Research on Medium and Long-term Power Market Operation Risk Analysis and Risk Management Suggestions Based on Big Data Analytics

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Abstract. With the acceleration of China's electricity market reform process, the number of market entities, transaction types, transaction frequency and scale in each provincial power market have increased significantly. In order to deal with the operational risks of the medium- and long-term power market, this study adopts risk identification and quantification methods based on big data analytics, and builds multiple power market operational risk analysis models by exploring the correlations among massive transaction data. Based on the research results, combined with the investigation and collection of relevant information, this study carried out the assessment of medium- and long-term market operation risks in Province A, and put forward risk management suggestions for power market operating institutes based on the analysis results.

Keywords: Power Market Operational Risks, Big Data Analysis, Risk Modeling, Risk Management, Quantification Analysis.

1 Introduction

The reform and restructure of China's power market has been expediting since 2015, as the depth and breadth of the reform continue to increase, the degree of domestic electricity marketization has deepened and market operation risks have also increased[1]. Effective electricity market risk analysis and management methods are urgently needed to ensure a steady and smooth market development.

China's power market operating institutes include system operators and power trading institutes (Power Exchange Centers, PEC). The power market operation risk analysis in this paper is mainly conducted from the perspective of PEC. Electricity trading institutes are responsible for the market organization, provision of settlement services, entrance and exit management of market entities, and information disclosure. In the year of 2021, the National Development and Reform Commission issued "Notice on Further Deepening the Market-oriented Reform of Electricity Pricing for Coal-fired Power Generation", promoting all users above 10kV to enter the market. Since then, the scale of electricity market has grown explosively, and the transaction volume and frequency of electricity markets have also increased significantly. Correspondingly, PECs are facing increasing pressures and challenges.

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While ensuring the orderly operation of the market, they also need to deal with various risks brought by the expansion of market scale[2].

2 Risk Assessment of Medium- and Long-Term Power Market

2.1 Classification of Medium- and Long-term Power Market Risks

This paper focuses on the power market operational risks that can carry out quantitative data analysis. Therefore, risk categories that depend on qualitative analysis, such as policy risks and compliance risks, are not included in the scope of this study for the time being.

Based on the observation of Province A power market, this study takes references from multiple existing researches[3][4][5][6][7] and classifies power market operational risks into the following six categories: market power risk, supply and demand imbalance risk, price fluctuation risk, liquidity risk, renewable energy consumption risk and settlement deviation risk, see Figure 1.

Figure 1: Classifications of power market risks

(a) Market Power Risk. From the definition of economics, market power is the ability to cast influences on market prices. "Market power" refers to the ability of market members to manipulate market prices in certain ways due to their relatively large market share in a non-perfectly competitive market. In the early stage of market construction, it is especially necessary to manage market power risks and safeguard the legitimate interests of market entities, especially vulnerable entities. When analyzing market power risks, this study will focus on both the market concentration on the power generation side and the demand side.

(b) Supply and Demand Risk. Unlike other general commodities, electricity has a strong correlation with people's livelihood and the development of the national economy. A tight supply and demand will cause users to face load interruptions and economic losses. Regularly monitoring the supply and demand structure of the electricity market to ensure market capacity margin is one of the responsibilities of the power market operating institute.

(c) Market price fluctuation Risk. The price risk in the medium and long-term electricity market mainly comes from the long-term changes and overall trends in electricity supply costs and the supply-demand imbalance. Medium and long-term transactions include annual transactions, monthly transactions, intra-month transactions, etc. Power trading institutions need to pay close attention to market price changes and take timely risk prevention measures.

