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Research on comprehensive evaluation method of distribution network based on AHP-entropy weighting method

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In the context of smart grid planning and construction, how to tackle the future distribution network, a comprehensive evaluation of smart distribution network planning has become an urgent problem to be solved. To address this issue, this research provides a method for comprehensive evaluation that combines subjective and objective weighing approaches. Firstly, a set of evaluation index system is constructed and quantified based on the characteristics of the future distribution network; after that a comprehensive evaluation model is established and a subjective and objective weighting method combining AHP-entropy weighting method is used to weight the indicators; Finally, the actual data from the distribution network is evaluated and scored. Based on the scoring verification results, the correctness and effectiveness of the method proposed in this paper are verified.

KEYWORDS

future distribution, smart grid planning and construction, overview, a method combining subjective and objective weighting methods, AHP-entropy weight method

Introduction

Smart grid offers unrivaled capabilities, making it an unavoidable trend in the evolution of modern electricity grids. The smart distribution network is especially important in a smart power grid (Zhang et al., 2014; Liu et al., 2015; Wang et al., 2015). The comprehensive evaluation of smart distribution networks is critical in the context of smart power grid design and development (Zeng et al., 2018; Yang et al., 2021a). The current comprehensive examination has yielded many benefits, but it is insufficient for the future distribution network's quick growth. Therefore, it is of far-reaching practical significance to establish a set of distribution network evaluation index system and evaluation method in line with China's national conditions (Yang et al., 2021b; Yang et al., 2021c; Yang et al., 2022a).

Nowadays, there are many literatures on comprehensive evaluation. Comprehensive evaluation includes two aspects: analysis and evaluation index system and evaluation method based on existing index system. Practical experience is frequently used in the

examination and evaluation of the index system. Subjective considerations have far too much influence, despite the fact that it is practical and intuitive. The other kind of evaluation approach examines a specific metric, such as economy, reliability, environmental protection, etc. (Zhang et al., 2015; Dong et al., 2016; Boutaba et al., 2018; Chen et al., 2018; He et al., 2018; Wei et al., 2018; Huang et al., 2019; Yang et al., 2021b; Yang et al., 2021c; Yang et al., 2022a; Yang et al., 2022b).

Literature (Wei et al., 2018) establishes an evaluation index system from five aspects: power supply capability, power supply reliability, power quality, economy and abundance, and then uses analytic hierarchy approach to create an evaluation model. Based on the evaluation method of analytic hierarchy Process, literature (Huang et al., 2019) analyses the technical, economic, and environmental aspects of distribution networks. Literature (He et al., 2018) is based on the construction of the evaluation system of the target grid, and quantitative evaluation of the distribution network is carried out with the comprehensive evaluation method of fuzzy mathematics. Chen B et al. used network analysis method with anti-entropy method to determine index weight and scoring function, and tackled the problem of cross and mutual influence among indicators caused by inaccurate weight (Chen et al., 2018). In the evaluation of distribution network, literature (Zhang et al., 2015; Dong et al., 2016) builds a comprehensive evaluation index system including economy, sociality and environment. Different from the previous literature that only studied a single user group, the traditional variable weight calculation method in literature (Yang et al., 2022b) is characterized by difficult selection of state variable weight vector and weak operability. As a result, this research provides a shape similarity-based variable weight computation method. In order to reduce disparities caused by artificial subjective selection and improve the credibility of evaluation results, literature (Boutaba et al., 2018) proposed the combinatorial fuzzy comprehensive evaluation method. Literature (Zhang and Lv, 2018) determined the weight assignment of each indicator based on analytic hierarchy process and enhanced entropy weight method, and established VIKOR multi-criteria evaluation system. Literature (Tian et al., 2019) provided a discrete energy flow calculation approach and an energy efficiency evaluation method based on a weighted directed graph equivalent model of the system. Literature (Yu et al., 2016) makes an overall review of distribution network evaluation. On the whole, the evaluation system cannot be studied solely from the subjective or objective standpoint. As a result, it is vital to investigate an evaluation process that incorporates both subjective and objective components in order to conduct a full evaluation that is more comprehensive and complete, as well as more accurate and compelling evaluation outcomes.

