Research on Regional Power Grid Investment Decision Model Based on Projection Pursuit and Grey Theory

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Abstract. Based on the development status and operational characteristics of regional power grids, an evaluation index system for investment capacity of power grid enterprises is established. The projection pursuit model is used to determine the weight of the index, and combined with grey correlation theory, the comprehensive benefit evaluation value of power grid enterprises in each region is calculated. On this basis, a multi-objective investment decision model based on benefits is proposed, which realizes the optimal allocation of investment to power grids in various regions and provides guidance for power grid enterprises in their investment planning.

Keywords: Regional power grid, investment decision, projection pursuit, grey theory

1 Introduction

It is clearly stated in the power development plan that the accuracy of power grid benefit evaluation plays an important role in achieving refined management of the power grid. For the hard problem of consciousness of identification of vulnerable nodes in complex power grids, the existing literature proposes the following solutions:

One is the comprehensive evaluation model of grey correlation degree using analytic hierarchy process (AHP), which achieves a good combination of expert experience subjectivity and node data objectivity [1]; The second is a comprehensive evaluation method based on the perspective of power grid operation [2]; The third is the fusion of subjective and objective weights [3]. Currently, some scholars have conducted research on investment allocation decisions in power grid enterprises. Based on the results of the benefit evaluation, funds are allocated proportionally, but the requirement for maximizing investment benefits is ignored [4]. By optimizing and solving the variable weight theory based investment decision model, the investment priorities of different enterprises are highlighted. However, the factors considered are

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limited, and budget allocation cannot be based on the development status of power grids in different regions [5].

In summary, existing literature on indicator weights has a certain subjectivity, and lacks research on the rational allocation of power grid funds in various regions. This paper introduces the projection pursuit and grey theory to evaluate the benefit of power grids in various regions, which can achieve reasonable allocation of budget funds and improve the level of refined management of power grids.

2 Construction of evaluation index system for regional power grid investment capacity

For the power grid, the evaluation of investment capacity has strong strategic significance for determining the reasonable investment scale of the power grid. According to the development status and operational characteristics of the regional power grid, the indicator system constructed should consider four aspects: economy, scale, operation, and society. The evaluation index system for the comprehensive investment capacity of regional power grids is shown in Table 1.

Table 1. Comprehensive evaluation index system for investment capacity of regional power grids

Level indicator	Secondary indicators	Indicator attribute
Economic Benefits (A)	Asset liability ratio (A2)	Cost type
	EBITDA profit rate (A3)	Benefit type
	Increased sales of electricity per unit investment (A4)	Benefit type
	Operation and maintenance fees for unit assets (A7)	Cost type
Grid scale (B)	Annual maximum load rate (B1)	Benefit type
	Installed capacity supported by unit substation (B2)	Benefit type
	Installed capacity supported by unit line (B3)	Benefit type
Operating efficiency (C)	Average load rate of the line (C1)	Cost type
	Average load rate of main transformer (C2)	Cost type
	Comprehensive line loss rate (C5)	Cost type
Social benefits (D)	Proportion of new energy access (D1)	Benefit type
	Saving standard coal (D2)	Benefit type
	CO2 reduction (D3)	Benefit type

3 Evaluation model of power grid investment benefit based on projection pursuit and grey theory

3.1 Projection pursuit model

(1) Data standardization processing

The problem of comprehensive benefit evaluation of power grid enterprises can be described as follows: the set of m objects to be evaluated is $Q = \{Q_1, Q_2, \dots, Q_m\}$, and the index set of n indicators is $S = \{S_1, S_2, \dots, S_n\}$. Each indicator has different physical meanings, and the evaluation matrix is $X = \left(X_{ij}\right)_{m\times n}$. The extreme value method is used for data processing, and it is as follows [6]:

$$Y_{ij} = \begin{cases} \frac{X_{ij} - \min X_{ij}}{\max X_{ij} - \min X_{ij}}, S_j \in S^b \\ \frac{\max X_{ij} - X_{ij}}{\max X_{ij} - \min X_{ij}}, S_j \in S^c \end{cases} \tag{1}$$

where $\max X_{ij}$ and $\min X_{ij}$ are the maximum and minimum values of the j-th indicator, respectively; X_{ij} is the evaluation value of the indicator; S^b and S^c are the subscript sets of benefit and cost type indicators in S.

