Research on comprehensive benefit evaluation of multi-energy complementation of power grid projects based on AHP-TOPSIS

Changzheng Gao, Xiuna Wang, Dongwei Li*, Weiyang You

*Corresponding author: 30307230@qq.com (Dongwei Li)

CEC Technical & Economic Consulting Center of Power Construction，Electric Power Development Research Institute Co.,Ltd , No. 13 Baiguang Road, Xicheng District, Beijing, 100053 , China

Abstract. This paper constructs an index system for evaluating the comprehensive benefits of power grid projects under the framework of multi-energy complementation, and combines the analytic hierarchy process (AHP) with the technique for order preference by similarity to ideal solution (TOPSIS) to evaluate the comprehensive benefit of projects with multi-energy complementation. It can effectively use expert knowledge and experience to scientifically evaluate the comprehensive benefits of grid projects. Finally, the evaluation ranking of the multi-energy complementary comprehensive benefits of grid projects using actual data shows the feasibility and effectiveness of the evaluation model.

Keywords- power grid projects; multi-energy complementarity; AHP-TOPSIS; evaluation

1. Introduction

The vigorous promotion of power grid projects in recent years is attributed to the demand for environmental improvement brought by new energy development on the one hand. On the other hand, grid construction and operation projects have equally strong research value in terms of cost control, benefit analysis and optimal design. With the continuous promotion of national energy saving and emission reduction policies, the development of multi-energy complementation and integration will become an important trend in the future development of energy systems.

Under the framework of multi-energy complementarity, the decision-making process of grid projects has obvious multi-criteria characteristics, including the multi-attribute characteristics of project resource demands and the multi-objective characteristics of project operation. Therefore, the traditional grid project evaluation also needs to be further improved, considering the comprehensive benefits of society and environment on the basis of the economic and technical indicators. At the same time, the comprehensive benefit evaluation method of multi-energy complementation for grid projects also needs to be combined with multi-attribute decision-making, so as to realize the comprehensive analysis [5-6].

In this paper, the analytic hierarchy process (AHP) and the technique for order preference by similarity to ideal solution (TOPSIS) are combined to construct the comprehensive benefit evaluation index system of power grid projects under the framework of multi-energy complementarity. This method effectively converts expert knowledge and experience into index

EMIS 2023, February 24-26, Chengdu, People's Republic of China

DOI 10.4108/eai.24-2-2023.2330651

weights, and scientifically ranks the evaluation schemes of power grid projects, and objectively evaluates the comprehensive benefits of power grid projects under the framework of multi-energy complementarity.

2. Multi-attribute comprehensive evaluation model based on AHP-TOPSIS

Referring to the relevant research on AHP and TOPSIS methods at home and abroad (Zhu M et al., 2020; Gong J et al., 2020), and evaluating the comprehensive benefits of multi-energy complementation of power grid projects, this paper constructs the power grid project evaluation process based on AHP-TOPSIS model, as shown in Figure 1.

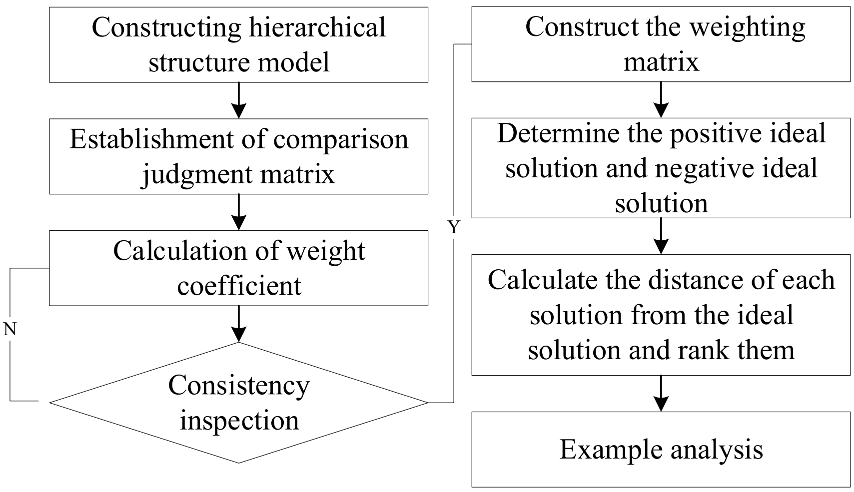

Figure.1 Power grid project evaluation process based on AHP-TOPSIS model

2.1. Calculate the evaluation index weights based on AHP method

2.1.1 Constructing hierarchical structure model

In this paper, on the basis of analyzing the evaluation of grid projects in China under the framework of multi-energy complementarity and drawing on relevant studies at home and abroad [1,3, 9], a comprehensive benefit evaluation index system for grid projects under the framework of multi-energy complementarity is constructed from four aspects: technical benefit, economic benefit, social benefit and environmental benefit, as shown in Figure 2.

