Research on Comprehensive Evaluation Model of Regional Power Grid Construction Cost Based on Combined Weight

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Abstract. With the introduction of the "carbon peak, carbon neutrality" action plan, it has become an inevitable trend to invest in promoting supply-side structural adjustment and demand-side response to achieve bilateral development. Therefore, the construction expansion and construction cost assessment of key areas of power grid in the future are the focus of power enterprises. In this paper, a comprehensive evaluation model of regional power grid construction cost suitable for various environments is proposed. The ANP-CRITIC method, which combines the analytic hierarchy process with the CRITIC objective evaluation method, is used to determine the subjective and objective weights of the indicators. The comprehensive evaluation results are obtained by calculating the combined weights based on Euclidean distance. In terms of model verification, based on PEST theory, this paper constructs a regional power grid construction cost index system from 4 levels: political environment, economic environment, social environment and technical environment. Through the evaluation and analysis of regional examples, the rationality of the model is verified, and the lowest expected construction cost area is selected to assist enterprise decision-making and ensure the effective realization of power grid construction benefits.

Keywords: Power grid construction; ANP-CRITIC method; Comprehensive evaluation model.

1. Introduction

With the gradual deepening of China 's electricity market reform, the current electricity market reform mainly aims at reducing the cost of power supply, improving the economic benefits of the power grid, and reducing risk investment[1,2]. Under the operation mechanism of vertically integrated electricity market, the evaluation of the expected cost of power grid investment has become a priority issue for power grid decision-making. At present, the evaluation of the cost of power grid construction is based on the influence of the internal project management level and project construction of the power grid, and does not take into account the possible cost increase caused by the external factors of the construction area. However, in the construction environment, in addition to the management level and construction of the power grid itself, the region will also bring many other influencing factors to the cost assessment of power grid construction projects, such as regional economic factors, regional social factors, etc. Under the premise of ensuring the reliability and safety of the power grid, it is a new topic for power grid enterprises to seek the maximum construction income with limited resource investment.

At present, China 's power grid construction evaluation is mainly from the economic point of view to evaluate and select the evaluation index, including financial analysis, national economic analysis and enterprise performance analysis, and focused on the benefit evaluation of a single power grid construction project[3,4,5], At the macro level, there are few studies on the evaluation of the expected cost of power grid construction. This paper considers the macro expected construction costs of power grid construction in different regions, and selects appropriate comprehensive evaluation methods to analyze and evaluate the construction costs that may be brought about by local policies, economy, society and technology.

About the evaluation methods, the mainstream subjective weighting methods mainly include analytic hierarchy process [7], delphi technique [8], binomial coefficient method [9], etc. Among them, the analytic hierarchy process has the quantitative characteristics that can include all decision-making elements, and can adapt to the comprehensive and flexible advantages of various types of decision-making environments. At the same time, in terms of objective weighting, the mainstream objective weighting methods mainly include the entropy weight method [10], TOPSIS method [11], variation coefficient method and CRITIC method [12] and so on. The CRITIC method can eliminate the influence of some indicators with strong correlation and reduce the information overlap between indicators, which is more conducive to obtaining credible evaluation results. The mainstream combination weighting methods generally use multiplicative synthesis and linear weighting to combine methods. The combination weight calculation based on Euclidean distance can effectively reflect the subjective preference of decision makers while maintaining the basic law of objective data, thus ensuring the rationality of comprehensive evaluation results.

Based on the above research, this paper selects the analytic hierarchy process and CRITIC method to determine the subjective and objective weights, and obtains the final evaluation results through the combination weight calculation based on Euclidean distance, and constructs the evaluation model of regional power grid construction cost. In the model verification, the index system is constructed from the aspects of policy, economy, society and technical environment. With the minimum cost of power grid construction as the basic goal, the possible cost of power grid construction in each region is comprehensively evaluated. The case analysis proves the rationality of the method proposed in this paper.

2. Regional Power Grid Construction Cost Evaluation Model

In order to ensure the scientificity and wide applicability of the evaluation model of regional power grid construction cost, this paper uses the analytic hierarchy process (AHP) and CRITIC objective evaluation method to carry out the subjective and objective weighting of the indicators respectively. Finally, the final weight of each index is calculated by the combination weight based on Euclidean distance, and the indicators are comprehensively analyzed and evaluated.

