International Journal of Power and Energy Systems, Vol. 43, No. 10, 2023
An Open Access Paper

AN EVALUATION METHOD WITH MULTI-TECHNICAL INDICATORS FOR CAPACITY CONFIGURATION SCHEME OF THE ENERGY STORAGE SYSTEM AT USER SIDE BASING ON GAME TOPSIS

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Abstract

Effective evaluation is conducive to optimising the reasonable allocation of user energy storage and promoting the healthy development of the energy storage industry. Aiming at the problems of low attention, imperfect evaluation system and insufficient quantification of traditional evaluation methods, an evaluation method based on combined weighting and improved TOPSIS method for the capacity allocation of user energy storage system is proposed. According to the operation process and characteristics, combined with the trend and distance indicators, a comprehensive evaluation system covering performance, economy and society is constructed. The G1 method and independent weight method are used to calculate the subjective weight and objective weight of the evaluation index, and the improved game theory method is used to calculate the comprehensive weight of the evaluation index. Taking the energy storage system of commercial users as an example, the effectiveness and practicability of the proposed method are verified.

Key Words

User energy storage system; capacity configuration; evaluation with multiple technical indicators; TOPSIS method; game theory

1. Introduction

The construction and development of new power system is an important way for the power industry to practice the dual-carbon goal. With the large-scale grid connection of a high proportion of new energy and the diversified energy demand of users, the "double-high" and "double-random" characteristics pose higher challenges to the reliability of the power system [1]–[5].

As massive distributed user energy storage systems are connected to the power grid at scale to participate in the interaction of source and charge, relevant studies on user energy storage system configuration are increasing year by year, and good research results have been achieved [6]–[18]. A joint market with electricity and gas is constructed for price uncertainties [12]. An optimal scheduling strategy is developed for peaking and valley load [13]. An optimal configuration model of dual-layer architecture energy storage system is proposed for auxiliary services of peak regulation [14]. An optimal configuration model of energy storage system using intelligent method and differential evolution algorithm [15]. An optimisation configuration model was built for user energy storage [16]. An evaluation model of energy storage system is presented using analytic hierarchy process (AHP) [17]. An optimal allocation model of energy storage in the whole life cycle is studied [18].

However, some questions remain unanswered from previous studies. 1) For the configuration of user energy storage system, the optimal allocation of energy storage is realised by optimising the scheduling model, and the impact assessment of energy storage system on users is often ignored, which is not conducive to the improvement of user economic benefits. 2) The configuration evaluation of user energy storage system has not yet formed a scientific and reasonable systematic index system. 3) The configuration evaluation index of the user energy storage system is more to consider only subjective needs or objective conditions. 4) The configuration evaluation of user energy storage system does not consider the adaptability of indicators, and it is difficult to use for effectiveness evaluation of a single indicator.

This paper proposes a ranking preference technique based on the similarity of ideal solutions (TOPSIS) to achieve comprehensive evaluation and effectively describe positive and negative effects of user energy storage system.

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Recommended by Gian Luca Foresti
(DOI: 10.2316/J.2023.203-0473)

2. The Weighting Method

2.1 Subjective Weight Calculation

G1 method is used for Subjective weight calculation. Matrix F is formulated:

$$F = [f_1, \quad f_2, \ldots, f_j, \ldots, f_m] \tag{1}$$

Where F is the matrix of evaluation indicators, $j = 1, 2, \ldots, m$, $m = 26$. f_j represents DD represents the indicator of performance, economy and society and is measured by equally important, slightly important, obviously important, strongly important and extremely important.

2.2 Objective Weight Calculation

In the comprehensive evaluation of the capacity configuration of the energy storage system at user side, 26 evaluation indicators are considered, and the complex correlation coefficient of the evaluation indicators f_j may be expressed as:

$$R_j = \frac{\sum_{j=1}^{m} \left(f_j - \overline{f}\right)\left(\widetilde{f} - \overline{f}\right)}{\sqrt{\sum_{j=1}^{m} \left(f_j - \overline{f}\right)^2 \sum_{j=1}^{m} \left(\widetilde{f} - \overline{f}\right)^2}} \tag{2}$$

where R_j is the coefficient of complex correlation of evaluation indicators f_j; $\widetilde{f}$ is the residual matrix without f_j; $\overline{f}$ is the average value of the matrix of the evaluation indicators F, $\overline{f} = \text{mean}\,(F) \circ$

There is an inverse proportional relationship between the weight of the evaluation indicators and the coefficient of complex correlation. Take the reciprocal of the coefficient of complex correlation as the weight of the evaluation indicators f_j, and normalise the reciprocal. The weight calculation result of the independence weight method is:

$$R = \left[\frac{1}{R_1}, \frac{1}{R_2}, ..., \frac{1}{R_n}\right] \tag{3}$$

$$\omega''_j = (R_j \sum_{j=1}^{n} R_j)^{-1} \tag{4}$$

where ω''_j is the jth evaluation indicators, and the weight calculation result of independence weight method is adopted.

