Establishment and Application of AHP-PCA-EMEM Model for Risk Evaluation of Electric Power Company's Business Expansion Project

Juhua Hong[1], Keyao Lin[2], Linyao Zhang[1], Zhenda Hu[1], Xiaofeng Li[3,*] and Jian Pan[3,*]

*E-mail: lixiaofeng@scu.edu.cn, 371171477@qq.com

[1]State Grid Fujian Electric Power Economic and Technical Research Institute, Fujian 350100, China
[2]State Grid Fujian Electric Power Co., Ltd, Fujian 350100, China
[3]Department of Management Science and Data Science, Business School, Sichuan University, Chengdu 610065, China

Abstract. The implementation of business expansion projects will not only help to improve the market size of the electric power company and increase competitive ability, but also help to improve customer satisfaction and promote economic and social development. However, there are lots of risk factors in the implementation of a business expansion project by the electric power company. In order to avoid and reduce the losses caused by these risk factors and turn threats into opportunities, the electric power company must strengthen risk management, and accurate risk evaluation is the basis for strengthening the risk management of business expansion project. Through literature research and expert consultation, a list of risk evaluation indexes for business expansion project of electric power company was established. Then, the dimensions of the evaluation indexes were reduced by using questionnaire survey and principal component analysis, and on this basis, the risk evaluation index system of business expansion project was formed. The evaluation index system includes 6 first-level indexes and 16 second-level indexes. Combining analytic hierarchy process method, principal component analysis method and extension matter-element method, the AHP-PCA-EMEM model for risk evaluation of business expansion project was established. The model can comprehensively consider various external and internal information about business expansion project, reflect the status of various risk factors of business expansion project, and accurately evaluate the comprehensive risk of business expansion project. Five business expansion projects were selected from LQY power company, which are PM_1, PM_2, PM_3, PM_4 and PM_5. The comprehensive risks of the five projects were evaluated by using the established model, and the comprehensive risks of the five projects are respectively high risk, very low risk, low risk, medium risk and low risk. The risk assessment results are consistent with the actual risk status of the five projects. The risks of PM_1 and PM_4 are relatively high, and low annual returns on investment, LQY power company needs a long time to recover its costs. The risks of PM_2, PM_3 and PM_5 are small, and the average annual returns on investment of these projects are high, reaching more than 23.5%, LQY power company can recover the costs in the next 6 years, and these three projects can continuously create economic benefits for LQY power company. Theoretical analysis and practical results show the feasibility and effectiveness of the established model, which provides a new way for the risk evaluation of business expansion project of electric power company.

Keywords- Electric power company; Business expansion project; Risk evaluation; Combination weighting method; AHP-PCA-EMEM model

MSEA 2023, May 26-28, Nanjing, People's Republic of China

DOI 10.4108/eai.26-5-2023.2334475

1. Introduction

With the continuous deepening of the reform of electric power system and the development of new energy, the internal and external environment faced by Chinese electric power companies has undergone profound changes, and the market competition has become increasingly fierce[1]. In the face of the new situation, Chinese electric power companies have expanded the business expansion project construction by extending the investment interface, which has not only effectively improved the market share and customer satisfaction, but also created a good investment environment and supported the economic and social development[2]. However, while the construction of large-scale business expansion projects has brought unprecedented development opportunities to electric power company, it has also brought huge challenges to electric power company[3]. Business expansion project is affected by many risk factors. Electric power company engaged in business expansion project often have insufficient awareness of these internal and external risk factors, which makes the implementation process and results of business expansion project unexpected and sometimes not only fails to achieve the expected goals, but also brings various losses to electric power company[4][5]. Therefore, it is necessary to use scientific and effective methods to evaluate the risk of business expansion project before the implementation of business expansion project. According to the result of risk assessment, the electric power company can take corresponding pre-control measures to reduce the adverse impact of risk factors, so as to ensure the smooth implementation of business expansion project. This not only helps to improve the economic benefits of the electric power company, but also helps to realize the "win-win" between customers and the electric power company.