2.1 Analytic Hierarchy Process (AHP)

Analytic hierarchy process (AHP) decomposes the construction cost of regional power grid into different levels, that is, index layer to criterion layer, criterion layer to target layer, and calculates the weight value of each index. The steps are as follows:

(1) Determine the evaluation index of regional power grid construction cost, which is mainly divided into target layer (A), criterion layer (B) and index layer (V).

(2) According to the1-9 scale method (see TABLE I), invite power grid construction related experts, related people on the same level of construction cost evaluation index of pairwise comparison and assignment.

Table 1. 1-9 scale method

Serial number	important level	Assignment
1	Indicator i is as important as indicator j	1
2	Indicator i and indicator j are slightly important	3
3	Indicator i and indicator j are obviously important	5
4	Indicator i and indicator j are strongly important	7
5	Indicator i and indicator j are extremely important	9
6	The value between the important levels of the above indicators	2，4，6，8

According to the scale method, the judgment matrix of pairwise comparison evaluation index is obtained, that is:

$$C = \begin{bmatrix} C_{11} & C_{12} & \cdots & C_{1n} \\ C_{21} & C_{22} & \cdots & C_{2n} \\ \vdots & \vdots & & \vdots \\ C_{n1} & C_{n2} & \cdots & C_{nn} \end{bmatrix} \tag{1}$$

(3) According to the Perron theorem, the corresponding weight vector W of the judgment matrix is calculated:

$$W = \left[\omega_1, \omega_2, \cdots \omega_n\right]^T \tag{2}$$

(4) The consistency test of the judgment matrix is to test the rationality of the weight of the given construction cost evaluation index, that is, the consistency index CR < 0.1, indicating that the weight of the given construction cost evaluation index is reasonable, the consistency test effect is satisfied, and the risk assessment can be carried out, and vice versa, the specific calculation expression is:

$$CR = \frac{\lambda_{\max}^{-n}}{(n-1)RI} < 1 \tag{3}$$

In the formula, RI is the average random consistency index.

2.2 CRITIC Objective Evaluation Method

In order to obtain more objective and comprehensive weighting results, the CRITIC objective weighting method is selected to correct the subjective weight. The main steps of the CRITIC method are as follows:

(1) Index normalization, normalization formula is :

$$a_{ij}' = \frac{a_{ij} - \min(a_j)}{\max(a_j) - \min(a_j)} \tag{4}$$

In the formula, a_{ij} and a'_{ij} are the index values before and after normalization respectively; $\max(a_j)$ and $\min(a_j)$ are the maximum and minimum values of the index, respectively.

(2) Determine the contrast strength S_j, conflict correlation coefficient ρ_{ij}

$$S_j = \sqrt{\frac{1}{x}\sum_{i=1}^{x}(a'_{ij} - \overline{a_j})^2}, j = 1, 2, \cdots, n \tag{5}$$

$$\rho_{ij} = \frac{\sum (i - \bar{i})(j - \bar{j})}{\sqrt{\sum (i - \bar{i})^2 (j - \bar{j})^2}} \tag{6}$$

In the formula, i and j are two sets of data ; $\bar{i}$ and $\bar{j}$ are the mean values of i and j, respectively.。

(3) Determine the comprehensive information content C_j of each index:

$$C_j = S_j \sum_{i=1}^{n} (1 - \rho_{ij}), j = 1, 2, \cdots, n \tag{7}$$

(4) Calculate the weight coefficient w_j:

$$\omega_j = \frac{C_j}{\sum_{j=1}^{n} C_j} \tag{8}$$

From the formula (7), it can be seen that the larger the C_j, the more information the index j has, and the greater the weight value.

2.3 Combined Weight Calculation Based on Euclidean Distance

When calculating the combination weight, many scholars assume the preference coefficient of subjective and objective weight according to the empirical value, which lacks objectivity and rationality. In order to reflect the subjective preferences and opinions of decision makers, while maintaining the basic laws of objective data, the degree of difference between subjective and objective weights is matched with the distribution coefficient, in order to describe the deviation between weighting methods, this paper adopts a combination weighting method based on Euclidean distance, the subjective weight obtained by ANP is w_j, the objective weight obtained by CRITIC method is w_j', and the function of Euclidean distance between subjective and objective weights is defined as $d(w_j, w_j')$.

$$d\left(w_j, w_j'\right) = \sqrt{\frac{1}{2}\sum_{j=1}^{n}\left(w_j - w_j'\right)^2} \tag{9}$$

The combined weight W_i is determined by linear weighting, and the expression is:

$$W_i = \alpha w_j + \beta w_j' \tag{10}$$

In the formula, α and β are the distribution coefficients of subjective weight and objective weight respectively.