(2) Construct projection index function

Essentially, the main purpose of projection is to map high-dimensional data to low-dimensional subspaces to find feature projection vectors that reflect the original high-dimensional data structure. Project the standardized evaluation matrix Y, and the projection value P_i of Y on the unit projection direction vector a is:

$$P_i = \sum_{j=1}^{n} a_j X_{ij} \tag{2}$$

where $a = [a_1, a_2, \dots, a_n]$ is the unit projection vector.

The local projection points of the projection value should be condensed into several point clusters as much as possible, and the point clusters should be scattered as much as possible. Therefore, the projection index function can be expressed as [7]:

$$Q(a) = G(a)H(a) \tag{3}$$

$$G(a) = S(a)/L(a) \tag{4}$$

$$S(a) = [\sum_{i=1}^{m} (P_i - \bar{P})^2/m]^2 \tag{5}$$

$$L(a) = \sqrt{\sum_{i=1}^{m} P_i^2} \tag{6}$$

where $G(a)$ is composed of the standard deviation $S(a)$ of P_i and the module length $L(a)$, with $\bar{P}$ being the mean of P_i. $H(a)$ describes the local density points after projection, and $H(a)$ can be defined as [8]:

$$H(a) = \sum_{i=1}^{m} \sum_{j=1}^{n} \left(R - r_{ij}\right) \varepsilon\left(R - r_{ij}\right) \tag{7}$$

where R represents the window radius of local density, and R is taken as $0.1L(a)$; $r_{ij} = \left|P_i - P_j\right|/L(a)$ represents the distance between samples; $\varepsilon(k)$ represents step function, and $k = R - r_{ij}$. When $k \geq 0$, $\varepsilon(k) = 1$; When $k < 0$, $\varepsilon(k) = 0$.

(3) Optimization model of projection index function

When the evaluation value of the indicator in the sample is determined, the size of $Q(a)$ is related to the direction vector a. By constructing a maximization optimization model, the optimal projection vector can be calculated. a is the unit projection direction vector, and it satisfies $\sum_{j=1}^{n} a_j^2 = 1$. Therefore, $\omega = (a_1^2, a_2^2, \dots, a_n^2)$ can be used as the indicator weight vector. This model can reflect the degree of impact of different indicators on overall benefits, and solve the problem of subjective factors in weight determination. The optimization model for projection index function is as follows:

$$\begin{cases} \max Q(a) = G(a)H(a) \\ \quad s.t. \sum_{j=1}^{n} a_j^2 = 1 \end{cases} \tag{8}$$

3.2 Grey relational projection theory

The grey relational projection method integrates projection theory with grey theory to quantitatively evaluate decision plans [9].

(1) Weighted grey correlation matrix

Let $Y_0 = (Y_{01}, Y_{02}, \dots, Y_{0j}, \dots, Y_{0n})$ be the ideal sample reference sequence, and Y_{0j} be the maximum value of the j-th indicator value. The correlation degree e_{ij} between the two sequences can be:

$$e_{ij} = \frac{\min\limits_{i=1,2,\dots,m} \min\limits_{j=1,2,\dots,n} |Y_{0j} - Y_{ij}| + \rho \max\limits_{i=1,2,\dots,m} \max\limits_{j=1,2,\dots,n} |Y_{0j} - Y_{ij}|}{|Y_{0j} - Y_{ij}| + \min\limits_{i=1,2,\dots,m} \min\limits_{j=1,2,\dots,n} |Y_{0j} - Y_{ij}|} \tag{9}$$

where ρ is the resolution coefficient, and there is $0 \le \rho \le 1$. This paper sets $\rho = 0.5$. The judgment matrix $\mathrm{E} = (e_{ij})_{(\mathrm{m}+1)\times \mathrm{n}}$ $(i = 0,1,2,\dots,m;\ j = 0,1,2,\dots,n)$ is composed of $(m+1) \times n\ e_{ij}$.

