Simulated Research on the Trading Mechanism of the Long-term Power Financial Market in China

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Abstract. This paper takes the pilot project of spot electricity market in Shanxi province as an example, conducting simulated research on the operation of the trading mechanism in the long-term power financial market in China, with a focus on simulating the operation of the futures market and the financial transmission rights market, aiming to provide theoretical basis for the design of China's long-term power financial market.

Keyword: power finance, power futures, financial transmission rights

1. Introduction

Currently, the construction of China's electricity market is continuously deepening. With the increasing growth of market-oriented traded electricity volume, the operation of China's electricity market will face challenges such as power quantity balance and severe price fluctuations. Therefore, as various physical electricity trading mechanisms are gradually improved, the types of traded products in China's electricity market will gradually extend from the electricity energy market and ancillary services market to futures, options, financial transmission rights, and other financial derivatives markets. In order to conduct in-depth research on the operation mechanism of electricity financial transactions, it is necessary to establish quantitative analysis methods and model tools as soon as possible to analyze the impacts and effects of financial transactions. Therefore, this project focuses on China's spot market and designs and simulates key financial derivatives for analysis, providing theoretical and quantitative references, as well as relevant policy suggestions, for the design of China's electricity financial market[1-2].

2. Simulation of Electricity Futures Market in China

Electricity futures refer to electricity commodities traded in the form of futures contracts, with specific prices for buying and selling, and delivery and completion within a specific time period in the future. In a mature futures market, market participants can engage in a series of arbitrage activities, such as hedging, based on the price difference between electricity futures and electricity spot prices. Without the possibility of making profits, it would be difficult for

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electricity futures markets to be profitable. Below is a simulation of futures arbitrage using Shanxi Province as an example[3].

2.1. Progress of Shanxi Spot Market

Since the launch of electricity spot pilot work in 2017, the first batch of spot pilots has all entered settlement trial operation, and characteristic mechanisms of electricity spot markets have been explored in combination with provincial situation and network situation. The Shanxi electricity spot market adopts the "medium and long-term price difference contract + full-load spot" model, with nodal electricity price pricing mechanism. On April 1, 2021, the Shanxi electricity spot market started settlement trial operation and has been running smoothly ever since.

The average annual weighted average price of day-ahead electricity in the Shanxi spot market is 430.10 yuan/MWh, and the arithmetic average price is 419.36 yuan/MWh. The maximum arithmetic average price on a single day in the year is 1500 yuan/MWh, as shown in figure 1.

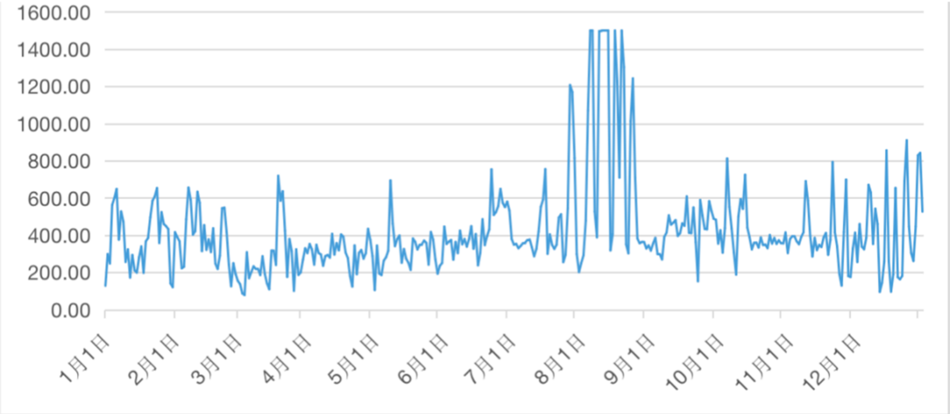

Figure 1 Shanxi Spot Pilot Day-Ahead Prices

As can be seen, the nodal electricity prices in the day-ahead market are extremely volatile, with the highest peak occurring in mid-August, with multiple days reaching the price upper limit of 1500 yuan/MWh.

