Research on Comparison Model of Connected Project Financing Model Based on Fuzzy Hierarchy Theory

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Abstract. A scientific and reasonable project financing mode is very important for the development of transnational grid interconnection projects. On this basis, this paper first analyzes the status of the interconnection project, and designs the interconnection project financing mode comparison index system from four dimensions: external financing environment, financing method, financing efficiency and financing risk. Secondly, with the help of fuzzy analytic hierarchy process, the comparison model and calculation process of the interconnection project financing model are established. Finally, the S interconnection project is selected for case analysis, and it is concluded that the interconnection project should adopt the BOT project financing model, which is helpful to reduce project financing risks and increase revenue.

1. Introduction

With the rapid development of the global economy and society, the continuous growth of energy consumption has effectively promoted China's "One Belt, One Road" development strategy [1]. As an important part of the "One Belt, One Road" development strategy, transnational interconnection project has attracted the attention of many scholars. Therefore, it is very important to choose a scientific and reasonable project financing mode.

The construction of interconnection project is a complex project [2]. Zhou et al. [3] conducted an in-depth discussion on the interconnection mode of the Asian power grid. Liu et al. [4] focused on the analysis of clean energy resources and distribution characteristics in Asia, Europe, Africa and the Americas. However, in the actual process of transnational grid interconnection projects, various project financing modes should be considered in order to obtain strong financial support. Lin et al. [5] analyzed the current project financing mode based on Tianjin smart grid as an example. Huang et al. [6] compared and analyzed several project financing modes, selected the financing mode suitable for power grid construction projects.

Based on this, this paper combines the characteristics of transnational grid interconnection projects, designs the interconnection project financing model comparison index system, establishes the interconnection project financing model comparison model, selects the S interconnection project for example analysis, and further validates the effectiveness and feasibility of the comparison model.

2. Interconnection project financing model comparison index system

In order to better implement the policy of "One Belt and One Road" proposed by the state, it is particularly important to choose the appropriate interconnection project financing mode [7]. According to the characteristics of large amount of investment and long payback period of interconnection ...
projects, and referring to many academic literatures, this paper designs the interconnection project financing model comparison index system from four dimensions, as shown in Fig.1.

Figure 1. Interconnection project financing model comparison index system

2.1. External financing environment
External financing environment is the main factor that affects the financing and long-term stability of Internet projects. GDP growth rate reflects the state of economic growth of the country, reflects the potential of economic development of the interconnected countries, and there is a significant correlation between GDP change and the power consumption of the whole society. Bilateral relations indirectly affect the development prospects of Internet projects, and should be carefully considered in decision-making. There is exchange rate risk in transnational grid interconnection project financing. The main body of the transnational project financing and negative fluctuations is caused by the exchange rate changes. Due to the strong volatility of the on-grid price, generation capacity, over network fee settlement and load forecasting, the interconnection project has strong flexibility.

2.2. Project financing method
According to the scale and term of financing of interconnection project, the merits and demerits of different financing modes of interconnection projects are evaluated. The financing scale is the first choice index to compare different financing models, and the financing scale that different financing models can bear is different. Financing operability is to match the actual situation of the project when choosing financing mode. The degree of property right change is to distribute the ownership of interconnected projects according to different project financing modes. Economic intensity is the standard to measure whether the project can repay the investor's debt smoothly, and it is an important factor considered in the process of project financing. Financing structure refers to the legal ownership of the assets and interests of the interconnection project sponsors and the legal cooperation between the sponsors.

2.3. Project financing efficiency
Project financing efficiency refers to whether the financing mode is mature, whether the process is tedious and whether the required capital can be obtained within the specified time. The financing complexity exists in the process of interconnection project financing. The complexity of financing procedures and processes of choosing different financing modes is different, which greatly reduces the efficiency of project financing. The financing time limit is based on the financing time limit required by different interconnection projects. Within the specified time limit, the fund demand for obtaining is also different.
2.4. Project financing risk
Project financing risk exists in the process of Internet project financing. The duration risk is an indicator to measure whether the financing mode can complete the interconnection project within the specified time. Business risk refers to whether the investor of the Internet project can operate the Internet project according to the requirements. Economic risk refers to the fluctuation of interest rate and exchange rate caused by policy, or the shrinkage of financial market, which leads to the risk of capital chain fracture.

