Structural Analysis and Comprehensive Evaluation of Economic Index of Distribution Network

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Abstract. With the orderly advancement of power system reform and the rapid development of incremental power distribution pilots, the investment process of power grid companies has become more and more transparent and standardized. However, in the current fierce environment, how to maintain certain economic benefits in various regional distribution networks has become a problem of concern. This paper establishes a distribution network asset economic index system from the three dimensions of investment cost, operating cost, and economic benefit. The hierarchical structure of indicators is clarified based on the interpretative structural model, and the economic level is measured based on the improved analytical hierarchy process AHP-fuzzy evaluation model. Finally, the analysis of calculation examples shows that: (1) The investment cost and operating cost of the distribution network indirectly affect the economic benefits of the power grid by affecting the electricity sales. (2) The economic levels of the distribution network in the three regions of X, Y, and Z are good, medium, and poor. The region X needs to strengthen the management of distribution network investment, and the region Y continues to improve the economy from all aspects of cost and income. The first thing in region Z is to improve the level of economic efficiency.

1. Introduction

With the acceleration of the construction of new infrastructure, there are more and more important power users such as high-precision manufacturing enterprises in urban areas. The residents' basic quality of life requirements are getting higher and higher. The construction of the domestic distribution network started late. At present, there are still many shortcomings in the distribution network in terms of distribution network structure, power supply reliability, distribution network automation, and unbalanced regional development [1-2]. However, the distribution network presents the characteristics of "multi-source", and new energy sources with fluctuating output such as wind power and photovoltaics urgently need to improve coordination [3]. Their access has a greater impact on the economics of the distribution network [4-5].

Scholars at home and abroad have constructed an evaluation index system from multiple perspectives such as economic benefits, safety level, and environmental protection to evaluate the operation of the distribution network [6-7]. When analyzing the internal influence relationship of indicators, the interpretation structure model is widely used, which can transform qualitative problems into quantitative problems [8]. When evaluating the comprehensive benefits of the distribution network, methods such as analytic hierarchy process and entropy weight method are usually used to calculate the index weights, and fuzzy evaluation methods, matter element extension models, etc. can be used to determine

the development level of the distribution network [9-10]. The traditional analytic hierarchy process has the problem of consistency checking, this article uses the three-scale method to improve it [11-12].

This article only conducts an in-depth analysis of one aspect of the economics of the distribution network, builds an indicator system of the economics of the distribution network assets, analyzes the influence relationships of indicators based on the interpretation structure model, and determines the economic level of the distribution network based on the improved AHP-fuzzy evaluation model.

2. Economic index

Lean management of power grid assets is mainly reflected in the distribution network link, and its economic level directly affects the vital interests of the power grid and users' electricity costs. The development of the distribution network is heavily influenced by external factors, coupled with a large number of equipment, which has the characteristics of small project scale and short construction period, and has higher requirements for lean management. There are also many differences in the development stage, electricity demand and electricity structure in various parts of our country. The development goals, construction standards, space resources, policy environment, and planning concepts of the distribution network are inconsistent. There are generally weak professional forces, poor related businesses, and technology. Problems such as weak

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support means cannot meet the needs of building a modern distribution network with reasonable structure, advanced technology, flexibility, reliability, and cost-effectiveness. Therefore, this paper establishes a general distribution network asset economic index system from the three dimensions of investment cost, operating cost, and economic benefit, as shown in figure 1. Then, based on the interpretation structure model to analyze the index structure relationship, and based on the AHP-fuzzy evaluation model to evaluate the economic level of the distribution network, which is of great significance for evaluating the operation efficiency of the distribution network and improving the lean level of the distribution network management.

Distribution network economy	Investment cost	S1	Annual investment cost
		S2	Investment cost of each voltage level
		S3	Substation cost per unit capacity
		S4	Transmission cost per unit capacity
	Operating costs	S5	Annual operation and maintenance costs
		S6	Annual overhaul cost
		S7	Annual breakdown cost
		S8	Decommissioning disposal costs
	Economic benefit	S9	Electricity sales quantity
		S10	Electricity sales revenue
		S11	Return on investment
		S12	Unit investment increase power supply
		S13	Unit investment increase load supply

Fig. 1. Distribution network economic index system.

The investment cost index mainly refers to the expenses incurred during the construction and expansion of the distribution network. The higher the value of this index, the worse the economy of the distribution network. The operating cost index mainly refers to the cost of fault handling and equipment maintenance of the distribution network. The higher the value of this index, the worse the economy of the distribution network. The economic benefit index mainly refers to the economic benefits brought by the operation of the distribution network. The higher the index, the better the economy of the distribution network.

