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Research on Benefit Evaluation Distribution Network Considering Incidence of Input-output

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Abstract. In order to improve the ability of resource optimization configuration in the development of distribution network, and clarify the investment direction and management focus, an evaluation index system model of distribution network benefit considering input-output relationship is put forward. Firstly, with the consideration of the input-output relationship, an input-output evaluation index system for a different category of distribution network is built. Secondly, through the relevance analysis of the distribution project, an input-output benefit evaluation model of the distribution network is established based on the comprehensive empowerment method. On this basis, the basic input-output data of the distribution network in the three cities of a certain province is selected to verify the example, and the sensitivity analysis is carried out for the evaluation categories of the cities. The results prove the effectiveness of the proposed method, and provide reference for the grid enterprises to scientifically and rationally allocate the investment of distribution network.

Keywords: Input-output benefit; distribution network investment; evaluation index system; comprehensive weight method; sensitivity analysis.

1. Introduction

With the continuous deepening of China's new round of power system reform, grid companies pay more attention to the economic and social benefits brought by distribution investment (DI) [1-2]. In the development planning of distribution network, in order to ensure the stable operation of the power grid and provide reliable power transmission and distribution and high-quality customer service, the power grid enterprise will invest a large amount of manpower, material resources and financial resources every year [3]; in the production and operation of distribution network, The enterprise measures the investment benefit by evaluating whether the production target is achieved, the performance appraisal of the management personnel, and the benchmarking of the industry. However, these assessment mechanisms do not fully reflect the benefits of the conversion of the resources input of the distribution network into output results, nor can it clarify the resource allocation and utilization capacity of the grid enterprises in the distribution network.

At home and abroad, some related researches have been carried out on the evaluation of investment efficiency of distribution network. Literature [4] constructed a two-stage input-output evaluation index system for intelligent construction efficiency and operational efficiency of distribution network, and established a comprehensive evaluation model for super-efficiency DEA considering undesired output. Literature [5] considers the network investment evaluation model of multi-cycle optimization trend and regulatory constraints under the incentive supervision environment. Literature [6] comprehensively considers the stochastic optimization model of new distribution network investment decisions that influences voltage control and demand side response. Literature [7-8] constructed an input-output evaluation index system based on system dynamics method, and established a distribution network investment optimization simulation model. Literature [9] established an economic evaluation model for grid-connected distribution network systems and photovoltaic energy storage under different investment and financing modes. In addition, the literature [10] calculated the cost and benefit of the distribution automation system in terms of reliability, and established a cost-benefit comprehensive analysis model of the distribution automation system.

In view of this, based on the work of the predecessors, this paper conducts further research on the evaluation of the input and output benefits of the distribution network. Firstly, considering the relationship between input and output of distribution network, eight evaluation indicators were selected from five aspects: unit reliability of power supply improvement and unit investment voltage quality improvement, and different types of distribution network input and output evaluation index system were constructed. Secondly, through the correlation analysis of distribution network project, the AHP method and the entropy weight method are used to establish a comprehensive evaluation model for the distribution of input and output benefits. On this basis, the basic data of the distribution network of the three cities in a certain province are selected to verify the results, and the sensitivity analysis is carried out for the evaluation categories of the cities. The results prove the effectiveness of the proposed method. Power grid enterprises provide support and reference for scientific and rational investment in distribution network. Although the above research has constructed different evaluation models for the analysis of the input and output benefits of the distribution network, it has not effectively considered the impact of uncertain factors on the distribution network during the operation process, and has not carried out the distribution results and input resources of the distribution network. Contrast and correlation analysis cannot reflect the overall input and output benefits of the distribution network.

2. Constructing Evaluation Index System

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2.1 Index Selection Ideas

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The construction of the distribution network benefit indicator system should clarify the types of input and output indicators, and analyze the relationship between the two.

Key indicators for input and output are produced. In general, input indicators are mainly involved in various types of distribution network project investments, such as transformation, technical transformation and maintenance investment, to meet the new load power supply requirements investment [5]; output indicators It mainly includes the quality and efficiency of the relevant outputs, which correspond to the attributes of the distribution network power supply and power supply quality. In addition, the supporting indicators of the distribution network, such as the grid operation level and the intelligent level, should also be considered as input and output. Therefore, this paper considers the relationship between input and output, and selects the evaluation attribute construction index system such as unit investment power supply reliability improvement, voltage quality improvement, and distribution automation level improvement. The specific explanation is as follows.