3. Interconnection project financing model comparison model

3.1. Fuzzy analytic hierarchy process
In 1983, the theory of fuzzy mathematics was introduced into the analytic hierarchy process (AHP), and the method of Fuzzy AHP was put forward [8]. The purpose of this method is to solve the multi-objective and multi-level problems. During the comparison and selection of financing modes of Internet projects, three elements of the evaluation object are determined, and the importance is scored by using expert interview or investigation method, so as to determine the importance of the factors and get the fuzzy comprehensive evaluation matrix. Finally, according to the FAHP evaluation Cheng, the final evaluation result of FAHP is obtained.

3.2. Financing model comparison model
According to the theory of Fuzzy AHP and the characteristics of project financing mode, the specific calculation process of comparison and selection model is as follows:

(1) Build a hierarchy evaluation model, combine the upper criteria to build its lower criteria, and get a more comprehensive evaluation index hierarchy model from the top objective to the bottom scheme.

(2) Construct the fuzzy judgment matrix \( A \). The fuzzy judgment matrix \( A \) of each layer is constructed on the basis of the comparison between the two according to the expert scoring or survey method. At the same time, when comparing elements in pairs, the 0.1-0.9 scale method is generally used and the fuzzy complementary judgment matrix \( A \) is obtained by comparing the two elements.

(3) Consistency test of fuzzy judgment matrix \( A \). Because the problems in practice are very complex, even the experts in the field have certain subjectivity in the analysis of practical problems, so it is necessary to test the consistency of fuzzy complementary judgment matrix \( A \).

(4) The fuzzy complementary judgment matrix \( A \) is transformed into the fuzzy consistent judgment matrix \( R \). Because any element of the consistency judgment matrix \( R \) can satisfy the condition

\[
0.5 \leq r_{ij} \leq 1
\]

If \( r_{ij} = \sum r_{ik} \), it is recorded that

\[
r_{ij} = \frac{r_{ij} - r_{ij}}{2n} + 0.5,
\]

then the fuzzy complementary judgment matrix \( A \) is transformed into the fuzzy consistent judgment matrix \( R \) by using the formula.

(5) Determine the weight of the fuzzy consistency judgment matrix \( R \). Under the target layer \( Q_k \), the weight formula of the element \( R_i \) is as follows:

\[
s^k_i = \frac{1}{n} - \frac{1}{2a} + \frac{\sum_{j=1}^{n} r_{ij}}{na}, i = 1, 2, 3, \ldots, n
\]

In the above formula, the parameter \( a \) is required to meet this condition \( a \geq (n-1)/2 \). \( s^k_i \) ranks from large to small. \( R_i \) indicates the importance of elements under the target layer \( Q_k \).

(6) overall arrangement of levels. The results of all alternative financing modes of the final interconnection project can be sorted by summarizing the criteria layer or scheme layer under the overall goal.
3.3. Calculation process of comparative financing mode

According to the comparison and selection model of project financing mode, the specific evaluation process of the above-mentioned interconnection project financing mode is shown in Fig.2.

![Diagram showing the calculation process of comparative financing mode](image)

Figure 2. Comparison and selection process of interconnection project financing mode

4. Example analysis

In order to verify the feasibility of the proposed comparison and selection model, an interconnection project S is selected.

4.1. Basic data

The project is an operational project, which mainly adopts the market-oriented project financing mode. Transmission mode, transmission capacity, voltage level, and submarine cable line type and other factors of the project intend to adopt the conventional or flexible tributary mode of asynchronous networking, with voltage level of ±500kV and transmission capacity of 2000MW. Because the interconnection project involves different countries, the frequency of China's power grid is 50 Hz. The frequency of interconnected national power grid is different from it, which is 60 Hz and 50 Hz, which brings difficulties for the actual interconnection project.