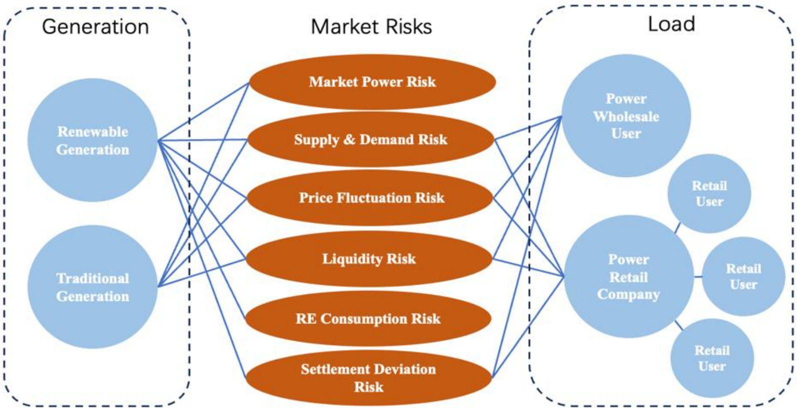

Figure 2: Power market risks mapping

(d) Liquidity Risk. Liquidity risk refers to the risk of failure to complete transactions due to insufficient market trading volume or lack of counterparties willing to trade. Liquidity risk in the power market is often caused by the combined effects of policies, prices, supply and demand, and other factors. When the volume of electricity traded in the mid- and long-term power market continues to decline, power trading institutions should pay attention to it.

(e) Power Settlement Deviation Risk. This index describes the deviation between the actual power settlement and the power purchase contract. When there is a large difference between the contract volume and real-time power consumption, defaults may occur, which will then affect other market entities and spread individual risks to the entire market. Market operating institute should regularly collect statistics on the power settlement deviations of all market entities, and improve their market participation ability through training and other means.

(f) Renewable Energy Consumption Risk. China officially proposed carbon peaking and carbon neutrality goals in 2020. Under this background, the consumption of renewable energy has gradually become an evaluation indicator to measure the healthy development of the local power market. Through data analysis methods such as the amount of feed-in renewable energy, the amount of consumed renewable electricity, and the proportion of renewable energy transactions, market operators can evaluate the greenness of the power market and clarify whether it has met the corresponding policy requirements.

The power market risk mapping is demonstrated in Figure 2, where the relationship between generation side and load side under risk anlysis is clearly depicted.

2.2 Application of Big Data Analysis in Risk Management

The concept of big data can be traced back to the 1980s[8]. Alvin Toffler compared big data to the cadenza of the future world in "The Third Wave". After entering the 21st century, with the rise of the Internet industry, big data has gradually become a popular buzzword. In the age of information, more and more industrial fields have begun to fully utilize big data analysis[9]. The characteristic of big data is summarized as ‘5V ’(volume, velocity, variety, value, veracity) ， which means large amount, high speed, diversity, value and authenticity. Compared with traditional data flow, big data describes a more complex and larger dataset.

As our production and life have become tightly bound to electronic devices and the Internet, our every move will be recorded in the form of data. This makes it more convenient to describe the behavior of individuals or organizations and predict future changes through data analysis. For example, in order to manage systemic risks, banks comprehensively evaluate people's credit solvency through multi-dimensional data such as asset size, income and expenditure, age, job, and even their home address. These risk management measures based on big data analysis provide sufficient reference for the development of the domestic electricity market.

From a functional perspective, big data analysis is divided into descriptive analysis, diagnostic analysis, predictive analysis and instructional analysis see Table 1.

Table 1 Types of Big Data Analysis Methods

	Basic Function	*Concrete Operation*
Descriptive analysis	Find out "What happened"	Identifying patterns and links by utilizing recent and historical data.
Diagnostic analysis	Explain "Why did it happen"	By applying data drilling and data mining to investigate the root cause of trends.
Predictive analysis	Forecast "What will happen"	Creating statistic models to find patterns and predict future outcomes.
Instructive analysis	Provide "What actions shall be taken"	Combining descriptive analysis, diagnostic analysis and predictive analysis to make informative suggestions.

