Risk Warning System of Market Power Monitoring in Electricity Market

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Abstract. The electricity market is involved in a large number of stakeholders, the risk is complex, and the market power will exacerbate the crisis after openness of the electricity market. If regulators can build the electricity market risk warning system in advance, they can detect risk signals in advance and take effective measures to avoid electricity power crisis. This paper focuses on building the electricity market power risk warning system. Thus, we firstly establish a set of indicators that can reflect the electricity market risk condition scientifically, and then estimate the threshold value of risk indicators by using the VaR method based on GARCH model. The risk warning system with five levels of signals is proposed by using the estimated VaR values of the indicator under different confidence, and it is validated to be feasible and effective. Finally, some measures are proposed to respond to different types of risk warning.

1. Introduction

With the electricity market reform, the electric trade has become more and more efficient. However, at the same time, regulators face greater challenges. How to effectively regulate the electricity market and ensure more competition is a difficult problem. The emergence of market power increases the electricity price, reduces the overall efficiency, and aggravates the problems of high peak price and power crisis. Reasons for the risk of market power are various, if the power regulator can establish the risk early warning system of the power market force in advance, the power crisis can be avoided in time and effectively. In the process of monitoring the market force, the risk signals are found in advance and effective measures are taken with an effective risk warning system.

Thus, we establish a set of indicators that can reflect the electricity market risk condition scientifically, and propose the risk warning system with five levels of signals by using the estimated VaR values of the indicator under different confidence. Finally, some measures are proposed to respond to different types of risk warning.
2. Literature review

2.1. Research on electricity market monitoring
Existing emerging markets have shown that their monitoring and oversight are necessary because market outcomes are not always competitive due to related structural problems and design flaws. Lakic et al. (2017) establish the importance of market monitoring for the electricity market and present market power detection techniques which have been proposed in literature with detail review of the tools which could be used in monitoring units of organised electricitymarket places such as power exchanges. Up to now, several literatures have proposed effective market monitoring indicators. Bajpai and Singh (2019) introduce a forward-looking market monitoring system to monitor India's electricity market with a new set of market monitoring indices.

2.2. Research on the risk of electricity market
There have been some achievements in the electricity market risk research, mainly focusing on risk management, risk control and risk assessment. On the basis of Woo et al. (2003), Collins (2002) analyses the operational risks of power grid companies in the competitive electricity market, and establishes the risk assessment index system. Qin et al. (2019) analyze the risk of transaction participants from three aspects, including risk analysis of power generation companies, power sales companies and power users.

2.3. Research on the risk warning of electricity market
The research on the risk warning of the electricity market is mainly based on the construction of the risk warning system and the quantitative study of the fluctuation risk of the price of electricity. For example, Huang et al. (2009) build the price risk early warning model of electricity market based on generalized autoregressive conditional heteroscedasticity and value-at-risk theory. Qin et al. (2019) design a pricing model for distribution information services and show that future research should focus on risk quantification methods. Viktorija et al. (2019) study the regulatory rules of market transparency that can be applied to the wholesale electricity market and the frequency voltage control market under the WEB-OF CELL (WOC) decentralized power control architecture.

Among the literatures, there is more qualitative research on the risk of electricity market, and the quantitative research is mainly about the risk of price fluctuation. However, the risk of price fluctuation cannot represent all the electricity market risks. Therefore, this paper first selects several market risk warning indicators from three aspects, and then estimate the threshold value of each risk indicator by using the VaR method based on GARCH model. Finally, some measures are proposed to respond to different types of risk warning.