To sum up, this research presents a comprehensive weight assignment mechanism based on AHP-entropy weighting method for future distribution network system (Xiong et al., 2022). The combination of subjective and objective weights makes the evaluation method more scientific, which makes up for the problems of too subjective and unstable weights in traditional AHP method. Firstly, a system of evaluation indexes is created, with the first level indexes being economy, dependability, environmental protection, and interactivity. Then, the comprehensive weighting method is used to assign weights to the indexes. Finally, the distribution network of Yichang city is selected to substitute the actual data to score and calculate the indexes. The results of an example verify the effectiveness of the proposed method, and the relevant research can provide an auxiliary decision-making basis for the construction and transformation of distribution network.

Comprehensive evaluation system construction

Comprehensive evaluation index

The establishment of a comprehensive evaluation index system is the basis of regional smart grid evaluation. It is necessary to cover all aspects of smart grid based on the development situation and objectives of China's smart grid and reflect the planning benefits and technical characteristics of regional smart grid (Ma et al., 2022). It mainly includes the following four indicators, Figure 1 shows the evaluation index system:

(1) Economic index

Economic index can reflect the interdependence of various technological and economic phenomena and processes. Also, it reflects the technical level, management level and economic results of production and management activities.

1) Investment Cost: It can be broken down into three categories: initial investment, operation and maintenance, and failure costs. The initial investment cost includes design and planning cost, equipment purchase cost and building installation cost. The design and planning cost and equipment purchase cost will vary substantially between regions, reflecting regional differentiation according to different coefficients. Operation and maintenance costs are made up of three components: operation, maintenance, and other charges, all of which are influenced by the line loss rate. Failure cost mainly includes outage loss cost and failure loss cost.

$$C_a = C_i + C_{OM} + C_F \quad (1)$$

In the equation: C_a is the investment cost, C_i is the initial investment cost, C_{OM} is the operation and maintenance cost, and C_F is the failure cost.

2) Comprehensive line loss rate: represents the percentage of the power lost on the line to the power output of the first section of the line.

$$\Delta P = \frac{Q_s - Q_p}{Q_s} \quad (2)$$

In the equation, ΔP is the comprehensive line loss rate, Q_s is the electricity supply, and Q_p is the electricity consumption.

3) Increased load of unit investment: refers to the ratio of increased load to investment cost.

$$Q_l = \frac{Q_{ln} - Q_{ll}}{Q_{al}} \quad (3)$$

In the equation: Q_l is the increased load of investment, Q_{ln} is the current year's load, Q_{ll} is the last year's load, and Q_{al} is the last year's grid investment cost.

(2) Reliability index

Power system reliability is measured by quantitative reliability indexes, which can be the probability, frequency and duration of unfavorable impacts caused by faults on power users, as well as the expected power loss and expected power energy loss caused by faults.

1) Total pass rate: refers to the ratio of the number of lines satisfying N-1 to the total number of lines.

$$K_{pr} = \frac{N_N}{N_{al}} \quad (4)$$

In the equation, K_{pr} is the total pass rate, N_N is the number of lines satisfying N-1, and N_{al} is the total number of lines.

2) Total main transformer overload rate: refers to the proportion of the number of overload main transformer stations in the total number of main transformer stations. Overload main transformer refers to a transformer that has a maximum load ratio of more than 80% and a single duration of more than 2 hours.

$$K_{ol} = \frac{N_{ol}}{N_{mt}} \quad (5)$$

In the equation, K_{ol} is the overall overload rate, N_{ol} is the number of overload main transformer stations, and N_{mt} is the total number of main transformer stations.

3) Average user outage time: refers to the ratio of the total user outage duration to total number of users in a unit of time.

$$T_{ap} = \frac{T_i}{N_i} \quad (6)$$

In the equation: T_{ap} is the average outage time of users, T_i is the total outage time of users, and N_i is the total number of users.

(3) environmental protection index

Under the influence of global warming and energy crisis, various governments in the world are vigorously advocating a low-carbon economy and building green power grid. The so-called development of green power grid refers to the construction of resource-saving and environment-friendly power grid based on the principles of "security, economy, green and harmony" (Guo and Xiang, 2022).

1) Distributed power permeability: refers to the ratio of distributed power installed capacity to 110 kV public substation capacity.

$$K_p = \frac{Q_{dg}}{Q_r} \quad (7)$$

In the equation, K_p is the permeability of distributed power; Q_{dg} is the installed capacity of distributed power; Q_r is 110 kV public substation capacity.

