging.

However, virtual bidding mechanism also brings certain risks. On the one hand, virtual bidders may abuse market power to affect their profits. Literature [5] shows examples of the Commission and Constellation Energy Commodities Group (CCG) using virtual bidding to manipulate the New York electricity market and the New England Electricity Market (ISO-NE) for $110 million unjust profits. Literature [6] suggests that improper virtual bidding may reduce the market efficiency of the California power market: the risk aversion parameters and market power of participants can decrease the market efficiency. On the other hand, virtual bidders can make cross-product manipulation to seek profit. Literature [7] analyzes the model of using virtual bidding to manipulate Financial Transmission...
Rights (FTR) products: the trader can purposely lose $500 on its virtual bids to create a $600 gain on its FTR. Literature [8] proposed a three-stage equilibrium model to study cross-product manipulation in the two-settlement energy market and evaluate its impact on other markets: cross-product manipulation may lead to the day-ahead prices at the FTR node increase by 2% to 3%.

Generally speaking, profitable virtual transactions tend to improve market efficiency, while unprofitable bidding usually leads to a larger spread between the day-ahead price and the real-time price, which further reduces the efficiency of power generation, power consumption and power transactions [9,10], as well as having a negative impact on the distribution of benefits among market participants. At present, markets such as PJM [11] and California Electricity Market [12] have established corresponding pre-event and post-event regulatory mechanisms. The pre-event mechanisms mainly supervise the bid specifications, while the post-screening mechanisms is to prevent market participants from using financial positions to create congestion and thus make profit from the FTR held by them. In addition, in recent years, the Federal Energy Regulatory Commission [5,13] has also carried out enforcement actions against such cross-product manipulation, and in some actual cases imposes millions of dollars in fines on participants who violate the regulations [14].

The paper is organized as follows. Section 2 analyzes the basic characteristics of virtual bidding mechanisms. Section 3 divides the supervision mechanisms of virtual bidding from the time scale and analyzes the characteristics of pre-supervision and post-supervision of virtual bidding. Then Section 3 analyzes the credit supervision of virtual bidding in detail. Aiming at the special behavior of cross-market manipulation of virtual bidding for cross-product profit, Section 4 analyze its principles and measures. Finally, Section 5 puts forward suggestions on the supervision mechanism of the virtual bidding mechanism in China's power market.

2. Design features of the virtual bidding mechanism
Virtual bidding (VB) was first introduced by PJM in June 2000. It is a strategy of PJM to make the day-ahead market and real-time market prices becoming relatively close. Subsequently, major regional power markets in the United States such as ERCOT (The Electric Reliability Council of Texas) and CAISO (California Independent System Operator) have also successively introduced similar power financial products. Although the product’s names are slightly different from VB, their nature and transaction mechanism are consistent with VB of the PJM market. Currently, all seven ISO/RTOs in the United States have adopted a virtual bidding mechanism.

2.1. The trading mechanism of virtual bidding
Virtual bidders and physical bidders make bid quotations in the day-ahead market in the same period in the same way, submitting generation curves or load curves. Virtual bids can be further divided into two types: the generation type (increment bids, INCs) and the load type (decrement bids, DECs). As shown in Figure 1, both physical bids and virtual bids are considered in the market clearing process, which will affect the market clearing price. However, virtual bidding is not considered in the reliability assessment to ensure the safety of the power system.

![Figure 1. The mechanism of virtual bidding in power market.](image-url)
The cleared virtual bid in the day-ahead market will be settled. The settlement of virtual bids is based on the price difference between the day-ahead market and the real-time market. The settlement formulas of INCs and DECs are as follows:

\[
R_{\text{INC}} = Q_{\text{INC}} (P_{\text{DA}} - P_{\text{RT}}) \quad (1)
\]

\[
R_{\text{DEC}} = Q_{\text{DEC}} (P_{\text{RT}} - P_{\text{DA}}) \quad (2)
\]

Where \( Q_{\text{INC}} \) and \( Q_{\text{DEC}} \) represent the cleared amount of INC and DEC respectively in the day-ahead market declared by market participants. \( P_{\text{DA}} \) and \( P_{\text{RT}} \) are the spot price of electricity in the day-ahead market and real-time market respectively; \( R_{\text{INC}} \) and \( R_{\text{DEC}} \) are the income obtained by the INC and DEC settlement of market members respectively.