3. Analysis of structure

3.1. Interpretative structural model

There are many differences in the development stage and operation efficiency of distribution network in China. The regional evaluation index system is constructed from three dimensions of investment cost, operation cost and economic benefit. Each dimension contains multiple indicators, and the hierarchical structure relationship between indicators is complex. The use of interpretive structure model can transform the fuzzy structure system of indicators into intuitive levels.

Establish adjacency matrix. It is 1 when the two indicators have a direct influence relationship, and it is 0 when the two indicators have no direct influence relationship. The adjacency matrix A of $n \times n$ is established.

Calculate reachability matrix is. When the integer m is large enough to satisfy the following conditions:

$$M = (I + A)^{m-1} = (I + A)^m = (I + A)^{m+1} \quad (1)$$

Draw a hierarchical structure diagram of the economic indicators of distribution network assets. First determine the highest-level factors in the set, and then, regardless of the highest-level factors, determine the second-level factors in the remaining factor sets. Follow this step to cycle to clarify the factors at each level, thereby forming the inter-level division area.

$$R_i = \{S_i \in N | a_{ij} = 1\} \quad (2)$$

$$T_i = \{S_i \in N | a_{ji} = 1\} \quad (3)$$

$$R_i = R_i \cap T_i \quad (4)$$

3.2. Interpretation structure model of economic index of distribution network

The adjacency matrix of economic indicators for distribution network is:

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
S1	1	0	1	0	0	0	0	1	1	1	0	1	1
S2	0	1	0	1	0	0	0	1	1	1	0	1	1
S3	0	0	1	0	0	0	0	1	1	1	1	1	1
S4	0	0	0	1	0	0	0	1	1	1	1	1	1
S5	0	0	1	1	1	0	0	1	0	0	1	1	1
S6	0	0	0	0	1	1	1	1	0	0	1	0	0
S7	0	0	0	0	1	1	1	1	0	0	1	0	0
S8	0	0	0	0	0	0	0	1	0	0	1	0	0
S9	0	0	0	0	0	0	0	1	1	0	1	0	0
S10	0	0	0	0	0	0	0	1	0	1	1	0	0
S11	0	0	0	0	0	0	0	1	0	0	1	0	0
S12	0	0	1	1	0	0	0	1	1	1	1	1	0
S13	0	0	1	1	0	0	0	1	1	1	1	1	1

The reachable matrix and sorted order of the economic indicators of the distribution network assets are:

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
S1	1	0	1	1	0	0	0	1	1	1	1	1	1
S2	0	1	1	1	0	0	0	1	1	1	1	1	1
S3	0	0	1	1	0	0	0	1	1	1	1	1	1
S4	0	0	1	1	0	0	0	1	1	1	1	1	1
S5	0	0	1	1	1	0	0	1	1	1	1	1	1
S6	0	0	1	1	1	1	1	1	1	1	1	1	1
S7	0	0	1	1	1	1	1	1	1	1	1	1	1
S8	0	0	0	0	0	0	0	1	0	0	1	0	0
S9	0	0	0	0	0	0	0	1	1	0	1	0	0
S10	0	0	0	0	0	0	0	1	0	1	1	0	0
S11	0	0	0	0	0	0	0	1	0	0	1	0	0
S12	0	0	1	1	0	0	0	1	1	1	1	1	1
S13	0	0	1	1	0	0	0	1	1	1	1	1	1

	S8	S11	S9	S10	S3	S4	S12	S13	S1	S2	S5	S6	S7
S8	1	1	0	0	0	0	0	0	0	0	0	0	0
S11	1	1	0	0	0	0	0	0	0	0	0	0	0
S9	1	1	1	0	0	0	0	0	0	0	0	0	0
S10	1	1	0	1	0	0	0	0	0	0	0	0	0
S3	1	1	1	1	1	1	1	1	0	0	0	0	0
S4	1	1	1	1	1	1	1	1	0	0	0	0	0
S12	1	1	1	1	1	1	1	1	0	0	0	0	0
S13	1	1	1	1	1	1	1	1	0	0	0	0	0
S1	1	1	1	1	1	1	1	1	1	0	0	0	0
S2	1	1	1	1	1	1	1	1	0	1	0	0	0
S5	1	1	1	1	1	1	1	1	0	0	1	0	0
S6	1	1	1	1	1	1	1	1	0	0	1	1	1
S7	1	1	1	1	1	1	1	1	0	0	1	1	1

Draw hierarchical structure diagram according to the reachable matrix, as shown in Figure 2:

Fig. 2. Hierarchical structure diagram.

Figure 2 shows the hierarchical structure of the 13 indicators, which are divided into five levels. The operating cost indicators and investment cost indicators of the bottom layer L4 and L5 affect the cost of power transformation and transmission per unit capacity, and then the influence relationship of economy is transmitted to the unit investment, increased power supply and load, until the economic benefit index of the last level. It is of great significance to clarify the structural relationship of indicators for evaluating the economy of distribution network.

