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Comprehensive Evaluation of Power System Flexible Resource Value Based on Typical Application Scenarios

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Abstract. For the sake of exploring how to apply new flexible resources to power system efficiently, it is urgent to study the comprehensive value of different flexible resources in typical application scenarios of power system. In this paper, a flexible resource value comprehensive evaluation index system is established from three dimensions: technical value, economic value and application value. Combined with the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) method, a comprehensive evaluation model of power system flexible resource value in typical application scenarios is constructed to evaluate the current value of flexible resources in China. The results show that the virtual power plant shows the highest flexible resource matching degree in the peak shaving and valley filling scenario and the auxiliary service scenario, and the electrochemical energy storage shows the highest flexible resource matching degree in the safety support scenario.

Keywords. Power system, flexible resources, comprehensive evaluation, TOPSIS method

1. Introduction

In order to solve the problem of insufficient flexible adjustment capacity of the new power system characterized by a high proportion of renewable energy, the new flexible resources have been put into use in the form of pilot projects. Therefore, it is necessary to build a comprehensive value evaluation index system of flexible resources and evaluate the comprehensive value of different flexible resources in typical application scenarios.

On the value evaluation of power system flexible resources, most scholars have adopted comprehensive evaluation methods, such as fuzzy analysis method, analytic hierarchy process, ideal point method, matter-element extension model and so on. Some scholars apply the comprehensive evaluation method to actual cases. Starting from the overall benefits, Yin built a comprehensive value evaluation system of electrochemical energy storage considering externalities [1]. Ju et al. established and verified the benefit evaluation model of demand response in new energy utilization from the perspective of economy, environment and society [2]. Walawalkar et al. introduced the demand response market operated by U.S. regional transmission organizations, quantified the

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benefits of load reduction caused by demand response based on the actual application data in the U. S., and summarized the role of demand response in the energy market [3]. Bai analyzed the market benefits of demand response, constructed the comprehensive benefit evaluation index system of demand response from different angles, and proposed a comprehensive benefit evaluation model of demand response by using the improved ideal point evaluation method [4]. Guo built a comprehensive benefit evaluation index system with four indicators of energy conservation, economy, environment and social benefits. After giving the weight of relevant indicators based on analytic hierarchy process, he made a comprehensive analysis for a regional virtual power plant project [5]. Huang and Wang proposed an energy storage value evaluation method based on solar power generation. The evaluation shows that the energy storage system can reduce the workload of grid transformation and power constraints caused by large-scale distributed photovoltaic power generation grid connection [6]. Some scholars used the principal component analysis method to establish a comprehensive evaluation model with economy, environment and reliability as index, and took the data of some new energy power stations in Europe as actual cases to verify the feasibility of the model [7, 8].

According to the existing literatures, many scholars have conducted in-depth research on value evaluation of electrochemical energy storage, demand response and virtual power plants, but most of the literatures have the problem of singularity, and only a few of the literatures have conducted comparative research on a variety of flexible resources. Therefore, combined with the index data of flexible resources in typical application scenarios, this paper selects the combination weighting and TOPSIS method to establish a value comprehensive evaluation model, which maximizes the value of flexible resources in power system, and provides a reference for the development and construction of flexible resources projects in power system in the future.

2. Methodology

In this paper, the addition combination weighting method is selected to combine the subjective and objective weights, and the game theory is drawn into so as to achieve the ideal weighting state [9, 10]. On this basis, the value of flexible resources in typical application scenarios is comprehensively evaluated by TOPSIS method.

2.1. Combination Weighting

The subjective weight obtained by analytic hierarchy process is $W_1=(\omega'_1, \omega'_2, \dots, \omega'_j)$. The objective weight obtained by entropy method is $W_2=(\omega''_1, \omega''_2, \dots, \omega''_j)$. From the perspective of game theory and mathematics, when the sum of the deviations among W_1, W_2 and the combined weight is the smallest, the optimal solution can be obtained.

At first, objective function and constraint conditions are established.

$$\min\left(\|W-W_1\|^2+\|W-W_2\|^2\right)=\min\left(\|\lambda_1W_1+\lambda_2W_2-W_1\|^2+\|\lambda_1W_1+\lambda_2W_2-W_2\|^2\right) \tag{1}$$

$$\text{s.t.} \quad \lambda_1+\lambda_2=1, \lambda_1, \lambda_2 \geq 0 \tag{2}$$

where, λ_1 is the subjective weight coefficient, λ_2 is the objective weight coefficient.