There are many complex factors affecting the risk of business expansion project of electric power company. How to correctly identify and measure the risk of business expansion project is a problem that has plagued the development of electric power company for a long time, and a unified understanding has not yet been formed. J Berny[6] proposed a method for quantifying and analyzing engineering project risk, which uses a tree structure to analyze project risk. V M Rao Tummala et al.[7] studied the safety problems existing in Hong Kong electric power company and rail company, and established a risk management model for safety and reliability. Irem Dikmen Ozdoganm[8] combined fuzzy mathematics with the image graph analysis method to analyze the cost overrun risk in international engineering project. J Peixoto et al.[9] studied EDP Distribution and adopted brainstorming, fault tree analysis, and RBS methods to identify and quantitatively analyze the risk of power grid engineering. Franck Taillandier et al.[10] believed that engineering project is affected by many factors, established a multi-agent model, and proposed risk management decisions for different research objectives. Jorge Ayala Cruz[11] combined PMI model with Monte Carlo simulation method to evaluate the construction period risk and cost control risk of engineering project, and put forward corresponding risk management countermeasures. Li and Yuan[12] used the grey system theory to evaluate the risk existing in the whole process of project construction, and proposed risk management strategies. Liu[13] constructed a risk evaluation index system for construction project and applied a fuzzy analysis method to conduct qualitative and quantitative analysis of risk factors in them. Shi[14] conducted a qualitative analysis on the risks of substation engineering construction projects, and proposed a corresponding risk management system. Zhu et al.[15], Cheng et al.[16], and Liu[17] used analytic hierarchy process (AHP) to analyze and evaluate the risks of electric power transmission and transformation project. It can be seen from the existing research results that there are the following deficiencies in the risk evaluation of business expansion project of electric power company. First, the evaluation index system is not systematic enough, which does not fully reflect the risk status of business expansion project. Second, in the process of determining the weights of the evaluation indexes, the subjectivity is strong and the objectivity is not enough. Third, there are few research results on risk evaluation of business expansion project.

Extension matter element method put forward on the basis of extension theory and matter element theory, is a method to solve contradiction problems from qualitative and quantitative perspectives through studying matter element and its change[18]. On the basis of constructing the risk evaluation index system of electric power company's business expansion project, the AHP-PCA-EMEM model of business expansion project risk evaluation was established by combining the combination weighting method and extension matter-element method, which can not only describe the status of various risk factors of business expansion project formally, but also evaluate the comprehensive risk of business expansion project qualitatively and quantitatively, so as to reflect the advantages and disadvantages of business expansion project comprehensively.

2. Risk evaluation index system of business expansion project

2.1. Construction principles of evaluation index system

Constructing a scientific and reasonable risk evaluation index system for electric power company business expansion project is the premise and necessary step of establishing the risk evaluation model. In order to make the evaluation indexes reflect the real risk level of business expansion project comprehensively and truly, the following principles should be followed when constructing the evaluation index system.

First, the principle of systematism and comprehensiveness. The evaluation indexes should be independent of each other and have a certain logical relationship to form an organic whole. At the same time, the evaluation indexes should be hierarchical and reflect the state of business expansion project risk completely from different aspects.

Second, the principle of adaptability. Since the external environment and internal environment of different electric power companies are not completely the same, the suitability of the indexes must be considered when constructing the risk evaluation index system of business expansion project, that is, to have a system that most electric power companies can refer to, with universality and flexibility in application.

Third, the principle of conciseness and science. The selection of evaluation indexes must be scientific in principle and reflect the risk characteristics of business expansion project objectively and truly. At the same time, each evaluation index should be representative, and should not be too detailed, too little or too simple to avoid information omission.

Fourth, the principle of comparability and quantification. The indexes at the same level in the index system should meet the principle of comparability, that is, each index has the same measurement range, measurement caliber and measurement method. At the same time, when selecting indexes, it is also necessary to consider whether quantitative processing can be carried out, so as to facilitate mathematical calculation and analysis.

2.2. Construction process of evaluation index system

2.2.1. Establishing the list of evaluation indexes.

Referring to the domestic and foreign research literature on electric power engineering project risk and business expansion project risk, a list of risk evaluation indexes for business expansion project was preliminarily established. Then, according to the relevant specifications of business expansion and installation management, electric power engineering construction and various records of business expansion projects of some electric power companies, on the basis of consulting relevant experts, a formal list of evaluation indexes is formed, which includes 32 evaluation indexes.

2.2.2. Conducting the questionnaire survey.

The "Questionnaire on the Importance of Risk Evaluation Indexes of Business Expansion Project of Electric Power Company" was designed, and the importance of evaluation indexes was divided into five levels: not important, somewhat important, important, very important, and extremely important. 50 experts in relevant fields were invited to score the importance of evaluation indexes between 0 and 10 (the higher the score of the index is, the more important it is), and 43 valid questionnaires were returned.

2.2.3. Principal component analysis.

Risk assessment indexes should be representative and not too many or too detailed, otherwise, redundancy will occur and the quality of assessment will be reduced. Principal Component Analysis (PCA) is a multivariate statistical analysis method that selects fewer important variables by linear transformation of multiple variables. Principal component analysis can be used to screen and optimize the evaluation indexes in the index list, retain a few important evaluation indexes, and make them retain the information of the original variables as much as possible, so as to greatly improve the efficiency and quality of risk assessment. The principal component analysis method in SPSS22.0 software was used to process the data of 43 valid questionnaires, and the eigenvalues, variance contribution rates and cumulative variance contribution rates of the evaluation index correlation coefficient matrix were obtained. According to the principle that the eigenvalue is greater than 1, six principal components (Z_1, Z_2, Z_3, Z_4, Z_5, Z_6) were obtained, and the cumulative variance contribution rates reaches 80.496%, as shown in table 1. That is to say, these 6 principal components contain most of the information of the entire risk factor set and are highly representative. Therefore, these 6 principal components were selected to reduce the dimensionality of the evaluation indexes.