(1) The reliability of unit investment power supply is improved. Select the average annual power reduction time A_{11} of the user and the average number of power outages by the user A_{12} to measure the reliability improvement index, as shown in formulas (1) and (2). (1) The reliability of unit investment power supply is improved. Select the average annual power reduction time A_{11} of the user and the average number of power outages by the user A_{12} to measure the reliability improvement index, as shown in formulas (1) and (2).

$$A_{11}=(T_1-T_0)/(I_1+I_2+I_3+I_4) \tag{1}$$

$$A_{12}=(C_0-C_1)/(I_1+I_2+I_3+I_4) \quad (2)$$

Among them, T_1 represents the average annual power outage time of the user in the year, T_0 represents the average annual power outage time of the user in the previous year; C_0 is the average number of power outages of the user in the previous year, C_1 is the average number of power outages of the user in the current year; and I_1 is the investment in eliminating equipment safety hazards. I_2 is to strengthen the investment in the grid structure, I_3 is the investment in technical transformation of the distribution network, and I_4 is the investment in maintenance of the distribution network.

(2) The unit investment voltage quality is improved. Select the solution to solve the voltage terminal over-limit problem number A_{21} and reduce the power-receiving terminal "low-voltage" user number A_{22} to measure the voltage quality improvement, as shown in equations (3) and (4).

$$A_{21}=Z/(I_1+I_2+I_3+I_4) \quad (3)$$

$$A_{22}=D/(I_1+I_2+I_3+I_4) \quad (4)$$

In the formula, Z indicates the number of problems with the voltage limit of the power supply terminal in the current year; D indicates the number of "low voltage" user problems at the power receiving end.

(3) The level of unit investment and distribution automation is improved. The evaluation index for solving the power supply terminal voltage limit problem number A_{31} and reducing the power receiving terminal "low voltage" user number A_{32} to measure the distribution automation level is selected, as shown in formulas (5) and (6).

$$A_{31}=[(P_1-P_0)/(J_1+J_2)]\times 100 \quad (5)$$

$$A_{32}=[(B_1-B_0)/J_1]\times 100 \quad (6)$$

Among them, P_1 represents the distribution automation coverage rate of the year, P_0 represents the distribution automation coverage rate of the previous year; B_0 is the smart meter coverage rate of the year, B_1 is the smart meter coverage rate of the previous year; J_1 is the intelligent investment of 10kV and below, J_2 Invested in 10kV substation technology.

(4) The level of unit investment in power grid dispatching has increased. Select the evaluation of the critical primary equipment risk number A_{41} to measure the improvement of the grid dispatch level, as shown in formula (7).

$$A_{41}=G/(I_1+I_2+I_4+I_5) \quad (7)$$

In the formula, G represents the resolution of the critical primary equipment risk; I_5 represents the solution of equipment overload and overload investment.

(5) The unit will invest in the power grid to raise the inspection level. Select the evaluation index of A_{51} to measure the level of power grid operation and inspection, as shown in formula (8).

$$A_{51}=[(X_1-X_0)/(I_3+I_4)] \quad (8)$$

2.2 Index System Design

According to the relationship between the input and output indicators of the distribution network, the evaluation index system of the distribution network input and output is shown in Table 1.

Table 1. Index System of distribution network efficiency considering input-output correlation

Benefit attribute	Evaluation attribute	Index name	Index meaning	Index unit
Optimal input-output benefitA	Power supply reliability improvementA_1	Average power outage time reduced by usersA_{11}	Average outage time per year for users with reduced related investment per million yuan	Hour / million yuan
		The average number of power outages is reduced by the userA_{12}	Relevant investment per million yuan reduces the average number of power outages per year for users	Per million yuan
	Voltage quality improvementA_2	To solve the voltage limit of the power supply terminalA_{21}	Refers to the number of over-voltage problems at the power supply end solved by related investment per million yuan.	One million yuan
		Reduce the number of low voltage users in the receiving endA_{22}	Refers to the number of "low voltage" subscribers per million yuan of related investment.	Household / million yuan
	Level upgrading of distribution automationA_3	Increase the coverage of distribution automationA_{31}	Increased distribution automation coverage per million yuan of related investment	1/Million yuan
		Increase the coverage of smart meterA_{32}	Increased smart meter coverage per million yuan of related investment.	1/Million yuan
	Upgrading of power grid dispatching levelA_4	Solving the key equipment risk numberA_{41}	Refers to the number of critical equipment risks solved per million yuan of related investment	Per million yuan
	Power grid should be checked and upgradedA_5	Improve the inspection rate of the equipment for inspectionA_{51}	Refers to the standardization rate of production and operation enhanced by related investment per million yuan.	1/Million yuan