2.2. Introduction of Futures Simulation in Shanxi Spot Market

Now, assuming that a market participant plans to purchase 80 MWh of electricity on August 10, 2022 to meet its own load demand. According to data, the average total cost was 120,000 yuan. This price is too high and will seriously affect the final profit of the participant.

If the market participant predicts in advance that the electricity price will be too high on August 10, they can use futures trading to arbitrage in advance, thereby offsetting some of the income losses. We design the 5MW futures products for in the day ahead market peak time, as follows:

Table 1 Daily 5MW Futures Contract for Peak Time Day Ahead

Trading Unit	5 Megawatts (5 MW)
Quotation Method	Delivered on a daily basis Peak hours are defined as 08:00-23:00 for a total of 16 hours, with a total trading volume of 80 MWh
Trading Period	Current month and next month
Last Trading Day	Last business day within the contract trading period
Delivery Method	Financial (cash) settlement

Now, assuming that the market participant has estimated in advance that the electricity price in the spot market will be too high on August 10, they purchase several contracts of this electricity futures in July to hedge against some of the spot electricity price risks. At this time, the futures market price is 300 yuan/MW. On August 10, the market participant sells an equal amount of the same type of electricity futures, and the futures price has risen to 1000 yuan/MW due to the increase in spot prices. At this time, the unit MW futures profit in the futures market is:1000 - 300 = 700 yuan/MW.

Converted to a total trading volume of 80 MWh, the total profit of one futures contract is 56,000 yuan; considering the average total cost of purchasing electricity in the spot market, the total expenses are:120,000 yuan - 56,000 yuan = 64,000 yuan.

Spread over 80 MWh of electricity, the cost per MWh of electricity is 800 yuan; if the market participant has more confidence in the futures market and trades 2 contracts, the cost per MWh of electricity will be further reduced to 100 yuan, which is already lower than the average nodal spot electricity price for the whole year. Overall, electricity futures play a role in hedging.

3. Financial Transmission Rights (FTR) Market Trading Simulation

3.1 Basic Concepts

Financial Transmission Rights (FTR) are financial instruments used to mitigate congestion risk in electricity markets. They are financial interests based on the locational marginal price (LMP) congestion component difference. There are two ways to obtain FTRs, through auctions and trading, corresponding to the FTR auction market and the FTR secondary market, respectively [4-5].

3.2 Mathematical Model of FTR Auction

The auction model for Financial Transmission Rights (FTR) is a typical linear programming (LP) problem. Therefore, based on a thorough understanding of the basic principles of FTR auctions, this paper constructs the following simple auction model. The FTR auction model is a simple linear programming model that uses the DC (direct current) model without considering network losses, with the starting point of the FTR as the injection point and the ending point as the withdrawal point. Since this model is applied to the pre-market clearing process, it does not consider the actual distribution of power flows. The most important data in the actual network topology are the generation shift distribution factors (GSDF) and the transmission capacity limits of the lines.

Objective function:

$$\mathrm{Max}\left((B_{ob})^T F_{ob} + (B_{op})^T F_{op}\right) \tag{1}$$

Constraints:

$$0 \le F_{ob} \le F_{ob}^{max} \tag{2}$$

$$0 \le F_{op} \le F_{op}^{max} \tag{3}$$

$$\alpha_{ob} \cdot M_{ob} \cdot F_{ob} + \alpha_{op} \cdot M_{op} \cdot F_{op} \le T_l \tag{4}$$

$$-\alpha_{ob} \cdot M_{ob} \cdot F_{ob} + -\alpha_{op} \cdot M_{op} \cdot F_{op} \le T_{-l} \tag{5}$$

The above linear programming can be interpreted as follows:

1）The subscript "ob" in all functions represents obligation-type FTRs, and the subscript "op" represents option-type FTRs. The following explanations are based on obligation-type FTRs.