Table 1. The eigenvalues, variance contribution rates and cumulative variance contribution rates of principle components.

Principle components	Initial eigenvalues		
	Eigenvalues	Variance contribution rate (%)	Cumulative variance contribution (%)
Z_1	3.167	17.892	17.892
Z_2	2.960	15.736	33.628
Z_3	2.508	13.837	47.465
Z_4	1.918	12.395	59.860
Z_5	1.755	10.911	70.771
Z_6	1.660	9.725	80.496

2.2.4. Dimension reduction of indexes.

In the first principal component Z_1, the evaluation index x_1 (degree of government policy support) and the evaluation index x_2 (changes in relevant norms of electric power company) have higher positive load. The first principal component Z_1 can be interpreted as "policy risk", which is regarded as the first first-level index in the evaluation index system. At the same time, the evaluation index x_1 (degree of government policy support) and the evaluation index x_2 (changes in relevant norms of electric power company) are taken as the second-level indexes of "policy risk". In the second principal component Z_2, evaluation index x_3 (degree of natural environment impact) and evaluation index x_4 (degree of construction environment restriction) have higher positive load. The second principal component Z_2 can be interpreted as "environmental risk" , which is regarded as the second first-level in the evaluation index system. At the same time, the evaluation index x_3 (degree of natural environment impact), evaluation index x_4 (degree of construction environment restriction) are taken as the second-level indexes of "environmental risk". In the third principal component Z_3, evaluation index x_5 (feasibility of power supply scheme), evaluation index x_6 (scientificity of drawing design), evaluation index x_7 (standardization of construction technology) and evaluation index x_8 (adequacy of power supply preparation) have higher positive load. The third principal component Z_3 can be interpreted as "technical risk", which is regarded as the third first-level in the evaluation index system. At the same time, the evaluation index x_5, evaluation index x_6, evaluation index x_7 and evaluation index x_8 are taken as the second-level indexes of "technical risk".

Similarly, the fourth principal component Z_4, the fifth principal component Z_5 and the sixth principal component Z_6 are respectively regarded as the fourth first-level index, the fifth first-level index and the sixth first-level index in the evaluation index system. They are interpreted as "security risk", "management risk" and "economic risk" respectively. At the same time, the evaluation indexes with higher positive load in the above principal components are selected as the corresponding second-level indexes.

Based on the methods above, the risk evaluation index system of business expansion project of electric power company was obtained, as shown in table 2, which includes 6 first-level indexes and 16 second-level indexes.

Table 2. Risk evaluation index system of business expansion project.

Goal	First-level indexes	Second-level indexes
Risk evaluation of business expansion project	Policy risk X_1	Degree of government policy support x_1
		Changes in relevant norms of electric power company x_2
	Environmental risk X_2	Degree of natural environment impact x_3
		Degree of construction environment restriction x_4
	Technical risk X_3	Feasibility of power supply scheme x_5
		Scientificity of drawing design x_6
		Standardization of construction technology x_7
		Adequacy of power supply preparation x_8
	Security risk X_4	Safety of equipment and materials x_9
		Safety awareness of construction workers x_{10}
	Management risk X_5	Ability to manage project team x_{11}
		Degree of coordination of the participants x_{12}
		Ability to manage project contract x_{13}
		Ability to manage project quality x_{14}

Economic risk X_6	Return on investment of the project x_{15} Cost control status of the project x_{16}

3. The AHP-PCA-EMEM model for risk evaluation of business expansion project

3.1. Overview of relevant methods

3.1.1. Methods to determine the weights of evaluation indexes.

At present, these methods to determine the weights of evaluation indexes are mainly divided into two categories: subjective weighting methods and objective weighting methods. The former with strong subjectivity mainly including analytic hierarchy process, expert scoring method, decision alternative ratio evaluation system, etc., relies on the experience of experts to artificially determine the weight of each index. The latter mainly including entropy method, coefficient of variation method, principal component analysis method, etc., is to obtain the weights after analyzing and processing the initial data of the indexes by statistical method, which can effectively overcome the interference of human factors. In short, different methods have their own advantages and disadvantages, and a single method often cannot be used for accurate and objective evaluation[19]. Therefore, it is necessary to combine subjective weighting methods with objective weighting methods to make the assignment of index weights more reasonable.

In this paper, analytic hierarchy process (a subjective weighting method) and principal component analysis (an objective weighting method) are combined to determine the combined weights of the evaluation indexes, which is helpful to improve the pertinence and reliability of the evaluation.

The main steps of using analytic hierarchy process (AHP)[20] to determine the index weights are as follows: first, the hierarchy structure of indexes according to the evaluation purpose is constructed; second, the judgment matrix of the second layer and the following layer in the hierarchy is established; third, the maximum eigenvalue and corresponding eigenvector of the judgment matrix of the second layer are calculated and the consistency test is carried out; fourth, the same method is applied to construct the matrix of the next layer of factors, and calculate the relative importance degree; fifth, after calculating the relative weights of the factors at the second layer and the following layer, the comprehensive weights of the indexes are calculated by applying weighted average operator.

