Research on Operation Risk Prevention and Control Method of Multi-energy Complementary New Energy Power Generation System under Market Mechanism

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Abstract. The development of multi-energy complementary new energy generation system is of great practical significance in today's era when the demand for electricity is increasing and environmental protection is imminent. However, due to the limitation of external environment, internal technology and materials, the development of new energy system with multi-energy complementary energy is faced with many risks, which have a certain impact on its development. Risks cannot be avoided and will exist for a long time. Therefore, it is of great significance for the development of this system to correctly identify risks and evaluate them, and to propose corresponding countermeasures and focus according to the assessment results. This paper first analyzes and identifies qualitatively the risks faced by the new energy system under the market mechanism from the aspects of policy risk, transaction risk, market risk and operation risk. Then, the risk index database was established, and the risk of various aspects were presented side by side, and the main influencing factors of the risk were listed correspondingly. Next, risk assessment model is established through analytic hierarchy process and fuzzy comprehensive evaluation method, aiming to evaluate the above risks qualitatively. At the same time, a concrete example is introduced to apply and test the above model, and a constructive conclusion is obtained for the example, and the feasibility of the risk assessment model established in this paper is verified, which can be applied to risk assessment of other similar projects.

1. Operational Risk Analysis of Multi-energy Complementary New Energy Power Generation System

1.1. Policy risk
New energy projects in the aspect of policy risk mainly include: industrial policy support, industry system, wind power subsidies, slope subsidies, photovoltaic subsidies, photothermal subsidies, and energy storage subsidies, etc. [1].
1.2. Transaction risk
The transaction risks considered in this paper mainly include the risks existing in the purchase of wind power, photovoltaic, solar energy and energy storage, which can be measured by year-on-year growth rate of on-grid electricity price for wind power, photovoltaic, solar energy and energy storage.

1.3. Market risk
Market risks mainly include demand risks, tax risks, competition risks and financing risks. In terms of demand risk, new energy power generation projects not only face fierce competition from other new energy projects, but also have no competitive advantage in the terminal market because compared with traditional energy projects such as thermal power generation, new energy power generation technology is not mature enough and the cost is relatively high. In terms of tax risks, the tax amount of power generation enterprises is relatively large while the tax management work of power generation enterprises is still insufficient at present. Tax risks still exist due to various reasons, such as irregular accounting, imperfect internal control system and insufficient attention to tax issues in front-end business. The financing risk is mainly the risk of income changes caused by financing planning in the financing activities of new energy power generation projects, which is mainly measured by the project financing level of Banks and financial institutions [2].

1.4. Operational risk
Operational risks of new energy projects mainly include technology maturity, reliable power supply, equipment maintenance and operation safety, etc. Operational safety risks are major risks faced by new energy power generation projects and exist in various stages of the project. This section is mainly investigated through line overload rate, relay protection level and operation failure rate.

1.5. Other risks
Other risks in new energy power generation projects mainly include resource conditions, natural disasters and personnel safety. Natural risks should be considered at the beginning of planning and design of new energy power generation projects because they are more relevant to natural conditions. The equipment of new energy power generation is exposed to the outside, so the impact of natural conditions is much more severe [3]. Weather conditions such as storms and severe cold, geological conditions such as soil conditions and rock conditions, and natural disasters such as floods, earthquakes and tsunamis are all important risk factors for new energy power generation projects. Therefore, great attention should be paid to the impact of natural risks and appropriate measures should be taken to control risks at all stages of the project. The safety of personnel is the most important problem in engineering construction projects. Due to the complexity and huge construction of new energy power generation project, there are many construction personnel involved, and the equipment installation structure is very complicated, the technology is numerous and the precision requirements are high. Therefore, the safety standards are more strict than the general construction projects. [4]

2. Design of operation risk indicator system of new energy power generation system

2.1. Indicator design principles
(1) Principle of conciseness and scientficity.
The definition and design of indicators must be based on science, which can objectively reflect the various risks that may occur in the operation process of new energy power generation system, including the key factors that affect the operation of new energy power generation system. Indicators should have strict and clear definition, conform to the specification, relatively uniform caliber, easy to calculate, and need to avoid the tedious derivation and conversion of multiple steps.