4.2. Analysis of calculation results

Based on the diversity of project financing subjects and innovation of project financing mode, this paper takes BOT mode, BT mode, TOT mode, ABS mode, PPP mode, TOT-BOT mode, BOT-ABS mode, PPP-BOT mode and BOT-TOT-PP mode as alternative financing schemes.

4.2.1. Calculation of index weight of first level

According to the expert scoring method, the complementary judgment matrix of the first level indexes of the index system for the comparison and selection of interconnected projects financing mode is obtained.

\[
\begin{bmatrix}
A_i & B_i & C_i & D_i \\
A_i & 0.50 & 0.40 & 0.60 & 0.34 \\
B_i & 0.60 & 0.50 & 0.52 & 0.56 \\
C_i & 0.40 & 0.48 & 0.50 & 0.52 \\
D_i & 0.64 & 0.44 & 0.48 & 0.50 \\
\end{bmatrix}
\]

\[
A = \begin{bmatrix}
A_i & B_i & C_i & D_i \\
A_i & 0.50 & 0.49 & 0.51 & 0.48 \\
B_i & 0.51 & 0.50 & 0.52 & 0.49 \\
C_i & 0.49 & 0.48 & 0.50 & 0.47 \\
The\end{bmatrix}
\]

In the above formula, \(A_i\) is the external environment index; \(B_i\) is the project financing mode index; \(C_i\) is the project financing efficiency index; \(D_i\) is the project financing risk index. The above complementary matrix \(A\) is transformed into the consistency matrix \(R\).

The consistency judgment matrix \(R\) meets the consistency test, and the first level index weight is obtained:

\[
w = [0.25, 0.24, 0.26, 0.24]^T
\]
4.2.2. Calculation of index relative weight of all levels

According to the expert scoring method, the fuzzy complementary judgment matrix of the second level index corresponding to the first level index for interconnection project financing model comparison index system is obtained.

The complementary judgment matrix of project external environment index is:

\[
\begin{bmatrix}
A_1 & A_2 & A_3 & A_4 \\
A_1 & 0.50 & 0.56 & 0.32 & 0.62 \\
A_2 & 0.44 & 0.50 & 0.66 & 0.45 \\
A_3 & 0.68 & 0.34 & 0.50 & 0.62 \\
A_4 & 0.38 & 0.55 & 0.38 & 0.50 \\
\end{bmatrix}
\]

In the above formula, \( A \) is the project external environment index; \( A_1 \) is the national GDP growth rate index; \( A_2 \) is the bilateral relations index; \( A_3 \) is the exchange rate index; \( A_4 \) is the market flexibility index. The above complementary matrix \( A \) is transformed into the consistency matrix \( A_R \).

The consistency judgment matrix \( A_R \) meets the consistency test, and the first level index weight is obtained:

\[
w_A = [0.25, 0.26, 0.24, 0.26]^T, w_B = [0.20, 0.21, 0.20, 0.29, 0.19]^T
\]

Similarly, the complementary matrix \( B \) for the project financing method is transformed into the consistency matrix \( B_R \).

The consistency judgment matrix \( B_R \) meets the consistency test, and the first level index weight is obtained:

\[
w_B = [0.57, 0.43]^T, w_C = [0.36, 0.31, 0.33]^T
\]

Similarly, the complementary matrix \( C \) for the project financing efficiency is transformed into the consistency matrix \( C_R \).

\[
R_C = \begin{bmatrix}
C_{11} & C_{12} \\
C_{11} & 0.50 & 0.43 \\
C_{12} & 0.57 & 0.50 \\
\end{bmatrix}, R_D = \begin{bmatrix}
D_{11} & D_{12} & D_{13} \\
D_{11} & 0.50 & 0.46 & 0.47 \\
D_{12} & 0.54 & 0.50 & 0.52 \\
D_{13} & 0.53 & 0.48 & 0.50 \\
\end{bmatrix}
\]

The consistency judgment matrix \( C_R \) meets the consistency test, and the first level index weight is obtained:

\[
w_C = [0.57, 0.43]^T, w_D = [0.36, 0.31, 0.33]^T
\]

Similarly, the complementary matrix \( D \) for the project financing risk is transformed into the consistency matrix \( D_R \).

