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Risk assessment of contract execution in large consumer direct power purchase

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Abstract. Nowadays, China is steadily advancing the reform of the electricity market. The direct power purchase by large consumers, as an important form of which has the characteristics of large participation of renewable energy and huge trading power, has a very important impact on the stability of the power system. Therefore, it is necessary to carry out an effective risk assessment method on the bilateral user transactions of supply and demand side, and to reasonably control the risk factors that have greater risk. Direct power purchase by large consumers involve both sides of supply and demand and many possible risk factors. We construct the risk assessment index system from five aspects and the corresponding 17 second-level evaluation indexes are established as AHP method to evaluate the risk. In addition, after rating the risk factors, the weights are determined and the consistency is verified. The results show that AHP can balance the subjective and objective factors and determine the relative weight of each evaluation index. It can also calculate the subordination degree of risk index to each level of risk level and achieve the combination of qualitative and quantitative analysis so that the result of risk assessment is more scientific and accurate.

1. Introduction
Comppared with conventional power trading, the supply side of existing direct power purchase by large consumers has a relatively high proportion of clean energy. Clean energy is highly uncertain and is highly random and volatile. From the physical point of view, clean energy may be due to the impact of seasonal, climatic and geographical location, resulting in difficult to complete the contract provides the amount of electricity sold. From the economic point of view, the supply side cannot obtain the corresponding benefits as expected due to fluctuations in the price of electricity or trading volume, so that its economic interests are threatened and its willingness to trade is frustrated. The demand side also faces many problems. From the physical point of view, the demand-side users may be subject to a certain degree of default due to changes in policies, such as the government's mandatory suspension of work. From the economic point of view, demand-side users may threaten their production and operations due to fluctuations in electricity prices or trading power. Due to the volatility of economic interests, there are often situations in which supply and demand parties have the willingness to trade but with no progress. Even the signing of the power trading contract is completed,
there is no guarantee that both parties will perform. The physical risks and contract settlement risks of both supply and demand users affect whether contracts can be completed.

Risk assessment refers to quantify and assess the various aspects of the risk factors impacting on the transactions and the possibility of loss after or before risk events happened. According to the actual situation, the risk can be qualitative or quantitative analyzed, commonly used methods are: expert scoring method, Monte Carlo simulation method, sensitivity analysis and decision tree method [1]. Reference [2] applied AHP to engineering projects to achieve ranking of risk factors and evaluation of total system risk. Reference [3] evaluated the implementation effect of service strategy of power supply enterprises by using AHP method and obtained scientific evaluation results. Reference [4] established a power customer risk assessment model to further explore the application of data mining technology for power customer risk analysis. Reference [5] do the risk assessment from a social point of view and then establish a complete evaluation system. However, the previous studies did not take the uncertainties of both supply and demand users into account, including cost-benefit analysis, cost-utility analysis, and multi-objective system analysis. While used in this question, none of these methods have effectively combined the risks of the two sides of the supply and demand users.

In this paper, AHP is used to evaluate the risk of direct power purchase by large consumers. It is a decision-making method that combines qualitative and quantitative methods, which has a wide range of practicality and scientific. Risk assessment index conclude five aspects: natural risk, admission risk, credit risk, transaction risk and settlement risk, and the corresponding 17 second-level evaluation indexes are established as AHP method to evaluate the risk in direct power purchase by large consumers. In addition, after rating the risk factors, the weights are determined and the consistency is verified. Finally, the serious risks are supposed to be prevented according to the calculation results.

2. Basic steps of AHP
Analytic Hierarchy Process (AHP) is an analysis method proposed by the American operations researcher T. L. Saaty et al. in the 1970s [6, 7]. It decomposes the relevant factors of the decision-making problem into the target level, the standard level and the indicator level. It objectively quantifies people's subjective judgment with a certain scale and establishes a hierarchical model to calculate the relative importance of the underlying factors to the top-level model. Specific steps are as follows.

2.1. Establish a hierarchy model
Before setting up the model, we must first identify the risk factors and determine the overall goals and the impact factors on the target. Afterwards, the influencing factors are classified and the hierarchical structure model is established. The hierarchy is divided into three layers, according to the top, respectively, the target layer, guideline layer and index layer.

2.2. Construction of comparison judgment matrix
The judgment matrix represents the relative importance of each factor of this level under the constraints of the previous level. We generally use 1 to 9 and its reciprocal as the scale to build the judgment matrix. Judgment matrix can be constructed as followed:

$$
A = \begin{bmatrix}
a_{11} & a_{12} & \cdots & a_{1n} \\
a_{21} & a_{22} & \cdots & a_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
a_{n1} & a_{n2} & \cdots & a_{nn}
\end{bmatrix}
$$

among them, $a_{ji} = (a_{ij})^{-1}$. 