(2) Principle of independence.
Each indicator should have a clear connotation, be independent of each other, and try to avoid information overlap. There is no correlation or direct causal relationship between indicators.
(3) Principle of combination of comprehensiveness and typicality.
Due to the large number and complex types of possible risks in the operation of new energy power generation system, which involve many aspects such as policies, transactions and markets, the selection of indicators should cover all dimensions of risks as far as possible to ensure that major risk factors are not omitted. At the same time, considering that most of the subdivision technology have limitations when dealing with high-dimensional data, in order to avoid "dimension disaster" problem and guarantee the comprehensiveness of indicator information, we should choose typical indicators which have a greater influence on the operation of new energy power generation system and filter out some minor factors in order to facilitate characterization of subdivision results while decrease the difficulty of segmentation.

(4) Principle of measurable.
The corresponding data of the operation of new energy power generation system on this indicator should be obtained from stable and reliable channels. In order to reflect the scientificity and rigor and avoid the influence of subjective and uncertain factors, it is necessary to select those indicators that can be obtained through quantitative calculation as much as possible, and reduce the proportion of qualitative indicators that are difficult to be quantified in the indicator concentration, so as to reduce the dependence on experts and improve the operability of segmentation variables.

2.2. Construction of operational risk indicator library

| Table 1. Operational risk indicator library |
|--------------------------------------------|
| **Policy risk**                            |
| Industrial support policy | The growth rate of new energy industry |
| Industry system | New energy industry standards |
| Wind power subsidy slope risk | Wind power subsidy price |
| Pv subsidy slope risk | Pv subsidy price |
| Photothermal subsidy risk | Photothermal subsidy price |
| Energy storage subsidy risk | Energy storage subsidy price |
| **Transaction risk**                       |
| Wind power on-grid risk | Year-on-year growth rate of feed-in tariff for Wind power |
| Pv on-grid risk | Year-on-year growth rate of feed-in tariff for Pv |
| Photothermal on-grid risk | Year-on-year growth rate of feed-in tariff for Photothermal |
| Energy storage on-grid risk | Year-on-year growth rate of feed-in tariff for energy storage |
| **Market risk**                            |
| Competition risk | Comprehensive electricity price of new energy power generation system |
| Demand risk | Year-on-year growth rate of power abandonment |
| Tax risk | Intensity of tax incentives |
| Financing risk | Project loan amount of various Banks and financial institutions |
| **Technology maturity**                    |
| Wind power conversion efficiency | Pv conversion efficiency |
| Photothermal conversion efficiency | Energy storage conversion efficiency |
| **Operational risk**                       |
| Power supply reliability | Wind power active power output volatility |
| Photothermal active power output volatility | Energy storage active power output volatility |
| Equipment maintenance | Damage rate of wind power equipment |
| Damage rate of photothermal equipment |
| Damage rate of energy storage equipment |
| Decay rate of Pv components |
| Decay rate of wind power components |
| Decay rate of photothermal components |
| Decay rate of energy storage components |
| Line load rate | Average time for fault isolation |
| **Operation safety**                       |
| Average time for fault isolation | Operation error rate |
| **Other risks**                            |
| Resource conditions | Technological exploitability |
| Natural disasters | Annual number of natural disasters |
| Personnel security | Equipment quality rating |
| Safety level | |
3. Design of Operation Risk Assessment Method for New Energy Power Generation System

