Comprehensive Evaluation Indexes Framework and Evaluation Method for Substation Site Selection

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Abstract. The optimal planning of substation location is very significant for the construction of a reliable and reasonable power system, for this purpose, the comprehensive evaluation index system and the evaluation method are researched. Firstly, for the optimal layout of substation location an evaluation index system, which covers four aspects, i.e., security, economy, environment and operation, is established. Then, with a comprehensive consideration of the subjective weights and the objective weights, optimal combination weighting based on moment estimation theory is used to determine the optimal combination weight of each index. On this basis, an improved grey relational analysis method is proposed through a combination of grey relational analysis and cosine sorting method, to determine the optimal site selection more accurately and reasonably. Finally, using the proposed evaluation index system and evaluation method, the location of the newly added substation location in Phnom Penh power system is researched and the conclusion that Plan I should be taken as the location for the newly added substation is attained. The effectiveness and feasibility of the proposed evaluation index system and evaluation method are verified by the attained conclusion. Moreover, it shows that it has good application value for the optimization of substation location planning.

1. Introduction

The placement of substations is an important part of power system planning, and its placement is of great significance to the grid structure, power supply quality, and power supply reliability. Therefore, researching and establishing a comprehensive evaluation index system and evaluation method for substation site selection has important theoretical and practical guidance for scientifically optimizing site selection.

Many scholars have studied the application of many optimization methods in substation location planning. Mainly use optimization methods, which can be divided into mathematical optimization algorithms [1-3], heuristic optimization methods [4], and modern intelligent optimization methods [5-7]. Early scholars used mathematical optimization algorithms to simplify the planning problems of substations into corresponding mathematical programming problems, such as linear programming [1],
mixed integer programming [3], and other problems to solve. However, these methods cannot guarantee the optimal solution in a limited time when the problem is large. In response to this problem, scholars have successively proposed heuristic algorithms. For example, reference [4] proposed an interactive expert system combined with an alternate positioning allocation algorithm, but this type of algorithm is highly dependent on the initial value, and it is difficult to obtain the global optimality of the solution. Modern intelligent optimization algorithms have gradually been applied in substation planning due to their unique advantages in solving complex combinatorial optimization problems, such as simulated annealing algorithm (SA) [5], genetic algorithm (GA) [6], and improved particle swarm optimization algorithm (IPSO) [7], etc. However, this kind of method has the characteristics of slow convergence speed and poor local optimization ability.

In recent years, scholars have researched the optimization planning method of the alternative site of substation planning. This stage is a typical multi-attribute optimization decision-making problem under the interaction of multiple factors. This type of decision-making method is mainly based on operations research and other mathematics. Methods such as the analytic hierarchy process (AHP) [8], fuzzy comprehensive evaluation [9], and hybrid comprehensive decision-making methods [10]. For example, reference [9] uses a fuzzy comprehensive evaluation method to evaluate the selected sites and determine their priority. When applying the above-mentioned comprehensive optimization method, the key to optimization is the reasonable weighting of each evaluation index. To overcome the shortcomings in the evaluation process of simply using subjective or objective weighting methods to weight indices, many scholars have proposed a combined weighting method that integrates subjective weight and objective weight [11-12]. Reference [11] studies the combination weighting method based on the combination of the G1 method and sequence synthesis method; reference [12] uses entropy weighting to determine the weight by combining with expert preference. However, because these combination weighting methods only use simple multiplicative synthesis normalization methods or linear weighted combination methods to integrate evaluation indices, there are still some problems. To solve these problems, reference [13] and reference [14] proposed the optimal combination weighting method based on the moment estimation theory and an improved grey relational analysis method respectively, which has a good effect and a certain reference effect for optimal allocation of the substation.

This paper first establishes a set of evaluation index system suitable for substation placement optimization, and then determines the weight of each evaluation index through the optimal combination weighting method based on the moment estimation theory, and combines the grey relational analysis method and the cosine sorting method. Comprehensively considering the information of “distance” and “angle”, it is possible to evaluate each plan more accurately and select the best-recommended plan, and finally use the improved grey relational analysis method to analyze the security, economy, environment, and operation. The site of the newly added substation in Phnom Penh was evaluated and optimized.

2. **Substation locating evaluation index system**

2.1. **Construction of index system framework**

The evaluation index system is not only the link between the decision-maker and the decision object but also the bridge between the decision method and the decision object. When establishing the evaluation index system for the location of the substation, the real situation of the power system in the area to be selected should be reflected as much as possible, and the characteristics of the optimized site
of the substation should be fully considered. Therefore, the determination of substation location evaluation indices should comply with the following principles as systematic, objectivity, typicality and practicality [15].

