Theoretical Foundation and Model Construction of Comprehensive Evaluation of Distribution Network

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Abstract. As my country's economy has shifted from a stage of rapid growth to a stage of high-quality development. The scale of the distribution network is gradually increasing, and the manpower, material and financial resources involved are increasing day by day. Therefore, scientific comprehensive investment evaluation and decision-making for the distribution network is of great significance to the sustainable development of the distribution network. Based on hierarchical analysis method and entropy weight method, this paper proposes an evaluation model of analytic hierarchy process based on entropy weight. Score the indicators of 142 substations in a city, and calculate the comprehensive score of each substation. According to the evaluation results, relevant suggestions are given for the next stage of investment in different power supply stations in a certain city. On this basis, the analytic hierarchy process based on entropy weight is improved. Combining the variable weight theory to optimize the weight calculated by the model, and then obtain a more reasonable comprehensive score of the substation.

1. Introduction
As an important part of the power system, the power distribution system involves many uncertain factors in terms of financial support, personnel deployment, construction and transformation. This has led to large-scale extensive investments by power companies, and continuous renovation and construction of the distribution system. This inevitably caused a huge waste of manpower, material resources, and financial resources.

In the face of changes in the country’s economic situation and changes in investment patterns, power companies need to establish a comprehensive, comprehensive, and comprehensive distribution network investment evaluation and decision-making system that takes into account economic and technical factors. The establishment of a distribution network investment evaluation and decision-making system is of great significance to the sustainable development of the power grid and the maximization of enterprise investment benefits.

In view of the current technological development, domestic and foreign research on the comprehensive evaluation and decision-making analysis of the distribution system mainly focuses on the evaluation indexes of safety, economy, reliability, power quality and so on. Evaluation methods are mainly subjective analysis and objective analysis. Through the establishment of corresponding models, the weights of various indicators are calculated and finally considered. The above methods have their own characteristics. Subjective analysis methods rely too much on expert experience and lack data
support. The objective analysis method relies too much on data, and bad data has a great influence on the results. The weight in the use of the above method is constant weight. In the process of actually solving the problem of investment evaluation, the setting of permanent power can easily lead to unscientific decision-making.

This article combines subjective analysis with objective analysis, and introduces variable weight theory to establish a model. The evaluation of the substations in this area is made through the change of weights, and corresponding suggestions are made for investment decisions.

2. Theoretical basis for comprehensive evaluation of distribution network

2.1. Analytic Hierarchy Process

The analytic hierarchy process decomposes the evaluation problem into a three-layer network, namely the target layer, the middle layer, and the index layer. The target layer is the target of the evaluation problem, that is, the comprehensive score of each substation. The middle layer is also called the criterion layer. When there are too many evaluation indicators, the evaluation indicators can be classified appropriately, and the category of the obtained indicators is the middle layer. The index layer stores various evaluation indicators, and the storage order should be classified according to the criterion layer to facilitate the algorithm to calculate the distribution weight.

The specific implementation steps are as follows:
1) Build a hierarchical model. All factors are based on different attributes to establish a top-down three-tier structure. The order is the target layer, the middle layer, and the indicator layer.
2) Construct a judgment matrix and assign values. Starting from the middle layer, analyze the influence degree of an indicator in the upper layer. Compare the relative importance of the various elements that affect the indicator. The weight \( a_{ij} \) is used to describe the influence degree of the i-th element relative to the j-th element. If there are n influence elements in total, a judgment matrix \((a_{ij})_{n \times n}\) is formed.

| Scaling | Meaning                                      |
|---------|----------------------------------------------|
| 1       | Two factors i and j are of equal importance. |
| 3       | Factor i is slightly more important than factor j. |
| 5       | Factor i is obviously more important than factor j. |
| 7       | Factor i is stronger than factor j.           |
| 9       | Factor i is extremely important than factor j. |
| 2,4,6,8 | The relative importance of factor i and j is between adjacent scales. |

3) Hierarchical order and inspection. Hierarchical single ordering is the ordering of the degree of influence of lower-level factors on its upper-level criteria. The specific method is the calculation of weighted phasors. Generally, the weight vector is calculated by the characteristic root method. It mainly includes: calculating the product of each row element of the judgment matrix, calculating the n-th root of the product, vector normalization, the characteristic root of the judgment matrix, and consistency checking.