3.1. Evaluation model

3.1.1. Analytic hierarchy process. Analytic hierarchy process (AHP) is an easy way to make decisions on some complicated and vague problems. It decomposes complex problems into several components, groups these components into hierarchical structure according to the dominant relationship, and obtains the relative importance of each factor through pairwise comparison. It is a qualitative, systematic and hierarchical analysis method. This section combines the subjective (ANP method) with the objective (entropy weight method) to combine and assign weights of indicators based on the anp-entropy weight method, so as to determine the weight of indicators. ANP can reflect the position of the evaluation subject, that is, according to experience and inference, subjectively reflect the importance of all levels of evaluation indicators to the business activities of electricity trading. However, due to its strong subjectivity, the weight obtained may be biased. Therefore, this project uses entropy weight method to objectively assign weight, calculate the weight of each index based on entropy weight to make up for the deficiency of ANP method[5]. Therefore, in this paper, the entropy weight method combined with ANP is adopted to obtain the comprehensive weight value:

Step 1: use the network analytic hierarchy process to calculate a group of weight values:
(1) Define program objectives, determine evaluation indicators and establish evaluation models.
(2) Construct comparison matrix. According to the importance degree between each of the two indicators, the positive integer 1-9 and its inverse are generally taken, as shown in the following table.

| The importance of indicator i to indicator k | Meaning                        | The importance of indicator k to indicator i |
|--------------------------------------------|--------------------------------|--------------------------------------------|
| 1                                          | i and k are equally important | 1                                          |
| 3                                          | i is slightly more important than k | 1/3                                         |
| 5                                          | i is significantly more important than k | 1/5                                         |
| 7                                          | i is more important than k     | 1/7                                         |
| 9                                          | i is extremely important than k | 1/9                                         |
| 2, 4, 6, 8                                 | Represents the intermediate value of two adjacent scales | 1/2, 1/4, 1/6, 1/8 |

(3) Calculate the maximum eigenvalue and the maximum eigenvector of the comparison matrix, and normalize the maximum eigenvector to be the weight of the metric.

(4) Consistency test. Firstly, calculate the consistency index according to the number of indicators n; then check the average random consistency index RI according to n; finally, calculate the consistency ratio. If CR<0.10, the consistency of the judgment matrix is considered acceptable; otherwise, the judgment matrix should be appropriately modified.

Step 2: Use the entropy weight method to find another set of weight values
(1) Suppose there are n regions to be evaluated, and each region includes m indexes. Set rij as the ith index of the jth region to be evaluated and form the original decision matrix $R = \left( r_{ij} \right)_{mn}$. Through data search. Normalize the original decision matrix $\hat{R}_{ij} = \frac{r_{ij}}{\sqrt{\sum_{j=1}^{m} r_{ij}^2}}$. (1)

(2) According to the definition of entropy, the entropy value of the ith index is calculated as:
\[ Q = \frac{1}{\ln n} \sum_{i=1}^{n} P_i \ln P_i \]  

\[ P_i = \frac{(1 + \hat{r}_i)}{\sum_{j=1}^{n} (1 + \hat{r}_j)} \]  

(3) Calculate the entropy weight of the ith index:

\[ \beta_i = \frac{1 - Q_i}{\sum_{i=1}^{n} (1 - Q_i)} \]

Step 3: Combine AHP and entropy weight method to calculate the comprehensive weight value

\[ A_i = \frac{\alpha \beta_i}{\sum_{i=1}^{n} \alpha \beta_i} \]

3.1.2. Fuzzy comprehensive evaluation method. From the above logic framework of risk assessment, it can be seen that most risks of new energy projects, such as natural disasters, operational risks, transaction risks and national policies, cannot be quantified, that is, there is a certain ambiguity. Fuzzy comprehensive evaluation is a method based on fuzzy mathematics, which quantifies some factors with unclear boundary and difficult to be quantified by applying the principle of fuzzy relation synthesis [6]. The general steps of fuzzy comprehensive evaluation are as follows.

(1) Determine the indicator evaluation factor U. Establish the evaluation index system of the evaluation object. Take the first layer factor set as \( U = \{u_1, u_2, u_3, \ldots, u_n\} \), the second layer factor set as \( U_i = \{u_{i1}, u_{i2}, u_{i3}, \ldots, u_{in}\} \).