The main steps of using principal component analysis (PCA)[21] to determine the index weights are as follows: first, determine the coefficients in the linear combination, that is, the ratio of the variable component matrix to the arithmetic square root of the eigenvalues of the principal elements; second, determine the coefficients of the comprehensive scoring model, that is, take the contribution rate of the principal component variance as the weight, and calculate the weighted average of the coefficients of the variables in the linear combination of the principal elements; third, determining the weights is to perform normalization processing on the basis of the comprehensive model variable coefficients.

Assuming that the subjective weight of each index calculated based on the AHP method is W_{1k} (k=1, 2, ..., m), and the objective weight of each index calculated based on the PCA method is

W_{2k} (k=1, 2, ..., m). Obviously, the closer W_{1k} and W_{2k} are, the better. According to the principle of minimum information entropy[22], the following programming model can be obtained:

$$\min F = \sum_{k=1}^{m} W_k (\ln W_k - \ln W_{1k}) + \sum_{k=1}^{m} W_k (\ln W_k - \ln W_{2k}) \tag{1}$$

$$s.t. \ \sum_{k=1}^{m} W_k = 1 \quad (W_k > 0, k = 1, 2, ..., m) \tag{2}$$

The Lagrange multiplier method is applied to solve the above optimization problem, and the following equation can be obtained.

$$W_k = \frac{\sqrt{W_{1k} W_{2k}}}{\sqrt{\sum_{k=1}^{m} W_{1k} W_{2k}}} \quad (k = 1, 2, ..., m) \tag{3}$$

Where, W_k (k=1, 2, ..., m) represents the combined weight of each evaluation index. Equation (2) above shows that when calculating the combined weight of the index, applying geometric mean requires the least amount of information, while other situations will increase the amount of information required.

3.1.2. Extension matter element method.

Extenics is a new discipline founded by Chinese scholar Cai Wen in 1983, which uses formal tools to study the extensibility of things as well as the laws and methods of extensibility to solve contradictory problems. The extension matter element method (EMEM) is a method formed on the basis of extenics and matter-element theory, which divides the level of the evaluation object into several levels and gives the numerical range of each level through databases or expert opinions. Then, the index values of the evaluation object are substituted into the set of each evaluation level, the degrees of correlation between the evaluation object and each level set are calculated, and the level of the evaluation object is judged according to the degrees of correlation. A detailed introduction of extension matter-element method can be found in reference [23].

3.2. Establishment processes of AHP-PCA-EMEM model

The establishment process of the AHP-PCA-EMEM model for the risk assessment of business expansion project of the electric power company mainly includes the following seven steps.

First, constructing the evaluation index system. In the above paper, the risk evaluation index system for business expansion project of electric power company was constructed by applying literature research method, expert consultation method, questionnaire survey method and principal component analysis method, as shown in table 1.

Second, determining the index weights. Combined with analytic hierarchy process method (subjective weighting method) and principal component analysis method (objective weighting method), the combined weight W_k (k=1, 2, ..., 16) of the risk evaluation index of business expansion project of electric power company is determined.

Third, classifying the evaluation level. According to China's power operation safety risk classification standards, the risk level of business expansion project of electric power company is divided into 5 levels (Level 1, Level 2, Level 3, Level 4, Level 5), and the score of these five levels ranges from 0 to 10. The specific score interval is defined as follows: overall score ≥ 8 means the risk is “very high”, and the corresponding level is Level 5; overall score between 6 and 8 means the risk is “high”, and the corresponding level is Level 4; overall score between 4 and 6 means the risk is “medium”, and the corresponding level is Level 3; overall score between 2 and 4 means the risk is “low”, and the corresponding level is Level 2; overall score < 2 means the risk is “very low”, with the corresponding level is Level 1.

Fourth, establishing the classical domain and node domain matrices. It is assumed that there are m risk evaluation indexes for business expansion project and n levels of risk. In this paper, there are 16 second-level indexes shown in table 2 and 5 levels of risk evaluation, so m=16, n=5. The risk evaluation indexes and corresponding values of business expansion project are represented by the following matrix.

$$R_{oj}=\begin{bmatrix} N_{oj} & x_1 & V_{oj1} \\ & x_2 & V_{oj2} \\ & \vdots & \vdots \\ & x_m & V_{ojm} \end{bmatrix}=\begin{bmatrix} N_{oj} & x_1 & <a_{oj1},b_{oj1}> \\ & x_2 & <a_{oj2},b_{oj2}> \\ & \vdots & \vdots \\ & x_m & <a_{ojm},b_{ojm}> \end{bmatrix} \tag{4}$$

The above matrix is the classical domain matrix, in which N_{oj} indicates that the risk level of the business expansion project is the j-th level, $j=1, 2, ..., n$; x_k represents the k-th risk evaluation index of the business expansion project, $k=1, 2, ..., m$; $V_{ojk}=<a_{ojk},b_{ojk}>$ indicates the value range when the index x_k is at the j-th level of risk.