2.3 Comprehensive Weight Determination

The subjective weight and objective weight are comprehensively analysed by using the improved game theory method [21], and the comprehensive weight of the jth evaluation indicators is calculated as follows:

$$\omega_i = \beta_1^* \left(\omega'_j\right)^T + \beta_2^* \left(\omega''_j\right)^T \tag{5}$$

where, β_1^* and β_2^* are comprehensive weight factors $j = 1, 2, \ldots, m$.

The calculation formulas of comprehensive weight factors β_1^* and β_2^* is formulated as follows:

$$\beta_1^* = \frac{\omega'_j \omega'^T_j + \omega''_j \omega'^T_j}{\omega'_j \omega'^T_j + \omega''_j \omega'^T_j + \omega'_j \omega''^T_j + \omega''_j \omega''^T_j} \tag{6}$$

$$\beta_2^* = \frac{\omega'_j \omega''^T_j + \omega''_j \omega''^T_j}{\omega'_j \omega'^T_j + \omega''_j \omega'^T_j + \omega'_j \omega''^T_j + \omega''_j \omega''^T_j} \tag{7}$$

3. Evaluation Model

3.1 Improved TOPSIS Method

TOPSIS is a comparative evaluation method. Its core idea is to determine the positive and negative ideal schemes through the cosine method, calculate the distance difference between the remaining schemes and the positive and negative ideal schemes by using the Euclidean distance, and form a multi-scheme ranking according to the distance difference, so as to realise the effective evaluation of the advantages and disadvantages of multi-schemes [19]–[24].

1) The matrix of initial evaluation indicators

The optimal and worst values of evaluation indicators may be determined by using the determination method of positive and negative ideal schemes in the improved TOPSIS method. To this end, the initial matrix of evaluation indicators is constructed:

$$F_{3\times m} = \begin{bmatrix} f_{11} & f_{12} & \cdots & f_{1m} \\ f_{21} & f_{22} & \cdots & f_{2m} \\ f_{31} & f_{32} & \cdots & f_{3m} \end{bmatrix} \tag{8}$$

where $F_{3\times m}$ is the initial matrix of evaluation indicators, the first line of $F_{3\times m}$ represents the vector of the initial worst value of all evaluation indicators, the second line of $F_{3\times m}$ represents the vector of the initial actual value of all evaluation indicators, and the third line of $F_{3\times m}$ represents the vector of the initial optimal value of all evaluation indicators; m is the number of evaluation indicators, $m = 26$.

2)Weighted dimensionless treatment

The dimensionless matrix $B = (b_{\text{pq}})_{3\times m}$ is constructed and evaluated as follows. The element of the dimensionless matrix is calculated:

$$b_{\text{pq}} = \frac{f_{\text{pq}}}{\sqrt{\sum_{p=1}^{3} f_{\text{pq}}^2}} \tag{9}$$

where b_{pq} is the element of dimensionless evaluation indicators matrix, $p = 1, 2, 3$, $q = 1, 2, ..., m$.

Using the calculation results, the dimensionless matrix is weighted and the weighted dimensionless evaluation indicators matrix $Z = (z_{\text{pq}})_{3\times m}$ is constructed. The calculation method is formulated as follows:

$$z_{\text{pq}} = \omega_{\text{ij}} b_{\text{pq}} \tag{10}$$

where z_{pq} is the element of weighted dimensionless evaluation indicators matrix, $i = 1, 2, 3$, $q = 1, 2, ..., m$.

3)The judging method for the advantages and disadvantages of evaluation indicators

All evaluation indicators only include the actual value, the optimal value and the worst value, which belong to one-dimensional data. The actual value is within the range from the worst value to the optimal value, and there is no case that the actual value is not collinear with the optimal value and the worst value. The distance may be calculated by directly using the European distance method. The specific calculation formulas are given as follows:

$$d'_q = |z_{1q} - z_{2q}| \tag{11}$$

$$d_q = |z_{1q} - z_{3q}| \tag{12}$$

$$d''_q = |z_{2q} - z_{3q}| \tag{13}$$

where d'_q is the distance from the actual value of the jth evaluation indicators to the worst value, and d_q is the distance from the actual value of the jth evaluation indicators to the optimal value; d''_q is the distance from the optimal value to the worst value of the jth evaluation indicators.