2）In the objective function, the vector $B_{ob} = [B_1\ B_2\ B_3\ \ldots\ B_n]^T$representsthe highest price that the bidder is willing to pay for the units of FTRs being bid, and $F_{ob} = [F_1\ F_2\ F_3\ \ldots\ F_n]^T$represents the cleared quantity of transmission rights, with a negative value indicating that the bidder is selling the transmission rights. The clearing goal of the auction market is to maximize the total revenue of transmission rights, i.e.,. $\mathrm{Max}\left((B_{ob})^T F_{ob} + (B_{op})^T F_{op}\right)$.

Here is an explanation for the matrices α_{ob}：

1）The matrix α_{ob} is the system's transfer distribution factor matrix, with dimensions of number of lines multiplied by number of nodes. α_{ki} represents the impact of power injection (or withdrawal) at node i on the power flow of transmission line k.

2）One node is chosen as the reference node, so one column in the matrix α_{ob} is all zeros.

3）For computational simplicity, α_i is the generation shift distribution factor (GSDF) matrix, which represents the change ΔP_i in active power flow on transmission line k (with nodes m and n as its endpoints) due to a change ΔP_k^i in power injection (or withdrawal) at node i, $\alpha_{ki} = \frac{\Delta P_k^i}{\Delta P_i}$. Here, the active power flow refers to FTR.

4）Based on the definition and calculation of generation shift distribution factor, $\alpha_{ki} = \frac{X_{mi} - X_{ni}}{x_k}$, the double-subscript elements related to matrix X represent the elements in matrix X, where X is the inverse matrix of B0 matrix in DC power flow. The B0 matrix is the node admittance matrix formed using 1/xij as the admittance of transmission line ij, and xk is the resistance of transmission line k.

5）α_{op} is the system's distribution transfer factor matrix α_{op} for option-type transmission rights, where the elements are in the form of $\max(0, \alpha_{ki})$. If the distribution transfer factor is negative, it is considered as zero in the calculation.

3.2.1 Clearance Model for FTR Auctions

The clearance quantity (MW) of FTRs that can be awarded can be obtained from the optimal solution of the linear programming model for the auction. From the clearance quantity of FTRs, the clearance price of FTRs at each node can be derived, and further, the clearance prices for each path can be calculated.

For Obligation-type FTRs, the clearance price (FCP) at each node is given by

$$\mathrm{FCP}_i^{ob} = -\sum_L \alpha_{l,i} (\mu_l - \mu_{-l}) \qquad （6）$$

For Option-type FTRs, the clearance price (FCP) at each node is given by

$$\mathrm{FCP}_i^{op} = -\sum_L \left(\max(0, \alpha_{l,i}\mu_l) - \max(0, -\alpha_{l,i}\mu_{-l})\right) \qquad （7）$$

The equations can be explained as follows:

1）$\alpha_{l,i}$ is the generation shift distribution factor (GSDF) matrix, where the elements represent the change ΔP_l^i in active power flow on branch l (with nodes m and n at the two ends) caused by a change ΔP_i in active power injection (or withdrawal) at node i, $\alpha_{li} = \frac{\Delta P_l^i}{\Delta P_i}$. In this case, the active power flow refers to FTRs.

2）According to the definition and calculation of generation shift distribution factors, $\alpha_{ki} = \frac{X_{mi} - X_{ni}}{x_k}$, where the double subscript element of X represents the element in matrix X, and X is the inverse matrix of B0 matrix in the DC power flow, where B0 matrix is the nodal admittance matrix constructed with 1/xij as the branch admittance, and xk represents the resistance of branch k.

3）For Option-type FTRs, when the blocked direction specified by the FTR is opposite to the actual blocked direction, the holder can avoid losses, and the reverse flow should not be included in the model calculation. Therefore, the calculation form of the clearance price for Option-type FTRs is $\max(0, \alpha_{l,i}\mu_l)$, where if the product of the distribution shift factor and the shadow price is negative, it is calculated as zero.

3.2.2 Analysis of IEEE-14 Bus System Case

In this section, based on the market rules of the Shanxi spot pilot, for simplification, we conduct a case analysis using the IEEE-14 bus system, and design the following for FTR auctions:

1）Annual auction

In this example, only one round of FTR auction is conducted, with a time span of one year for the cleared FTRs, providing open auctions for all system capacities. 2）Full-time FTRs

In this example, only full-time FTRs are available for auction. Full-time FTRs include all components of nodal price blockage for the entire time period (off-peak and peak hours) in the FTR blockage revenue.