When conducting power market risk management, the ultimate target is to inform the market operators the potential risks and possible control measures. By collecting as much historical data as possible and applying trend analysis based on risk modeling, analysts are able to provide systematic answers to the four questions above and help market operators insure the steady functioning of local power market. Multiple researches have applied the idea of big data analysis in the prosess of evaluating power market operations[10][11][12].

2.3 Quantitative Analysis

The data possesed by PECs include market scale, transaction volume, market price, power settlement, etc. By building interactive relationships between massive amounts of data, we can discover the information hidden behind the data and identify market risks in advance.

According to the risk classification in Section 2.1 and the basic ideas of big data analysis described in Section 2.2, this study uses the following indicators to model and analyze market operation risks, so as to provide a reference for PEC on market risk evaluation and precaution.

(a) HHI Index. The HHI index, also known as the Herfindahl-Hirschman Index, is a comprehensive calculation method that measures industry concentration. It is a commonly used model for market power analysis, see formula (1).

$$HHI = \sum_{i=1}^{N} (100 \times x_{i,share})^2 \ (1)$$

In the formula, N is the number of power generation groups in the power market, and $x_{i,share}$ is the market share of the i-th power generation group. Market share is calculated using installed capacity, the installed capacity is an average value based on the evaluation period.

$$x_{i,share} = \frac{p_i}{P} \ (2)$$

Where p_i is the installed capacity of the i-th power generation group, and P is the total installed capacity of the market. The larger the HHI index is, the higher the market concentration is and the higher the degree of monopoly. When there is sufficient competition in the market, the HHI index is closer to 0.

(b) Top-m Index. The Top-m indicator is used to characterize the market concentration of the top m market entities on the supply side. When quantifying the market power risk, market operators often address this indicator to evaluate the potential of unfair competition. Equation (3) is quoted below to describe Top-m index.

$$\mathrm{Top} - \mathrm{m} = \sum_{i=1}^{m} x_{i,share} \ (3)$$

In power market, regulators normally care about the market share of the top 4 generation entities, when measurement results are higher than 65%, operators shall raise awareness of the market power risk.

(c) Market Activity Indicator. The market activity indicator is used to describe the frequency of power market transactions. Similar to the stock market, the turnover rate of stocks reflects the liquidity of the entire market and the willingness of entities to participate in market transactions. This paper calculates the market activity indicators by using equation (4).

$$M_{act} = \frac{Q_{trade}}{Q_{settlement}} \ (4)$$

Where Q_{trade} represents the market-based transaction volume during the evaluation period, $Q_{settlement}$ is the realized power consumption during the evaluation period. When $M_{act} \leq 1$, it means that there may still be some planned electricity volume in the market; when $M_{act} > 1$, it means that part of the electricity has been traded in multiple lots, and the larger the value of M_{act}, the higher the degree of marketization process.

(d) Comprehensive Deviation Rate of Power Settlement. This indicator is used to describe the difference between the market entity's settled electricity volume and the contractual electricity volume, see equation (5). For electricity retail companies, the comprehensive deviation rate of settled electricity volume is calculated by the equation below:

$$D_{stm} = \sqrt{\frac{\sum_{i=1}^{n} (x_i - C_i)^2}{n}} \ (5)$$

Where D_{stm} is the comprehensive deviation rate of settled electricity, x_i is the actual settled electricity of the entity, C_i is the contractual electricity of the entity, and n is the total number of entities. When talking about electricity retail companies, n is the number of retail users it represents, When the subject is a wholesale user, n equals to 1.

(e) Medium- and Long-term Supply-demand Ratio. This index is created to reflect the balance between supply and demand in the electricity market, see equation (6).

$$R_{S-D}=\frac{P_{market}}{L_{market}}\times 100\% \quad (6)$$

Where P_{market} represents the market-oriented installed capacity, L_{market} represents the market-oriented load level.