4)The judging method for the advantages and disadvantages of criterion level indicators

The criterion level indicators are composed of multiple evaluation indicators. With the increase of the number of evaluation indicators, the dimension of criterion level indicators increases, and the nonlinearity intensifies. In other words, the actual value of the criterion level indicators may be collinear or non-collinear with the optimal value and the worst value, as shown in Fig. 1. The actual value of the criterion level indicators may appear at any position within two straight lines (including two straight lines). Considering that the actual value of the criterion level indicators may not be collinear with the optimal value and the worst value, only using the Euclidean distance to calculate the advantages and disadvantages of the criterion level indicators will not effectively describe the distance difference from the actual value to the optimal value and the worst value. It is necessary to consider the influence of the correlation of the trend, and optimise the calculation method of the distance difference from the actual value of the criterion level indicators to the optimal value and the worst value from the perspective of distance value and trend value.

a) The line segment of criterion level indicators

Considering that the actual value, the best value and the worst value of the standard level indicator may not be collinear, the distance from the actual value to the best value and the distance from the actual value to the worst value of the standard level indicator are mapped on the line segment between the best value and the worst value, and the calculation formula is given as follows:

$$d_i = \|z_{3q} - z_{1q}\| = \sqrt{\sum_{q\in j} (z_{3q} - z_{1q})^2} \tag{14}$$

$$d'_i = \|z_{1q} - z_{2q}\| = \sqrt{\sum_{q\in j} (z_{1q} - z_{2q})^2} \tag{15}$$

$$d''_i = \|z_{3q} - z_{2q}\| = \sqrt{\sum_{q\in j} (z_{3q} - z_{2q})^2} \tag{16}$$

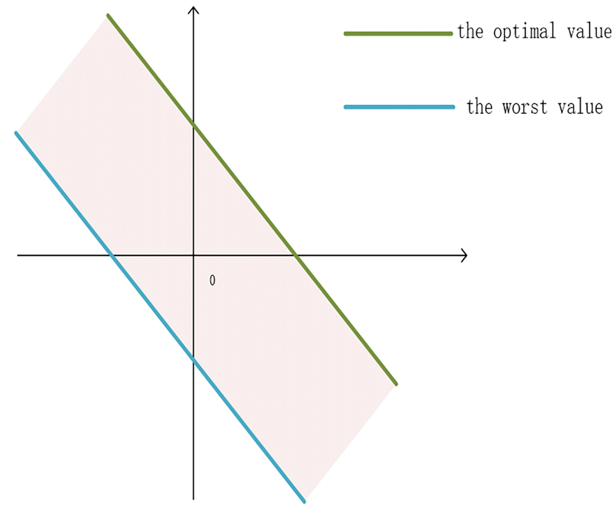

Figure 1. Actual value range of criteria level indicators (taking two-dimensional as an example).

where d_i is the distance between the vector of the optimal value and the vector of the worst value of the ith indicators; d'_i is the distance between the vector of the worst value of the ith indicators of the criterion level and the vector of the actual value; d''_i is the distance between the vector of the optimal value of the ith indicators and the vector of the actual value; j_i refers to all evaluation indicators included in the ith indicators.

The distance between the actual value and the worst value of the ith indicators is mapped on the line segment:

$$D'_i = \|z_{1q} - z_{2q}\| \cos\theta = \frac{{d'}_i^2 + d_i^2 - {d''}_i^2}{2d_i} \tag{17}$$

where D'_i is the line segment of the worst value mapping of the ith indicators in the criterion level; $\cos\theta$ is the cosine of the angle between the worst value vector and the actual value vector.

The distance from the actual value of the ith indicators in the criterion level to the optimal value is mapped on the line segment between the optimal value and the worst value:

$$D''_i = \|z_{3q} - z_{2q}\| \cos\psi = \frac{{d''}_i^2 + d_i^2 - {d'}_i^2}{2d_i} \tag{18}$$

where D''_i is the line segment of the optimal value mapping of the ith indicators in the criterion level; $\cos\psi$ is the cosine of the angle between the vector of the optimal value and the actual value vector.

b)The distance value

By comparing the difference between the line segment mapped by the optimal value of the ith indicators in the criterion level and the line segment mapped by the worst value of the, the difference matrix of the ith indicators in the criterion level is established:

$$\Delta S_{1,i} = D''_i - D'_i \tag{19}$$

where $\Delta S_{1,i}$ is the difference matrix of the mapped line segment of the ith indicators, $\Delta S_{1,i} \in [-d_i, d_i]$.