There is the following relationship equation between subjective and objective weight and distribution coefficient:

$$\begin{cases} (\alpha-\beta)^2 = d^2\left(w_j, w_j'\right) \\ \alpha+\beta = 1 \end{cases} \tag{11}$$

The distribution coefficients α and β are solved by combining Formulas (9) and (11), and the combined weight W_i of the evaluation index is obtained by using Formula (10).

3. Example Analysis

3.1 A.Construction of Regional Power Grid Construction Cost Evaluation Index System

The construction cost of the power grid in a certain area will be affected by a variety of factors in the region. It is necessary to screen the factors that have the greatest impact on the construction cost of the power grid. PEST analysis is a commonly used macro-environment analysis method. P is politics, E is economy, S is society, and T is technology. When analyzing the external environment of an enterprise, it is usually through these four factors to analyze the situation faced by the enterprise group, which is also applicable to the cost evaluation of regional power grid construction. Based on the PEST theory, this paper takes the cost evaluation system of regional power grid construction as the target layer, and constructs the criterion layer of the cost evaluation index system of regional power grid construction from 4 aspects: policy and regulatory environmental factors, economic environmental factors, social and natural environmental factors, and technical environmental factors. The indicators at all levels are as follows:

Table 2. Construction cost evaluation index

Target layer	Criterion layer	Index layer
Regional power grid construction cost evaluation system (A)	Policy and regulatory environment factors B1	Policy incentives and policy restrictions at the national level C11
		Local regional policy support or policy constraints C21
		Strategic development goals are consistent with local policy orientation C22
	Economic environmental factors B2	Growth rate of consumption C31
		Regional GDP growth rate C41
		Regional material prices C51
		Development of regional competitors C61
	social and natural environmental factors B3	Total population growth rate C71
		Growth rate of regional urbanization level C72
		Feasible site selection for regional power grid construction C81
	technical environmental factors B4	Power supply reliability C91
		Grid securityC92
		Wind-solar grid-connected capacity C01
		Renewable energy power consumption accounts for the proportion of regional electricity consumption C02

In order to ensure the rationality of the data, 6 typical regions in China are selected as the research objects, and the index data are selected with 2022 as the time node. The evaluation index system and comprehensive evaluation method of regional power grid construction cost formed in this paper are verified and analyzed. The selected areas include more developed cities, developing cities and less developed cities, which can represent the average level of urban development in China and can test the rationality of the evaluation method more scientifically.

3.2 Index Data Processing

Because there are subjective indicators that cannot be directly quantified in the indicators, the average score of each indicator is obtained in the form of expert meeting scoring, which is used as the indicator data. The maximum and minimum normalization of all index data is performed to measure the distance from the minimum value in the distance index. After processing all the data, the normalized index results shown in Table 3 are obtained.

Table 3.Index data processing results

Index	C11	C21	C22	C31	C41
Region 1	0.667	1	0.909	1	0.833
Region 2	0.333	0.267	0	0.71	0.333
Region 3	0	0.133	0.364	0	0
Region 4	0.222	0	0.091	0.258	1
Region 5	1	0.667	1	0.452	0.5
Region 6	0.444	0.333	0.364	0.581	0.033
mean value	0.444	0.4	0.455	0.5	0.45

Index	C51	C61	C71	C72	C81
Region 1	0	0.8	0	0.24	0.6
Region 2	0.714	0.846	0.153	0	0.6

Region 3	0.357	0	0.168	0.98	0.4
Region 4	0.857	0.585	0.536	0.4	0
Region 5	0.143	1	0.798	0	1
Region 6	1	0.631	1	1	0.6
mean value	0.512	0.644	0.443	0.437	0.533

Index	C91	C92	C01	C02
Region 1	1	0.097	1	0.477
Region 2	0.064	0.28	0	0.992
Region 3	0.106	1	0.599	0.191
Region 4	0	0.624	0.4	0
Region 5	0.042	0	0.595	1
Region 6	0.059	0.344	0.425	0.422
mean value	0.212	0.391	0.503	0.514

3.3 Subjective Empowerment of AHP Method

Invited 10 experts to score and sort each index, and investigated the quantitative index, so as to obtain the weight of each risk evaluation index in the criterion layer and the index layer.