(f) RE consumption rate. This indicator describes the consumption rate of renewable energy under the background of "Double Carbon" target. Similar to the US RPS market, the Chinese government has set a consumption rate for each province every year. To avoid policy incompliance, PECs need to dynamically evaluate the 'greenish level' of the market.

$$\mu_{RE}=\frac{\sum_{i=1}^{m}Q_{RE}^{i}+\sum_{i=1}^{m}Q_{RE.dis}^{i}}{Q_{consumption}}\times 100\% \quad (7)$$

The indicator is modeled in equation 7, where Q_{RE}^{i} represents the quantity of renewable energy consumed through market transaction of user i, $Q_{RE.dis}^{i}$ represents the consumption of distributed renewable energy of user i, and $Q_{consumption}$ is the total electricity consumption of the entire market.

(g) Fluctuation of Wholesale Electricity Price. This indicator is used to measure the fluctuation of mid- and long-term power transaction prices in the wholesale market, as is described in equation (8):

$$R_{f}=\frac{P_{m}}{P_{m-1}}\times 100\% \quad (8)$$

Where P_m is the average wholesale price in Month m, and P_{m-1} is the average wholesale price in Month m-1.

2.4 Data Preparation

Table 2 Data Acquisition in the Process of Market Risk Analysis

Data Preparation Before Proceeding Analysis

Data Name	Covered Entities	Cover Time Periods	Volume
Installed Capacity	All generation company	NA	213 pieces
Transaction Prices	All wholesale and retail users	Jan 2023 – Oct 2023	6,500+ pieces
RE Feed-in Volume	All RE generation company; End users with distributed RE generation	Jan 2023 – Oct 2023	12,600+pieces
Power Settlement Volume	All RE generation companies and wholesale/retail users.	Jan 2023 – Oct 2023	45,000+pieces
Contractual Volume	Wholesale and retail users.	Jan 2023 – Oct 2023	3,500+pieces
Number of Entities	All Entities	Jan 2023 – Oct 2023	3,900+pieces
Intra-Provincial Transaction	NA	Jan 2023 – Oct 2023	10 pieces

Power exchange centers possess large amount of power market related data, including the number of market entities, installed capacity, power consumptions, contract status, transaction price, etc. These data are currently highly discrete. Due to the lack of in-depth information mining, it is difficult to provide systematic risk analysis for PECs.

Through investigating the medium and long-term market-related data in Province A, this paper selects appropriate evaluation indicators discussed above, and uses big data analysis methods that consider time series to deeply explore the correlation between massive data in the power market. To conprehensively describe the real operation status of power market in Province A, this paper acquired relavant data of the most recent 10 months, see Table 2. By applying data visualization techniques, the evaluation results can be clearly summerized.

2.5 Data Analysis Results

Through data analysis and visualization process, the risk assessment results of the medium and long-term power market in Province A are obtained.

2.5.1 Market Power Risk Analysis

By processing the monthly changes in the installed capacity scale on the power generation side and the power procurement scale on the demand side in Province A, the mid- and long-term power market concentration ratio in Province A is concluded in Figure 3. The HHI index on the power generation side in Province A fluctuates between 1100-1300, and between 400-500 on the user side. According to the U.S. Department of Energy's evaluation standard, when HHI <1000, the market is fully competitive; when HHI is in the range of 1000-1800, the market is moderately concentrated; when HHI>1800, the market is highly concentrated. Based on the calculation results, the market power risk on the power generation side in Province A is moderate, while the user side is in full competition condition. A fully competitive environment on the user side should be maintained, more entities on the power generation side should be appropriately introduced, and market power risks should be reasonably managed and controlled.