The allowable value range of each risk evaluation index of the business expansion project is represented by the following matrix.

$$R_{p}=\begin{bmatrix} N_{p} & x_1 & V_{p1} \\ & x_2 & V_{p2} \\ & \vdots & \vdots \\ & x_m & V_{pm} \end{bmatrix}=\begin{bmatrix} N_{p} & x_1 & <a_{p1},b_{p1}> \\ & x_2 & <a_{p2},b_{p2}> \\ & \vdots & \vdots \\ & x_m & <a_{pm},b_{pm}> \end{bmatrix} \tag{5}$$

The above matrix is the node domain matrix, in which N_p indicates the risk level of the business expansion project; $V_{pk}=<a_{pk}, b_{pk}>$ indicates the allowable value range of the index x_k, $V_{ojk}\subset V_{pk}$, $k=1, 2,...,m$. In this paper, the value range of $<a_{pk}, b_{pk}>$ is [0, 10].

Fifth, determining the matter element to be evaluated. The risk evaluation index $x_1, x_2, ..., x_m$ of a business expansion project P of the power company is evaluated, and the evaluated values $v_1, v_2... v_m$ are represented by the following matter element matrix.

$$R=\begin{bmatrix} N & x_1 & v_1 \\ & x_2 & v_2 \\ & \vdots & \vdots \\ & x_m & v_m \end{bmatrix} \tag{6}$$

In the above matrix, v_k represents the evaluation value of the k-th index in the risk evaluation index system of the business expansion project P (k=1, 2, ..., m).

Sixth, calculating the degree of correlation. In the extension matter element method, the following two formulas are used to calculate the "proximity" of equation (6) and equation (4), equation (6) and equation (5) respectively:

$$p(v_k,V_{ojk})=\left|v_k-\frac{a_{ojk}+b_{ojk}}{2}\right|-\frac{1}{2}(b_{ojk}-a_{ojk})\quad (k=1,2,...,m;\quad j=1,2,...,n) \tag{7}$$

$$p(v_k,V_{pk})=\left|v_k-\frac{a_{pk}+b_{pk}}{2}\right|-\frac{1}{2}(b_{pk}-a_{pk})\quad (k=1,2,...,m;\quad j=1,2,...,n) \tag{8}$$

On the basis of calculating "proximity", the following formula is used to calculate the degree of correlation between the k-th index xk and the j-th risk in the risk evaluation index system of business expansion project P.

$$K_j(v_k)=\frac{p(v_k,V_{ojk})}{p(v_k,V_{pk})-p(v_k,V_{ojk})}\quad (j=1,2,\dots,n;\ k=1,2,\dots,m) \tag{9}$$

Seventh, determining the level of risk. Since the weight of each index of risk evaluation of business expansion project is not the same, the comprehensive correlation degree of risk is calculated by considering the influence of weights of different indexes. If W_k ($\sum_{k=1}^{m}W_k=1$) is the weight of the risk evaluation index x_k of the business expansion project, then the comprehensive correlation degree between the risk of the business expansion project P to be evaluated and the j-th risk is

$$K_j(R)=\sum_{k=1}^{m}W_kK_j(v_k) \tag{10}$$

Based on the principle of maximum membership, the following formula can be obtained:

$$K_{j_0}(R)=\max_{1\le j\le m}K_j(R) \tag{11}$$

According to the above formula, it can be known that the risk of business expansion project P is the j_0 risk level.

4. Empirical study

Sichuan LQY Electric power company is located in the west of China, which was established in August 2013. The company is mainly responsible for power production and sales, power transmission, demonstration, survey, design and construction of electric power projects, unified planning, construction, dispatching and operation management of power grid, etc. In January 2020, the company launched five business expansion projects, namely: power distribution project of Huarui company (referred to as PM_1), electric vehicle charging station power distribution project (referred to as PM_2), and kindergarten power distribution project (referred to as PM_3), department store power distribution project (referred to as PM_4), technology development zone power grid reconstruction project (referred to as PM_5). These five projects are implemented by different project teams. In this section, the AHP-PCA-EMEM model was used to evaluate the risks of these five business expansion projects.

4.1. Calculating the combined weights of risk evaluation indexes

Ten experts in related fields were invited to construct a pairwise comparison judgment matrix of risk evaluation indexes of business expansion project by using pairwise comparison method and 1-9 comparison scale. Then, AHP method was used to calculate the subjective weight W_{1k} (k=1, 2, ..., 16) of these evaluation indexes.

In section 2.2 of this paper, a questionnaire survey was conducted on the importance of risk evaluation indexes for business expansion project. Based on the questionnaire survey data, the principal component analysis method was used to calculate the objective weight W_{2k} (k=1, 2, ..., 16) of the risk evaluation indexes of business expansion project.

According to equation (3), the combined weight W_k (k=1, 2, ..., 16) was calculated and the calculation results are shown in the third column of table 3.

