Multi-dimensional risk assessment of electricity market based on cloud model

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Abstract. Aiming at various potential risks in the electricity market, this paper establishes a risk assessment index system for the electricity market from four dimensions of structural risk, operation risk, fairness risk, and behavioral risk. The analytic hierarchy process is used to determine the subjective weight of risk evaluation indicators, and the entropy method is used to determine the objective Weight, according to the least squares optimization idea to get the comprehensive weight. Then, the basic theory and calculation method of cloud model are introduced, and the standard cloud of risk level evaluation is constructed. Finally, the analysis of a calculation example shows that the risk evaluation level of the selected regional electricity market is moderate, which verifies the validity and feasibility of the model proposed.

1. Introduction
The electricity market will be affected by multiple factors in the operation process. The fluctuation of market factors, such as interest rate, exchange rate, stock price, commodity price, will lead to the risk of asset value change of electricity market participants [1]. As the counterparts fail to fulfill their due debts, it will threaten the trading process of the electricity market [2]. The main way to solve this problem is to establish a set of market evaluation index system suitable for the actual demand [3], and carry out risk assessment on fair competition and stable operation of the market. Based on the previous research results, the risk evaluation index of electricity market is established from the aspects of structural risk [4-5], operation risk and price risk, which involves multiple indicators such as supply-demand balance, new energy access, price fluctuation, quotation behavior, information disclosure[6-8].

In the study of comprehensive evaluation, the methods to determine the index weight can be generally divided into subjective evaluation method and objective evaluation method. Subjective evaluation method includes analytic hierarchy process [9], fuzzy evaluation method [10], and objective evaluation method includes entropy weight method [11] and TOPSIS method [12]. Cloud model can realize the uncertain transformation between qualitative concept and quantitative description, which is widely used in risk assessment, data mining and other fields, and is very practical in solving the evaluation of random and fuzzy problems. It is not difficult to find that the randomness and fuzziness of electricity market risk are not considered in the evaluation of electricity market risk. Therefore, the multi-dimensional risk assessment cloud model of electricity market is constructed to analyze the risk level in this paper.
2. Electricity market risk assessment index system
Following the principles of independence, systematicness, comprehensiveness and acquirement, the electricity market risk assessment index system is established from the four dimensions of structural risk, operational risk, fair risk and behavioral risk, including ten indicators in total.

| First level index | Second level index | Third level index | Type    |
|-------------------|--------------------|-------------------|---------|
| Electricity market risk | Structural risk B1 | Supply demand ratio C11 | Reverse index |
|                    |                    | Proportion of new energy installed capacity C12 | Positive indicators |
|                    |                    | Market concentration C13 | Reverse indicators |
| Electricity market risk | Operational risk B2 | Lerner index C21 | Positive indicators |
|                    |                    | Electricity price volatility C22 | Positive indicators |
|                    |                    | Reserve ratio C23 | Reverse index |
|                    |                    | Unfair degree of annual base contract of coal fired units C31 | Positive indicators |
| Fair risk B3       |                    | Unfair degree of peak valley power distribution C32 | Positive indicators |
| Behavioral risk B4 |                    | High bid winning ratio C41 | Positive indicators |
|                    |                    | Quotation consistency C42 | Positive indicators |

2.1. Risk index of electricity market structure
(1) Supply demand ratio. The ratio of supply and demand is the ratio of electricity supply and demand, which can be used to measure the supply and demand of electricity in medium and long-term market, and can directly reflect the competition between supply and demand in electricity trading.

(2) Proportion of new energy installed capacity. In the process of development and utilization of new energy, the problems such as the disconnection of planning, the difficulty of transmission and consumption, and the abandonment of wind and light and water are emerging.

(3) Market concentration. The index of market concentration can be measured by the sum of squares of the market share of each power generation enterprise, and the market share can be expressed approximately as the proportion of electricity consumption.

2.2. Risk index of electricity market operation
(1) Lerner Index. The Lerner Index represents the relative level of the average electricity price above the average marginal cost.