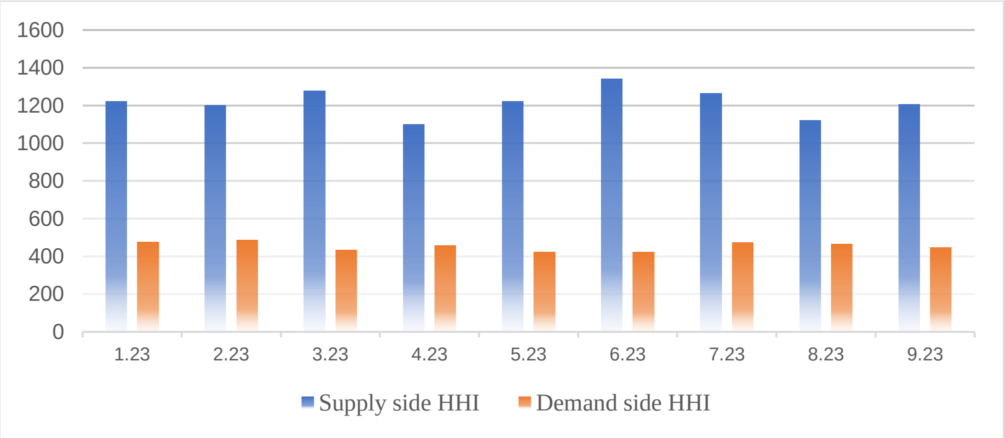

Figure 3: Supply and demand side HHI index

2.5.2 Medium- and Long-term Supply-Demand Analysis

Judging from the medium- and long-term supply and demand ratio analysis results, province A has relatively tight power supply in summer and winter, see Figure 4. Due to the existence of cooling and heating demands, the load of Province A in summer and winter is relatively high. On the other hand, because of high penetration of wind power in Province A, the system adjustment ability is poor, causing the supply-demand ratio to approach warning values. In this context, combined with the advancement of the domestic "carbon peaking and carbon neutrality" target, the proportion of energy storage installed capacity should be increased, and the demand-side response capability should be strengthened to alleviate the seasonal tight supply and demand ratio in the mid- and long-term market.

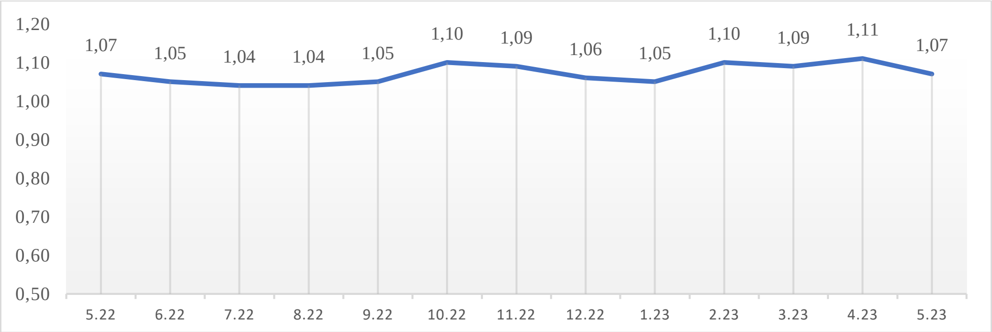

Figure 4: Supply-demand ratio in Province A for the past 1 year

2.5.3 Price Fluctuation in Wholesale Market

From the perspective of mid- and long-term electricity prices, this study analyzed the electricity price data of 12 most recent transactions organized by Province A since February 2023, as shown in Figure 5.

