Simulation and Derivative Analysis of Operation Effect of Electricity Spot Market

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Abstract. Under the background of global power market reform, the construction of China's electricity spot market is a hot spot in China. In order to ensure the safe and stable operation of the power system, it is necessary to carry out detailed simulation before the reform. In this paper, a simulation platform is developed to fit the characteristics of the spot market, and a set of evaluation indexes that can be used to quantify the market operation effect is designed. Based on the data of typical summer and winter load days in an area of East China, the operation of the spot market is simulated. The results show that the index can reasonably evaluate the operation effect of the market in a variety of scenarios.

Keywords: Spot market, simulation platform, evaluation index, operation analysis.

1. Introduction

Since the 1980s, various countries in the world have carried out market-oriented reforms in the power industry, aiming at improving the competitiveness of the market and establishing a power market in which all the links of generation, transmission, distribution and sale can compete freely [1],[2],[3]. The establishment of the market can break the bottleneck of industry development under the vertical integration structure, improve production efficiency, reduce overall production costs, and realize the optimal allocation of resources [4].

The construction and development of power market is not achieved overnight. Because the reform of power market involves the stability and security of power grid structure, the market-oriented reform has brought great challenges to the smooth operation of power system. At the beginning of the century, for example, the prices of wholesale electricity in California electricity market rose sharply, a large number of distribution companies were on the verge of bankruptcy, and the power system was once paralysed, resulting in huge economic losses. Such failure experience has warned us that electricity, as the pillar of the national economy and the people's livelihood, can tolerate little difference. On the basis of scientific research and demonstration, the construction of the electricity market needs to undergo a rigorous simulation deduction before it can be put into actual market use.

The research on power market simulation derivation can be traced back to the 1980s, from the initial simple demonstration system to the current multi-mode, joint market simulation software and productized market simulation analysis system. From the functional orientation of simulation deduction, these software and systems for power market simulation deduction research can be divided into research experiment type and enterprise product type [5],[6],[7],[8],[9],[10],[11],[12]. The main classification is shown in the figure 1. Among them, the simulation platform mentioned in this paper, drawing on the existing research foundation, has been independently developed and classified into the field of scientific research.
2. Platform Construction

Due to space limitation, the specific process of platform construction is no longer introduced in detail. In brief, the preliminary construction of the experimental platform includes the following aspects:

- The establishment of operation simulation environment, including physical model access, market model access, grid operation data access;
- The deductive environment configuration, including market commodity composition configuration, transaction rules configuration, transaction timing configuration;
- Clearing algorithm; Including day-ahead market and real-time market.

The business function framework of experimental platform is shown in figure 2. The experimental platform can be used to process and access data, obtain a variety of functional services, and implement simulation and deduction.

Figure 1. Classification of existing simulation platforms.

Around the economic benefits of users, there has been an evaluation of the wholesale competitive market in the early 21st century[13],[14] In the retail market, cost and benefit are the subject of index evaluation [15][16]. Based on the existing research, this paper focuses on the market structure and economic benefits of a provincial spot market in China, and carries out index research.
3. Evaluation Index Design

In a broad sense, the market operation effect can be evaluated from different perspectives. The operation evaluation of electric power spot market mainly focuses on the comparative evaluation of market structure, market economy, power grid security, social welfare and other aspects. In this paper, through research and analysis, a reliable evaluation system will be established to objectively and fairly evaluate the operation effect of the spot market in various market scenarios.

3.1. Market Structure Index

It mainly represents the composition of market participants to reflect the monopoly of the market. It is the most commonly used index for all aspects of market evaluation.

3.1.1. Herfindahl-Hirschman Index. HHI, i.e., the relative concentration of transactions, is mainly used to measure the concentration of the market. In mature markets, in order to reflect the fairness and competitiveness of the market, the transaction shares of each member in the market should be decentralized rather than centralized. In markets with high concentration, the price of the market is easy to be manipulated by market members with large transaction shares. The calculation formula of the relative concentration of transactions is:

$$C_{HHI} = \frac{1}{T} \sum_{t=1}^{T} \sum_{i=1}^{N_t} \left( \frac{Q_i^t}{\sum_{i=1}^{N_t} Q_i^t} \right)^2$$  \hspace{1cm} (1)

Where: $C_{HHI}$ is the relative concentration of transactions in the electricity market all day, $Q_i^t$ is the volume of transactions of bidding unit $i$ in period $t$, and $N_t$ is the number of bidding units in period $t$. If the $C_{HHI}^t$ of the continuous trading cycle increases, it shows that this clearing method will lead to
the increase of market share, the deterioration of monopoly and the increase of market power of a few power generation enterprises.