(2) Electricity price volatility. Price is the core content of market transaction and operation. If the price level is too high or too low or fluctuates greatly, it will have a significant impact on the safe and stable operation of the electricity market.

(3) Reserve ratio. Reserve capacity ratio, referred to as reserve rate, refers to the ratio of reserve capacity to peak load.

2.3. Fair risk index of electricity market
(1) Unfair degree of annual base contract of coal fired units. The annual base energy of coal-fired units accounts for the largest proportion in the grid connected electricity structure of power generation companies, and its completion consistency is one of the main embodiment of dispatching fairness.

(2) Unfair degree of peak valley power distribution. The more base power is allocated in the peak period, the less competitive power is reserved and the profit opportunity is reduced.

2.4. Behavioral risk index of electricity market
(1) High bid winning ratio. The index reflects the situation that the power plant can not only raise the declared price, but also get close to the declared electricity quantity. It also reflects the match between the bidding strategy of power generation enterprises and their own strength.
(2) Quotation consistency. Quotation consistency is an index to identify the quantity guarantee of "collusion". The probability of the same or similar price quoted by the market subject is low. The index of quotation consistency can directly reflect the collusion behavior of the quotation subject.

2.5. Standardization of indicators
The bigger the positive index is, the higher the risk level of electricity market is, and the bigger the reverse index is, the lower the risk level of electricity market is.

\[ x_{mn}' = \frac{x_{mn} - x_{mn}^{\min}}{x_{mn}^{\max} - x_{mn}^{\min}} \]  
\[ x_{mn}' = \frac{x_{mn}^{\max} - x_{mn}}{x_{mn}^{\max} - x_{mn}^{\min}} \]  

Where, \( x_{mn} \) is the value of the index n; \( x_{mn}^{\min} \) and \( x_{mn}^{\max} \) is the minimum and maximum value.

2.6. Determination of index weight

2.6.1. Analytic hierarchy process.
Analytic hierarchy process (AHP) uses the idea of pairwise comparison, the importance degree is expressed by the scale of 1-9 and its reciprocal.

\[ A = (a_{ij})_{n \times n}, a_{ij} = \frac{1}{a_{ji}} \]  

2.6.2. Entropy weight method.
According to the data of the index, the original matrix is constructed, and the entropy \( e_n \) and weight of the index n are calculated as follows:

\[ e_n = -\frac{1}{\ln(q)} \sum_{m=1}^{q} \frac{P_{mn}'}{\sum_{m=1}^{q} P_{mn}'} \ln\left(\frac{P_{mn}'}{\sum_{m=1}^{q} P_{mn}'}\right), k > 0, q = 1, 2, \ldots, n \]  
\[ g_i = 1 - \frac{e_j}{m - E} = \frac{1 - e_j}{m - \sum_{j=1}^{m} e_j} \]  
\[ w_j = \frac{g_i}{\sum_{j=1}^{m} g_i} \]  

2.6.3. Comprehensive weight.
In order to reduce the deviation between subjective weight and objective weight, the proportion coefficient of weight is determined by least square optimization:

\[ w_n = \alpha w_n + (1 - \alpha) w_{n,j} \]  
\[ \min F = \sum_{j=1}^{m} \left[ (w_n - w_n) + (w_n - w_{n,j}) \right]^2 \]
Where, $\alpha$ is the weight coefficient; $W_{n,i}$ represents the subjective weight of the index $n$; $W_{n,j}$ represents the objective weight of the index; $F$ represents the minimum objective value.

3. **Cloud model of electricity market risk assessment**

3.1. **Basic theory of cloud model**
Cloud model combines probability theory with fuzzy mathematics, comprehensively considers the internal relationship of randomness and fuzziness. Let $U$ be the universe of discourse, $T$ be the qualitative description of $U$, and $x$ be the numerical representation of $U$. For $\forall x \in U$, there is a membership degree $\mu_i(x)$ with clear tendency corresponding to it. The distribution of $x$ on the universe $U$ is cloud, and $x$ is cloud droplet.