Table 4. Subjective Weight

Criterion layer	Subjective weights	Index layer	Subjective weights
B1	0.438	C11	0.087
		C21	0.184
		C22	0.167
B2	0.194	C31	0.010
		C41	0.157
		C51	0.002
		C61	0.025
B3	0.079	C71	0.002
		C72	0.035
		C81	0.042
B4	0.289	C91	0.157
		C92	0.035
		C01	0.010
		C02	0.087

3.4 Objective Empowerment of CRITIC Method

According to the data in Table 3, combined with Formulas (5) to (8), the objective weights are obtained as follows:

Table 5. Objective weight

Criterion layer	Objective weights	Index layer	Objective weights
B1	0.213	C11	0.064
		C21	0.075
		C22	0.074

B2	0.239	C31	0.057
		C41	0.074
		C51	0.064
		C61	0.044
B3	0.207	C71	0.073
		C72	0.084
		C81	0.050
B4	0.342	C91	0.148
		C92	0.076
		C01	0.053
		C02	0.065

3.5 Solution of Combined Weights

According to Table 4 and Table 5, combined with Formulas (9) to (11), the combined weights of each index are obtained as follows:

Table 6. Combined weight

Criterion layer	Combined weights	Index layer	Combined weights
B1	0.325	C11	0.075
		C21	0.129
		C22	0.120
B2	0.217	C31	0.034
		C41	0.115
		C51	0.033
		C61	0.035
B3	0.143	C71	0.038
		C72	0.060
		C81	0.046
B4	0.316	C91	0.152
		C92	0.056
		C01	0.032
		C02	0.076

3.6 Evaluation Results and Analysis

After obtaining the combined weight, combined with the index data of Table 3, the index scores and total scores of each region can be obtained as follows:

Table 7. Regional power grid construction cost level

Index	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6
C11	0.050353	0.025139	0	0.016759	0.075492	0.033518
C21	0.129461	0.034566	0.017218	0	0.086351	0.043111
C22	0.109505	0	0.04385	0.010963	0.120467	0.04385
C31	0.033517	0.023797	0	0.008647	0.01515	0.019473
C41	0.096187	0.038452	0	0.115471	0.057735	0.003811

C51	0	0.023578	0.011789	0.0283	0.004722	0.033022
C61	0.027605	0.029193	0	0.020186	0.034507	0.021774
C71	0	0.005741	0.006304	0.020113	0.029945	0.037525
C72	0.014284	0	0.058327	0.023807	0	0.059517
C81	0.027602	0.027602	0.018401	0	0.046003	0.027602
C91	0.152497	0.00976	0.016165	0	0.006405	0.008997
C92	0.005385	0.015544	0.055514	0.034641	0	0.019097
C01	0.031515	0	0.018878	0.012606	0.018752	0.013394
C02	0.036248	0.075384	0.014515	0	0.075992	0.032069
Total	0.714159	0.308755	0.260961	0.291493	0.57152	0.39676

From the table, the following conclusions can be drawn:

(1) The power grid construction cost of region 1 is the highest, and the indicators with the highest expected cost are mainly concentrated in the local regional policy constraints, the consistency of strategic development goals and local policy orientation, power supply reliability and regional GDP growth rate. Region 1 itself is a poorly developed region in all regions, and it is at a disadvantage in terms of economic development level and power grid facilities construction, which leads to the high cost of power grid construction in region 1. At the same time, the related problems of region 5 are similar to that of region 1, and the lack of local support policies and poor economic development have increased the construction cost of the power grid in the region. Therefore, it should not be given priority to promote the construction of power grid in region 1 and region 5.

(2) Region 3 is the region with the lowest expected construction cost of power grid in all regions. Because region 3 is the most developed region in all regions, the regional economic development degree is higher, and the supporting facilities for power grid construction are also relatively perfect. The local government has formulated positive relevant policies, and the support for power grid investment is greater. Therefore, region 3 is the most suitable region for power grid construction.

(3) It is worth noting that the expected cost of region 6 is also higher in policy and regulatory environmental indicators, which indicates that although the overall environment of region 6 is close to that of region 2 and region 4, region 6 does not actively carry out support for grid-related investment. Compared with region 2 and region 4, region 6 has a lower priority for grid construction.