3. Construction of market power risk warning system in electricity market

3.1. Electricity market risk warning indicator system
In the electricity market, the participants may violate market rules. There are also acts that do not violate market rules but are directly or potentially harmful. These, then, are the main areas of concern. Pinczynski and Kasperowicz (2016) give a scientific assessment of some existing market forces index. Based on Qin et al. (2019), the market force risk warning index system is built from three aspects, including market structure, market conduct and market performance.

| Table 1. Indicators for early risk warning of market power |
|----------------------------------------------------------|
| **Indicators**                                           |
| market structure                                        |
| Herfindahl-Hirschman index (HHI)                         |
| Residual supply index                                    |
| Market share of supplier $i$                             |
| market conduct          | Declare capacity retention        |
|------------------------|----------------------------------|
|                        | Margin unit formation rate       |
|                        | Report high price ratio          |
|                        | Report high price success rate    |
| market performance     | Market clearing price deviation (CPD) |
|                        | Market clearing price distribution index (CPDI) |
|                        | Lener index                      |

Hertlndahl-Hirschman Index (HHI) measures the market share of the largest \( m \) suppliers in the market.

\[
HHI = \sum \left( \frac{MWH_i}{\text{Total}_c} \times 100 \right)^2
\]

\( \text{Total}_c \) is the total electricity generation while the \( MWH_i \) is generation of \( i \) company.

The residual supply index refers to the proportion of the total demand in which the total supply of other suppliers is insufficient to meet the total market demand except this supplier.

Market share of supplier \( i \) is calculated by estimating the share of company \( i \)’s electricity generation.

Declare capacity retention is equal to generator's generating capacity minus actual declared capacity and then divided by the generator's generating capacity. Margin unit formation rate means the proportion of the total time of the total bidding period for a certain one. Report high price ratio is the proportion of times the market supplier reports the price near the highest in a certain period of time.

Report high price success rate is equal to the number of applying high-price strategies and reporting successfully divided by the number of applying high price strategies in a period of time. Lener index is the ratio of gross profit to price.

The market clearing price deviation (CPD) and market clearing price distribution index (CPDI) can be calculated as follows.

\[
CPD = \sqrt{\frac{\sum_{i=1}^{L} (MCP_i - \text{AvgMCP})^2}{L}}
\]

\[
CPDI = \frac{CPD}{\text{AvgMCP}} \times 100\%
\]

\( MCP \) is the market clearing price. \( \text{AvgMCP} \) means average market clearing price. \( L \) means the number of LMP (locational marginal prices or spot prices) locations.

In conclusion, ten indicators from three aspects are selected to measure the electricity market power risk. The weight of each index can be determined by the AHP method.

### 3.2. The VaR method based on GARCH model

The threshold of the monitoring indicator is very important. Before that measure the risk may occur is necessary, the VaR is the most common method.

\[
P(\Delta P > \text{VaR}) = 1 - \alpha
\]

\( P \) is probability, \( \Delta P \) usually means the loss value of the asset at a certain period of time, \( \text{VaR} \) is value at risk under the confidence level \( 1 - \alpha \).

Most of the fluctuations of electricity market information do not obey the independent homoscedasticity hypothesis or the normal distribution, so the conditional variance is generally used to describe the dynamic changes of elements. Therefore, the autoregressive conditional heteroscedasticity (GARCH) model is more suitable. Equation (5) is the GARCH(p,p) model.

\[
\sigma_i^2 = \alpha_0 + \alpha_1 \varepsilon_{i-1}^2 + \cdots + \alpha_p \varepsilon_{i-p}^2 + \beta_1 \sigma_{i-1}^2 + \cdots + \beta_p \sigma_{i-p}^2
\]
If both the index value and the error term of the mean value equation obey t distribution, the following formula can be used to calculate the relative VaR value in the GARCH model:

$$VaR_t = \rho_{t-1} \tau_{\alpha} \sigma_t$$  \hspace{1cm} (6)

where $p_{t-1}$ is the indicator in last period; $\tau_{\alpha}$ is the quantile of the t-distribution, $\sigma_t$ is conditional standard deviation of GARCH model.

LR test can be used to test the validity of the estimation of VaR value.

$$LR = -2 \ln \left[ \left(1 - \alpha \right)^N \left( \alpha \right)^{N-N} \right] + 2 \left[ \left( \tau_{\alpha} / \sqrt{T} \right)^2 \left( \alpha / \sqrt{T} \right) \right]$$  \hspace{1cm} (7)

$T$ is the sample size. $N$ is the number of failures. $(1 - \alpha)$ means the confidence level. If the null hypothesis is correct, it can be proved that the likelihood ratio LR follows the $\chi^2$ distribution with 1 degree of freedom.