2) Percentage of installed renewable energy: refers to the percentage of installed renewable energy power generation capacity in the total installed regional power generation capacity.

$$K_r = \frac{Q_{re}}{Q_{al}} \quad (8)$$

In the equation: K_r is the proportion of installed renewable energy, Q_{re} is the installed capacity of renewable energy power generation, and Q_{al} is the total installed capacity.

3) Proportion of renewable energy generation in electricity generation: refers to the proportion of renewable energy generation in electricity generation.

$$K_p = \frac{Q_{rp}}{Q_{al}} \quad (9)$$

In the equation: K_p is the proportion of renewable energy in electricity generation, Q_{rp} is the amount of renewable energy, and Q_{al} is the total installed capacity.

(4) interactive index

Interaction is another crucial feature of intelligent distribution network (Li et al., 2021a). The interaction of distribution networks not only alters the traditional distribution network's single direction of source-load and enables power distribution to be connected to the grid, but also alters the traditional distribution network's monogeneity of power flow, and increases the network frame's flexibility.

1) Power distribution information collection rate: refers to the ratio of the number of distribution transformers that collect information to the total number of distribution transformers.

$$K_{as} = \frac{N_{as}}{N_{um}} \quad (10)$$

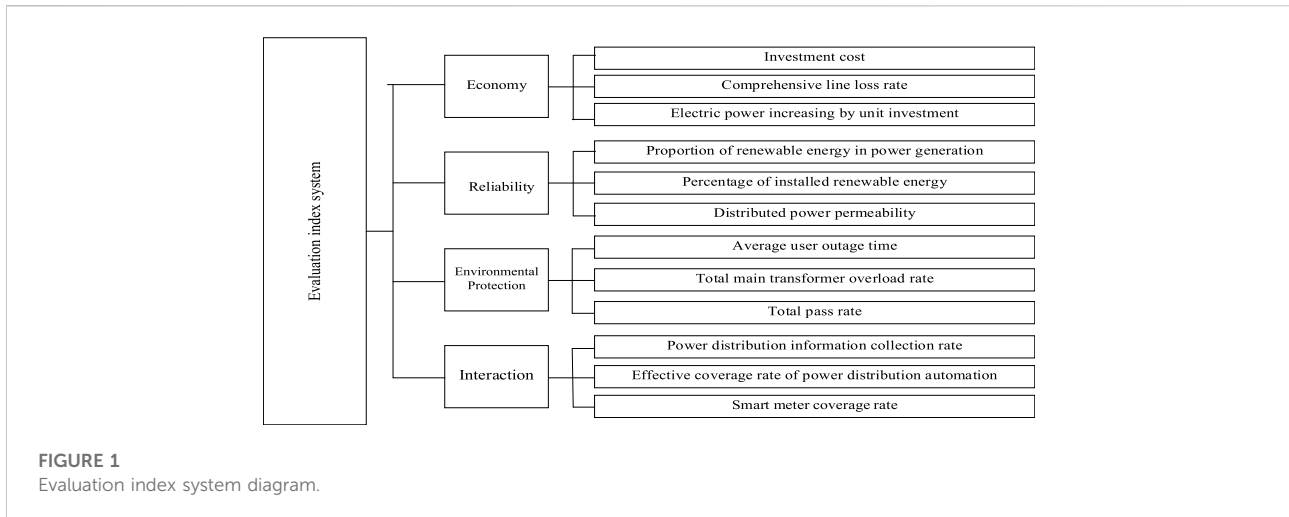


TABLE 1 Evaluation criteria of comprehensive evaluation indexes.

First-level Index	Second-level Index	Criteria					
		0	20	40	60	80	100
Economy	Investment cost (100 Million Yuan)	30	26	22	18	14	10
	Comprehensive line loss rate (%)	4.2	4.0	3.8	3.6	3.4	3.2
	Electric power increasing by unit investment (kWh/10 Thousand-yuan)	0	4,000	8,000	12000	16000	20000
Reliability	Total pass rate (%)	0	20	40	60	80	100
	Total main transformer overload rate (%)	10	8	6	4	2	0
	Average user outage time(h)	20	16	12	8	4	0
Environmental Protection	Distributed power permeability (%)	0	2	4	6	8	10
	Percentage of installed renewable energy (%)	0	20	40	60	80	100
	Proportion of renewable energy in power generation (%)	0	20	40	60	80	100
Interaction	Power distribution information collection rate (%)	95	96	97	98	99	100
	Effective coverage rate of power distribution automation (%)	0	20	40	60	80	100
	Smart meter coverage rate (%)	0	20	40	60	80	100

TABLE 2 Distribution network comprehensive score of Yichang in 2021.