(4) The indicators with large expected cost gap brought by the indicators in the figure are mainly concentrated in the regional policy and legal indicators and reliability parts, which are also indicators that directly affect the stable operation of power grid construction projects. In order to absorb more power grid construction projects, the region should give priority to the establishment of relevant active policies, while focusing on the supporting construction of local power construction-related infrastructure to enhance the ability to attract investment.

4. Conclusion

In this paper, the regional power grid construction cost is divided into different levels of indicators by combining the analytic hierarchy process and the CRITIC objective evaluation method, and the subjective and objective weighting is carried out for each indicator. Based on the Euclidean distance, the combined weight of each indicator is calculated to form a regional power grid construction cost evaluation model. In the model verification analysis, based on the PEST theory, from the 4 dimensions of policy and regulatory environment, economic environment, social and natural environment and technical environment, the evaluation index system of regional power grid construction cost is constructed to evaluate the expected cost of regional power grid investment. Through the comprehensive evaluation of the actual cases in 6 different regions, it can be seen that the regional power grid construction cost evaluation model constructed in this paper has certain advantages in dealing with large-scale index data, and can dynamically adapt to different evaluation scenarios and needs. The rationality of the evaluation model constructed in this paper is verified, and suggestions and planning opinions are put forward for typical regions.

Acknowledgement

This study is supported by the science and technology project of State Grid corporation of China (Power grid investment quality improvement under electricity-carbon market linkage, 1400-202256459A-2-0-ZN).

References

[1] GUO Xiaomin, HUANG Jun, YANG Jianwei, HE Zhengyou . Application of Power Betweenness Theory in Assessment on Line-Breakage Risk in Transmission Network [J] . Power System Technology, 2015, 39(2) : 486 − 493.

[2] YE bin， LI Wanqi， WANG Xuli, et al. Risk Planning of Distribution Network with Distributed New Energy ［J］ . Electric Power Construction, 2016, 37(4) : 117 − 123.

[3] Ahmad A, Bosze E J, Nutt S R. A Composite Core Conductor for Low Sag at High Temperatures[J].IEEE Transactions on Power Delivery,2005,20(3) :2 193-2 199.

[4] Burks B,Armentrout D L, Kumosa M S. FailurePrediction Analysis of an ACCC Conductor Subiected to Thermal and Mechanical Stresses[J]. IEEEIransactions on Dielectrics and Electrical Insulation,2010,17(2).588-596.

[5] PENG Linbi . The Investment Decision Research of EHV AC-DC Transformer Technology Reconstruction Project of TBEA Hengyang Transformer Co. ［D］ . Hunan University, 2014

[6] YANG Liu, YANG Jing, LIU Junting . Post-evaluation Method and Index System for Technical Renovation of Power Grid Projects ［J］ . Energy Technology and Economics, 2010,22(2):29-34.

[7] GE L, LI Y, LI S, et al. Evaluation of the situational awareness effects for smart distribution networks under the novel design of indicator framework and hybrid weighting method[J]. Frontiers in Energy, 2021, 15(1): 143-158.

[8] KONG X Y, YONG C S, WANG C S, et al. Multi-objective power supply capacity evaluation method for activedistribution network in power market environment[J]. International Journal of Electrical Power & Energy Systems,2020: 115: 105467.

[9] CHENG Mingxi. The binomial coefficient weighted sum method for dealing with multi-objective decision-making problems [J]. System Engineering Theory and Practice, 1983(4): 23-26.

[10] HU C, LIU F, HU C. A hybrid fuzzy DEA/AHP methodology for ranking units in a fuzzy environment[J]. Symmetry-Basel, 2017, 9(11): 273.

[11] LI Zhijun, XIANG Jianjun, SHENG Tao, XIAO Bingsong. G1-variation-coefficient-KL based TOPSIS radar jamming effectiveness evaluation [J]. Journal of Beijing University of Aeronautics and Astronautics, 2021,47(12):2571-2578.DOI:10.13700/j.bh.1001-5965.2020.0493.

[12] JIANG Huan, WU Jia hui, SANIYE Mahmuti, et al. Comprehensive Vulnerability Evaluation of Power Systems Structure Based on VIKOR Method and Complex Network Theory[J]. Water Resources and Power, 2023,41(03):216-220.DOI:10.20040/j.cnki.1000-7709.2023.20221819.