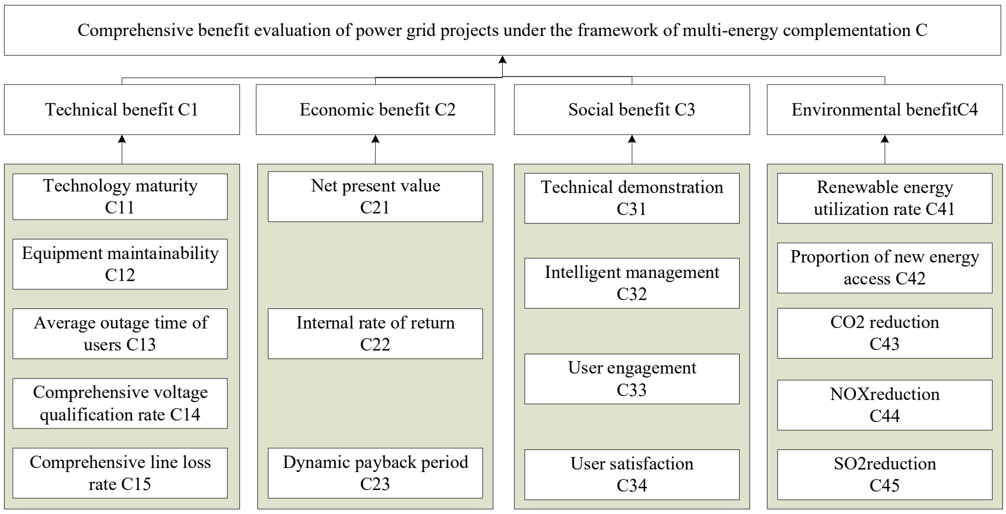

Figure 2 Comprehensive benefit evaluation index system of power grid projects under the framework of multi-energy complementation

2.1.2 Establishment of comparison judgment matrix

The above evaluation indexes were compared and scored by several experts through discussion, and the scoring criteria are shown in Table 1.

Table 1 Comparison value and meaning of AHP

Value	Meaning
1	Equal importance of indicators
3	Indicators are slightly important
5	Indicators are obviously important
7	Indicators are strongly important
9	Important indicators
2、4、6、8	The importance of the two indicators is between the above intermediate values

The judgment matrix $E = (E_{ij})_{m\times m}$of evaluation indicators can be obtained from Table 1. The matrix form is as follows:

$$E = \begin{pmatrix} E_{11} & E_{12} & \cdots & E_{1m} \\ E_{21} & E_{22} & \cdots & E_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ E_{m1} & E_{m1} & \cdots & E_{mm} \end{pmatrix} \tag{1}$$

2.1.3 Calculation of weight coefficient

The judgment matrix E can be normalized by using formulas (2) and (3), and the weight of each evaluation index can be calculated.

$$M_i = E_{11}E_{12} \cdots E_{im} \tag{2}$$

$$W_i = \frac{\sqrt[n]{M_i}}{\sum_{i=1}^{n}(\sqrt[n]{M_i})} \tag{3}$$

2.1.4 Consistency inspection

The above indicator weights also need to be tested for consistency. After passing the consistency inspection, the indicator weight coefficient can be used for model evaluation. If the consistency inspection is not passed, the judgment matrix needs to be adjusted again (see Fig.1). In general, when the consistency inspection index CR does not exceed 0.1, the judgment matrix passes the consistency inspection, and it can be considered that the weight value of the evaluation index meets the requirements.

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(EW)_i}{W_i} \tag{4}$$

$$CI = \frac{\lambda_{max}-n}{n-1} \tag{5}$$

$$CR = \frac{CI}{RI} \tag{6}$$

where, λ_{max} is the maximum eigenvalue of the matrix, $(EW)_i$ is the product of the judgment matrix and the index weights, and RI is the random consistency index, the value of which is related to the matrix order n and can be obtained by looking up the table.

2.2. TOPSIS Evaluation Method

TOPSIS analysis, also known as technique for order preference by similarity to ideal solution, was first proposed by C.L. Hwang and K. Yoon in 1981 and is a commonly used method in multi-attribute decision making [7-8].

The method constructs the ideal solution (optimal solution, inferior solution) of multi-attribute decision making, and then calculates the Euclidean distance between the evaluation object and the ideal solution, and finally obtains the order of superiority and inferiority of the evaluation object.