3.3. The warning signals for electricity market monitoring

VaR value at different confidence levels can be used as the boundary value of different warning levels. The international community usually uses five colors -- red, orange, yellow, blue and green -- to represent the levels of different risks in the market, which correspond to the more high, high, medium, low and more low risk levels respectively.

4 Case analysis

4.1. Data collection and statistical analysis

The US PJM market’s day-ahead hourly locational marginal pricing is updated hourly. The data from January 1, 2020 to December 31, 2020 is chosen to simulation GARCH model and estimate the threshold value of indicators. Then, check the system of warning signals by using the day-ahead energy market locational marginal pricing data of US PJM market from January 1, 2021 to June 16, 2021. Because some of the data is not available, CPDI is taken as an example. Anyway, the analysis of other indicators is exactly the same.

Table 2. The statistical characteristics of CPDI

|     | Obs. | Mean | S.D. | Min. | Max. |
|-----|-----|------|------|------|------|
|     | 8761| 0.256| 0.248| 0.000| 2.387|

Figure 1 shows the time trend of CPDI, the cluster effect (that is, a large fluctuation is often accompanied by a large fluctuation, and a small fluctuation is often accompanied by a small fluctuation) is glaringly obvious.
4.2. Tests of CPDI

The result of augmented Dickey-Fuller test of CPDI is reported in Table 3. The probability is 0, which means the sequence of CPDI is highly persistent time series.

Table 3. Augmented Dickey-Fuller test of CPDI

| Test statistic | 1% critical value | 5% critical value | 10% critical value | Prob. |
|---------------|-------------------|-------------------|-------------------|-------|
| Z(t)          | -25.537           | -3.43             | -2.86             | -2.57 | 0     |

Secondly, the serial correlation of the residual is tested. The Durbin-Watson d-statistic is 1.999956, which is close to 2. Therefore, we can assume that the residuals of the sequence of CPDI do not have serial correlation.

Thirdly, the autoregressive conditional heteroscedasticity is tested. The results of LM test accept the autoregressive conditional heteroscedasticity, which can be also proved by Figure 2 and Figure 3.

Finally, by comparing the kernel density estimation of CPDI with the normal density from Figure 4, the kernel density estimation of CPDI has sharp peak and thick tails, especially on the right side. The normal distribution cannot properly describe its characteristics.
4.3. VaR calculation of CPDI
From the above, GARCH model with t-distribution is appropriate. GARCH(1,1) model is chosen according to AIC and HQIC criterion. By using 8760 day-ahead energy market locational marginal pricing from US PJM market, the parameters of the GARCH(1,1) model is estimated.

The conditional variance of the GARCH(1,1) model is predicted, as well as the value of VaR. Table 4 shows the estimation for VaR of CPDI at different level of confidence.

| Confidence level | Mean  | S.D.  | Min.  | Max.  |
|------------------|-------|-------|-------|-------|
| 0.99             | 0.071 | 0.158 | 0.000 | 2.800 |
| 0.95             | 0.050 | 0.112 | 0.000 | 1.980 |
| 0.9              | 0.039 | 0.087 | 0.000 | 1.543 |
| 0.8              | 0.032 | 0.070 | 0.000 | 1.247 |

The validity of the estimated VaR values is tested in two ways, namely the failure rate and the LR test. It is failure when the real indicator is greater than the maximum of the value at risk. In table 5, there are number of failures and failure rate at different level of confidence, and the failure rate is less than 1.5%. Thus, this estimation method based on GARCH model is effective.

| Confidence level | Number of failures | Failure rate (%) | LR    |
|------------------|--------------------|------------------|-------|
| 0.99             | 0                  | 0                | -     |
| 0.95             | 12                 | 0.137            | 420.97|
| 0.9              | 45                 | 0.5137           | 887.55|
| 0.8              | 98                 | 1.1187           | 1815.87|