Year	Category	Total Score	First-level Index Score			
			Economy	reliability	Environmental protection	Interaction
2021	Full Mark	100	29.65	36.4	18.45	15.5
	Actual Point	59.085	15.72	20.56	11.02	11.785
	Loss Point	40.915	13.93	15.84	7.43	3.715
2025	Full Mark	100	29.65	36.4	18.45	15.5
	Actual Point	79.86	23.72	29.02	11.62	15.5
	Loss Point	20.14	5.93	7.38	6.83	0

In the equation, K_{as} is the distribution information collection rate, N_{as} is the number of distribution stations for information collection, and N_{mm} is the total number of distribution stations.

2) Effective coverage rate of distribution automation: refers to the ratio of the number of 10 kV lines effectively covered by distribution automation in a region to the total number of 10 kV lines in a region.

$$K_c = \frac{N_{dc}}{N_{10a}} \tag{11}$$

In the equation, K_c is the effective coverage rate of power distribution, N_{dc} is the number of 10 kV lines effectively covered by power distribution automation, and N_{10a} is the total number of 10 kV lines.

3) Smart meter coverage rate: refers to the proportion of smart meters installed in the total number of installed meters.

$$K_{sm} = \frac{N_{sm}}{N_{um}} \tag{12}$$

In the equation: K_{sm} is the coverage rate of smart meter; N_{sm} is the number of smart meter users; N_{um} is the total number of power users.

Comprehensive evaluation method

The first step in a complete evaluation of a system is to weight the index, and then use the weight analysis method to obtain the final result of the evaluation. The selection of weight method and weight evaluation method is particularly important in the process (Li et al., 2021b). Typical systematic evaluation methods are mainly weighted by subjective analysis or objective data. When either of them is used alone, the evaluation results will be overly subjective or too objective. Therefore, the complete weighting approach, which combines subjective and objective weighting methods, can be applied.

The analytic hierarchy process is commonly used in the subjective weighting method. The weighting of each tier in the analytic hierarchy process will eventually effect the result, either directly or indirectly, and the degree of influence of each component in each layer on the result is quantifiable and extremely evident. This method can be used especially for the system evaluation of unstructured characteristics and the system evaluation of multi - objective, multi - criteria and multi—period (Li, 2022a). The analytic hierarchy process is focused mainly on the evaluator’s understanding of the essence and elements of the evaluation problem, and focuses on qualitative analysis and judgment more than general quantitative methods.

The entropy weight technique is commonly used in objective weighting method, which can profoundly reflect the ability to distinguish indicators, determine better weight, weighting is more objective, has theoretical basis, and has higher credibility.

As a result, the index weight adopts the method of combining subjective and objective weights. The analytic hierarchy process is used to calculate the subjective weight, and the entropy weight method is used to evaluate the objective weight. In this way, the subjective error can be minimized as much as possible, resulting in more scientific and fair outcomes (Li, 2022b).

(1) Basic steps of analytic hierarchy process

1) Build a hierarchy model. A clear hierarchy structure is established for the evaluation target. Then, an evaluation index system is formed.

2) Construct the judgment matrix and form the comparative judgment matrix of every two indexes layer by layer.

Construct the judgment matrix X , and its expression is denoted as:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1p} \\ x_{21} & x_{22} & \cdots & x_{2p} \\ \cdots & \cdots & \cdots & \cdots \\ x_{n1} & x_{n2} & \cdots & x_{np} \end{bmatrix} \tag{13}$$

In the equation, x_{ij} represents the importance of x_i relative to x_j .

3) Take consistency test, the calculation equation of consistency index CR is as follows:

$$CR = \frac{CI}{RI} \tag{14}$$

In the equation, when CR is less than 0.1, the judgment matrix satisfies the consistency requirements, CI stands for the consistency index, RI is the average random consistency index, and the consistency index CI is calculated as follows:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{15}$$

4) After passing the consistency test, the vector of the maximum characteristic root of λ_{max} is solved, which is the weight of the index through normalization.