Table 1
Relationship Between Comprehensive Evaluation Results and Capacity Configuration of Energy Storage System at User Side

Comprehensive evaluation results	0–0.2	0.2–0.6	0.6–0.8	0.8–1
Energy storage configuration status	Abnormal	Normal	Good	Excellent

The evaluation result of the distance value of the criterion level indicators is obtained by substituting the difference matrix of the criterion level indicators into the following formula:

$$F_{1,i} = \frac{1}{2}\left(1 + \frac{\Delta S_{1,i}}{d_i}\right) \tag{20}$$

where $F_{1,i}$ is the evaluation result of the distance value of the ith indicators in the criterion level.

c)The trend value

By comparing the mapping line segment of the worst value of the ith indicators in the criterion level with the mapping line segment of the optimal value of the quotient matrix of the ith indicators in the criterion level is established:

$$\Delta S_{2,i} = \frac{D'_i}{D''_i} \tag{21}$$

where $\Delta S_{2,i}$ is the quotient matrix of the mapping line segment of the ith indicators in the criterion level, $\Delta S_{2,i} \in [0, \infty]$.

By substituting the quotient matrix of the indicators in the criterion level into the following formula, the evaluation result of the distance value of the indicators in the criterion level is obtained:

$$F_{2,i} = e^{\frac{1}{\Delta S_{2,i}}} \tag{22}$$

where $F_{2,i}$ is the evaluation result of the trend item of the ith indicators in the criterion level.

3.2 Comprehensive Evaluation

The distance value and trend value of the ith indicators of the criterion level are accumulated using the proportion coefficient to obtain the comprehensive evaluation result:

$$F_i = \alpha F_{1,i} + (1-\alpha)\, F_{2,i} \tag{23}$$

The relationship between the comprehensive evaluation results and the status of the capacity configuration scheme of the energy storage system at the user side is shown in Table 1.

3.3 The Evaluation Steps

The specific steps are given as follows:

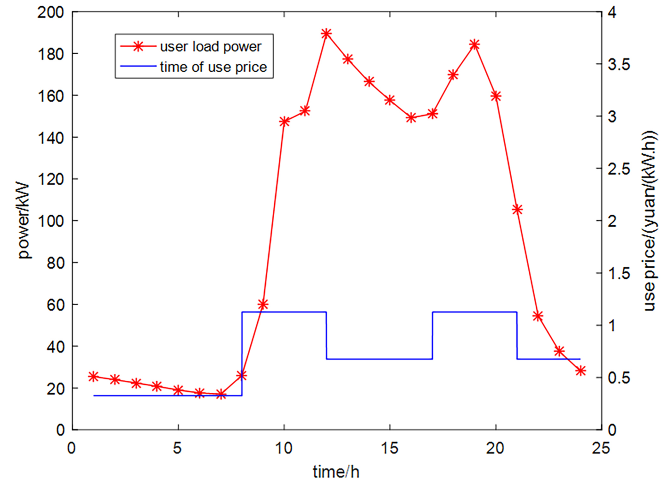

Figure 2. Power load curve and price time curve.

1) Collect user sample data and conduct dimensionless processing.
2) Select 26 indicators from three aspects of performance, economy and society to build a three-level evaluation system of scheme level, standard level and evaluation level.
3) G1 method is used to calculate the subjective weight coefficient; The independence weight method is used to calculate the subjective weight coefficient using (3) and (5).
4) Use (6) and (7) to calculate the comprehensive weight of evaluation indicators.
5) The improved TOPSIS method is used to quantify the positive and negative ideal scheme, and the best value, worst value and actual value in single object-oriented evaluation is used to improve the practicability of the TOPSIS method.
6) Use the constructed difference matrix and quotient matrix to calculate the standard-level index value of distance value and trend value.
7) Calculation of comprehensive evaluation results of criteria level indicators. Use (23) to calculate the values of distance value and trend value to obtain the comprehensive evaluation results of the criterion level indicators.

The comprehensive evaluation results of the energy storage system at user side are calculated by using the comprehensive evaluation results of the criteria level indicators and the corresponding comprehensive weights, and the state level of the energy storage system is judged according to Table 1.

4. Calculation and Analysis for Study Case

A commercial user in Jiangsu Province is used for example calculation. The power load curve of the user and the time of use price curve of the region are shown in Fig. 2. The capacity of the user energy storage system is 4MW//24MWh.