2.2. Entropy method

Entropy method is a method to measure multiple index systems. It provides to compare the degree of dispersion or variance between various indicators, and calculate the entropy value and coefficient of difference of each indicator. Thus, the weight is calculated. The greater the degree of variation of an indicator calculated by the entropy method, the smaller the information entropy, indicating that the indicator can provide more effective information to the problem, so the greater the weight. Entropy method is more objective than analytic hierarchy process.
According to the information entropy theory, the entropy value can be expressed as:

\[ H(X) = -\sum_{i=1}^{n} p(x_i) \ln p(x_i) \]  

(1)

In the formula, \( n \) is the number of source messages; \( p(x_i) \) is the probability of occurrence at time \( i \).

The specific steps are:
1) Construct evaluation index matrix \( X \).
2) Normalization of indicators.
3) Calculate the proportion \( \frac{x_{ij}}{x_{i-}} \) of the index of the \( i \)-th evaluation object under the \( j \)-th index.

\[ \frac{x_{ij}}{x_{i-}} = \frac{\sum_{i=1}^{n} x_{ij}}{\sum_{i=1}^{n} x_{i-}}, (i = 1, 2, ..., p; j = 1, 2, ..., n) \]  

(2)

4) Calculate the entropy value of the \( j \)-th index \( e_j \).

\[ e_j = -\sum_{i=1}^{n} p_{ij} \ln p_{ij}, (j = 1, 2, ..., n) \]  

(3)

5) Calculate the entropy value \( E_j \) of the relative importance of the indicator \( j \). When all the indicators are equal, select the largest entropy value and normalize it.

\[ E_j = e_j / (e_j)_{\text{max}} = (\sum_{i=1}^{n} p_{ij} \ln p_{ij}) / (\ln n) = (\frac{\sum_{i=1}^{n} p_{ij} \ln p_{ij}}{\ln n}), (j = 1, 2, ..., n) \]  

(4)

6) Calculate the difference coefficient of the \( j \)-th index. The smaller the index entropy, the greater the degree of variation of the index.

\[ g_j = 1 - E_j, (j = 1, 2, ..., n) \]  

(5)

7) Calculate the weight of the \( j \)-th index.

\[ \omega_j = g_j / \sum_{j=1}^{n} g_j = (1 - E_j) / (n - \sum_{j=1}^{n} E_j), (j = 1, 2, ..., n) \]  

(6)

2.3. Variable weight theory

The weight of each index calculated by the analytic hierarchy process based on entropy weight is constant weight. In the process of actually solving the problem of investment evaluation, the setting of permanent power can easily lead to unscientific decision-making. In order to reflect the changing laws within the data, this article introduces the idea of changing weights. The evaluation of the substations in this area is made through the change of weights, and corresponding suggestions are made for investment decisions.

The idea of variable weight is based on the theory of shape similarity. The core is to compare the attribute measurement value curve of the planning scheme with the weighted curve measurement value curve, and introduce a penalty factor to modify it. When the attribute measurement value curve of the planning scheme is the same as the weighted attribute measurement value curve, it means that all the indicators of the planning scheme meet the standards. When the attribute measurement value curve of the planning scheme is different from the weighted attribute measurement value curve, it indicates that there is a certain gap between the planning scheme and the weighted reference scheme. It needs to be corrected, which has the effect of changing the weight.

The calculation steps of the variable weight method based on shape similarity are:

1) Use subjective weighting method, objective weighting method or combination weighting method to obtain constant weight \( W = [w_1, w_2, ..., w_n] \).
2) Determine the sequence of mathematical measure values for each planning scheme 
\[ X_i = (x_{i1}, x_{i2}, \ldots, x_{in}) \].

3) Determine the reference value sequence of a planning scheme 
\[ X_i^* = (x_{i1}^*, x_{i2}^*, \ldots, x_{in}^*) \].

\[ x_{ij}^* = \begin{cases} x_{ij}, & x_{ij} \geq \alpha \\ \alpha, & x_{ij} < \alpha \end{cases} \] (7)

Among them \( \alpha \) is the index reaching the qualified value, usually 60.