2.3. Check consistency
Theoretically, through the above definition, if matrix $A$ satisfies $a_{ij}a_{jk} = a_{ik}, i, j, k = 1, 2, ..., n$, then matrix $A$ is called the consistency matrix. However, in practice, a consistent matrix that satisfies the above equation cannot be constructed, and then the eigenvalues that require conversion to the largest absolute value of the matrix $A$ are not significantly different from the dimensions of the matrix. In this paper, we use the root method to calculate the maximum eigenvalue of the matrix [8]. Then use it to calculate the consistency ratio CR and a consistency of matrix $A$ should be tested. When $CR < 0.1$, it can be considered that the consistency of the judgment matrix is acceptable, on the contrary, the judgment matrix needs to be adjusted.

2.4. Total weight of the hierarchy
The total level of ranking refers to the relative weight of each factor of each judgment matrix to the target level. Assume that there are $m$ factors in the hierarchy model guideline and $n$ factors in the indicator tier. From the second step, the weight of the criterion layer relative to the target layer is $\omega^T = (\omega_1, \omega_2, ..., \omega_m)^T$; The weight of the $n$ factors of the indicator layer relative to the $j$th factor of the indicator layer is $\omega_j = (\omega_{j1}, \omega_{j2}, ..., \omega_{jn})^T$; The overall rank order of the target layer to the target layer is $\omega$.

3. Risk assessment model of direct power purchase by large consumers

3.1. Identification of risk factors
For power generation enterprises, it is difficult to accurately predict the amount of power generation due to natural factors. Changes in natural conditions will have an impact on the production and trading of electricity [9]. For wind, light and hydropower output, the size of the wind, cloudy and clear days, precipitation and seasonal changes will greatly affect the power generation, and these factors are not controllable. Due to this uncertainty, the three forms of power generation are less dominant in the electricity market. Before the power transaction delivery, taking into account the many factors of the electricity market, supply and demand situation may change. In the meantime, power generation enterprises across the country have different access requirements and relaxation of access conditions may be mixed with malicious competition. Therefore, in the direct transaction of large users, power generation enterprises are faced with two types of risks: natural and access risks.

For demand-side users, their credit will have a big impact on the direct transaction of large users. Changes in electricity reform policy, poor economic environment, market capacity constraints and other external factors that will affect the ability of electricity companies to fulfil their obligations. Second, credit risk for demand-side users is also affected by their production and operating conditions. The better the company's operating conditions, the higher the market share and the risk is relatively small. Demand side financial status reflects the level of operation and management of an enterprise and will have an impact on the development and competitiveness of an enterprise. It is mainly divided into solvency risk, profitability risk and development capability risk. Finally, the credit risk of the transaction exists on the demand side, mainly considering the default rate of electricity fee payment, the contracting rate of sales contract and the actual power deviation rate.

In the transaction process between both sides of supply and demand, they also co-exist transaction risk and contract settlement risk. Present transactions have a variety of modes, which will produce a series of different risks. As output and load are difficult to predict accurately, so before the delivery of electricity trading, transaction price and electricity prices may change which will have a direct impact on the completion of the transaction. Finally, after the direct transaction of large users is reached, the power generation enterprises are faced with the risk of contract settlement. The recovery of electricity tariffs by the power generation enterprises will be affected by the settlement patterns of bilateral users and the intention of implementation.
3.2. Build structure model of risk factors

According to 3.1, the structure of hierarchical model is shown in figure 1.

![Risk assessment hierarchy model of direct power purchase by large power customers.](image)

**Figure 1.** Risk assessment hierarchy model of direct power purchase by large power customers.

3.3. Construct judgment matrix

When constructing a judgment matrix, generally 1 to 9 and its reciprocal are used as scales, and the scale definition of nine scales are as shown in table 1:

There are methods for obtaining the scales of different factors, such as the extreme difference method, the extreme ratio method [10], the simple tabular method [11] and the expert scoring method. In the large customer direct transaction risk assessment, firstly we should determine importance of the impact of factors. The first few methods will complicate the issue and have little significance for the results. Therefore, expert scoring is used to solve the problem. The expert scoring method is not only easy to operate but also provides accurate data. Conduct research on different expert opinions and perform weighted averaging on the data obtained. Based on this, a judgment matrix $W_{A-B}$ can be set up to indicate the importance of the influencing factors in the criterion layer relative to the target layer.

| Scale of judgement | Definition                                                      |
|--------------------|----------------------------------------------------------------|
| $a_{ij} = 1$       | Element $i$ and element $j$ are equally important for the upper level factor |
| $a_{ij} = 3$       | Element $i$ and element $j$ are slightly important to the upper level factor |
| $a_{ij} = 5$       | Element $i$ and element $j$ are obviously important to the upper level factor |
| $a_{ij} = 7$       | Element $i$ and element $j$ are more important to the upper level factor |
| $a_{ij} = 9$       | Element $i$ and the element $j$ are absolutely important to the upper level factor |
| $a_{ij} = 2n, n = 1, 2, 3, 4$ | The importance of element $i$ and element $j$ is between $2n-1$ and $2n + 1$ |

$$W_{A-B} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{15} \\ a_{21} & a_{22} & \cdots & a_{25} \\ \vdots & \vdots & \ddots & \vdots \\ a_{51} & a_{52} & \cdots & a_{55} \end{bmatrix}$$ (2)
among them, \( a_{ij} \) represents the degree of importance of the layer B element i and the element j to the target layer A.