To make the evaluation index system fully reflect the actual status and feasibility of the substation, this paper takes the relevant factors of substation location selection from the perspective of considering the security, economy, environment and operation of the substation to the regional power grid as the starting point, relevant standards selection of indices, and according to the construction principles of the evaluation index system, combined with the characteristics and purpose of the substation location, a set of evaluation index system suitable for the selection of the substation location is constructed, as shown in Figure 1. It can be seen from Figure 1 that the constructed index system is composed of 4 indices and 15 sub-indices.

![Figure 1. Framework of assessment index system for substation locating](image)

2.2. Definition of evaluation index

2.2.1. **Security index.** Security index mainly reflects that the substation can maintain safe operation for a long time after it is put into operation, will not be affected by floods, ensure that the geology is relatively stable and close to the load center ensure that the grid structure is safer also. It mainly includes flood threat, geology and geographic location.

2.2.2. **Economy index.** Economy index mainly reflects all construction costs related to the location of the substation to be connected to the regional power grid. It mainly includes compensation for demolition, land occupation, amount of earthwork, power grid layout and construction conditions.

2.2.3. **Environment index.** Environment index is selected for the purpose of reflecting the degree of influence of the location of the substation on the surrounding environment and neighbouring area. It mainly includes local planning, electromagnetic radiation, domestic garbage and operational pollution.
2.2.4. **Operation index.** Operation index mainly considers the impact of operation and maintenance on the surrounding environment after the construction of the substation is completed. It mainly includes transportation, living conditions and line connecting conditions.

3. **Improved grey relational analysis and moment estimation theory**

3.1. **Improved method based on grey relational analysis method and cosine sorting method**

3.1.1. **Grey relational analysis method.** The grey relational analysis method is to compare the similarity of the geometric shape of the sequence vector of the plan with the ideal optimal sequence vector curve to select the best plan. The more similar the geometric shape of the sequence curve, the closer the comparison plan is to the optimal plan [16].

There are options to be selected, and each option corresponds to comparison indices. First, the data of the evaluation index is normalized, and the evaluation matrix of the index set is recorded as

\[ K = \left( k_{ij} \right)_{m \times n}, k_{ij} \in [0,1]. \]

Let \( K^* = \left[ k_1^*, k_2^*, \ldots, k_n^* \right] \) be the ideal solution, If the corresponding value of the index is larger, the better, then the ideal plan should take the maximum value of each plan; if the corresponding value of the index is smaller, the better, the ideal plan should take the minimum value of each plan. Then there is the normalized decision matrix \( K = \left( k_{ij} \right)_{(m+1) \times n} \) shown in equation (1).

\[
k = \begin{bmatrix}
k_{11}^* & k_{12}^* & \ldots & k_{1n}^* \\
k_{21} & k_{22} & \ldots & k_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
k_{m1} & k_{m2} & \ldots & k_{mn}
\end{bmatrix}
\]

(1)

In the equation, each element \( k_{ij} \) is the attribute value of the \( j^{th} \) evaluation index of the scheme \( i \) after normalization processing. The first-row vector is the optimal value of each evaluation index in the decision plan. The principle of determining the optimal value is that when the index is very large, the optimal value is the maximum value of the index in each plan; if it is a very small index, the optimal value is the minimum value of the index in each plan. The optimal value constitutes the reference sequence in the grey relational method.

The correlation coefficient \( \varepsilon_j^i \) is the relative difference between the curve of the comparison series and the curve of the reference series at the \( j^{th} \) index. The magnitude of the difference can be used as a measure of the degree of association. The correlation coefficient \( \varepsilon_j^i \) between the \( j^{th} \) evaluation index of the \( i^{th} \) scheme and the optimal value of the index can be obtained by equation (2).

\[
\varepsilon_j^i = \frac{\min_i \min_j |k_j^* - k_{ij}| + \rho \max_i \max_j |k_j^* - k_{ij}|}{|k_j^* - k_{ij}| + \rho \max_i \max_j |k_j^* - k_{ij}|}
\]

(2)
where \( k_j^* \) is the reference value of the evaluation index; \( k_j \) is the comparison value; \( \rho \) is the resolution coefficient taking \( \rho = 0.5 \); \( \min \min_i |k_j^* - k_i| \) is the absolute minimum value; \( \max \max_j |k_j^* - k_j| \) is the absolute maximum value.

3.1.2. Cosine sorting method. The cosine sorting method judges the degree of association between the alternative sequence vector and the ideal optimal sequence vector through the cosine value of the included (acute angle) angle between the two. The smaller the column vector angle, the greater the cosine value of the angle, indicating that the greater the degree of association, the closer the solution is to the ideal optimal; vice versa [17].