3.2.2.1Basic Information of the Case System

①Case System Data

1） Transmission Capacity Upper Limits

There are a total of 20 lines in the node system, and the transmission capacity upper limits for each line are shown in Table 2.

Table 2 Transmission Capacity Upper Limits and Congestion Component Predicted Values of Lines.

Line Number	Start/End Node Number	Transmission Capacity Limit (MW)	LMP Congestion Component Difference Forecast Value (￥/MW)
1	1-2	±500	12.6
2	1-5	±470	45.4
3	2-3	±270	49.8
4	2-4	±240	35.0
5	2-5	±540	23.2
6	3-4	±300	26.1
7	4-5	±150	3.5
8	4-7	±230	21.9
9	4-9	±460	21.7
10	5-6	±340	6.3
11	6-11	±310	30.7
12	6-12	±120	43.0
13	6-13	±290	39.2
14	7-8	±470	-38.4
15	7-9	±240	29.7
16	9-10	±240	32.6
17	9-14	±290	42.1
18	10-11	±120	31.6
19	12-13	±170	36.6
20	13-14	±210	8.3

3.2.2.2 Market Participants Bidding

In this case, only one round of FTR auction is conducted with a time span of one year for the cleared FTRs. Except for the portion of FTR capacity reserved for ARR conversion, the remaining capacity of the entire system is open for auction.

Based on the above rules, a total of 8 market participants, including 2 point-to-point transmission users and 6 off-exchange investors, participated in the FTR auction. The risk factor, i.e., the probability corresponding to the predicted value of the difference between LMP congestion components for each line, is set in this case.

3.2.2.3Clearing Results

The clearing results are shown in the table below:

Table 3 FTR Clearing Results

FTR Index	Participant Index	Participant Type	Path	FTR Type	Cleared Quantity (MW)	Bid Quantity (MW)	Cleared Price (￥/MW)	Bid Price (￥/MW)
1	1	Point-to-point Transmission User	2->3	Obligation	298.3	300	29.2	29.9
2	3	Point-to-point Transmission User	6->13	Obligation	247.0	400	23.5	23.5
3	5	Offshore Investor	9->14	Obligation	389.6	400	25.3	25.3
4	6	Offshore Investor	4->9	Obligation	449.8	500	10.8	10.9
5	7	Offshore Investor	2->3	Obligation	200.0	200	29.2	34.9
6	8	Offshore Investor	9->10	Obligation	177.6	500	21.2	21.2
7	9	Offshore Investor	9->10	Option	600.0	600	25.2	27.7
8	10	Offshore Investor	12->13	Option	181.9	600	29.3	29.3

It can be seen that for the same path, option-type FTRs have higher prices than obligation-type FTRs. The overall cleared quantity is relatively large, due to cautious bidding by investors at the beginning of market establishment. It is noted that Transmission User 4 converted their ARR for the 9->14 path into FTRs with the same path and capacity. Meanwhile, Off-market Investor 5 won 389.6 MW of FTRs for the 9->14 path at a bidding price of 25.3 yuan/MW, and Investor 5 believes that their congestion revenue will be around 42 yuan/MW. If these assumptions hold, the self-scheduled FTR selection of Transmission User 4 has helped them achieve additional revenue of 17 yuan/MW.

4. Conclusion

First, with the deepening of China's spot market construction, the drastic fluctuations in market prices have caused economic losses to users. Simulation results show that introducing futures trading can play a hedging role and stabilize electricity purchasing expenses for users.

Second, financial transmission rights are an effective way to solve the transmission congestion problem in the electricity market, and the settlement and income distribution of financial transmission rights are closely related to the clearing results of the electricity market. In the nodal electricity market, the coordination issue of benefits during congestion can be compensated through the financial revenue of FTRs, effectively promoting full competition in the electricity market.

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