3.2. **Cloud generator computing method**
According to different directions, cloud model calculation methods can be divided into forward cloud generator, forward cloud generator and reverse cloud generator.

Cloud droplets of risk assessment are generated to the cloud generator

- Random number $Ex'$ obeys normal $N(En, He^2)$ distribution.
- Random number $x$ obeys normal $N(Ex, En'^2)$ distribution.
- Degree of membership $\mu_i(x) = e^{-\frac{(x-Ex)^2}{2(En)^2}}$.

Numerical characteristics of cloud clusters generated by reverse cloud generator:

- Expectations $Ex = \frac{\sum_{i=1}^{n} x_i}{n}$.
- Entropy $En = \sqrt{\frac{\pi}{2} \frac{1}{n} \sum_{i=1}^{n} |x_i - \bar{x}|}$.
- Super entropy $He = \sqrt{S^2 - En^2}$, among it, $S^2 = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}$.

3.3. **Building evaluation level standard cloud**
According to reference [7], the risk level of electricity market can be divided into five levels, and the standard cloud of electricity market risk assessment is generated by using forward cloud generator.

$$
Ex_i = \begin{cases} 
0, & i = 1 \\
\frac{L_{\min} + L_{\max}^i}{2}, & i = 2, 3, 4 \\
1, & i = 5
\end{cases} 
$$

(9)

$$
En_i = \frac{L_{\max}^i - L_{\min}^i}{3}
$$

(10)

$$
He_i = 0.01
$$

(11)
Where, $L_{i}^{\text{max}}$ and $L_{i}^{\text{min}}$ represent the upper and lower limits of the risk level interval. The five interval characteristics are C1, and the standard cloud is shown in Figure 1.

$$\left[\text{Ex}_{i}^{\text{inf}}, \text{En}_{i}^{\text{sup}}, \text{He}_{i}^{\text{inf}}\right] = \left[w_1, w_2, \ldots, w_n\right]$$ (12)

3.4. Integrated cloud computing method

According to the normalization weight and characteristic number of the third level index, the characteristic number of the second level index can be calculated.

4. Example analysis

Taking the electricity market in a certain region of China as an example, eight professors from power industry, trading center and university are invited to generate a questionnaire for experts to comment.

| Index                                | Data       | Subjective weight | Objective weight | Comprehensive weight |
|--------------------------------------|------------|-------------------|------------------|----------------------|
| Supply demand ratio C11              | 1.153      | 0.052             | 0.102            | 0.077                |
| Proportion of new energy installed capacity C12 | 20.2%     | 0.042             | 0.023            | 0.033                |
| Market concentration C13             | 0.052      | 0.074             | 0.101            | 0.088                |
| Lerner index C21                     | 0.201      | 0.102             | 0.093            | 0.098                |
| Electricity price volatility C22     | 0.154      | 0.152             | 0.086            | 0.119                |
| Reserve ratio C23                    | 1.286      | 0.075             | 0.114            | 0.095                |
| Unfair degree of annual base contract of coal | 0.285      | 0.162             | 0.098            | 0.130                |
fired units C31
Unfair degree of peak valley power distribution C32
0.157 0.221 0.184 0.203
High bid winning ratio C41
0.084 0.084 0.128 0.106
Quotation consistency C42
0.063 0.036 0.071 0.054

In order to use cloud model to evaluate the risk level of the regional electricity market, the eight experts mentioned above provide relevant information of the electricity market.