(2) Basic steps of entropy weight method

1) The original data matrix is selected and the calculation equation is as follows:

$$R = \begin{bmatrix} r_{11} & r_{12} & r_{13} & \cdots & r_{1n} \\ r_{21} & r_{22} & r_{23} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & r_{m3} & \cdots & r_{mn} \end{bmatrix} \tag{16}$$

In the equation, $r_{ij(m \times n)}$ represents the j th evaluation value of i evaluation objects.

2) Calculate the characteristic proportion of the evaluation object i under j th index, and the calculation equation is as follows:

$$p_{ij} = r_{ij} / \sum_{i=1}^n r_{ij} \tag{17}$$

3) Calculate the entropy value of j th index, and the calculation equation is as follows:

$$e_j = -k \sum_{i=1}^n p_{ij} \ln p_{ij} \tag{18}$$

4) To calculate the difference coefficient of j th index, the equation is as follows:

$$g_j = 1 - e_j \tag{19}$$

5) Determine the weight coefficient of j th index, and the calculation equation is as follows:

$$w_j = e_j / \sum_{j=1}^m e_j \tag{20}$$

(3) Comprehensive weighting method

According to their own experience and subjective assessment of the scenario, experts determine the subjective weighting technique. The weight of indicators is directly given by experts, and the rationality of the weight is affected by their subjective understanding. Combination weighting method is the combination of subjective weighting method and objective weighting method, which can ensure not only the important index judgment of experts, but also the value of data information, resulting in a more appropriate weight obtained by combination weighting.

If the subjective weight obtained by analytic hierarchy process is:

$$z = [z_1 \quad z_2 \quad \dots \quad z_n] \tag{21}$$

If the objective weight obtained by the entropy weight method is:

$$w = [w_1 \quad w_2 \quad \dots \quad w_n] \tag{22}$$

Then, the calculation equation of combination weighting is:

$$u = \beta z + (1 - \beta)w \tag{23}$$

In Eq 23, β is the resolution coefficient, usually defined as 0.5.

(4) Comprehensive evaluation model

In order to obtain the final comprehensive evaluation results, a comprehensive evaluation model is established, as shown below:

$$P = \sum S_{ij} F_{ij} \tag{24}$$

In the equation, S_{ij} represents the weight of j th index at the i th index level, and F_{ij} represents the score value of j th index at the i th index level.

According to the comprehensive evaluation index system of smart distribution network established above, a two-layer index system of economy, reliability, environmental protection and interaction is established. The comprehensive evaluation model of smart distribution network planning is shown as follows:

$$P = S_1 \times F_1 + S_2 \times F_2 + S_3 \times F_3 + S_4 \times F_4 \tag{25}$$

In the equation, S_1, S_2, S_3 and S_4 represent the weights of first-level indicators of economy, reliability, environmental protection and interaction respectively. Moreover, $S_1 + S_2 + S_3 + S_4 = 1$. F_1, F_2, F_3 and F_4 represent the score values of first-level indicators of economy, reliability, environmental protection and interaction respectively, and their calculation equations are as follows:

$$P = \sum S_{ij} f_{ij} \quad (i = 1, 2, 3, 4, 5) \tag{26}$$

In the equation, s_{ij} represents the weight of second-level indicators under first-level indicators, and f_{ij} represents the score value of second-level indicators under first-level indicators.

Index weight determination and criterion selection

According to Eqs 13–15, the weight of economy, reliability, environmental protection and interaction of the first-level index can be obtained: $z = [0.33 \quad 0.47 \quad 0.13 \quad 0.07]$

In the same way, the weight of investment cost, comprehensive line loss rate and power supply increment per unit investment for second-level index under economy of first-level index is: $z = [0.54 \quad 0.30 \quad 0.16]$

Under the reliability of the first-level index, the weights of the second-level index, such as total pass rate, total main transformer overload rate and average user outage time, are as follows: $z = [0.24 \quad 0.14 \quad 0.62]$

The weight of distributed power permeability, installed proportion of renewable energy, and proportion of renewable energy power in electricity generation under environmental protection are as follows: $z = [0.5 \quad 0.25 \quad 0.25]$

Through analytic hierarchy process, the initial weight of the 12 indexes are 0.1782.0.099.0.0528.0.1128.0.0658.0.2914.0.065.0.0325.0.0325.0.065.0.0325.0.0325.

According to Eq 18, the index entropy value e_j can be obtained as follows: 0.48.0.622.0.441.0.514.0.5.0.562.0.434.0.631.0.617.0.631.0.419.0.631.