If there is a price difference between the day-ahead and the real-time price, the virtual bidding has profit margin, and there will be virtual entities to make quotations until the ideal equilibrium state (the price difference is zero). Therefore, virtual bidding can play a role in promoting price convergence, suppress bad competition on a single node, increase market liquidity, reduce market fluctuations, and help the market make more effective price discovery.

2.2. The spatial granularity of virtual bidding

Virtual bidding will not affect the actual power flows, and bidding methods can also be rich and diverse. From the perspective of spatial granularity, virtual bidding can be divided into nodal type and regional type:

(1) Nodal virtual bidding. Virtual bidding is similar to physical bidding, and participants can bid to a specific point in the power system. Markets such as PJM and ISO-NE adopt this model.

(2) Regional virtual bidding. Virtual bidders can bid to the generation-side price area or user-side price area. It can be specified that all virtual bidders bid to the generation-side price area, or all bid to the user-side price area, or INCs bid to the generation-side price area, while DECs bid to the user-side price area, etc. For example, NYISO (New York Independent System Operator) adopts a regional virtual bidding model and virtual bid needs to be defined on Load Aggregation Points (LAPs). Currently, there are 15 LAPs in the New York power market.

2.3. Potential problems of introducing virtual bidding mechanism

The power market model can be divided into the centralized model represented by the United States and the decentralized type represented by Europe. At present, many provinces in China have adopted the centralized model in their power market reforms. In particular, the reform pioneer provinces such as Guangdong and Jiangsu, have adopted the United States as a template for their electricity market design. In order to solve the problem of price convergence between day-ahead market and real-time market under the two-settlement model, it is necessary to introduce virtual bidding. In fact, the power market of Yunnan Province has begun to design the virtual bidding mechanism suitable for China.

The introduction of the virtual bidding mechanism in China will bring the following potential problems:

1) The volume problem of virtual bidding. From the perspective of the transaction mechanism, virtual bidding is the same as physical bidding in the day-ahead clearing process. Therefore, excessive virtual bidding will increase the burden on the clearing software, and further cause market clearing difficulties or even failure to clear. Therefore, virtual bidding cannot participate in the market without restrictions.

2) The price issue of virtual bidding. Although virtual bidding can promote price discovery, virtual bidding does not represent the actual physical power generation or consumption. If it is a marginal unit, the main body may maliciously disturb the market price. Therefore, virtual bidding needs to be set with a certain price cap.
3) Cross-product manipulation of virtual bidding. Market entities can use virtual bidding to influence electricity prices and obtain the benefits of other power products. Therefore, this type of cross-market manipulation is special and requires special attention.

4) Credit issues of virtual bidding. The credit mechanism in the electricity market is one of the important measures to ensure market safety and stability. After the introduction of virtual bidding mechanism, more attention should be paid to the credit mechanism.

3. Virtual bidding supervision measures

In terms of time scale, the supervision measures of virtual bidding can be divided into pre-event supervision and post-event supervision.

3.1. Pre-event supervision

3.1.1. Distinguishing between virtual bidding and physical bidding. Most markets such as PJM and NYISO require the flagging of virtual bids to distinguish them from physical bids, allowing ISO to better monitor the market. Only ISO-NE does not require marking of virtual bids.

3.1.2. Limits on the number of segments and volume of virtual bidding. As shown in Table 1, different markets have different restrictions on the quantity of virtual bids and bid segments. Most ISOs in the United States do not specify the total amount of virtual bids in the whole market, but restrict individual virtual bids. For example, NYISO believes that the virtual bid collateral requirement of $200/MWh has been set in the rule design, and the excessive number of virtual bids also means that the potential risk related to spread fluctuations is large, so that the total amount of virtual bids for a single participant will not be very large, and there is no need to limit the total amount.