3.1.2. Market bid winning rate. The winning rate of market bidding reflects the degree of market competition. When there are many market participants, there is a possibility that some market members can't trade at last, which is a reasonable phenomenon of market trading. Excessive bidding rate will make the market lose vitality, there is the possibility of price monopoly, too low bidding rate will make the competition too fierce, there is the possibility of malicious competition. The calculation formula of market bidding winning rate is as follows:

$$\lambda = \frac{1}{T} \sum_{t=1}^{T} \left( \sum_{i=1}^{N^w} \frac{Q^g_i}{B^g_i} \right)^2$$

(2)

Where, \( \lambda \) is the bid winning rate of the declared electricity in the whole day of the market, \( N^w_t \) is the number of bidding units traded in the period \( t \), \( N^b_t \) is the number of units participating in the market bidding, \( Q^g_i \) is the trading power of bidding unit \( i \) in the period \( t \), \( B^g_i \) is the total declared power of bidding unit \( i \), the smaller \( \lambda \) is, the more intense the competition in the power market.

3.2. Market Economy Index

Market economy index is used to reflect the economic attributes of transaction scale and transaction price. Market economy index is the most intuitive one that can reflect the trading results of the platform. Market economy index includes total transaction amount and average transaction price.

3.2.1. Market average price. Market transaction price is the core issue concerned by all parties. In a fully competitive market, transaction price should be slightly higher than the cost of market members. Reasonable transaction price can effectively promote the healthy development of the market, while unreasonable transaction price often reflects the imperfect transaction system. In the spot market, the transaction prices of each market member and each period are different, so the average market price is used as the evaluation index of the overall market price level. The average market price is calculated as follows:

$$\bar{p} = \frac{\sum_{t=1}^{96} \sum_{i=1}^{N^w} p^g_{i,t} \times Q^g_{i,t}}{\sum_{t=1}^{96} \sum_{i=1}^{N^w} Q^g_{i,t}}$$

(3)

Where: \( p^g_{i,t} \) is the transaction price of unit \( i \) in period \( t \) and \( Q^g_{i,t} \) is the transaction quantity of unit \( i \) in period \( t \).

3.2.2. Blocking surplus. Blocking surplus refers to the trading surplus caused by the transmission resistance plug. The existence of grid congestion will result in significant differences in the price of electricity at each node. Thus, there is a difference between the fees charged by the system operator to the load side and the fees paid to the power generation side. The difference between the two is the blocking surplus. The calculation of the blocking surplus is as follows:

$$M_{\text{block}} = \frac{1}{4} \left( \sum_{t=1}^{96} \sum_{j=1}^{M^w} p^l_{j,t} \times Q^l_{j,t} - \sum_{t=1}^{96} \sum_{i=1}^{N^w} p^g_{i,t} \times Q^g_{i,t} - \sum_{t=1}^{96} \sum_{k=1}^{P^w} p^k_{k,t} \times Q^k_{k,t} \right)$$

(4)

Where, the total selling cost of the system is the sum of the product of the active power \( Q^l_{j,t} \) of all load bus nodes in the province and the electricity price of the node; the total purchasing cost of the system is the sum of the product of the output \( Q^g_{i,t} \) and the electricity price of all the units in the unified dispatching in each period, plus the sum of the product of the tie line output \( Q^k_{k,t} \) and the electricity price of each period; the total blocking surplus \( M_{\text{block}} \) is the difference between the total selling cost and the total purchasing cost.
3.2.3. Social welfare. In economic theory, the social welfare of industry is equal to the sum of consumer surplus plus producer surplus. Consumer surplus refers to the difference between the highest price consumers are willing to pay for a certain amount of goods and the actual market price of these goods. Producer surplus refers to the additional benefit to producers due to the difference between the minimum supply price of production factors and products and the current market price. Therefore, social welfare is equal to the sum of the differences between the buyer and the seller on the value judgment of the same commodity.

Because in this simulation case, the demand side does not bid, so this paper calculates the social welfare from the perspective of the generator. According to the definition of producer surplus, its calculation formula is as follows:

$$R_s = \frac{1}{4} \sum_{i=1}^{96} \sum_{l=1}^{N^w} (p_{i,l}^g \times Q_{i,l}^g - \sum_{l=1}^{L} b_{i,l}^g \times S_{i,l}^g)$$

Where, $R_s$ is the producer surplus, $b_{i,l}^g$ is the quotation of section $l$ of unit $i$, $Q_{i,l}^g$ is the declared power of section $l$ of unit $i$, and $L$ is the maximum number of declared segments specified by the market.