4) Determine the weighted reference value sequence of each planning scheme 
\[ X_i^w = (w_1 x_{i1}^*, w_2 x_{i2}^*, \ldots, w_n x_{in}^*) \].

\[ w_i = \frac{1}{\sum_{j=1}^{n} w_j} \] (8)

5) The slope of the weighted attribute measurement value sequence is the same as the slope of the weighted reference value sequence to obtain the variable weight vector of the index \( w_j(X_i) \).

\[
\begin{bmatrix}
    x_{i1}^* - x_{i2}^* \\
    x_{i2}^* - x_{i3}^* \\
    \vdots \\
    x_{(n-1)i}^* - x_{ni}^*
\end{bmatrix}^{-1} = \begin{bmatrix}
    x_{i1}^* - x_{i2}^* \\
    x_{i2}^* - x_{i3}^* \\
    \vdots \\
    x_{(n-1)i}^* - x_{ni}^*
\end{bmatrix}
\]

Based on the weights calculated by the analytic hierarchy process based on entropy weights, using the variable weight theory based on shape similarity, the weights of various evaluation indicators after correction can be calculated. Furthermore, the various indicators of each substation can be scored and the comprehensive score can be calculated.

2.4. AHP based on entropy weight

According to the research on the comprehensive evaluation theory and comprehensive evaluation index system of distribution network, a comprehensive evaluation model based on entropy weight analytic hierarchy process is proposed. When the analytic hierarchy process and entropy method are used alone, the results will be too subjective or the objective weights are not accurate enough due to bad data. Therefore, in order to take into account the advantages of subjective weighting method and objective weighting method, and combining the relevant characteristics of distribution network operation, choose the analytic hierarchy process and entropy weight method for combined weighting, and propose a comprehensive evaluation model based on the entropy weighted analytic method.

\[ \text{Start} \]

Data collection

Construct a hierarchical structure index system

Calculate index value

Data standardization

Analytic hierarchy process to construct judgment matrix

Calculate subjective weight of indicators

Combination weight

Entropy method to calculate objective weight

Calculate indicator score

Calculate the comprehensive score of the evaluation object

Classification and follow-up evaluation

\[ \text{End} \]

Figure 1. Flow chart of analytic hierarchy process based on entropy weight.
3. Case analysis

3.1. Comprehensive score calculation of analytic hierarchy process based on entropy weight

The calculation example gives 14 evaluation indexes of 142 substations in city A in three years. The data obtained can be roughly divided into three categories: economic efficiency A1, power supply reliability A2, coordination adaptability A3, and these three categories constitute the criterion layer. In the indicator layer, economic benefit A1 includes comprehensive line loss rate B1, power supply per unit distribution capacity B2, new power supply per unit investment B3, and power loss reduction per unit investment B4. Power supply reliability A2 includes power supply reliability rate B5, average number of user outages B6, average user outage time B7, line N-1 pass rate B8, and comprehensive voltage qualification rate B9. Coordination adaptability A3 includes contact rate B10, wire cross section B11, capacity ratio B12, average household capacity B13, and cable rate B14.

3.1.1. Use analytic hierarchy process to calculate subjective weight. The weights of hierarchical single sorting are shown in the following table:

| G  | Total ranking weight | A1 Single sort weight | A2 Single sort weight | A3 Single sort weight |
|----|----------------------|-----------------------|-----------------------|-----------------------|
| A1 | 0.4000               | B1 0.4000             | B5 0.1667             | B10 0.2000             |
| A2 | 0.4000               | B2 0.2000             | B6 0.1667             | B11 0.2000             |
| A3 | 0.2000               | B3 0.2000             | B7 0.3333             | B12 0.2000             |
|    |                      | B4 0.2000             | B8 0.1667             | B13 0.2000             |
|    |                      |                       | B9 0.1667             | B14 0.2000             |

Single ranking is the relative weight of the judgment matrix relative to the previous layer. The total ranking is the relative weight of the judgment matrix relative to the target layer. The calculation adopts a top-down method, layer by layer synthesis. After inspection, it meets the consistency requirements, and the specific weights are as follows:

| Index | Weight | Index | Weight |
|-------|--------|-------|--------|
| B1    | 0.1600 | B8    | 0.0667 |
| B2    | 0.0800 | B9    | 0.0667 |
| B3    | 0.0800 | B10   | 0.0400 |
| B4    | 0.0800 | B11   | 0.0400 |
| B5    | 0.0667 | B12   | 0.0400 |
| B6    | 0.0667 | B13   | 0.0400 |
| B7    | 0.1333 | B14   | 0.0400 |

3.1.2. Entropy method to calculate objective weight. The calculation method of entropy method calculates the weight value of each index, as shown in the following table:

| Index | Weight | Index | Weight |
|-------|--------|-------|--------|
| B1    | 0.0762 | B8    | 0.0720 |
| B2    | 0.0732 | B9    | 0.0695 |
| B3    | 0.0725 | B10   | 0.0709 |
| B4    | 0.0703 | B11   | 0.0681 |
| B5    | 0.0770 | B12   | 0.0706 |
| B6    | 0.0702 | B13   | 0.0671 |
| B7    | 0.0735 | B14   | 0.0681 |
3.1.3. Analytical hierarchy process based on entropy weight to calculate combination weight. The combined weight of each indicator is calculated as follows:

Table 5. Index weight of analytic hierarchy process based on entropy weight.

| Index | Weight |
|-------|--------|
| B1    | 0.1265 |
| B2    | 0.0773 |
| B3    | 0.0770 |
| B4    | 0.0761 |
| B5    | 0.0708 |
| B6    | 0.0680 |
| B7    | 0.1094 |
| B8    | 0.0688 |
| B9    | 0.0678 |
| B10   | 0.0523 |
| B11   | 0.0512 |
| B12   | 0.0522 |
| B13   | 0.0508 |
| B14   | 0.0512 |

3.1.4. Comprehensive score of each substation. Since the scoring of each substation is not the focus of this article, I will not repeat it. According to the calculated comprehensive scores of each substation, combined with the opinions of relevant experts, the scores are divided into the following intervals:

Table 6. Hierarchical interval.

| Score  | Corresponding grade of substation |
|--------|----------------------------------|
| 90-100 | A                                |
| 80-90  | B                                |
| 70-80  | C                                |
| 60-70  | D                                |

Table 7. Number of 142 substations in city A by level from 2014 to 2016.

| Corresponding grade of substation | 2014 | 2015 | 2016 |
|----------------------------------|------|------|------|
| A                                | 28   | 28   | 43   |
| B                                | 52   | 50   | 82   |
| C                                | 62   | 64   | 17   |
| D                                | 0    | 0    | 0    |

3.2. Improved analytic hierarchy process based on entropy weight

Combining the theory of variable weights, comprehensively score each substation. Due to the variable weight theory, the weight of each index of each substation will change according to the internal law of the actual data of the substation. That is, every index of every substation is a brand new weight. Score according to the given index weight, and count the number of substations of different grades as shown in the table below.

Table 8. Using the improved method, the number of 142 substations in city A from 2014 to 2016.

| Corresponding grade of substation | 2014 | 2015 | 2016 |
|----------------------------------|------|------|------|
| A                                | 16   | 16   | 30   |
| B                                | 42   | 42   | 52   |
| C                                | 67   | 67   | 60   |
| D                                | 17   | 17   | 0    |

3.3. Suggestions on Investment Decisions for City A Distribution Network

Based on the analysis of the distribution network of City A in the previous sections, the following suggestions are given for the investment decision of the distribution network of City A:

1) Strengthen investment in rural substations. Although the rural areas have less capital and low load density, the agricultural load is higher, and the load is greatly affected by the season. Therefore, it is
necessary to optimize the structure of rural power grids, increase investment in substations in rural areas, and increase the power utilization rate in low-load rural areas.

2) Develop different investment strategies for different grades of substations. Class A substations are generally located in urban areas, with high population density and capital intensive, showing a certain degree of saturation. The focus of investment should be on improving power supply reliability and optimizing the grid structure. Class B substations are generally located in the central developed areas of counties and districts, with higher population density, higher capital, and faster load growth. Reasonable load forecasting can be used to optimize the power grid. C and D substations are generally located in underdeveloped rural areas or areas that have suffered severe natural disasters. What load distribution should be done in rural areas so as not to waste excessive investment capital. The disaster-affected areas should strengthen the reliability of power supply, and carry out regular maintenance to return to the previous level.

3) Strengthen the management of important indicators. Increase the management and optimization of indicators that have a large impact on investment decisions, such as line loss rate and average user outage time, and increase investment in optimization of these indicators.

4. Conclusion
The use of scientific methods to comprehensively evaluate the distribution network is conducive to the high-quality development of the power grid. This paper proposes an analytic hierarchy process model based on entropy weight and an improved model. Conduct a comprehensive evaluation and analysis of the 142 substation in City A, and give corresponding investment suggestions. The analytic hierarchy process is used to resolve the number of indicators in the article into a multi-level single-objective problem, which is convenient for analysis. On the other hand, the entropy method relies on sample data and can be used as a supplement to the analytic hierarchy process to make the calculation results more comprehensive. Finally, the variable weight theory is introduced to compare the attribute measurement value curve and the weighted curve measurement value curve of the planning scheme, and a penalty factor is introduced to modify it. The evaluation of the substations in this area is carried out by changing the weights. The calculation example shows that the model can truly reflect the actual investment level and shortcomings of the substation.

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