(2) Determine the index evaluation grade V. The purpose of evaluation is to know the overall situation of new energy projects. Therefore, according to the evaluation index system, the establishment of corresponding comments that can reflect the actual situation of each index of new energy projects is the basis of comprehensive evaluation. We establish an evaluation grade \( V = \{\text{very large, general, not large}\} \) for the intensity index of tax incentives in this paper.

(3) According to experience, experts grade the degree to which each evaluation factor belongs to the evaluation level, then continuously improve it according to the actual effect, and finally determine the membership of factors. Let the ith factor in the evaluation factor U be expressed by \( r_{ij} \) for the membership degree of the jth rating in the evaluation level V, then the membership relationship of the factor \( u_i \) for the entire evaluation level set V can be expressed as \( R = \{r_{i1}, r_{i2}, r_{i3}, \ldots, r_{in}\} \). Next, we will synthesize the weight vector A and R to get the final comprehensive evaluation result vector B:

\[ B = A \circ R = [a_1, a_2, a_3, \ldots, a_n] \circ \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nn} \end{bmatrix} \]

A is the weight vector, \( a_i \) is the weight value of the ith index, and R is the fuzzy judgment matrix.

3.2. analysis of calculation examples
Based on the model proposed above, this section takes a multi-energy complementary new energy park as an example for case analysis. The planned area of the park is 100km² and the park's main energy sources include electrical load, cold load and heat load. In terms of electrical load, according to the load density plan, the final load of the park is 511MW. In terms of cold and hot load, according to the progress of investment promotion, it is expected to have a good growth in the future three years. To 2020, the park's largest hot load is 65 t/h and largest cold load is 3.2 t/h. The park has built a multi-energy complementary energy supply project mainly consisting of natural gas triple supply, photovoltaic power generation, electric vehicle charging station and water source heat pump. We evaluate the operation risk of the multi-energy complementary new energy generation system according to the evaluation model proposed in section 5.3.1.

Firstly, based on the limitations of data source and computing ability, the operational risk indicator library in section 5.2 is simplified to form the following simplified indicator system [7].

| Table 3. Operational risk indicator database |
|---------------------------------------------|
| **Policy risk (A)** | Industrial support policy (A1) | The growth rate of new energy industry (A11) |
| | Industry system (A2) | New energy industry standards (A21) |
| **Transaction risk (B)** | Wind power on-grid risk (B1) | Year-on-year growth rate of feed-in tariff for Wind power (B11) |
| | Pv on-grid risk (B2) | Year-on-year growth rate of feed-in tariff for Pv (B21) |
| | Photothermal on-grid risk (B3) | Year-on-year growth rate of feed-in tariff for Photothermal (B31) |
| | Energy storage on-grid risk (B4) | Year-on-year growth rate of feed-in tariff for energy storage (B41) |
| **Market risk (C)** | Competition risk (C1) | Comprehensive electricity price of new energy power generation system (C11) |
| | Demand risk (C2) | Year-on-year growth rate of power abandonment (C21) |
| | Tax risk (C3) | Intensity of tax incentives (C31) |
| **Operational risk (D)** | Technology maturity (D1) | Wind power conversion efficiency (D11) |
| | Equipment maintenance (D2) | Pv conversion efficiency (D12) |
| | Operation safety (D3) | Photothermal conversion efficiency (D13) |
| | Operation error rate (D31) | Energy storage conversion efficiency (D14) |
| **Other risks (E)** | Resource conditions (E1) | Damage rate of Pv equipment (D21) |
| | Natural disasters (E2) | Damage rate of wind power equipment (D22) |
| | Personnel security (E3) | Damage rate of photothermal equipment (D23) |
| | Equipment quality rating (E31) | Damage rate of energy storage equipment (D24) |
Construct a judgment matrix for each risk factor in the criterion layer of the indicator system by using the criteria in table 2, and then the corresponding weights are solved by using the method mentioned in 5.3.1 above. The solution values are as follows:

**Table 4.** Weights of three levels of operational risk

| Level 1                  | Level 2                                      | Level 3                                      | AHP weight | Entropy weight | Combination weight |
|--------------------------|----------------------------------------------|----------------------------------------------|------------|----------------|-------------------|
| Policy risk(A)           | Industrial support policy(A1)                | The growth rate of new energy industry(A11)  | 0.054      | 0.066          | 0.039             |
|                          | Industry system(A2)                          | New energy industry standards(A21)           | 0.047      | 0.064          | 0.033             |
| Transaction risk(B)      | Wind power on-grid risk(B1)                  | Year-on-year growth rate of feed-in tariff for Wind power(B11) | 0.105      | 0.035          | 0.040             |
|                          | Pv on-grid risk(B2)                          | Year-on-year growth rate of feed-in tariff for Pv(B21) | 0.102      | 0.032          | 0.036             |
|                          | Photothermal on-grid risk(B3)                | Year-on-year growth rate of feed-in tariff for Photothermal(B31) | 0.104      | 0.033          | 0.038             |
|                          | Energy storage on-grid risk(B4)              | Year-on-year growth rate of feed-in tariff for energy storage(B41) | 0.101      | 0.030          | 0.033             |
| Market risk(C)           | Competition risk(C1)                        | Comprehensive electricity price of new energy power generation system(C11) | 0.102      | 0.031          | 0.035             |
|                          | Demand risk(C2)                             | Year-on-year growth rate of power abandonment(C21) | 0.068      | 0.091          | 0.068             |
|                          | Tax risk(C3)                                | Intensity of tax incentives(C31)             | 0.045      | 0.062          | 0.030             |
| Operational risk(D)      | Technology maturity(D1)                     | Wind power conversion efficiency(D11)       | 0.114      | 0.103          | 0.128             |
|                          |                                              | Pv conversion efficiency(D12)               | 0.117      | 0.104          | 0.133             |
|                          |                                              | Photothermal conversion efficiency(D13)     | 0.113      | 0.098          | 0.121             |
|                          |                                              | Energy storage conversion efficiency(D14)   | 0.112      | 0.089          | 0.109             |
|                          | Equipment maintenance(D2)                   | Damage rate of Pv equipment(D21)            | 0.015      | 0.036          | 0.006             |
|                          |                                              | Damage rate of wind power equipment(D22)    | 0.019      | 0.075          | 0.016             |
|                          |                                              | Damage rate of photothermal equipment(D23)  | 0.013      | 0.068          | 0.010             |
|                          |                                              | Damage rate of energy storage equipment(D24)| 0.023      | 0.123          | 0.031             |
| Other risks(E)           | Operation safety(D3)                        | Operation error rate(D31)                   | 0.032      | 0.108          | 0.006             |
|                          | Resource conditions(E1)                     | Technological exploitability(E11)           | 0.028      | 0.132          | 0.040             |
|                          | Natural disasters(E2)                       | Annual number of natural disasters(E21)     | 0.029      | 0.133          | 0.042             |
|                          | Personnel security(E3)                      | Equipment quality rating(E31)               | 0.033      | 0.019          | 0.007             |
Thus, the combined weight values of various second-level indicators can be obtained, as shown in table 5, and the combined weight values of various first-level indicators can be obtained, as shown in table 6.

**Table 5. Weighted value of level 2 operational risk**

| Level 1       | Level 2                                      | AHP weight | Entropy weight | Combination weight |
|---------------|----------------------------------------------|------------|----------------|--------------------|
| Policy risk(A)| Industrial support policy(A1)                | 0.054      | 0.066          | 0.039              |
|               | Industry system(A2)                          | 0.047      | 0.064          | 0.033              |
| Transaction  | Wind power on-grid risk(B1)                  | 0.105      | 0.035          | 0.040              |
| risk(B)       | Pv on-grid risk(B2)                          | 0.102      | 0.032          | 0.036              |
|               | Photothermal on-grid risk(B3)                | 0.104      | 0.033          | 0.038              |
| Market risk(C)| Competition risk(C1)                        | 0.102      | 0.031          | 0.035              |
|               | Demand risk(C2)                             | 0.068      | 0.091          | 0.068              |
|               | Tax risk(C3)                                | 0.045      | 0.062          | 0.030              |
| Operational  | Technology maturity(D1)                     | 0.456      | 0.394          | 0.491              |
| risk(D)       | Equipment maintenance(D2)                   | 0.070      | 0.302          | 0.062              |
|               | Operation safety(D3)                        | 0.032      | 0.108          | 0.006              |
| Other risks(E)| Resource conditions(E1)                     | 0.028      | 0.132          | 0.040              |
|               | Natural disasters(E2)                       | 0.029      | 0.133          | 0.042              |
|               | Personnel security(E3)                      | 0.033      | 0.019          | 0.007              |