4.2. Determining the evaluation values of risk evaluation indexes

13 experts familiar with project PM_1 were invited to score the project's risk evaluation index x_k (k =1, 2, ..., 16) according to the index comment set. The scoring criteria are as follows.

Let u_i denote the evaluation score of the risk evaluation x_k given by the i-th (i=1, 2, ..., 13) expert. If the risk evaluation index x_k of project PM_1 is considered to be very low by an expert, then the score for this index is u_1 ($u_1 \in [0, 2)$); If the risk evaluation index x_k is considered to be low, then the score for this index is u_2 ($u_2 \in [2, 4)$); by analogy, If the risk evaluation index x_k is considered to be very high, then the score for this index is u_5 ($u_5 \in [8, 10)$). Then the evaluation value of the risk evaluation index x_k is $v_k = \frac{1}{13}\sum_{i=1}^{13} u_i$.

According to the above method, the evaluation values of risk evaluation indexes of the business expansion project PM_1 were obtained. Similarly, through the expert scoring method, the evaluation values of risk evaluation indexes of the business expansion project PM_2, PM_3, PM_4, and PM_5 were obtained, as shown in table 3.

Table 3. Combined weights and evaluation values of risk evaluation indexes of business expansion projects.

First-level indexes	Second-level indexes	Combined weights of second-level indexes	PM_1	PM_2	PM_3	PM_4	PM_5
X_1	x_1	0.1340	6.95	1.76	1.83	6.82	2.53
	x_2	0.0943	2.92	1.23	1.52	2.97	2.83
X_2	x_3	0.0246	9.02	1.12	2.13	2.01	3.26
	x_4	0.1120	8.91	1.35	2.89	2.63	3.59
X_3	x_5	0.0260	4.97	1.65	1.93	2.89	2.72

	x_6	0.0405	3.11	2.32	3.56	4.76	3.95
	x_7	0.0646	5.35	2.15	3.53	4.41	2.79
	x_8	0.0205	5.17	1.93	3.86	4.95	3.90
X_4	x_9	0.0943	3.19	1.38	3.16	3.45	2.77
	x_{10}	0.1189	5.85	2.01	2.89	4.74	3.12
	x_{11}	0.0264	7.56	3.09	3.91	6.81	3.82
X_5	x_{12}	0.0165	8.79	2.32	3.75	7.36	3.71
	x_{13}	0.0083	7.86	2.83	2.91	6.85	3.75
	x_{14}	0.0289	5.92	1.13	1.31	4.89	1.67
X_6	x_{15}	0.1555	8.95	1.02	2.23	8.86	2.97
	x_{16}	0.0345	7.97	2.15	3.03	5.89	3.13

4.3. Determining the classical domain and node domain matrices

According to the risk evaluation index x_k (k =1, 2, ..., 16) of the business expansion project in the value range of different levels of risk, the classical domain matter element matrices for the comprehensive risk evaluation of the business expansion project were obtained. These matrices are shown as follows:

$$R_{01}=\begin{bmatrix} N_{01} & x_1 & <0,\ 2> \\ & x_2 & <0,\ 2> \\ & \vdots & \vdots \\ & x_{16} & <0,\ 2> \end{bmatrix}, R_{02}=\begin{bmatrix} N_{02} & x_1 & <2,\ 4> \\ & x_2 & <2,\ 4> \\ & \vdots & \vdots \\ & x_{16} & <2,\ 4> \end{bmatrix}, R_{03}=\begin{bmatrix} N_{03} & x_1 & <4,\ 6> \\ & x_2 & <4,\ 6> \\ & \vdots & \vdots \\ & x_{16} & <4,\ 6> \end{bmatrix}$$
$$R_{04}=\begin{bmatrix} N_{04} & x_1 & <6,\ 8> \\ & x_2 & <6,\ 8> \\ & \vdots & \vdots \\ & x_{16} & <6,\ 8> \end{bmatrix}, R_{05}=\begin{bmatrix} N_{05} & x_1 & <8,\ 10> \\ & x_2 & <8,\ 10> \\ & \vdots & \vdots \\ & x_{16} & <8,\ 10> \end{bmatrix} \quad (12)$$

According to the allowable value range of each risk evaluation index of the business expansion project, the node domain matter element matrix for the comprehensive risk evaluation of the business expansion project was obtained. The matrix is shown as follows:

$$R_p=\begin{bmatrix} N_p & x_1 & <0,\ 10> \\ & x_2 & <0,\ 10> \\ & \vdots & \vdots \\ & x_{16} & <0,\ 10> \end{bmatrix} \quad (13)$$

4.4. Determining the matter element to be evaluated

There are 5 business expansion projects to be evaluated, which are PM_1, PM_2, PM_3, PM_4 and PM_5. In the following, the risk of PM_1 was evaluated first, and then the risks of the other four business expansion projects were evaluated.