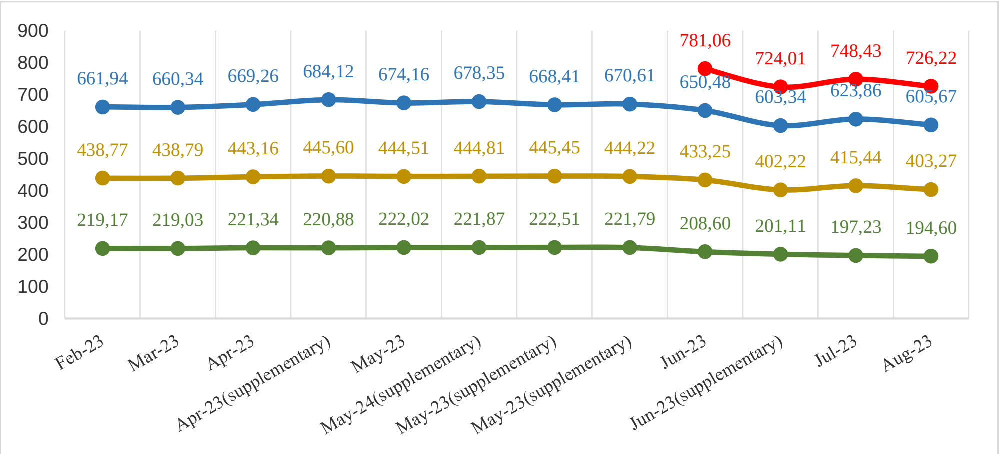

Figure 5: Electricity wholesale price fluctuation in Province A

The overall trend of electricity prices is relatively stable, with the maximum fluctuation rate of electricity prices no larger than 7%. Based on trend analysis, the market price risk in Province A is relatively controllable.

2.5.4 Market Activity Analysis

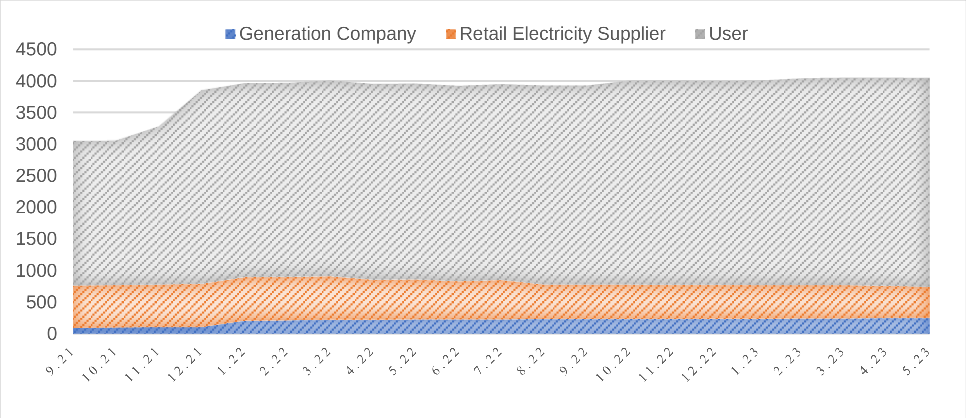

Figure 6: Changes of market entities from Sep 2021

In terms of market activity, this study analyzed the entrance and exit of electricity market entities in Province A since September 2021, and compiled the charts as shown in Figure 6. Since the release of Document No. 1439 in October 2021, it can be seen that the scale of the electricity market in Province A has significantly expanded. Among all the market players, the number of electricity users entering the market has grown the fastest, with an increase of nearly 40%. Since then, the number of electricity sales companies in Province A shows a slow downward trend, the total number of entities shows a slow upward trend, and market activity is relatively stable.