The consistency judgment matrix \( D_R \) meets the consistency test, and the first level index weight is obtained:

Based on the above, the first level index weight and the second level index weight for interconnection project financing model comparison index system can be obtained, as shown in Tab 1.
Table 1. The comparison index relative weight of all levels for interconnection project

| First level index          | Index relative weight | Second level index                      | Index relative weight |
|----------------------------|-----------------------|----------------------------------------|-----------------------|
| project external environment | 0.25                  | national GDP growth rate 0.25           |                       |
|                            |                       | bilateral relations 0.26                |                       |
|                            |                       | exchange rate 0.24                     |                       |
|                            |                       | market flexibility 0.26                 |                       |
| project financing method    | 0.24                  | project financing scale 0.20            |                       |
|                            |                       | project financing operability 0.21       |                       |
|                            |                       | project property change degree 0.20     |                       |
|                            |                       | project economic strength 0.19          |                       |
|                            |                       | project financing structure. 0.19       |                       |
| project financing efficiency | 0.26                  | project financing complexity 0.57       |                       |
|                            |                       | project financing time limit 0.43        |                       |
| project financing risk      | 0.24                  | duration risk 0.36                      |                       |
|                            |                       | business risk 0.31                      |                       |
|                            |                       | economic risk 0.33                      |                       |

4.2.3 Calculation of index weight of scheme level

Combined with the alternative interconnection project financing model, the alternatives are marked by A, B,..., I. Five experts are invited to score each model under the basis of each evaluation index in combination with the practical features of the interconnection project. Then the average score of each model in each comment set was counted, and finally the results were summarized for analysis, as shown in Tab 2.

Table 2. The index fuzzy evaluation for interconnection project financing model comparison index

| First level index          | Second level index                      | (A, B, C, D, E, F, G, H, I) |
|----------------------------|----------------------------------------|-----------------------------|
| project external environment (0.25) | national GDP growth rate (0.25) | (3.6, 4.2, 2.8, 3.2, 3.1, 3.4, 3.6, 4.0, 3.2) |
|                            | bilateral relations (0.26)             | (3.2, 3.4, 3.7, 3.5, 3.2, 2.1, 3.0, 3.1, 3.3) |
|                            | exchange rate (0.24)                   | (3.6, 3.8, 3.3, 3.5, 3.6, 3.2, 2.9, 3.1, 3.2) |
|                            | market flexibility (0.26)              | (3.1, 3.7, 2.9, 3.2, 3.4, 3.5, 3.3, 3.4, 3.5) |
| project financing method (0.24) | project financing scale (0.20)       | (3.4, 4.4, 2.6, 3.4, 2.9, 3.3, 3.5, 3.8, 3.4) |
|                            | project financing operability (0.21)   | (3.4, 3.5, 3.0, 3.7, 3.3, 2.5, 2.7, 3.5, 3.2) |
|                            | project property change degree (0.20) | (3.2, 3.7, 3.2, 3.6, 3.2, 3.3, 3.0, 3.2, 2.8) |
|                            | project economic strength (0.19)       | (3.1, 4.6, 2.7, 2.6, 3.8, 3.6, 3.2, 3.6, 3.6) |
|                            | project financing structure. (0.19)    | (4.0, 4.5, 3.3, 3.6, 4.0, 4.1, 4.2, 2.9, 3.4) |
| project financing efficiency (0.26) | project financing complexity (0.57) | (3.1, 3.6, 3.3, 3.2, 3.1, 2.9, 3.3, 3.2, 3.4) |
|                            | project financing time limit (0.43)    | (3.5, 3.4, 3.2, 6.3, 4.3, 3.2, 8.2, 2.9, 3.1) |
| project financing risk (0.24) | duration risk (0.36)                   | (3.3, 3.8, 3.5, 3.4, 3.0, 3.3, 3.6, 3.8, 3.3) |
|                            | business risk (0.31)                   | (3.5, 3.6, 3.6, 3.4, 3.2, 3.2, 3.5, 3.4, 2.9) |
|                            | economic risk (0.33)                   | (3.8, 4.0, 3.2, 6.3, 3.2, 3.3, 8.3, 3.2, 2.8) |