According to the evaluation values of risk evaluation indexes of PM_1 (these values are shown in table 3), the matter element matrix R of PM_1 was obtained.

$$R = \begin{bmatrix} N & x_1 & 6.95 \\ & x_2 & 2.92 \\ & x_3 & 9.02 \\ & \vdots & \vdots \\ & x_{15} & 8.95 \\ & x_{16} & 7.97 \end{bmatrix} \quad (14)$$

4.5. Comprehensive risk evaluation

When evaluating the comprehensive risk of PM_1, first, establish the risk correlation degree matrix between PM_1 and each risk level; then, calculate the comprehensive risk correlation degree according to the correlation degree matrix; finally, determine the risk level of PM_1 based on the comprehensive risk correlation degree.

4.5.1. Establishing the risk correlation degree matrix.

According to equation (9), the correlation degree matrix $K = \left[K_j(v_k)_{16\times5} \right]$ between each risk evaluation index of PM_1 and each risk level is calculated. The calculation results are as follows.

$$K=\left[K_j(v_k)_{16\times 5}\right]=\begin{bmatrix} -0.4160 & -0.2980 & -0.1203 & 0.1583 & -0.1313 \\ -0.2396 & 0.4600 & -0.2700 & -0.5133 & -0.6350 \\ -0.4377 & -0.3575 & -0.2508 & -0.1016 & 0.1219 \\ -0.4368 & -0.3553 & -0.2462 & -0.0927 & 0.1138 \\ -0.3741 & -0.1633 & 0.2425 & -0.1717 & -0.3788 \\ -0.2630 & 0.4009 & -0.2225 & -0.4817 & -0.6113 \\ -0.3851 & -0.2015 & 0.1383 & -0.1083 & -0.3313 \\ -0.3801 & -0.1845 & 0.1912 & -0.1383 & -0.3538 \\ -0.2717 & 0.3403 & -0.2025 & -0.4683 & -0.6013 \\ -0.3969 & -0.2403 & 0.0263 & -0.0250 & -0.2688 \\ -0.4238 & -0.3201 & -0.1711 & 0.0618 & -0.0550 \\ -0.4358 & -0.3527 & -0.2409 & -0.0825 & 0.0987 \\ -0.4271 & -0.3294 & -0.1914 & 0.0181 & -0.0175 \\ -0.3984 & -0.2449 & 0.0137 & -0.0133 & -0.2600 \\ -0.4371 & -0.3561 & -0.2479 & -0.0960 & 0.1188 \\ -0.4283 & -0.3325 & -0.1982 & 0.0038 & -0.0038 \end{bmatrix} \tag{15}$$

4.5.2. Calculating the comprehensive risk correlation degree.

In the above paper, the AHP method and PCA method were used to determine the combined weight W_k (k=1,2... 16). According to equation (10), the correlation degree between PM_1 and the j-th risk is

$$K_j(R)=\sum_{k=1}^{16} W_k K_j(v_k) \qquad (j=1,2,3,4,5) \tag{16}$$

The combined weight of each risk evaluation index of PM_1 and the values in the correlation degree matrix are substituted into the above equation to obtain the comprehensive risk correlation degree.

$$K_j(R)=\sum_{k=1}^{16} W_k K_j(v_k)=(-0.3801,-0.1374,-0.1362,-0.1358,-0.2028) \tag{17}$$

That is

$$\begin{gathered} K_1(R)=-0.3801,\quad K_2(R)=-0.1374,\quad K_3(R)=-0.1362 \\ K_4(R)=-0.1358,\quad K_5(R)=-0.2028 \end{gathered} \tag{18}$$

And

$$K_{j_0}(R)=\max_{1\le j\le 5} K_j(R)=K_4(R)=-0.1358 \tag{19}$$

It can be seen that the comprehensive risk level of PM_1 is level 4, that is, the risk is high. Similarly, the above methods were also applied to evaluate the comprehensive risks of business expansion project PM_2, PM_3, PM_4 and PM_5 (the calculation process was omitted due to limited space).

After calculation, the comprehensive risks of PM_2, PM_3, PM_4 and PM_5 are respectively very low (Level 1), low (Level 2), medium (Level 3) and low (Level 2).

The above evaluation results are consistent with the actual risk status of the five business expansion projects. After the completion of PM_1, the average annual return on investment is less than 8%. It is expected that in the next 15 years, LQY Electric Power Company will find it difficult to recover the cost. This project has increased the asset-liability ratio of LQY Electric Power Company. After the completion of PM_4, the average annual rate of return on investment is 12.3%. It is expected to take 10 years for LQY Electric Power Company to recover the cost, and the cost recovery cycle is too long. After the completion of PM_2, PM_3 and PM_5, the average annual returns on investment of these projects are higher, reaching more than 23.5%. It is expected that in the next 6 years, LQY Electric Power Company can recover the costs, and these three projects can continue to create economic benefits for LQY Electric Power Company.