2.5.5 Revenue Analysis on Power Retail Companies

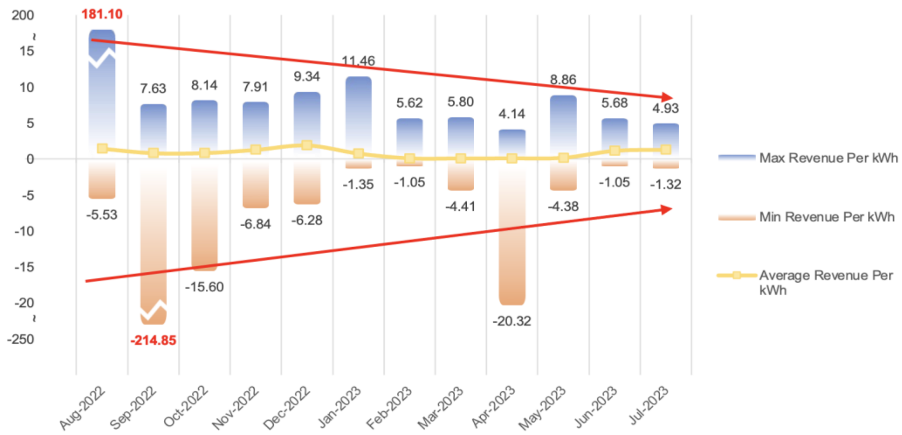

Figure 7: Revenue analysis of power retail company in Province A

This study also analyzes the income of electricity sales companies in Province A in the past year. As market entities gradually become more familiar with the supply and demand relationship and market rules in the province, the phenomenon of excessive arbitrage or serious losses is gradually decreasing, see Figure 7. The income situation gradually converges and stabilizes. In this process, it is also accompanied by the reshuffling and restructuring of market entities. Electricity retail company that cannot adapt to the reform of power market are gradually replaced by those who can master key market information.

2.5.6 Power Settlement Deviation Analysis

Lastly, this study also conducted in-depth analysis of the settlement deviation of market entities in Province A. By sorting out more than 45,000 pieces of data, the chart was drawn in Figure 8. The horizontal axis represents the absolute value of the deviation of the settled electricity volume compared to the medium- and long-term contractual electricity volume. The vertical axis represents the number of market entities. It can be concluded that there are still a considerable number of market entities whose settlement deviations are quite large. To deal with this situation during electricity settlement, market operating institutes may conduct professional trainings for entities and improve their load forecasting capabilities.

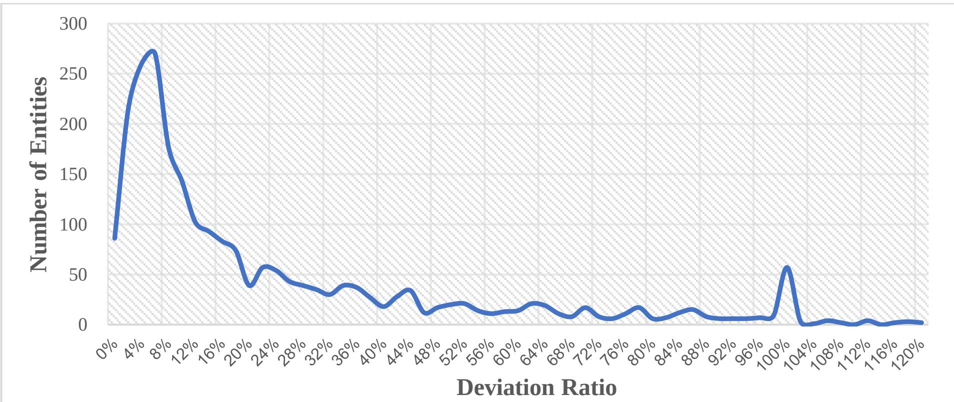

Figure 8: Distribution of power settlement deviation ratio in Province A

Furthermore, to better understand individual performance in power market of Province A, this research also analyzed the settlement deviations of every power retail company, see Figure 9. The horizontal axis represents the number of bonded retail users, while the vertical axis represents the deviation ratio of power settlement. It can be observed that the deviation of Company A has reached 176%, which may cause serious default risk. In this situation, market operators may send alarm to entities and provide market training as soon as possible.