4. Evaluation of economic benefit

4.1. Improved AHP

When using traditional AHP to calculate weights, decisions cannot be made because the judgment matrix does not meet the consistency test. In addition, there are many influencing factors in a complex system, and the workload of frequently adjusting the judgment matrix is too large. Therefore, AHP is improved. Use three-scale theory to build index comparison matrix:

$$A = \begin{bmatrix} a_{11} & \cdots & a_{12} & \cdots & a_{1n} \\ \vdots & & \vdots & & \vdots \\ a_{n1} & \cdots & a_{n2} & \cdots & a_{nn} \end{bmatrix}, a_{ij} = \begin{cases} 1, I \text{ is more important than } J \\ 0, I \text{ is as important as } J \\ -1, I \text{ is not as important as } J \end{cases} \quad (5)$$

Establish the optimal transfer matrix and the comprehensive judgment matrix:

$$R = \begin{bmatrix} r_{11} & \cdots & r_{12} & \cdots & r_{1j} \\ \vdots & & \vdots & & \vdots \\ r_{i1} & \cdots & r_{i2} & \cdots & r_{ij} \end{bmatrix}, r_{ij} = \frac{1}{n} \sum_{n=1}^n (a_{in} + a_{nj}) \quad (6)$$

$$P = \begin{bmatrix} p_{11} & \cdots & p_{12} & \cdots & p_{1n} \\ \vdots & & \vdots & & \vdots \\ p_{n1} & \cdots & p_{n2} & \cdots & p_{nn} \end{bmatrix}, p_{in} = e^{r_{in}} \quad (7)$$

The product square root is used to calculate the weight:

$$w = (w_1, w_2, \dots, w_n), w_i = (\prod d_{in})^{1/n} / \sum_{n=1}^n (\prod d_{in})^{1/n} \quad (8)$$

4.2. Economic fuzzy evaluation model of distribution network

Fuzzy comprehensive evaluation is a method to quantify factors that are not easy to quantify and fuzzy boundaries by using the principle of fuzzy relationship synthesis, and to judge and analyze the evaluation results of the evaluation object based on the membership levels of multiple factors.

Create a set of factors. According to the scope and level of the evaluation object, a hierarchical evaluation index system is established. The collection of elements in the factor layer in the index system constitutes the factor set $U = \{U_1, U_2, \dots, U_n\}$.

Create a comment set. The evaluation level is determined based on the specific situation of the evaluation object, the number of levels and the range setting. It is assumed that N evaluation levels are given, and each level standard is an interval number.

Construct a fuzzy relationship matrix. The fuzzy relationship matrix is the membership degree matrix, which quantifies each index of the evaluation object in turn. The matrix represented by the degree of membership has a value range of [0,1].

Use fuzzy matrix synthesis operations. The relationship between the evaluation index and the comment set is obtained through synthetic calculation. According to the principle of maximum membership degree, the level corresponding to the maximum value in B is taken as the economic benefit evaluation result of the distribution network.

$$B = w \square R \quad (9)$$

4.3. Economic evaluation results of distribution network

Obtain the economic evaluation index data of the distribution network in three different areas of the city through fund collection research and consulting power companies, and evaluate the economics of the distribution network in different regions. Experts, engineers, and professors from power systems, distribution network planning, economic and technological research institutes, colleges and universities, etc. are invited to determine the judgment matrix of the importance of characterization indicators based on senior experience, as shown in figure 3.

A	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13
B1	0	1	1	-1	1	1	1	1	-1	-1	-1	-1	-1
B2	-1	0	1	-1	1	1	1	1	-1	-1	-1	-1	-1
B3	-1	-1	0	-1	1	1	1	-1	-1	-1	-1	-1	-1
B4	1	1	1	0	1	1	1	1	-1	-1	-1	-1	-1
B5	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1
B6	-1	-1	-1	-1	1	0	-1	-1	-1	-1	-1	-1	-1
B7	-1	-1	-1	-1	1	1	0	-1	-1	-1	-1	-1	-1
B8	-1	-1	1	-1	1	1	1	0	-1	-1	-1	-1	-1
B9	1	1	1	1	1	1	1	1	0	-1	-1	1	1
B10	1	1	1	1	1	1	1	1	1	0	1	1	1
B11	1	1	1	1	1	1	1	1	1	-1	0	1	1
B12	1	1	1	1	1	1	1	1	-1	-1	-1	0	0
B13	1	1	1	1	1	1	1	1	-1	-1	-1	0	0

Fig. 3. Judgment matrix.