3. Input-output Benefit Model based on Comprehensive Empowerment

The comprehensive improved analytic hierarchy process and entropy weight method respectively calculate the index weights, and use the combined weighting calculation method to establish a distribution network input-output benefit evaluation model.

3.1 AHP Method

The Analytic Hierarchy Process (AHP) is a hierarchical weighted decision analysis method proposed by American operations researcher T.L. Saaty. The method decomposes the elements related to decision-making into goals, criteria, programs, etc., which not only follows the objective relationship between the indicators, but also the experts' judgment on the importance of the indicators. The specific steps of the AHP method are as follows:

(1) Construct a judgment matrix. For each upper element, consider the lower element that has a logical relationship with it and make a pairwise judgment between the lower elements. The judgment matrix of the criterion layer to the target layer is:

$$B = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1m} \\ b_{21} & b_{22} & \cdots & b_{2m} \\ \vdots & \vdots & \cdots & \vdots \\ b_{n1} & b_{n2} & \cdots & b_{nm} \end{bmatrix} \tag{9}$$

(2) normalization of judgement matrix. By normalizing the judgment matrix, the eigenvalue lambda max of the matrix and its corresponding eigenvector ω are calculated, as shown in formula (10) - (12).

$$\overline{b_{ij}} = b_{ij} / \sum_{i=1}^{n} b_{ij} \qquad j = 1, 2, \cdots, m \tag{10}$$

$$\omega_i = \overline{\omega}_i / \sum_{i=1}^{m} \overline{\omega}_i \qquad i = 1, 2, \cdots, n \tag{11}$$

$$\lambda_{\max} = \sum_{i=1}^{m} (B\omega)_i / n\omega_i \tag{12}$$

(3) consistency check. The random consistency ratio CR=CI/RI of the test judgment matrix, where CI= (lambda max-n)/(n-1), n is the order of the judgment matrix. Normally, when CR<0.1 is satisfied, consistency checking is required.

(4) Total ordering of levels. Sort the results from top to bottom, layer by layer, using the same level of single-sorted results.

3.2 Entropy Weight Method

The entropy weight method is a method for determining the weight according to the amount of information transmitted by each indicator to the decision maker [6]. The larger the difference between an indicator, the smaller the entropy value, and the more information the indicator contains and transmits, the greater the corresponding weight. The specific steps of calculating the weight by the entropy method are as follows:

(1) Assuming that m investment benefit evaluation indicators are used to evaluate n regional power grid samples, x_{ij} is a predetermined value of sample $i(i \le n)$ relative to attribute $j(j \le m)$, forming a raw indicator data matrix $X = (x_{ij})_{n \times m}$.

(2) Take the optimal value of each evaluation index x_j^*, where j is a positive indicator, x_j^* is the better; if j is an inverse indicator, x_j^* is as small as possible. Define x_{ij} for a proximity of D_{ij} to x^* and get matrix $D = (D_{ij})_{n \times m}$.

$$D_{ij} = \begin{cases} \dfrac{x_{ij}}{x_j^*}, x_j^* = \max\left\{x_{ij}\right\} \\ \dfrac{x_j^*}{x_{ij}}, x_j^* = \max\left\{x_{ij}\right\} \end{cases} \tag{13}$$

(3) Normalize D_{ij} to obtain matrix $d = (d_{ij})_{n \times m}$.