| Market   | Product granularity | Quantity requirement                                      | Price cap                      | Marking |
|----------|---------------------|---------------------------------------------------------|--------------------------------|---------|
| PJM      | 0.01 MW             | 3000 bidding sections/SC/day; limits on total bid volume per node | Same as physical bid price cap | Yes     |
| NYISO    | At least 1MW initially, in increments of 0.1MW | Three bidding sections/area/hour                       | Same as physical bid price cap | Yes     |
| MISO     | 0.1 MW              | Up to 9 bidding sections                               | Same as physical bid price cap | Yes     |
| ISO-NE   | 1 MW                | —                                                       | Same as physical bid price cap | No      |
| CAISO    | 1 MW                | starts from 0, up to 10 segments                       | Same as physical bid price cap | No      |

ISO's restrictions on a single virtual bid include requirements such as collateral and product granularity. The purpose is to limit complexity of the virtual bidding process. NYISO adopted a guarantee requirement of $200/MWh, which was successful in incenting participants to submit fewer bids with more segments. Both ISO-NE and NYISO only allow virtual bids with a granularity of an integer multiple of 1MWh. ISO-NE charges fees for each virtual bidding transaction, which can effectively prevent participants from submitting complicated bids with too many segments, thereby eliminating bid “spamming” on the market clearing.

In addition, each ISO also charges fees for virtual bidding to further restrict malicious virtual bidding that disrupts the market, as shown in Table 2.
Table 2. Requirements of fees for virtual bidding.

| Market  | Market management fee $/ each cleared virtual bid | Transaction fee $/each bidding segment | Uplift charges |
|---------|---------------------------------------------------|----------------------------------------|---------------|
| PJM     | 0.045                                             | 0.045                                  | Virtual generation/load |
| NYISO   | 0.05                                              | 0.1                                    | Virtual generation allocation only |
| MISO    | 0.85                                               | -                                      | Virtual generation/load |
| ISO-NE  | 0.06                                              | 0.005                                  | Virtual generation/load |
| CAISO   | 0.0876                                            | 0.005                                  | Virtual generation/load |

3.2. Post-event supervision

In order to evaluate the impact of virtual bidding on day-ahead and real-time prices, market monitors often adopt a post-mortem mode of transaction resumption, that is, re-run the market without considering virtual bidding.

For most electricity markets that distinguish between virtual bidding and physical bidding, such as NYISO and PJM, a software package called PROBE is used for post-mortem transaction review. This software can be used to perform quick settlement calculations.

For markets that do not distinguish between virtual bids and physical bids, since the number of real virtual bids cannot be known when the transaction is resumed, the virtual bid will be calculated. For example, in ISO-NE, market monitors calculate the total amount of virtual bids based on the comparison of actual load/power generation in the market with the total bids, so as to conduct transaction resumption.

3.3. Credit supervision of virtual bidding

The credit mechanism is significant to ensure market stability in the electricity market. The electricity market in China has already imposed corresponding credit requirements on physical bidding. For virtual bidding, the virtual bidding credit mechanism in the US electricity market is similar, mainly focusing on risk exposure calculations, reference prices, and collaterals of virtual bidding.

There are two main differences in virtual bid credit mechanisms: whether it is distinguished from physical bids, and the granularity of virtual bid credit lines. On the one hand, some electricity markets calculate the credit of virtual bidding separately (NYISO, etc.); while some electricity markets use the participant as a unit to conduct credit management together with virtual bidding and physical bidding (PJM, etc.). On the other hand, due to the different node granularity in product design of virtual bidding, the credit mechanism is divided into node type (PJM, etc.) and regional credit mechanism (NYISO, etc.). This paper takes NYISO and PJM as examples for analysis as follows.

3.3.1. Trading exposure

The amount of virtual bidding risk exposure is related to bidding’s volume and spot price, and the specific rules of different markets are slightly different.

In NYISO, the exposure of virtual transactions is:

$$C_v = q_v \times |p_R - p_D|$$

(3)

Where $q_v$ represents the volume of virtual bids, $p_R$ and $p_D$ represents the price in the day-ahead market and real-time market respectively.