Then, the constraints are solved and λ_1, λ_2 to λ^*_1, λ^*_2 are normalized. Finally, the combined weight W^* is obtained:

$$W^* = \begin{bmatrix} \omega_1^* \\ \omega_2^* \\ \vdots \\ \omega_j^* \end{bmatrix} = \begin{bmatrix} \lambda_1^* \omega_1^{'} + \lambda_2^* \omega_1^{''} \\ \lambda_1^* \omega_2^{'} + \lambda_2^* \omega_2^{''} \\ \vdots \\ \lambda_1^* \omega_j^{'} + \lambda_2^* \omega_j^{''} \end{bmatrix} \tag{3}$$

2.2. TOPSIS Method

TOPSIS is a classical multi-attribute decision-making method, which is widely used in various fields for decision-making or evaluation [11]. The basic steps of TOPSIS method are as follows.

The first step is to establish a decision matrix. We suppose that the solution set of all schemes in the system is $a=(a_1,a_2,\cdots a_n)$. The set contained in the index layer is $b=(b_1,b_2,\cdots b_n)$, and the value of b corresponding to a is $x_{ij}(i=1,2,\cdots,m; j=1,2,\cdots n)$. The decision matrix X of the comprehensive scheme can be obtained.

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \tag{4}$$

The second step is to normalize the data. If there are differences in the units and orders of magnitude of indexes, peer comparison cannot be performed. In this paper, dimensionless normalization is performed on the index data for the operation among the index data.

The third step is to calculate the normalized decision matrix $Z=(z_{ij})_{m\times n}$ after weighting, where z_{ij} can be obtained from the equation (5).

$$z_{ij} = x_{ij}^{*} \times w_j \tag{5}$$

where w_j is the combined weight of the j-th index.

The fourth step is to calculate the positive ideal solution and the negative ideal solution. We extract the highest data and the lowest data of each index in all schemes and reconstruct the matrix vector to form a positive ideal distance vector $z^+ = (z_1^{\,+}, z_2^{\,+}, \cdots z_n^{\,+})$ and a negative ideal distance vector $z^- = (z_1^{\,-}, z_2^{\,-}, \cdots z_n^{\,-})$.

The fifth step is to calculate the distance from the scheme to the positive or negative ideal solution. The numerical distances from the positive ideal solution D_i^+ and the negative ideal solution D_i^- of each scheme are obtained according to the following equations.

$$D_i^+ = \sqrt{\sum_{j=1}^{n}\left(z_{ij} - z_i^{\,+}\right)^2},\ i=1,2,\cdots,m \tag{6}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n}\left(z_{ij} - z_i^-\right)^2},\ i = 1,2,\cdots,m \tag{7}$$

The sixth step is to calculate the comprehensive evaluation value. The comprehensive evaluation value of each scheme is calculated by equation (8).

$$A_i = \frac{D_i^-}{D_i^+ + D_i^-}, i = 1,2,\cdots,m \tag{8}$$

where A_i is the closeness of the *i*-th scheme to the ideal solution. In this paper, it is the closeness of the value matching of the flexible resources in the typical scenarios to the optimal matching, and its value range is between [0, 1]. The larger the A_i, the closer the flexible resource is to the optimal matching level of the application scenarios.

3. Value Evaluation Index System and Weight Determination

3.1. Value Evaluation Index System

Based on the analysis of literatures, this paper selects technical value, economic value and application value as the criteria layer, and constructs the comprehensive value evaluation index system of flexible resources in three typical application scenarios: peak shaving and valley filling, safety support and auxiliary service. The index data are derived from the national specifications of the National Bureau of statistics, industry standards, academic literatures and relevant website data, as shown in Table 1.

Table 1. Index data for comprehensive evaluation of flexible resource value.