(4) Calculate the conditional entropy of the evaluation index j, normalize it with Emax and Ej , and get the entropy value which indicates the importance of the evaluation index j:

$$e\left(d_j\right)=\frac{1}{\ln n}E_j \tag{14}$$

(5) determine the weight of evaluation index J by λ_j , $E_e=\sum_{i=1}^{n}e\left(d_j\right)$,and $0\le\lambda_j\le 1$, $\sum_{j=1}^{m}\lambda_j=1$.

$$\lambda_j=\frac{1}{n-E_e}\left[1-e\left(d_j\right)\right] \tag{15}$$

3.3 Solving Process

Relying on the constructed distribution network output evaluation index system and evaluation model, with the help of a large number of historical data, the quantitative relationship between indicators is analyzed and determined. Firstly, the indicators are standardized and dimensionless. On this basis, the AHP method is used to obtain the first-level index weights, the second-level weights are calculated by the entropy weight method, and the simple algorithm is used to comprehensively empower; finally, based on the prefecture-level Conduct a comprehensive evaluation of the distribution network input and output, and conduct a sensitivity analysis. The solution process is as follows:

(1) Consistent treatment of evaluation indicators. For a very small indicator x, let x*=M-x, where M is an allowable upper bound of the index x.

(2) The dimension lessness of the evaluation indicators. Because the indicators are different in units and orders of magnitude, they are incommensurable and need to be dimensionless. This paper adopts standardized treatment.

(3) Determine the type of membership function of the indicator. In order to obtain the functional relationship between the two variables, the relationship between the variables can be fitted by means of functions such as quadratic, cubic, and logarithm. Among them, the cubic function has the highest degree of fitting, and the quadratic function is like the cubic function. Considering that the relationship between unit grid investment and its input-output rating is more complicated, this paper uses quadratic function as the relationship function between input-output score and evaluation index, ie. Where y represents the evaluation score, x represents the evaluation index value, a and b are secondary and primary term coefficients, respectively, and c is a random error term.

(4) Determine the quadratic function curve of each evaluation function, and score the input-output indicators according to the scoring function, to weight the scores of each level of evaluation indicators. According to the weight of the distribution network input and output evaluation indicators, the overall input and output evaluation scores in the power supply area are obtained.

4. Example Analysis

4.1 Basic Data

In order to verify the practicability of the proposed model, the actual distribution network of three cities in a certain province in 2015 was selected as the research object, and the actual distribution network output and output data of each city were comprehensively evaluated. For comparison, Table 2 shows the relevant data of 10kV distribution network input by local cities.

4.2 Example Solution and Result Analysis

Based on the established input-output indicator system, the weights and comprehensive weights of each indicator are determined by AHP method and entropy weight method. The calculation results are shown in Table 3.

Table 2. Basic data of 10kV distribution input index

Distribution index of distribution network (ten thousand yuan)		A City	B City	C City
Total input in classification	New line investment	35213	35002	28900
	New transformer investment	11005	14140	12100
Investment in distribution network infrastructure	Solve equipment heavy, overload investment	9979	12113	15259
	Solving low voltage platform investment	10467	6651	9957
	Meet the demand of new load power supply	13300	20400	9537
	Eliminating the hidden danger investment of equipment	795	1238	1405
	Strengthening the investment of the grid structure	23605	22790	31481
	Transformation of high loss and distribution of investment	2421	2004	2523
	Intelligent investment in distribution network	2273	2216	1695
Technical reform of distribution network	Investment in technical transformation of line	399	235	454
	Conversion of electricity to investment	478	432	445
Overhaul investment in distribution network	Line maintenance investment	2197	2245	2131
	Investment in substation maintenance	1557	1134	1324

Table 3. Weight of synthetic index

First level index	weight	Two level index	weight	Comprehensive weight
A1	0.254	A11	0.546	0.139
		A12	0.454	0.115
A2	0.236	A21	0.518	0.122
		A22	0.482	0.114
A3	0.218	A31	0.459	0.100
		A32	0.541	0.118
A4	0.131	A41	1.000	0.131
A5	0.125	A51	1.000	0.125

In the case of comprehensive consideration of the first and second indicators, the weight of the four indicators, such as the average annual reduction of power outage time, the resolution of key equipment risk, the improvement of inspection equipment inspection rate, and the power supply terminal voltage limit problem, are relatively large.

According to formulas (1)-(8), determine the input and output benefits of each evaluation index, and carry out dimensionless processing to determine the coefficient of the second scoring function curve $y=ax^2+bx+c$, and finally obtain the input-output index score. The evaluation results are shown in Table 4.

Based on the evaluation scores, the differences between the input and output efficiency indicators of each city are analyzed and compared, as shown in Figure 1.