According to the interconnection project financing model comparison index system, the fuzzy evaluation results of the external environment index layer are firstly calculated.

\[
A = \begin{bmatrix}
0.25 & 0.26 & 0.24 & 0.26 \\
3.6 & 4.2 & 2.8 & 3.2 & 3.1 & 3.4 & 3.6 & 4.0 & 3.2 \\
3.2 & 3.4 & 3.7 & 3.5 & 3.2 & 2.1 & 3.0 & 3.1 & 3.3 \\
3.6 & 3.8 & 3.3 & 3.5 & 3.6 & 3.2 & 2.0 & 3.1 & 3.2 \\
3.1 & 3.7 & 2.9 & 3.2 & 3.4 & 3.5 & 3.1 & 3.4 & 3.5
\end{bmatrix}
\]
The fuzzy evaluation results of the project external environment index layer are:
\[ A = \begin{bmatrix} 3.402 & 3.808 & 3.208 & 3.382 & 3.355 & 3.074 & 3.182 & 3.434 & 3.336 \end{bmatrix} \]

Similarly, the fuzzy evaluation results of the project financing method index layer are:
\[ B = \begin{bmatrix} 3.383 & 4.084 & 2.930 & 3.355 & 3.395 & 3.308 & 3.273 & 3.370 & 3.242 \end{bmatrix} \]

Similarly, the fuzzy evaluation results of the project financing efficiency index layer are:
\[ C = \begin{bmatrix} 3.272 & 3.514 & 3.257 & 3.372 & 3.229 & 3.072 & 3.085 & 3.071 & 3.271 \end{bmatrix} \]

Similarly, the fuzzy evaluation results of the project financing risk index layer are:
\[ D = \begin{bmatrix} 3.527 & 3.804 & 3.432 & 3.466 & 3.128 & 3.269 & 3.635 & 3.478 & 3.011 \end{bmatrix} \]

On the basis of the fuzzy evaluation of the interconnection project financing model comparison index system, the highest fuzzy comprehensive evaluation can be carried out for different financing models. The results are as follows:
\[ A_{hl} = \begin{bmatrix} 3.402 & 3.808 & 3.208 & 3.382 & 3.355 & 3.074 & 3.182 & 3.434 & 3.336 \\ 3.383 & 4.084 & 2.930 & 3.355 & 3.395 & 3.308 & 3.273 & 3.370 & 3.242 \\ 3.272 & 3.514 & 3.257 & 3.372 & 3.229 & 3.072 & 3.085 & 3.071 & 3.271 \\ 3.527 & 3.804 & 3.432 & 3.466 & 3.128 & 3.269 & 3.635 & 3.478 & 3.011 \end{bmatrix} \]

The final result of fuzzy evaluation is obtained:
\[ A_{hl} = \begin{bmatrix} 3.359 & 3.758 & 3.175 & 3.360 & 3.243 & 3.145 & 3.255 & 3.300 & 3.185 \end{bmatrix} \]

According to the principle of maximum membership, the score of BOT project financing model is the highest, reaching 3.758 points. The second is the TOT project financing model, with a score of 3.360 points. Therefore, the transnational grid interconnection project should choose the BOT project financing model for interconnection project financing.

5. Conclusion
The conclusions are as follows:
(1) This paper designs a comparison index system of interconnection project financing mode from the four dimensions of external financing environment, project financing mode, project financing efficiency and project financing risk.
(2) With the help of fuzzy analytic thinking, a comparison model of interconnection project financing model is established.
(3) The S interconnection project is selected to determine that the interconnection project will adopt the BOT project financing model, which will help to minimize project financing risks and increase revenue.

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