(1) Data assimilation processing. For n evaluation objects, if each object has m evaluation indicators, the original data matrix can be constructed:

$$X = \begin{pmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ x_{n1} & x_{n1} & \cdots & x_{nm} \end{pmatrix} \tag{7}$$

For the reverse indicators in the evaluation indicators (such as the investment payback period, the smaller the value of the indicator, the better the evaluation effect), the same trend processing is required, and the processed data can be obtained by using Formula (8).

$$y_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})} \tag{8}$$

(2) Construct the weighting matrix. Continue to normalize the evaluation index data, as shown in Formula (9).

$$y'_{ij} = \frac{y_{ij}}{\sqrt{\sum_{i=1}^{n} y_{ij}^2}} \tag{9}$$

Continue the weighting process to obtain the weighted standardization matrix of the evaluation data $\boldsymbol{Z}_{ij}$.

$$\boldsymbol{Z}_{ij} = w_i y'_{ij} \tag{10}$$

(3) Determine the positive ideal solution and negative ideal solution of the evaluation scheme. The positive ideal solution Z^+ of the evaluation scheme is constructed. Z^+ is composed of the maximum value of each column of data in matrix $\boldsymbol{Z}$, as shown in Formula (11). Continue to construct the negative ideal solution Z^- of the evaluation scheme. Z^- is composed of the minimum value of each column of data in matrix $\boldsymbol{Z}$, as shown in Formula (12).

$$Z^+ = (max\{z_{11}, z_{21}, \cdots, z_{n1}\}, max\{z_{12}, z_{22}, \cdots, z_{n2}\}, \cdots, max\{z_{1m}, z_{2m}, \cdots, z_{nm}\}) = (Z_1^+, Z_2^+, \cdots, Z_m^+) \tag{11}$$

$$Z^- = (min\{z_{11}, z_{21}, \cdots, z_{n1}\}, min\{z_{12}, z_{22}, \cdots, z_{n2}\}, \cdots, min\{z_{1m}, z_{2m}, \cdots, z_{nm}\}) = (Z_1^-, Z_2^-, \cdots, Z_m^-) \tag{12}$$

(4) Calculate the Euclidean distance between each evaluation scheme and the positive and negative ideal solution. Calculate the Euclidean distance between each evaluation scheme and the positive and negative ideal solution, which is the Euclidean distance between the $i-th$ evaluation scheme and the positive ideal solution, which can be calculated by Formula (13):

$$D_i^+ = \sqrt{\sum_{j=1}^{m} (Z_j^+ - z_{ij})^2} \tag{13}$$

D_i^- is the Euclidean distance between the $i-th$ evaluation scheme and the negative ideal solution, which can be calculated by Formula (14):

$$D_i^- = \sqrt{\sum_{j=1}^{m} (Z_j^- - z_{ij})^2} \tag{14}$$

(5) Calculate the relative proximity $\boldsymbol{C_i}$ between each evaluation scheme and the ideal solution. the relative proximity C_i between each evaluation scheme and the ideal solution can be calculated by Formula (15).

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{15}$$

The higher the value of C_i, the closer the $i-th$ evaluation scheme is to the positive ideal solution, that is, the higher the priority of the evaluation scheme. Finally, each evaluation scheme is ranked according to the value of C_i, and the evaluation results are given.

3. Comprehensive evaluation example analysis

The above AHP-TOPSIS multi-attribute comprehensive evaluation model can be used to evaluate the multi-energy complementary comprehensive benefits of power grid projects, and the order of each evaluation scheme can be obtained.

3.1. Data collection

This paper collects the data of projects involving multi-energy complementation in a regional power grid project, and uses the multi-attribute comprehensive evaluation model based on AHP-TOPSIS to evaluate the comprehensive benefits of six projects [2]. The specific indicator data of projects A to F are shown in Table 2.

Table 2 Evaluation index data of a regional power grid project

Primary Indicators	Secondary Indicators	A	B	C	D	E	F	unit	weigh
C1（0.088）	C11	6.4	5.7	8.2	7.5	4.8	2.9	-	0.0046
	C12	9.5	8.6	7.4	9.4	8.5	3.6	-	0.0359
	C13	0.25	0.35	0.17	0.32	0.24	0.19	Hour/10000 households	0.0281
	C14	100%	80%	96%	85%	88%	92%	%	0.0108
	C15	0.15%	0.21%	0.35%	0.17%	0.32%	0.24%	%	0.0087
C2（0.221）	C21	812	1242	586	1616	681	1446	yuan	0.0591
	C22	9.47%	15.6%	8.70%	18.39%	8.95%	16.11%	%	0.0258
	C23	15.3	9.4	11.3	11.6	16.2	12.7	year	0.1353
C3（0.304）	C31	8.5	9.2	8.8	8.9	8.7	9.5	-	0.0598
	C32	8.3	9	9.6	8.5	9.5	9.1	-	0.0377
	C33	9.3	9.4	8.9	8.9	9.2	9.7	-	0.0793