Table 4. Score of input-output evaluation index

First level index	Two level index	A City (a=88; b=50; c=0)		B City (a=88; b=50; c=0)		C City (a=88; b=50; c=0)	
		Dimensionless results	Benefit score	Dimensionless results	Benefit score	Dimensionless results	Benefit score
A1	A11	0.7146	81.7	0.7546	87.8	0.6946	77.2
	A12	0.6875	76.0	0.6905	76.5	0.7507	87.1
A2	A21	0.6952	77.3	0.7322	83.8	0.7632	89.4
	A22	0.6596	71.3	0.6894	76.3	0.6939	77.0
A3	A31	0.7003	78.2	0.7053	79.0	0.7457	86.2
	A32	0.7325	83.8	0.7426	85.7	0.742	85.5
A4	A41	0.7775	92.1	0.727	82.9	0.7631	89.4
A5	A51	0.7649	89.7	0.6997	78.1	0.7219	82.0

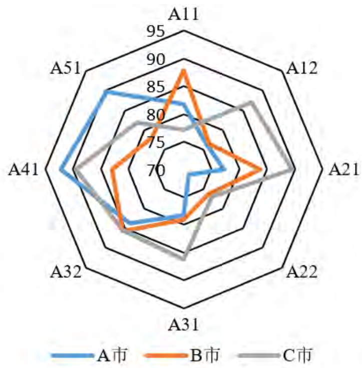

Figure 1. Evaluation scores of input output benefit of different cities.

In the case of the same level of distribution network input, the output efficiency of City B is higher, and the output benefits are more balanced. The scores of the two indicators for solving the key primary equipment risk and improving the inspection rate of the inspection equipment are relatively high, indicating that the contribution rate of the unit investment grid dispatching level in the power supply area is higher. C City has the lowest investment in solving the power supply terminal voltage limit and improving the distribution automation coverage rate, but the output efficiency is the highest, which indicates that the distribution network investment is relatively more effective. In addition, the scores of the indicators of the three cities and cities have a large change, indicating that the cities of A, B and C have their respective focuses on the allocation of distribution networks.

4.3 Sensitivity Analysis

In terms of sensitivity analysis of output indicators, this paper selects the sensitivity analysis of the relationship between the two key output indicators and the output benefit of unit investment power supply reliability improvement and unit investment voltage quality improvement, respectively, with 5%, 10%, and 15% respectively. The proportion changes, quantitative analysis of the rationality of input and output benefits of distribution networks in different cities, the analysis results are shown in Figure 2, Figure 3.

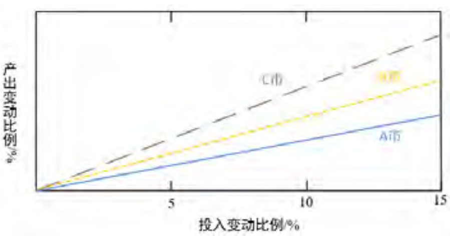

Figure 2. Input output sensitivity analysis of power supply reliability.

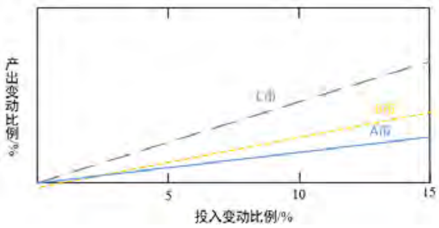

Figure 3. Input output sensitivity analysis of power quality improvement.

The input and output sensitivity of the power supply reliability improvement and power quality improvement indicators of C City is significantly higher than that of other cities, and the related investment can be further increased in the future to improve output efficiency. The two indicators of City A have low input-output sensitivity, and it is urgent to optimize investment strategies, improve investment results, and promote output efficiency.

5. Conclusion

Aiming at the problem of evaluation of input and output efficiency of distribution network, this paper proposes an input-output benefit evaluation model based on comprehensive weighting method. The model comprehensively considers five aspects such as the reliability improvement of unit investment power supply, and selects eight indicators including the average annual power reduction time of users and the average number of power outages by users to construct an evaluation index system. Through empirical calculations, it is found that the output of the same investment category is quite different in different cities. The results of benefit sensitivity analysis also verify the effectiveness of the proposed method, and provide support and reference for grid enterprises to better make distribution network investment decisions.

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