In the same way, we can construct the judgment matrix \( W_{B_1-C}, W_{B_2-C}, W_{B_3-C}, W_{B_4-C} \) and \( W_{B_5-C} \).

3.4. Calculate weight of each influencing factor and test consistency

The square root method is used to calculate the maximum eigenvalue of the matrix and the consistency of the judgment matrix constructed in 2.3 is checked. The specific steps are as follows:

### 3.4.1. Calculate the largest eigenvalue of the matrix \( \lambda_{\text{max}} \)

Calculate the weight vector for each factor:

\[
\omega = (\omega_1, \omega_2, \ldots, \omega_n)^T; \quad \omega_j = \sqrt[j]{\prod_{i=1}^{j-1} a_{ij}}
\]  

(3)

After normalizing \( \omega \), we will get:

\[
\omega = (\omega_1, \omega_2, \ldots, \omega_n)^T; \quad \omega_j = \frac{\omega_j}{\sum_{i=1}^{n} \omega_j}
\]  

(4)

From (2), (3), we can calculate the maximum eigenvalue of the matrix:

\[
\lambda_{\text{max}} = \sum_{i=1}^{n} \frac{(A\omega)_i}{n\omega_i}
\]  

(5)

\( (A\omega) \) represents the i-th element of \( A\omega \).

### 3.4.2. Find out the average random consistency index RI according to relevant data.

The average random consistency index RI is only related to the order \( n \) of the judgment matrix A, as shown in the following table 2 [12]:

| Order | RI   | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   |
|-------|------|-----|-----|-----|-----|-----|-----|-----|-----|
| RI    | 0    | 0   | 0.52| 0.89| 1.12| 1.26| 1.36| 1.41|
| RI    | 1.46 | 1.49| 1.52| 1.54| 1.56| 1.58| 1.59|

### 3.4.3. Calculate consistency ratio CR

\[
CR = \frac{CI}{RI}
\]  

(6)

specially, \( CI = \frac{\lambda_{\text{max}} - n}{n-1} \), \( n \) is the order of matrix A.

### 3.4.4. Total weight of the hierarchy

In the risk assessment model, there are five factors in the criteria layer, 17 indicators in the indicator layer, and the weight of the criterion layer relative to the target layer is \( T_{1,2,3,4,5} \). The weights of the 17 factors of the indicator layer relative to the j-th factor of the indicator layer are \( \omega_j = (\omega_{j1}, \omega_{j2}, \ldots, \omega_{j17})^T \) and the total ranking weight of the factors in the indicator layer relative to the target layer is [13]:

\[
\omega_i = \sum_{j=1}^{5} \omega_j \times \omega_i, i = 1, 2, \ldots, n
\]  

(7)

The total ranking of the level weights of the indicator layer on the target layer is:
\( \omega = (\omega_1, \omega_2, \ldots, \omega_{17})^T \)  \hspace{1cm} (8)

\( \omega \) represent the index layer of 17 factors relative to the target layer total weight of the final order.

4. Analysis of an example

Suppose that in a fair competitive electricity market environment, power generation company X and power purchasing company Y conduct free bilateral transactions and reach an agreement. The trading plan for the coming full year is the trading price \( P \) and the trading volume \( Q \). According to the large-user direct transaction risk assessment hierarchy model in 2.1, five experts in related fields are asked to score and determine the importance of the influencing factors. Make the results weighted average and then build judgment matrices as shown in figure 2:

![Figure 2. Judgment matrices.](image)

According to the above-mentioned alignment criteria and index layer, the factors affecting the factors are ranked by single rank, that is, the weight of each factor in the judgment matrix is calculated and they are tested for consistency. Table 3 shows that the matrix \( W \) satisfies the consistency requirements.