(2) Grey correlation projection value

Each evaluation scheme is treated as a row vector, where θ_i is the gray correlation projection angle and ω_j is the indicator weight column vector. The cosine of the angle between the evaluated solution Q_i and the ideal solution Q_0 is [10]:

$$\cos\theta_i = \frac{Q_i Q_0}{\|Q_i\| \cdot \|Q_0\|} = \frac{\sum_{j=1}^{n} \omega_j e_{ij} \omega_j}{\sqrt{\sum_{j=1}^{n} \omega_j^2} \sqrt{\sum_{j=1}^{n} (\omega_j e_{ij})^2}}, i = 0,1,2,\dots,n \tag{10}$$

The projection value of the evaluated scheme Q_i on the ideal scheme Q_0 is the gray correlation projection value T_i, which is:

$$T_i = \|T_i\| \cos\theta_i = \frac{\sum_{j=1}^{n} \omega_j^2 e_{ij}}{\sqrt{\sum_{j=1}^{n} \omega_j^2}} = \sum_{j=1}^{n} \overline{\omega_j} e_{ij} \tag{11}$$

where $\overline{\omega_j} = \frac{\omega_j^2}{\sqrt{\sum_{j=1}^{n} \omega_j^2}}$.

Using the T_i value of each evaluated object as the benefit measurement standard, the larger the T_i value, the higher the corresponding benefit value of the evaluated object.

4 The benefit based investment allocation decision method

Based on the grey theory, the evaluation value of power grid benefits is obtained to achieve fund allocation for power grid investment decisions, maximizing the comprehensive benefits of the power grid, while minimizing the allocation results and plans of different allocation funds, so as to improve business performance, and optimize enterprise resource allocation. This paper establishes a multi-objective investment fund allocation optimization model as follows.

$$\min O = \frac{1}{m}\sqrt{\sum_{i=1}^{m}(f_i - f_i^0)} \tag{12}$$

$$\max Z = \sum_{i=1}^{m} f_i T_i \tag{13}$$

$$\text{s.t.} \sum_{i=1}^{n} f_i = F \tag{14}$$

$$\left|\frac{f_i^U + f_i^L}{2} - f_i\right| \leq \frac{f_i^U + f_i^L}{2} \tag{15}$$

In the formula, f_i^0 is the predicted investment funds for the i-th region's power grid, f_i is the actual investment funds that can be allocated to the i-th region's power grid, F is the total investment funds for each region's power grid, f_i^U and f_i^L are the corresponding lower investment limit and upper investment limit for the i-th region's power grid.

5 Case analysis

This paper selects four regional power grids under the jurisdiction of a certain province, namely Q1, Q2, Q3, and Q4, as the research objects.

(1) Determination of index weights by projection pursuit model

Solve the projection index function optimization model using linear decreasing weight particle swarm optimization algorithm. Set the initial condition as: number of particle swarm $\mathrm{N} = 50$, learning factor $U_1 = 2, U_2 = 2$, maximum iteration number $\mathrm{M} = 1000$, $u_{max} = 0.9$, $u_{min} = 0.4$, and the calculated optimal projection direction and weight of each evaluation index are shown in Table 2.

Table 2. Optimal projection direction and weights of indicators

Indicator	Optimal projection direction	Weights	Indicator	Optimal projection direction	Weights
A2	0.034	0.0015	C1	0.273	0.1133
A3	0.290	0.1269	C2	0.158	0.0378
A4	0.154	0.0378	C5	0.278	0.1163
A7	0.135	0.0272	D1	0.241	0.0921
B1	0.067	0.0076	D2	0.302	0.0876
B2	0.235	0.0831	D3	0.236	0.1375
B3	0.295	0.1314			

(2) Calculate grey correlation projection values

According to the standardized judgment matrix, the positive ideal solution of each indicator to be evaluated is 1. Calculate the grey correlation coefficient under each indicator according to formula (9). According to formula (11), combined with the weights of various indicators, the comprehensive benefit evaluation values of power grid enterprises in various regions can be calculated, that is, 0.0185, 0.0271, 0.0259 and 0.0323.