Table 4. Electricity market risk evaluation index value

| Index | One | Two  | Three | Four  | Five  | Six   | Seven | Eight |
|-------|-----|------|-------|-------|-------|-------|-------|-------|
| C11   | 0.85| 0.89 | 0.83  | 0.79  | 0.9   | 0.87  | 0.84  | 0.85  |
| C12   | 0.78| 0.8  | 0.76  | 0.81  | 0.79  | 0.83  | 0.8   | 0.79  |
| C13   | 0.4 | 0.37 | 0.42  | 0.41  | 0.39  | 0.36  | 0.4   | 0.38  |
| C21   | 0.53| 0.48 | 0.51  | 0.5   | 0.49  | 0.51  | 0.52  | 0.49  |
| C22   | 0.68| 0.7  | 0.73  | 0.69  | 0.67  | 0.72  | 0.71  | 0.73  |
| C23   | 0.44| 0.42 | 0.39  | 0.43  | 0.42  | 0.4   | 0.39  | 0.43  |
| C31   | 0.9 | 0.87 | 0.93  | 0.89  | 0.92  | 0.91  | 0.88  | 0.92  |
| C32   | 0.27| 0.31 | 0.29  | 0.3   | 0.28  | 0.29  | 0.32  | 0.32  |
| C41   | 0.85| 0.89 | 0.83  | 0.81  | 0.83  | 0.8   | 0.86  | 0.88  |
| C42   | 0.35| 0.39 | 0.32  | 0.34  | 0.35  | 0.37  | 0.31  | 0.3   |

Then, three digital features are generated according to the reverse cloud generator.

Table 5. Cloud digital characteristics of electricity market risk assessment

| First level                  | Second level                  | Third level | Index                       | Digital characteristics |
|------------------------------|--------------------------------|-------------|-----------------------------|-------------------------|
| Electricity market risk       | Structural risk B1            | Supply demand ratio C11 | (0.883, 0.056, 0.010) |
|                              | Weight: 0.197                 | Proportion of new energy installed capacity C12 | (0.780, 0.050, 0.013) |
| A (0.559, 0.048, 0.017)      | (0.668, 0.041, 0.009)        | Market concentration C13 | (0.439, 0.024, 0.007) |
|                              | Operational risk B2           | Lerner index C21     | (0.494, 0.060, 0.027) |
|                              | Weight: 0.311                 | Electricity price volatility C22 | (0.676, 0.047, 0.018) |
|                              | (0.540, 0.043, 0.017)        | Reserve ratio C23    | (0.415, 0.020, 0.007) |
|                              | Fair risk B3                  | Unfair degree of annual base contract of coal fired units C31 | (0.864, 0.047, 0.017) |
|                              | Weight: 0.332                 | Unfair degree of peak valley power distribution C32 | (0.228, 0.066, 0.028) |
|                              | (0.477, 0.058, 0.024)        | High bid winning ratio C41 | (0.789, 0.039, 0.011) |
|                              | Behavioral risk B4            | Quotation consistency C42 | (0.323, 0.063, 0.014) |
|                              | Weight: 0.160                 |                            |                            |
|                              | (0.630, 0.047, 0.012)        |                            |                            |

According to the digital characteristics of the first level indicators in Table 5, the forward cloud generator is applied to generate the electricity market risk assessment cloud and standard cloud, as shown in Figure 2. It can be seen that the span of evaluation cloud is inconsistent with the standard cloud, indicating that the evaluation result is fuzzy; the thickness of evaluation cloud is inconsistent with the standard cloud, indicating that the evaluation result is random. The evaluation results of electricity market risk level are close to moderate risk, and the highest membership degree is 0.559.
5. Conclusion
The pace of China's electricity market construction is accelerating, but affected by price fluctuations, supply and demand imbalance, information distortion and other factors, this paper proposes a multi-dimensional risk assessment of electricity market based on cloud model. Firstly, according to the potential risk of electricity market, the index system of electricity market risk assessment is established from the four dimensions of structure risk, operation risk, fair risk and behavior risk. In order to overcome the defects of subjective evaluation and objective evaluation, the least square optimization method is used to reduce the deviation between subjective weight and objective weight. Then, the cloud model of electricity market risk assessment is constructed, and the risk distribution level of electricity market is characterized by expectation, entropy and super entropy. Finally, the case analysis shows that the risk level of the regional electricity market is moderate.

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