According to the rules of the total hierarchy, the project can be evaluated comprehensively and the importance of each factor relative to the target level can be calculated. Results are shown in table 4.

| Table 3. Matrix W single rank order and consistency test index. |
|-----------------|-----------------|-----------------|
| \( W \)         | Weights         | CI              |
| \( W_{A-B} \)   | (0.51 0.0636 0.1296 0.2638 0.0329)^T | 0.0530          |
| \( W_{B_1-C} \) | (0.0500 0.1178 0.2634 0.5638)^T    | 0.0438          |
| \( W_{B_2-C} \) | (0.1047 0.6370 0.2583)^T            | 0.0370          |
| \( W_{B_3-C} \) | (0.5638 0.1178 0.0500 0.2634)^T     | 0.0438          |
| \( W_{B_4-C} \) | (0.0550 0.5638 0.1178 0.2634)^T     | 0.0438          |
| \( W_{B_5-C} \) | (0.1047 0.2583 0.6370)^T            | 0.0370          |

Through the above table, it can be seen that the natural risks and the changes in electricity prices and electricity prices have a greater impact on project risks. When the supply side is clean energy, it is difficult to accurately predict the output. Therefore, when the natural conditions change, the output will also change, leaving the project some risk. For the transaction itself, both supply and demand users may have the intention to change the electricity price or power during the execution of the
transaction. This would make the actual transaction at the time of power delivery inconsistent with the forecasted transaction when signing the contract, and impact greatly on the process. At the same time, the risk factors can be rated according to their weights. The rating standards are shown in table 5 [14]. The risk factors in direct power purchase projects are classified into Type I (serious) and Type II (general) risks. While focusing on Type I risks, it should also give sufficient attention to Type II risks.

Table 4. Ranks of risk index system weights.

| First-level indicator | Weights | Secondary indicators | Weight | Total weight order |
|-----------------------|---------|----------------------|--------|--------------------|
| Natural risk          | 0.312   | Precipitation        | 0.361  | 0.1125             |
|                       |         | Wind size            | 0.315  | 0.0983             |
|                       |         | Weather conditions   | 0.174  | 0.0542             |
|                       |         | Seasonal conditions  | 0.150  | 0.0470             |
| Admission risk        | 0.175   | Changes in supply and demand situation | 0.487 | 0.0852             |
|                       |         | Market status        | 0.164  | 0.0287             |
|                       |         | Access conditions are relaxed | 0.349 | 0.0611             |
| Credit risk           | 0.203   | External environment | 0.102  | 0.0208             |
|                       |         | Production and management | 0.264 | 0.0535             |
|                       |         | Financial credit     | 0.486  | 0.0986             |
|                       |         | Trading credit       | 0.148  | 0.0301             |
| Transaction risk      | 0.256   | Trading mode selection | 0.052 | 0.0133             |
|                       |         | Transaction price changes | 0.461 | 0.1179             |
|                       |         | Turnover volume      | 0.361  | 0.0924             |
|                       |         | Output and load forecasting accuracy | 0.126 | 0.0324             |
| Contract settlement risk | 0.054  | Contract settlement | 0.404  | 0.0218             |
|                       |         | Deviation assessment and settlement | 0.596 | 0.0322             |

Table 5. Risk factors rating criteria.

| Risk level                  | Weight range       | Management attitude |
|-----------------------------|--------------------|---------------------|
| Type I (serious)            | 0.1 ≤ weight ≤ 1.0 | Highly protective   |
| Type II (general)           | 0.01 ≤ weight ≤ 0.1 | Enough attention    |

5. Summary
Steadily advancing power reform is an important part of the current wave of reform. Orderly promotion of direct power purchase by large consumers is the indispensable and important means. The transaction nowadays has large amounts of renewable energy, huge transaction volumes, and long-distance load centres. If the transaction happens unexpectedly, it will cause great losses. Therefore, it is necessary to conduct a reasonable and effective risk assessment method on this question.

There are few relevant literatures on risk assessment of direct power purchase by large consumers. The existing methods cannot effectively combine the risks of the two sides of supply and demand. In the power market, the establishment of a hierarchy of direct trading risks for large consumers can link the risks of the supply side and demand side users to the risks inherent in the transaction itself, making the considered risk factors more comprehensive. In addition, through the calculation of the weights of risk factors, the risks that need to be prevented can be rated, and precautions can be taken according to priorities.

Through the examples, it can be seen that the two sides of the supply and demand users have the most weight in the natural risk and transaction price changes, and the transaction risk is the second
highest. It shows that the change in natural conditions has the greatest impact on the trading of both users on the supply and demand side. Therefore, during the execution of the transaction, certain precautionary measures and countermeasures should be taken for this risk, such as preparing enough standby power in avoid of bad weathers’ effects. The transaction risk is mainly reflected in the forecast accuracy of output and load of both users. Therefore, in the calculation of the future output and load, a more scientific method should be adopted and more data collected in previous years, so that the final result is more in line with reality. At the same time, access risk, credit risk and contract settlement risk should not be ignored.

The research done in this paper fills the gap that there is no risk assessment for direct power purchase by large consumers in China. The research also has a positive reference meaning for the smooth promotion of the reform and can provide a theoretical reference for the subsequent direct power purchase, making it possible to develop faster and better.

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