4. Simulation Example

In order to verify the availability of the platform and the rationality of the evaluation indexes, two sets of data are selected for simulation, which are typical autumn day and typical summer day. Based on the electric power spot market model and operation rules of a province in China, we simulate the process of market member declaration, transaction clearing and revenue calculation in the actual electricity spot market, in which the declaration data of market members is generated based on the estimated cost plus profit margin.

The basic rules of the simulation deduction are as follows:

- In the simulation system, there are 221 generator units, 973 loads and 23 connecting lines for power transmission with other areas.
- The generator adopts the form of multi-stage quotation. With the increase of output, the price increases, reflecting the scarcity of resources; in addition, market members test the market price by gradually raising the quotation, the first few quotations are low, to ensure the basic winning power, and then increase the quotation to seek more profits. As shown in Figure 3.
- Demand-side does not bid.
- Clearing time is 96 time periods (by every 15 minutes)
- Settlement adopts unit combination considering safety constraints and full-capacity clearance of economic dispatch (excluding price difference contracts), takes the lowest generation cost as the optimization objective, and adopts the bidding mode of power plant on the grid side.
- Set the price by the locational marginal price (LMP).
Based on the load data and clearing rules, the platform simulation can get the following results.

**Table 1.** Evaluation index data.

| Index list                      | Autumn day   | Summer day   |
|---------------------------------|--------------|--------------|
| HHI                             | 2.657x10^{-2} | 1.767 x10^{-2} |
| Market bid winning rate         | 1.499x10^{-1} | 2.990x10^{-1} |
| Market average price            | 2.932x10^{2}  | 5.070x10^{2}  |
| Blocking surplus                | 1.462x10^{7}  | 2.219x10^{8}  |
| Social welfare                  | 5.118x10^{7}  | 1.636x10^{8}  |

5. **Analysis**

From the results, we can see that the typical day in autumn has higher HHI index and lower Market bid winning rate index than that in summer. Meanwhile, The Market average price, Blocking surplus and Social welfare indexes of autumn days are significantly lower than that of summer days.

In terms of market structure index, it is not difficult to know that this is because the load in autumn is relatively small, as shown in table 2, which does not cause serious congestion. So the lower cost generating units can be cleared without restriction. Therefore, in the final clearing results, the winning power is concentrated in the lower cost units, which makes HHI index higher and Market bid winning rate index lower.

In terms of market economy index, because the autumn day’s power is smaller, the response of the actual line blocking is less. As a result, the blocking component in LMP is greatly reduced, which makes the final LMP close to the system energy price, so the Market average price in autumn is lower, which also reduces the blocking surplus and the social welfare of the generating units.

**Table 2.** Comparison of two typical daily loads.

|                           | Autumn day | Summer day |
|---------------------------|------------|------------|
| Total load power(MW)      | 4.086x10^{6} | 5.348 x10^{6} |

In addition, in the clearing result, the load with the highest and lowest average LMP, as well as the most typical nodes, are shown as figure4 and 5. In summer, the load node with the highest average LMP is 82, the node with the lowest price is 316, and the load node closest to the weighted price of the whole system node is 105. In autumn, the corresponding node location is 702,221 and 98.
Figure 4. Typical node full time price chart in summer.

Figure 5. Typical node full time price chart in autumn.

It can be seen from the results that for some nodes, due to their special location, the LMP will reach a special peak in a specific period of time, which also makes the average LMP in the whole period increase. It should be noted that in autumn, due to less congestion in the whole network, the price curve of the lowest price point is basically the same as the weighted price curve of the whole system.

6. Conclusion

Based on the load data of typical load days in summer and autumn, the operation simulation of spot market is carried out. According to the experimental deduction results, the market operation results and power grid characteristics under different experimental scenarios are analyzed and compared. The results show that in summer, the index represented by market average price is significantly higher than that in autumn day, which is consistent with the historical data of seasonal difference of power consumption in this area, which proves that the deduction results of the platform can adapt to the current grid characteristics.

Compared with the existing indexes, the evaluation index proposed in this paper can reflect the data concerned by the current engineering situation more systematically. In order to describe the engineering situation in more detail, it is necessary to further explore the evaluation indexes.

The results show that the evaluation index designed in this paper can reasonably evaluate the operation effect of the market in a variety of scenarios.

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