	C34	9.5	9.3	8.3	9.5	9.6	8.3	-	0.1268
C4（0.387）	C41	14%	21%	17%	19%	31%	22%	%	0.1125
	C42	18%	37%	15%	32%	24%	28%	%	0.1478
	C43	24.07	29.59	11.5	6.6	15.14	34.12	million tons	0.0679
	C44	7.92	18.91	9.1	4.7	10.84	20.35	million tons	0.0365
	C45	1.62	2.34	1.25	0.49	2.47	1.36	million tons	0.0235

3.2. Index weight calculation

The maximum eigenvalue of the judgment matrix calculated by the AHP method is 4.1649, and the consistency test index of the judgment matrix is CR=0.0618<0.1. The judgment matrix passes the consistency test. The calculation result of the index weight is shown in Table 3.

Table 3 Comprehensive evaluation results of power grid project based on AHP-TOPSIS

Scheme				Ranking
A	0.1003	0.032	0.242	6
B	0.0299	0.111	0.788	1
C	0.0750	0.069	0.477	4
D	0.0588	0.078	0.569	3
E	0.1008	0.048	0.322	5
F	0.0541	0.074	0.577	2

3.3. TOPSIS evaluation ranking

Based on TOPSIS method, the positive ideal solution and negative ideal solution of the project evaluation scheme as well as the relative proximity of each evaluation scheme and ideal solution are calculated respectively, and the final order of the project evaluation scheme is shown in Table 3. It can be seen from Table 3 that the comprehensive evaluation result of Scheme B is the best, while the comprehensive evaluation result of Scheme A is poor.

4. Conclusion

In this paper, a multi-attribute comprehensive evaluation model based on AHP-TOPSIS is established to evaluate the comprehensive benefits of power grid projects under the framework of multi-energy complementarity. By analyzing the actual project data, it can be seen that the multi-attribute comprehensive evaluation model based on AHP-TOPSIS is feasible to apply to the comprehensive benefit evaluation of power grid projects. Meanwhile, the evaluation model also has some shortcomings. For example, the AHP evaluation method may have subjectivity in determining the evaluation index weights. In the subsequent research practice, we can consider adding objective weighting method to further improve the comprehensive benefit evaluation method of power grid projects, so as to make the evaluation results more scientific and reasonable.

Reference

[1] Chai Y, Xiang Y, Liu J. (2020) “Optimization model and method of distribution network investment planning driven by association rules for reliability improvement,” Pow. Auto. Equi., vol. 40, no. 03, pp. 85-92.

[2] Chen T, Wang H, Peng W, Jia W, Sun Y. (2019) “Analysis on safety risks and control measures of power grid regulation and operation,” Elec. Comp. Infor. Tech., vol. 3, no. 06, pp. 59-61.

[3] Gao B, Liu Y, Liu Y. (2019) “Comprehensive evaluation of regional distributed multi-energy complementary energy system scheme,” Smar. City., vol. 5, no. 15, pp. 1-4.

[4] Gong J, Dang D, Zhang B, Xu P. (2020) “Post-evaluation index system and method of intelligent distribution network project based on attribute theory,” Pow. Dem. Side. Manage., vol. 22, no. 04, pp. 8-12+30.

[5] Lu D, Liu Z, Bai Y, Cheng R, Gong M. (2022) “Study on the multi-energy complementary absorption system applied for combined cooling and heating in cold winter and hot summer areas. Appl Ener,2022,312.

[6] Sapkota B, Vittal V. (2009) “Dynamic VaR planning in a large power system using trajectory sensitivities,” IEEE. Trans. on Pow. Sys., vol. 25, no. 01, pp. 461-469.

[7] Wu J, Sun J, Zha Y. (2011) “Ranking approach of cross-efficiency based on improved TOPSIS technique,” Jour. Sys. Engi. Elec., vol. 22, no. 05, pp. 604-608.

[8] Yang Y. (2011) “Discussion on load control during small isolated network operation in regional power grid,” Elec. Comp. Infor. Tech., vol. 4, no. 01, pp. 141-142.

[9] Zhang M, Nan J, Li D, Li Y. (2012) “TOPSIS for multi-attribute decision making with triangular intuitionistic fuzzy numbers,” Oper. Rese. Manage., vol. 21, no. 05, pp. 96-101.

[10] Zhu M, Chen S, Shao Y. (2020) “Evaluation of regional innovation resource planning capability based on AHP-TOPSIS and SOM clustering,” Scien. Rese. Manage., vol. 41, no. 02, pp. 40-50.