(3) Decision allocation of investment funds

While meeting the development of power grids in various regions, it is necessary to reduce investment in inefficient or ineffective assets, improve the overall investment efficiency of power grid enterprises, and further optimize the resource allocation of enterprises. The total investment budget of a certain provincial power grid enterprise is 1.052 billion yuan, and the investment capacity and predicted funds of power grid enterprises in various regions are shown in Table 3.

Table 3. Investment capacity and predicted funds of power grid enterprises in various regions

Regions	Lower investment limit/ million yuan	Upper investment limit/ million yuan	Predicted budget/ million yuan
Q1	213	261	231
Q2	225	282	274
Q3	217	265	258
Q4	234	294	289

Using the investment allocation model mentioned above and substituting the data in Table 3, and then using the gamultiobj function to solve, it is Q1=216 million yuan, Q2=280 million yuan, Q3=264 million yuan, and Q4=292 million yuan. The corresponding decision accuracy (the difference ratio between allocated funds and predicted funds) is 6.49%, 2.19%, 2.33%, and 1.04%, respectively. It can be seen that the decision model of investment funds proposed in this paper provides a scientific decision-making method for improving the overall efficiency of power grid enterprises and optimizing resource allocation.

6 Conclusions

This paper considers the investment benefits of power grids and conducts research on power grid investment decisions. The projection pursuit theory effectively solves the problem of subjective factors interfering with the determination of indicator weights in the process of evaluating the benefits of regional power grids. Furthermore, combined with grey theory, the comprehensive benefits of each regional power grid are determined by solving the grey projection values. On this basis, with the goal of maximizing comprehensive benefits and minimizing investment differences, a benefit based investment allocation decision model is constructed, and a case study is carried out with an actual case of a region. The results show that the regional power grid investment decision model proposed in this paper can comprehensively consider the investment benefits and investment capacity of the regional power grid, thus providing a new method for power grid enterprise benefit assessment and investment decision-making.

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References

1. Han, B., Ming, Z., Zhao, Y., Wen, T., Xie, M. (2021) Comprehensive risk assessment of transmission lines affected by multi-meteorological disasters based on fuzzy analytic hierarchy process. International Journal of Electrical Power & Energy Systems., 133: 107-190.
2. You, P., Guo, S., Zhao, H., Zhao, H. (2017) Operation performance evaluation of power grid enterprise using a hybrid BWM-TOPSIS method. Sustainability., 9: 23-29.
3. Yuan, J., Li, X., Xu, C., Zhao, C., Liu, Y. (2019) Investment risk assessment of coal-fired power plants in countries along the Belt and Road initiative based on ANP-Entropy-TODIM method. Energy., 176: 623-640.
4. Gao, L., Zhao, Z. Y., Li, C. (2022) An investment decision-making approach for power grid projects: a multi-objective optimization model. Energies., 15: 11-12.
5. Zhang, L., Wu, J., Zhang, J., Su, F., Bian, H., Li, L. (2022) A dynamic and integrated approach of safety investment decision-making for power grid enterprises. Process Safety and Environmental Protection., 162: 301-312.
6. Zhong, K., Wang, Y., Pei, J., Tang, S., Han, Z. (2021) Super efficiency SBM-DEA and neural network for performance evaluation. Information Processing & Management., 58: 102-728.
7. Liu, Z., Liu, M. (2021) Quality evaluation of enterprise environmental accounting information disclosure based on projection pursuit model. Journal of cleaner production., 279: 123-679.
8. Zhang, L., Li, H. (2022) Construction risk assessment of deep foundation pit projects based on the projection pursuit method and improved set pair analysis. Applied Sciences., 12: 19-22.
9. Zhicai, Z., Li, C. (2018) Analysis on decision-making model of plan evaluation based on grey relation projection and combination weight algorithm. Journal of Systems Engineering and Electronics., 29: 789-796.
10. Guo, X., Xu, P., Shao, X. (2022) Comprehensive evaluation of power quality of coal mine power grid based on equilibrium empowerment and improved grey relational projection method. Energy Reports., 8: 1680-1688.