4.4. The early warning signal system
The estimated VaR values of CPDI under different confidence can be used as threshold value, the index interval can be divided into five categories and each category represents a degree of risk. The details are indicated in Table 6.
Table 6. The early warning signals

| Signals | Risk interval |
|---------|--------------|
| Red     | $(\max VaR_{99, 0}, +\infty)$ |
| Orange  | $(\max VaR_{95, 0}, \max VaR_{99, 0})$ |
| Yellow  | $(\max VaR_{90, 0}, \max VaR_{95, 0})$ |
| Blue    | $(\max VaR_{85, 0}, \max VaR_{90, 0})$ |
| Green   | $(-\infty, \max VaR_{85, 0})$ |

Then, by using the LMP data of US PJM market from January 1, 2021 to June 16, 2021, the early warning signal system is checked. There are 4008 observations from January 1, 2021 to June 16, 2021, and it displays 71 warnings of red light, 48 warnings of orange light, 67 warnings of yellow light, and most of them are in green light.

Table 7. The number of warnings under the early warning signal system

| Signals | Red | Orange | Yellow | Blue | Green |
|---------|-----|--------|--------|------|-------|
| January | 0   | 0      | 1      | 4    | 734   |
| February| 69  | 28     | 30     | 45   | 500   |
| March   | 0   | 5      | 5      | 9    | 749   |
| April   | 0   | 4      | 7      | 15   | 670   |
| May     | 2   | 7      | 14     | 17   | 704   |
| June(16 days) | 0 | 4 | 10 | 19 | 356 |
| Total   | 71  | 48     | 67     | 109  | 3713  |

The US PJM market fluctuations in February with 69 warnings of red light, 28 warnings of orange light, 30 warnings of yellow light. This results are consistent with the evidence that the severe snowstorm hit the United States in February which caused a massive power outage. Thus, the estimation threshold given by our warning system is basically reasonable.

4.5. Response and measures for risk warning

Different warning response measures are developed according to different risk levels of the electricity market.

The yellow warning shows that there is a mild risk in the electricity market and risk-averse countermeasures can be taken. The risk events should be taken into consideration, as well as the risk subject, risk factor, risk object, state of risk. Stop implementing various programs which may cause risk loss. Also check that what is the potential loss if the risk event occurs and how much it will be? It is to reduce the possibility of risk occurring, or reduce the possibility of loss, such as pure preventive measures and protective measures. Some plan of risk mitigation strategies can also be prepared in advance.

The orange warning shows that there is a moderate risk in the electricity market, measures which can avoid risk or mitigate the risk will be appropriate. The risk-averse countermeasures is the same as the yellow warning response. The risk mitigation means that some protective measures can be taken to reduce the possibility of risk occurring.

The red warning shows that there is a high risk in the electricity market, which requires immediate measures to reduce the risk. Measures should be taken to control and defuse market risks through control response and diverting response. The control response measures combine the risk-averse
countermeasures of the yellow with the measures of orange warning. The transfer response is to take the appropriate measures to pass the risk loss through the legitimate channels or to the other parties that are relevant to the relevant parties.

5. Conclusions
The risk warning system of market power monitoring is indispensable after openness of the electricity market. This paper focuses on building the market power risk warning system of electricity market.

Firstly, the indicator system is established which can reflect the electricity market risk condition scientifically. The system includes ten indicators from three aspects.

Secondly, taking one indicator CPDI as an example, using the US PJM market’s day-ahead hourly locational marginal pricing date from January 1, 2020 to December 31, 2020, the threshold value of CPDI based on the VaR method and GARCH model is estimated. The risk warning system with five levels of signals is proposed by using the estimated VaR values of the indicator under different confidence, and it is validated to be feasible and effective by a different set of relatively new data from January 1, 2021 to June 16, 2021.

Finally, some measures are proposed to respond to different types of risk warning. Measures of control response and transfer response can be taken when the red alert is issued and measures of risk-averse and risk mitigation can be taken when the orange warning signal appears.

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