5. Conclusions

With the constant changes in the internal and external environment of the construction of business expansion projects, electric power company will face more challenges and risks in the management of business expansion projects. How to evaluate and pre-control the risk of business expansion project is a difficult problem that has plagued the development of electric power company for a long time. Based on the theory and method of project risk management, the risk evaluation index system was constructed, and the AHP-PCA-EMEM model for risk evaluation of business expansion project was established, then an empirical study was carried out. The research shows that:

First, based on the questionnaire survey method and principal component analysis method, the dimension reduction of the risk evaluation indexes of business expansion project was carried out, which not only helps to eliminate the correlation between indexes, but also helps to improve the efficiency of index data collection and reduce the workload of evaluation model calculation.

Second, the AHP method (a subjective weighting method) and PCA method (an objective weighting method) were used to calculate the combined weight of risk evaluation indexes, which not only fully reflects the professional opinions of experts, but also comprehensively reflects the objective information of evaluation indexes, to make the weighting results of evaluation indexes more objective and authentic.

Third, the AHP-PCA-EMEM model can qualitatively and quantitatively evaluate the comprehensive risk of business expansion project, which is helpful for electric power company to fully understand the risk status of business expansion project, and take corresponding measures to prevent and control risks, and effectively reduce the impact of unfavorable factors.

Fourth, the method proposed in this paper not only provides a useful basis for electric power company to strengthen the risk management of business expansion project, but also provides new ideas and new approaches for project risk assessment in other fields.

Acknowledgments

This research is supported by the project of power grid investment benefit evaluation and strategy optimization for investment interface extension of State Grid Fujian Electric Power Co., Ltd. Economic and Technical Research Institute, China, No. SGFJJY00GHJS2200046. And this research is supported by the project of Sichuan University, China, No. 00502055A1004. The corresponding authors of the paper are Xiaofeng Li and Jian Pan.

References

[1] Zheng C 2022 Optimization of marketing service mode in the process of electric power system reform *Rural power management.* **3** 56-58

[2] Ou B H 2017 Research on the current situation and development direction of customer service in electric power enterprises in the new era *Technology innovation and application.* **28** 161-162

[3] Tan Y 2018 Analysis of business expansion and installation work problems and measures in electric power marketing services *Hydropower and water resources.* **2** 33-34

[4] Liang J Y 2016 Safety risk analysis and preventive measures for acceptance of customer business expansion project of electric power supply enterprise *New technology and new products of China.* **19** 174-175

[5] Fang Y 2018 Current situation and measures of customer service management in electric power marketing of electric power enterprises *Hydropower and water resources*. **2** 58-59

[6] Berny J and Townsend P R F 1993 Macrosimulation of project risks—a practical way forward *International journal of project management.* **11** 201-208

[7] Tummala V M R and Leung Y H 1996 A risk management model to assess safety and reliability risks *International journal of quality & reliability management.* **13** 53-62

[8] Ozdoganm I D and Talat Birgonul M 2000 A decision support framework for project sponsors in the planning stage of build-operate-transfer (BOT) projects *Construction management & economics*. **18** 343-353

[9] Peixoto J, Tereso A, Fernandes G, et al 2014 Project risk management methodology: a case study of an electric energy organization *Procedia technology.* **16** 1096-1105

[10] Taillandier F, Taillandier P, Tepeli E, et al 2015 A multi-agent model to manage risks in construction project (SMACC) *Automation in construction*. **58** 1-18

[11] Ayala-Cruz J 2016 Project risk planning in high-tech new product development *Academia revista latinoamericana de administración*. **29** 110-124

[12] Li D and Yuan Y 2007 Risk assessment of construction project based on grey system theory *Construction economy*, (S2): 96-98

[13] Liu X P 2015 Research on risk evaluation indexes of construction project based on FAHP *Value engineering*. **34** 22-24

[14] Shi G Y 2016 Research on risk management system of substation engineering construction project *Low carbon world*. **15** 91-92

[15] Zhu B Q, Zou A and Ma Z J 2010 Application of AHP in risk management of power transmission and transformation projec *Power system engineering*. **26** 71-72

[16] Cheng G P, Xu W H, and Guan X J 2015 Application of AHP in construction risk evaluation of engineering project *Value engineering*. **34** 7-11

[17] Liu L 2021 Research on risk management of H substation engineering construction project *University of Electronic Science and Technology of China*, Chengdu.
[18] Cai Wen, Yang Chunyan and Lin Weichu 2021 Extension engineering method, *Science press*, Beijing.
[19] Chen T 2008 Analysis and research of multi-indexes comprehensive evaluation method *Science and technology information*. **9** 350-352
[20] Zhao Y F, Chen J F and Guo W L 2005 Application of analytic hierarchy process in decision-making problem of power industry *Power system protection and control*. **3** 83-88
[21] Wang D and Yang Y B 2015 Correlation analysis of power user energy saving and emission reduction factors based on principal component analysis *Electrical and energy management technology*. **12** 66-69
[22] Zhu X L 2001 Foundation of applied information theory *Tsinghua university press*, Beijing.
[23] Cai W and Yang C Y 2013 Basic theory and methodology of extenics *Chinese science bulletin*. **58** 1190-1199