Criteria layer	Index layer	Unit	Order of magnitude	Electrochemical energy storage	Demand response	Virtual power plant
Technical value	Schedulable potential γ_1	kW	10^3	5790	158	6341
	Flexibility γ_2	—	1	0.2365	0.6025	0.5112
	Response time γ_3	second	1	5	15	15
	Technology maturity γ_4	—	1	3822.3	3870.1	708.6
Economic value	Power grid construction cost saved per unit cost γ_5	—	1	0.7720	0.7934	0.7857
	Power generation construction cost saved per unit cost γ_6	—	1	0.2272	0.2235	0.2446
	Operation and maintenance cost saved per unit cost γ_7	—	1	0.1962	0.2192	0.2254
Application value	Carbon emissions that can be reduced per unit cost γ_8	Ton/yuan	10^{-2}	0.8749	1.0218	1.0224
	User satisfaction γ_9	%/ 0.01 million yuan	10^{-4}	0.1403	0.1533	0.1512
	Grid connection difficulty γ_{10}	%	1	0.1000	0.9998	0.9999

3.2. Combined Weight Results

According to the combination weighting method established in this paper, the value evaluation combined weight of each flexible resource under typical application scenarios is obtained as shown in Table 2.

Table 2. Combined weight results of each index.

Index	Peak cutting and valley filling	Safety support	Ancillary service
γ_1	0.1569	0.1494	0.1301
γ_2	0.108	0.1075	0.1037
γ_3	0.1335	0.1611	0.125
γ_4	0.1034	0.1345	0.1408
γ_5	0.103	0.0894	0.0805
γ_6	0.1035	0.0934	0.102
γ_7	0.085	0.0651	0.1058
γ_8	0.0825	0.0577	0.0809
γ_9	0.0558	0.0663	0.0695
γ_{10}	0.0632	0.0472	0.0613

4. Comprehensive Evaluation Results

Based on the principle of TOPSIS method, the positive and negative ideal solutions of each index can be obtained by SPSSPRO software, as shown in Table 3.

Table 3. Calculation results of comprehensive evaluation.

Scenario type	Flexible resources	Positive ideal solution distance D^+	Negative ideal solution distance D^-	Comprehensive score index	Sort
Peak shaving and valley filling	Electrochemical energy storage	0.60997478	0.54844476	0.47344226	2
	Demand response	0.6275997	0.55443949	0.46905339	3
	Virtual power plant	0.52240528	0.62227425	0.54362312	1
Safety support	Electrochemical energy storage	0.49739782	0.6758504	0.57605065	1
	Demand response	0.71165353	0.47029778	0.39789945	3
	Virtual power plant	0.61255395	0.56432429	0.4795095	2
Auxiliary service	Electrochemical energy storage	0.67895052	0.38651499	0.36276631	3
	Demand response	0.4142714	0.66964657	0.61780189	2
	Virtual power plant	0.36830676	0.62965181	0.63093983	1

According to the model calculation results, in the peak shaving and valley filling scenario, the flexible resource matching degree from high to low is virtual power plant, electrochemical energy storage and demand response. In the safety support scenario, the flexible resource matching degree is in the order of electrochemical energy storage, virtual power plant and demand response from high to low. In the auxiliary service scenario, the flexible resource matching degree from high to low is virtual power plant, demand side response and electrochemical energy storage. It can be seen that the virtual power plant has great advantages in a variety of scenarios, and eliminates the disadvantages of environmental pollution of traditional power plants. It does not occupy land, can make efficient use of power resources, avoid energy waste, and has high application value in typical application scenarios.

5. Conclusion

This paper establishes the evaluation index system of power system flexible resource value based on typical application scenarios. At the same time, considering the characteristics of flexible resources and the needs of typical application scenarios, analytic hierarchy process is used to determine the subjective weight, entropy method is used to determine the objective weight, and game theory is introduced to combine the subjective and objective weights. Finally, TOPSIS method is used to establish a comprehensive evaluation model for the value of flexible resources in power system. The model can be used to compare and select flexible resources in typical application scenarios, and provide a reference for the project development and evaluation of flexible resources.

With the in-depth reform of China's power system and the development of science and technology, the flexible resource evaluation index system based on typical application scenarios established in this paper needs to be comprehensively revised and improved according to new technologies and requirements to ensure its applicability and accuracy. In the future, demand response, virtual power plant, electrochemical energy storage and other flexible resources will gradually realize large-scale use. Therefore, we should continue to mine the characteristic data of flexible resources and constantly enrich the model indexes, so as to evaluate the value of new flexible resources in power system more comprehensively and completely.

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