In PJM, the participant’s credit exposure is set equal to the maximum settlement amount for two consecutive months. PJM assumes that virtual transactions are included in these settlement amounts, so usually virtual transactions do not require additional credit lines. The ‘credit limit available for virtual bidding’ refers to the total credit limit established by a participant minus the current unpaid amount, then minus the member's fixed 15% credit requirement for normal market activities. ISO
monitors virtual bids every day and calculates their virtual bid credit exposure for all virtual bids submitted by market participants on the next day:

\[ C_v = \min \left( C_v^1, C_v^2 \right) \]  

\[ C_v^1 = \max \left( b_g, b_l \right) \times p_{ref} \times 2 \]  

\[ C_v^2 = \max \left( b_g, b_l \right) \times p_{ref} \times 1 + \sum_{i=1} \Delta p_i \times p_{ref} \]  

Where credit exposure is the smaller value of the first type of virtual credit limit \( C_v^1 \) and the second type \( C_v^2 \). Equation (5) indicates that the node credit limit = the total volume on the node per hour (including generation bids or load bids, whichever is greater, once per hour) \( \times \) node reference price \( p_{ref} \) \( \times 2 \) days. The virtual credit limit \( C_v^2 \) is divided into two parts. The first part is similar to \( C_v^1 \), except that the number of days is 1 day, that is, the sum of the node credit limit (1 day) of all nodes for all hours. The second part of \( C_v^2 \) is the total bidding power deviation of all nodes for all hours in the previous three days (the deviation between power generation bidding and load bidding) \( \times \) node reference price \( p_{ref} \).

3.3.2. Reference price of virtual bidding. The virtual bid reference price varies according to the node granularity of the virtual bid product design.

NYISO divides the timeline of VB’s reference price into the following 6 periods each year: January-February, March-April, May-June, July-August, September-October, and November-December. NYISO determines the reference price based on the price in the same period of the previous two years, and generally selects the higher of the two-year price difference. The reference price of virtual bidding is the highest regional price change range (the absolute value of the difference between the day-ahead and real-time prices) at the 97th percentile. Since the granularity of NYISO's virtual bidding is regional, ISO determines the credit line required for virtual bidding for each virtual trading area.

In the PJM power market, the reference price of virtual bidding is calculated separately for each node. It is also divided into six periods same as NYISO. For each time period, calculate the absolute value deviation between the settled day-ahead price and the real-time price for each hour of the previous year during the time period, and then sort such deviation values and select the 97th percentile value as a reference for this location. The reference price is applicable to the bid position associated with it, and the bid volume of different positions will be multiplied by different reference prices when calculating the credit exposure.

3.3.3. Collateral for virtual bidding. NYISO monitors the credits and usage of participants every day, and monitors bids submitted by virtual traders. If the submitted volume exceeds the threshold, all virtual bids of the participant will be rejected by NYISO on that day. If a virtual bidding entity has used 50% of the credit, NYISO will notify the entity and require it to provide other collateral within 1 working day, otherwise the entity may be prevented from further participating in virtual transactions; if the credit is used 100%, NYISO could cancel its virtual bidding and suspend its qualification for virtual transaction bidding until the entity submits collateral to meet the credit requirements again.

Similar to NYISO, PJM monitors the credit limit of virtual bidders and their usage every day. If a participant’s virtual bidding credit exposure exceeds its available limit, PJM will notify the participant through eMKT and refuse its virtual bids. After receiving such notifications, market participants can change their DECs and INCs so that their credit exposure does not exceed their credit threshold, and then resubmit the bids.
4. Cross-product manipulation supervision of virtual bidding

4.1. Using physical bids to profit from virtual products
Participants with physical generation assets may exercise market power to influence real-time prices, thereby profiting from virtual bidding products at corresponding nodes. To this end, ISO can supervise such behavior.

NYISO stipulates the uninstructed deviation penalties (UDP), if an entity's deviation exceeds +3%, it will not receive additional benefits; if an entity's deviation exceeds -3%, it must accept the reserve price related punishment. For markets without UDP, the uplift apportionment of markets such as ISO-NE and PJM also played a similar role.

4.2. Use virtual bidding to profit from FTRs
Market participants may use virtual bidding to create congestion in the day-ahead market to increase the revenue of congestion revenue rights (CRRs). Since participants often lose money in virtual bidding in order to create congestion, such supervision is difficult.