Table 2
Comprehensive Weight of Different Indicators of Energy Storage System at User Side

criterion level	Indicators Weight
F_1	$[0.028; 0.041; 0.024; 0.035; 0.027; 0.033]$
F_2	$\begin{bmatrix} 0.073; 0.058; 0.029; 0.033; 0.087; 0.065; \\ 0.029; 0.036; 0.82; 0.074; 0.025; 0.026; \\ 0.027; 0.018; 0.013 \end{bmatrix}$
F_3	$[0.034; 0.015; 0.022; 0.019; 0.047]$

Table 3
Calculation Results of Different Indicators of Energy Storage System at User Side

Level	Weight	Distance value	Trend value	Evaluation value	Evaluation level
F_1	0.188	0.543	0.618	0.581	Normal
F_2	0.675	0.725	0.788	0.757	Good
F_3	0.137	0.682	0.704	0.693	Good

4.1 Indicators Weight Calculation

The G1 method is used to calculate the subjective weight of the evaluation indicators, the independence weight method is used to calculate the objective weight of the evaluation indicators, and the game theory method is used to calculate the comprehensive subjective and objective weight to form the comprehensive weight of the evaluation indicators. The calculation results of comprehensive weight of evaluation indicators are shown in Table 2.

4.2 Indicators Analysis

Use the improved TOPSIS method to calculate the distance value and trend value of standard-level indicators, as shown in Table 3. It is verified that the comprehensive evaluation result of capacity configuration of the user-side energy storage system proposed by the improved TOPSIS method is more consistent with the actual operation of the energy storage system and can effectively evaluate the capacity configuration of the user-side energy storage system.

4.3 Method Effectiveness Analysis

In order to further illustrate the effectiveness of the proposed improved TOPSIS method in the comprehensive evaluation of energy storage system, a multi-object comprehensive evaluation scenario is constructed. 2846 energy storage systems configured by commercial users in a region in Jiangsu Province are selected to comprehensively evaluate the energy storage system at user side by using the traditional TOPSIS method and the improved TOPSIS method. The evaluation results are shown in Fig. 3.

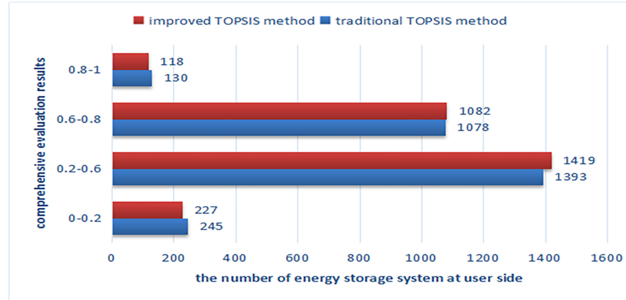

Figure 3. Comparison results of different methods for comprehensive evaluation of energy storage capacity at user side.

It may be seen from Fig. 3 that the evaluation results of the improved TOPSIS method and the traditional TOPSIS method are relatively close, which shows that the improved TOPSIS method proposed in this paper is also effective in the multi-object-oriented comprehensive evaluation of the capacity configuration of the energy storage system at user side. At the same time, it is found that 245 users are found to have abnormal status when evaluating with the traditional TOPSIS method, while 227 users are found with the improved TOPSIS method. Through the field investigation of all energy storage systems evaluated as abnormal, it is found that there are 230 users with abnormal operation state of energy storage system, which shows that compared with the traditional TOPSIS method, the improved TOPSIS method may effectively comprehensively evaluate the capacity configuration of the energy storage system at user side from multiple criteria layer indicators, and the evaluation of abnormal state of energy storage system is more strict and comprehensive, with higher accuracy.

5. Conclusions

1) The comprehensive evaluation of the capacity configuration of energy storage at the user side involves many aspects. The multi-dimensional technical indicators are selected from the performance, economy and society of the energy storage system at user side to build a comprehensive evaluation indicators system, which may make a more effective comprehensive evaluation of the capacity configuration of the energy storage system at user side from multiple criteria layer indicators.
2) In view of the difficulty of weighting the evaluation indicators, G1 method and independence weight method are used to calculate the subjective weight and objective weight of the indicators, respectively, and the multi-technical indicators weighting of the evaluation indicators is realised by using the method of game theory, which improves the rationality of determining the weight of the evaluation indicators.

6. Acknowledgements

This work is supported by Science & Technology Projects of China Southern Power Grid Co. (03600KK52200049(GDKJXM202019 78)).

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