| Level 1       | AHP weight | Entropy weight | Combination weight |
|---------------|------------|----------------|--------------------|
| Policy risk(A)| 0.101      | 0.130          | 0.072              |
| Transaction  | 0.412      | 0.130          | 0.146              |
| risk(B)       | 0.215      | 0.184          | 0.133              |
| Market risk(C)| 0.558      | 0.714          | 0.560              |
| Operational  | 0.090      | 0.284          | 0.089              |
| risk(D)       | 0.027      | 0.106          | 0.027              |
| Other risks(E)| 0.027      | 0.106          | 0.027              |

It can be seen that in the evaluation index system, operation risk factor accounts for a bigger weight compared with other indicators, which is followed by trade risk and market risk. It suggests that in the process of new energy power generation system operation, operation risk, especially the technical maturity has the greatest influence [8]. Therefore, attention should be paid to in the actual control operation risk guard, especially the improvement of the technical maturity.

Then, based on the expert experience, we evaluate the indicators in the multi-energy complementary new energy park. By determining the membership degree of the evaluation factors and solving them, we obtain the comprehensive evaluation vector:

\[ B = W \times R = [0.076, 0.466, 0.325, 0.106, 0.027] \]

Then we can get the higher risk level according to the principle of maximum membership. The maximum degree of membership is 0.466, which indicates that the operational risk of the new energy power generation system in the park is at a high risk level.

4. Conclusions and prospects

Due to the limitations of external environment and internal technology and materials, the development of multi-energy complementary new energy power generation system faces many unavoidable and long-term risks. This paper established a risk assessment model qualitatively. The project's risk management provides an effective risk prevention and control method, and it is easy to propose risk prevention and control recommendations and measures, which is of great significance for the development of the system. In the future development of multi-energy complementary new energy power generation systems, the
risks are diverse, and the reasonable identification of risks and response is an important process for system development. Through the application of the model, it is possible to achieve effective avoidance of risks and reduce the adverse effects of risks, which is conducive to system development.

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References
[1] liu xiuru. Development and policy research of China's multi-energy complementary energy system [J]. Environmental protection and circular economy, 2008, 38(07): 1-4.
[2] Peng chengcheng, li yanan. Key technologies and development trends of grid-connected power generation system of new energy [J]. China new technology and new products, 2018(22): 83-84.
[3] Wu linjie, li chunyan. Application research of new energy power generation in power system [J]. Residential and real estate, 2019 (18): 277.
[4] Duan zhanxiang. Application of new energy generation in power system [J]. China high technology, 2018 (13): 97-99.
[5] li jianzhou, zhang tianwen, liu jiebin, yu qiaoling, lu chuan. Risk management of photovoltaic power generation project based on AHP analytic hierarchy process [J]. China high technology, 2018 (05): 76-78.
[6] tang jiehong. Application discussion of fuzzy analytic hierarchy process in power plant safety evaluation [D]. Capital university of economics and business, 2016.
[7] wang qandong. Fuzzy comprehensive risk assessment of photovoltaic power generation enterprises based on ahp-entropy method [D]. Harbin Institute of Technology, 2017.
[8] xie chuangsheng, xu yalun, dong dapeng, hua shengping. Research on risk assessment of China's solar photovoltaic power generation industry based on multi-level fuzzy comprehensive evaluation [J]. Science and technology and industry, 2011, 11(01): 45-48.