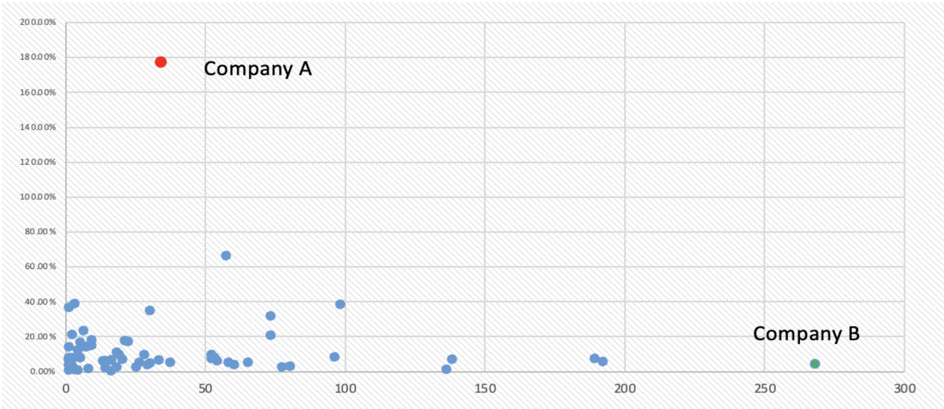

Figure 9: Power settlement deviation of individual power retail company

3 Suggestions on Risk Management for Power Market Operators

Table 3 Summerization of Power Market Risks

Risk Type	Risk Sources	Risk Management Measures
Market Power Risk	Change in Market Shares	Testing market power; Improving Market rules; Introducing multiple entities.
Supply & Demand Risk	Demand growth; Penetration of renewable energy	Increasing system capacity; developing demand response scheme.
Price Fluctuation Risk	Market power; Participant behaviors	Introducing price caps and floors.
Market Activity Risk	Low marketization degree	Improving market rules.
RE Consumption Risk	Lack of RE generation; Lack of flexible resources	Increasing RE generation; Developing energy storage.
Settlement Deviation Risk	Low accuracy of demand forecasting	Providing market training.

The smooth functioning of electricity markets is critical to maintaining stable energy supplies. However, market operating institutions face various challenges in managing market power risks, supply and demand risks, price risks, etc. This paper aims to provide more specific and scientific suggestions to help market operators manage these risks more effectively and ensure the sustainability and stability of the entire power market. Based on the risk classification and in-depth mining and analysis of market operation data in described in Table 3, the risk management recommendations for power trading institutions in this study are as follows.

Faced with multiple factors such as penetration of renewable energy, lack of flecxible resouces, change in market shares, it is necessary to develope a risk control scheme and dynamically update. As per summerized in Table 3, when dealing with various of medium- and long-term power market risks, market operators shall clearly enumerate the risk sources through data analytics and explore as much control measures as possible.

For market power risks, testing techiques such as replacing bidding price shall be introduced. In order to ensure fair competition in the market, a strong regulatory agency shall be established and the diversified development of the power generation side should be continued, such as distributed new energy, energy storage, virtual power plants and other new types of power generation.

The price caps and floors are set to regulate the total revenues that power generation companie can charge for services. This measure is suitable for the early stage of power market when entities are relatively immature. On the other hand, It is recommended that market operating agencies continue to optimize information disclosure, improve the transparency of market information, and ensure that market participants can obtain data on market prices and demand in a timely manner.

With the development of local power market, various of financial derivatives can be gradually introduced to help market entities to hedge the price risks. This is also a powerful measure to reduce the motivation of market participants to exercise market power.Besides, regular revision of market rules is strongly suggested to manage market operational risks. Under extreme circumstances, instead of using clearing results, market operator shall intervene or even terminate power market to protect interests of all parties.

4 Conclusions

This paper conducted research on the identification, analysis, prevention and control of power market operational risks under the background of the rapid advancement of China's power market construction. With the help of big data analysis methods, this study conducted an in-depth exploration of the medium and long-term power market data of Province A. By establishing multiple risk analysis models, this research discovered the interactive relationships between massive power transaction data, then evaluated the current operating status of the power market in Province A, and eventually made corresponding risk management suggestions. In the future, as China's electricity market continues to evolve and improve, big data analysis will play a greater role in ensuring the stable operation of the market. Provincial electricity market operating institutes like PECs should raise their awareness on market data analysis and establish professional market risk analysis platform to improve data mining and integration capabilities to detect and intervene risks in a timely manner.

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