According to the entropy value e_j and Eq 19, the index difference coefficient g_j are 0.52.0.378.0.559.0.486.0.5.0.438.0.566.0.369.0.383.0.369.0.581.0.369.

According to Equation 20, the weight coefficient w_j of the 12 indicators can be obtained as 0.094.0.068.0.101.0.088.0.091.0.079.0.103.0.067.0.069.0.067.0.105.0.068.

According to Eq 23, the initial weight obtained by analytic hierarchy process is modified by weight coefficient, and the combined weight of 12 indexes is finally calculated as follows: 0.1361,0.0835,0.0769,0.1004,0.0784,0.1852,0.084,0.04975, 0.05075,0.051,0.06125,0.04275.

Because the index value is in a certain range, the distribution network can ensure proper operation. In combination with the values specified in some indicators in technical Guidelines for Distribution Network Planning and Design of State Grid, and the experience of several experts in existing studies, the evaluation criteria of indicators are finally determined. The Table 1 shows the specific standard setting.

Example analysis

This paper takes the actual data of urban distribution network planning in Yichang, Hubei Province in 2021 as an example and compares it with the planning data in 2025. The data comes from the city power company. The comprehensive evaluation index system and comprehensive evaluation model method established in this research are used to analyze the urban distribution network of the city and validate the rationality and practicality of this study.

From the four aspects of distribution network economy, reliability, environmental protection and interaction, the actual situation of distribution network operation in Yichang city is described. According to the indexes established above, the situation of power grid in Yichang region in 2021 is completely assessed, and the specific work is as follows. The Table 2 shows the Distribution network comprehensive score of Yichang in 2021.

(1) Economic analysis

1) Investment cost: The investment cost of Yichang Power grid in 2021 is 1996.004 million yuan, and the score calculated according to the weight is 6.83 points (full mark 13.61 points);

2) Comprehensive line loss rate: the comprehensive line loss rate of Yichang power grid is 3.6% in 2021, and the score calculated according to the weight is 5.01 points (full mark 8.35 points);

3) Electric power increasing by unit investment: electric power increasing by unit investment of Yichang Power grid is 10100 (kWh/ten thousand yuan) in 2021, and the score calculated according to the weight is 3.88 points (full mark 7.69 points).

(2) Reliability analysis

1) Total pass rate: In 2021, the total pass rate of Yichang Power grid is 59.8%, and the score calculated based on weight is 6.00 points (full mark 10.04 points);

2) Total main transformer overload rate: In 2021, the total main transformer overload rate of Yichang power grid is 4.4%, the score calculated according to the weight is 4.39 points (full mark 7.84 points);

3) Average user outage time: In 2021, the average power outage time of Yichang power grid users is 9.02 h, and the score calculated according to the weight is 10.17 points (full mark 18.52 points).

(3) Environmental protection analysis

1) Distributed power permeability: the distributed power permeability of Yichang power grid in 2021 is 3.55%, with a score of 2.98 points (full mark 8.4 points) calculated based on weights;

2) Percentage of installed renewable energy: the percentage of installed renewable energy in Yichang power grid in 2021 will be 80%, with a score of 3.98 points (full mark 4.975 points) calculated based on weights;

3) Proportion of renewable energy in power generation: the proportion of renewable energy in power generation of Yichang power grid in 2021 will be 80%, with a score of 4.06 points (full mark 5.075 points) calculated according to the weight.

(4) Interactive analysis

1) Power distribution information collection rate: the power distribution information collection rate of Yichang power grid in 2021 is 100%, with a score of 5.1 points (full mark 5.1 points) calculated based on weights;

2) Effective coverage rate of power distribution automation: the effective coverage rate of power distribution automation of Yichang power grid in 2011 is 39.35%, and the score calculated based on weight is 2.41 points (full mark 6.125 points);

3) Smart meter coverage rate: The coverage rate of smart meters in Yichang power grid will be 100% in 2021. The score calculated based on weights is 4.275 points (full mark 4.275 point).

Similarly, from four aspects of distribution network economy, reliability, environmental protection and interaction, the planning data of Yichang power distribution network in 2025 are comprehensively scored, and the specific work is as follows.