The simplest case of using virtual bidding to create congestion to obtain CRR revenue is to conduct virtual bidding in two CRR nodes. However, due to the power flow characteristics of the real power system, virtual bidding of nodes near the CRR nodes is located may also affect revenue. In the system shown in Figure 2, the load of area C can only be satisfied by the generators of area A. If a company owns CRR from area A to area B, and submits a virtual load bid in area C. The virtual bid may increase congestion between area A and area B, and therefore increase CRR revenue of company A.

The supervision of using virtual bidding for CRR profit depends on the granularity of the product. For node-based virtual bidding, there is a greater possibility of cross-product manipulation. Therefore, markets such as PJM and ISO-NE have stricter supervision of such behaviours, which are considered in the settlement mechanism: when a participant’s virtual bidding may increase its CRR income, restrict the its CRR income. Consider two situations: (1) The subject makes a virtual bid at the node of the CRR owned by it or a node near the CRR, and the virtual bid is cleared, which may increase the price difference between the two CRR nodes, thereby increasing its revenue; (2) The day-ahead spread between two points of a certain CRR is greater than its real-time spread. If the two situations occur, the participant’s CRR income will be limited to no more than the average hourly cost of the CRR paid by the participant in the monthly or annual auction of CRRs.

Among them, the definition of "nearby" is based on Power Transfer Distribution Factors (PTDFs). If an INC is located at a low-price/non-blocking node, it will be paired with another load node. If the minimum difference between a DEC’s PTDF and the INC’s PTDF is greater than or equal to ±75%, the location is considered a "nearby node". Similarly, if the DEC’s node is located at a high price/blocking point, it is paired with another power generation node. If the maximum difference between a INC’s PTDF and the DEC’s PTDF is greater than or equal to ±75%, the location is also regarded as a "nearby node". For example, if a virtual supply bid is made in Zone A where the PTDF
is 20%, and withdrawn in Zone C where the PTDF is -55%, the difference between the two nodes’ PTDF is 75%.

For regional virtual bidding, the possibility of cross-product manipulation is small, so markets such as NYISO often do not regulate this. In the NYISO market, CRR and virtual bidding are located in a relatively large geographic area. Therefore, a large amount of virtual bidding is required to cause obvious congestion in areas where participants have CRR. Therefore, California does not consider the association between virtual bidding and CRR in the settlement rules. However, market monitors will track the profits and losses of each entity with virtual bids, and the behaviour of entities with larger losses or profits may be marked for follow-up review. Among them, continuous virtual bidding loss may indicate that participants are trying to profit indirectly from CRR; continuous and large virtual bidding profits may indicate that participants can manipulate the market in some way and affect real-time prices, so that they can benefit from virtual bidding Profit (such as disconnection of the unit, unindicated deviation, etc.).

5. Conclusions and suggestions
In the construction of power market in China, the virtual bidding mechanism could be considered to improve market efficiency and promote price discovery; however, in order to ensure market stability, it is also necessary to focus on the construction of the corresponding regulatory mechanism. From the perspective of supervisory level, it is recommended to conduct multi-party supervision of virtual bidding: at the level of laws and regulations; the energy supervision bureau and other national institutions; the market management committee and other industry self-discipline; the market operating agency, and the third-party regulatory agencies. From the perspective of time scale, it is recommended to adopt a full-process supervision method of pre-supervision and post-supervision for virtual bidding: pre-supervision is mainly to limit the quantity and price of virtual bids; post-supervision is to analyze the behavior of virtual bidders through transaction review. In addition, the credit mechanism of virtual bidding is vital to restrict the entity’s manipulation. Taking into account the particularity of virtual bidding, it is recommended to distinguish it from physical bidding for easy management.

In addition, the supervision of virtual bidding for cross-product manipulation is relatively special, so this type of issue should be focused on. Since the financial transmission rights has not been introduced in China, the cross-product manipulation using virtual bidding to gain profits from physical bids should be focused on. After FTR mechanism is established in China, it is necessary to supervise the use of virtual bidding for profiting from FTRs.

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