According to the judgment matrix in Table 2, the index weight is calculated as $w=(0.066,0.056,0.041,0.076,0.026,0.030,0.035,0.048,0.121,0.165,0.141,0.096,0.096)$. The above experts, etc., are requested to establish the classification standard of index data, as shown in Table 1. Then, the membership degree of each index of distribution network economy in different regions is scored, and the judgment matrix is obtained, as shown in Table 2, 3, 4.

Table 1. Index classification table.

Excellent (E)	Good (G)	Moderate (M)	Poor (P)
[90,100]	[81,90]	[61,80]	[0,60]

Table 2. Judgment matrix of membership of X.

Index	X			
	E	G	M	P
S1	0.25	0.375	0.25	0
S2	0.3	0.5	0.2	0.3
S3	0.3	0.4	0.2	0.1
S4	0.1	0.375	0.4	0.3
S5	0.25	0.5	0.25	0
S6	0.25	0.5	0.25	0
S7	0.25	0.375	0.25	0.25
S8	0	0.625	0.25	0.125
S9	0.25	0.25	0.5	0
S10	0.25	0.5	0.25	0
S11	0.45	0.55	0	0.15
S12	0	0.2	0.6	0
S13	0.35	0.45	0.2	0

Table 3. Judgment matrix of membership of Y.

Index	Y
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	E	G	M	P
S1	0.125	0.25	0.375	0.25
S2	0.1	0.25	0.45	0.2
S3	0.3	0.4	0.2	0.1
S4	0.1	0.375	0.4	0.125
S5	0	0.25	0.5	0.25
S6	0	0.4	0.4	0.2
S7	0.25	0.375	0.25	0.125
S8	0	0.425	0.45	0.125
S9	0	0.25	0.6	0.15
S10	0	0.3	0.4	0.3
S11	0.1	0.55	0.35	0
S12	0	0.2	0.6	0.2
S13	0.35	0.45	0.2	0

Table 4. Judgment matrix of membership of Z.

Index	Z			
	E	G	M	P
S1	0	0.2	0.3	0.5
S2	0.3	0.5	0.2	0
S3	0.1	0.2	0.3	0.4
S4	0.3	0.2	0.4	0.1
S5	0	0.4	0.2	0.4
S6	0	0.35	0.15	0.5
S7	0.25	0.6	0.15	0
S8	0.125	0.125	0.25	0.5
S9	0	0.1	0.25	0.65
S10	0	0.1	0.15	0.75
S11	0.15	0.2	0.25	0.4
S12	0	0.2	0.6	0.2
S13	0	0.25	0.35	0.45

According to the above weight vector and fuzzy matrix, the economic membership degree of the distribution network of X, Y, Z is calculated, as shown in Table 5. The level corresponding to the maximum degree of membership is the regional economic level of the distribution network, and the total score is calculated based on the upper limit of the interval. Figure 2 shows the scores of each dimension in the three regions of X, Y, and Z.

Table 5. Membership of different regions.

Regions	E	G	M	P	Score
X	0.2452	0.4228	0.2804	0.0516	88.1
Y	0.0906	0.3483	0.4098	0.1513	82.3
Z	0.0800	0.2134	0.2830	0.4285	75.6

Fig. 4. Scores of each dimension of X, Y and Z.

It can be seen from Table 5 and Figure 4 that the overall economic performance of the distribution network in region X is good. Among them, the economic benefit score is higher, and the investment cost score is lower. In the future, the level of refined management can

be improved and the scale of distribution network investment can be reasonably controlled. The overall economic performance of the distribution network in region Y is moderate, with similar scores for investment costs, operating costs, and economic benefits. This shows that the development of the distribution network is balanced. There is no large investment, cost, and income imbalance. The distribution network in region Z has the worst economic performance, with the lowest economic benefit score. It is necessary to further strengthen the connection with the power supply special plan. Changing the wiring method, optimizing the grid structure can improve the utilization of transformers, lines and other equipment to increase electricity sales.

5.Conclusion

In view of the poor economic performance of distribution network in some areas, this paper constructs an index system from the three dimensions of investment cost, operation cost and economic benefit, determines the structural relationship of indicators based on the interpretative structural model, and clarifies the transmission relationship of influence factors. Then, aiming at the drawbacks of the one-time inspection, the AHP method is improved, and then the fuzzy comprehensive evaluation method is used to determine the economic subordination level of the distribution network. Finally, the conclusions are as follows: (1) The investment cost and operating cost of the distribution network are located at the bottom, which indirectly affects the economic benefits of the distribution network by affecting the electricity. (2) The economic levels of the distribution network in the three regions of X, Y, and Z are good, medium, and poor. The region X needs to strengthen the management of distribution network investment, and the region Y continues to improve the economy from all aspects of cost and income. Region Z can improve the utilization of equipment such as transformers and lines by changing the wiring method and optimizing the grid structure to ultimately achieve the goal of improving economic benefits.

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