(1) Economic analysis

1) Investment cost: The investment cost of Yichang Power grid in 2025 is 1,400 million yuan, and the score calculated according to the weight is 10.89 points (full mark 13.61 points);

2) Comprehensive line loss rate: the comprehensive line loss rate of Yichang power grid is 3.4% in 2025, and the score

calculated according to the weight is 6.68 points (full mark 8.35 points);

3) Electric power increasing by unit investment: electric power increasing by unit investment of Yichang Power grid is 16000 (kWh/ten thousand yuan) in 2025, and the score calculated according to the weight is 6.15 points (full mark 7.69 points).

(2) Reliability analysis

1) Total pass rate: In 2025, the total pass rate of Yichang Power grid is 75%, and the score calculated based on weight is 7.53 points (full mark 10.04 points);

2) Total main transformer overload rate: In 2025, the total main transformer overload rate of Yichang power grid is 0%, the score calculated according to the weight is 7.84 points (full mark 7.84 points);

3) Average user outage time: In 2021, the average power outage time of Yichang power grid users is 5.26 h, and the score calculated according to the weight is 13.65 points (full mark 18.52 points).

(3) Environmental protection analysis

1) Distributed power permeability: the distributed power permeability of Yichang power grid in 2025 is 7%, with a score of 3.48 points (full mark 8.4 points) calculated based on weights;

2) Percentage of installed renewable energy: the percentage of installed renewable energy in Yichang power grid in 2025 will be 80%, with a score of 3.98 points (full mark 4.975 points) calculated based on weights;

3) Proportion of renewable energy in power generation: the proportion of renewable energy in power generation of Yichang power grid in 2025 will be 82%, with a score of 4.16 points (full mark 5.075 points) calculated according to the weight.

(4) Interactive analysis

1) Power distribution information collection rate: the power distribution information collection rate of Yichang power grid in 2025 is 100%, with a score of 5.1 points (full mark 5.1 points) calculated based on weights;

2) Effective coverage rate of power distribution automation: the effective coverage rate of power distribution automation of Yichang power grid in 2011 is 100%, and the score calculated based on weight is 6.125 points (full mark 6.125 points);

3) Smart meter coverage rate: The coverage rate of smart meters in Yichang power grid will be 100% in 2025. The score calculated based on weights is 4.275 points (full mark 4.275 point).

Conclusion

In this paper, a comprehensive weight assignment method based on AHP-entropy weight method is proposed for future distribution network system. According to the simulation example, after comparing the actual data in 2021 with the planned data in 2025, the conclusions are as follows:

Following the implementation of the evaluation system in Yichang, the comprehensive evaluation results can clearly reflect the overall development level of the future distribution network in Yichang, and are essentially consistent with Yichang's economic and social positioning, which verifies the feasibility and rationality of the comprehensive evaluation system and evaluation method proposed in this paper.

- 1) In terms of economy, the power grid investment in 2021 is excessive, resulting in a low value of increased power per unit investment, and a high comprehensive line loss rate due to the influence of the management system, resulting in a negative economic score.
- 2) In terms of reliability in 2021, the line with heavy load is not properly distributed and the load rate of the line is not balanced. A low total pass rate is caused by an invalid connection and a high line load rate. Meanwhile, the average power outage time of users is long, resulting in a low final reliability score.
- 3) In 2021, The poor score of distributed power permeability owing to the little amount of distributed power is the key element impacting the environmental protection score.
- 4) In 2021, The main element effecting the score of interactive index is that at least two "three-remote" switches are configured on the main line, as well as a low number of 10 kV lines with at least three sections, resulting in a low effective coverage rate of distribution automation.

In this paper, only a few representative indicators are selected in the selection of indicators, and more indicators can be selected for subsequent calculation to make the evaluation system more complete and scientific. In the present and the future integrated energy system is the development trend of future energy field, with the emergence of integrated energy system, various forms of energy can replace, mutual transformation and ensure the operation of power system great changes have taken place, its running state will be more complex, not only at this time to study distribution network from the distribution network more extended to evaluate the whole integrated energy system.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material further inquiries can be directed to the corresponding author.

Author contributions

ZL: Conceptualization, Software, Investigation, Formal Analysis, Writing—Original Draft; QX: Data Curation, Methodology, Writing—Original Draft; LuD: Visualization; HW: Visualization; LiD: Investigation; CW: Investigation; YZ: Supervision; XZ: Supervision; CY: Visualization; CX: Writing—Review and Editing; SQ: Writing—Review and Editing.

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