Denoting the plan \( k_i = \{ k_{i1}, k_{i2}, \ldots, k_{im} \} \) as an \( m \) dimensional coordinate system \( \{ a_{i1}, a_{i2}, \ldots, a_{im} \} \). Selecting a certain point in the space as the common starting point, and use the index value corresponding to the ideal plan \( K^* \) as the end point to form a directed line segment \( oa_j \); the index value corresponding to the evaluation plan \( k_i \) is used as the end point to form a directed line segment \( oa_j \). The directed line segment set of the ideal site plan is \( \{ oa_{i1}, oa_{i2}, \ldots, oa_{im} \} \), the directed line segment set of the site evaluation plan is \( \{ oa_{i1}, oa_{i2}, \ldots, oa_{im} \} \), and the angle between the directed line segments \( oa_j \) and \( oa_j \) is \( \theta_j \). From the vector space model, the cosine of the angle \( \theta_j \) is:

\[
\cos \theta_j = \frac{k_{ij} k_j^*}{\sqrt{\sum_{j=1}^{m} k_{ij}^2} \sqrt{\sum_{j=1}^{m} k_j^*^2}}
\]

(3)

3.1.3. Improved grey relational analysis method. Combining the grey relational analysis method and the cosine sorting method, an improved grey relational analysis method is proposed. This method integrates the information of “distance” and “angle”, which can not only make up for the incomparability of plans with the same distance in the grey relational analysis method but also make up for the incomparability of plans with the same angle in the cosine sorting method.

Based on the improved grey relational analysis method, the correlation coefficient of the \( j^{th} \) index of the \( i^{th} \) plan is:

\[
\psi_j = e_j \cos \theta_j
\]

(4)
The correlation coefficient \( \psi_{ij} \) can not only compare the distance between the curves, but also the angle between the curves. The combination of the two can better compare the degree of correlation between the two.

The correlation between the \( i^{th} \) evaluation plan and the ideal plan is:

\[
\gamma_i = \sum_{j=1}^{n} \psi_{ij}w_j
\]  

(5)

where \( w_j \) is the optimal combination weight corresponding to index \( j \).

Compare the degree of similarity between the “distance” information and “angle” information between the various alternatives and the ideal plan, prioritize and sort them, and select the best one from the alternatives.

3.2. Optimal combination weighting based on moment estimation theory

The weighting of evaluation indices is the key to the improved grey relational analysis method. Whether the weights are reasonable or not directly affects the scientific rationality of the optimization results. To reflect the subjectivity of decision-making and the objectivity of decision-making in the evaluation, it is necessary to integrate the subjective and objective weighting of the above indices \[18\].

There are \( y \) kinds of subjective weighting methods to weight the evaluation indices, and the subjective weight set of the evaluation indices is:

\[
w_k = \left( w_{kj} \mid 1 \leq k \leq y; 1 \leq j \leq n \right); \quad \forall k, \sum w_{kj} = 1, w_{kj} \geq 0
\]  

(6)

After the decision matrix is normalized, using \( g-y \) kinds of objective weighting methods to weight the evaluation indicators, the objective weight set obtained is:

\[
w_p = \left( w_{pj} \mid y+1 \leq p \leq g; 1 \leq j \leq n \right); \quad \forall p, \sum w_{pj} = 1, w_{pj} \geq 0
\]  

(7)

Assuming that the integrated weight vector of the evaluation index is \( \left[ w_1, w_2, \cdots, w_n \right] \). For the subjective weighting value, due to \( 0 \leq w_j \leq 1, 1 \leq j \leq n \), if the number of decision-makers tends to be large, the statistical law of large numbers shows that the result of the weight vector integration judgment will be close to the integration vector \( \left[ w_1, w_2, \cdots, w_n \right] \); for the objective weighting value, the results obtained by different algorithms are repeatable. Therefore, from the perspective of statistics, it can be regarded as a sample drawn from the population to estimate the integrated weight vector \( \left[ w_1, w_2, \cdots, w_n \right] \).

Supposing \( y \) sample and \( g-y \) sample are drawn from the subjective weight and the objective weight respectively, for each evaluation index \( c_j \) \((1 \leq j \leq n)\), there are \( g \) weight samples, for the
integrated combination weight \( w_j \) of each evaluation index, it needs to be satisfied that the deviation between \( w_j \) and its subjective and objective weights is as small as possible. At the same time, since the relative importance of the subjective weight and the objective weight are different for different evaluation indices, if the relative importance of the subjective weight and the objective weight are respectively set as \( \alpha \) and \( \beta \), the integration shown in equation (8) can be constructed.

\[
\begin{align*}
\min H(w_j) &= \alpha \sum_{k=1}^{y} (w_j - w_{kj})^2 + \beta \sum_{p=j+1}^{g} (w_j - w_{pj})^2 \\
0 \leq w_j \leq 1, \ 1 \leq j \leq n
\end{align*}
\]

(8)

The \( g \) samples come from two populations. According to the basic idea of moment estimation, for each evaluation index \( c_j \) (1 \( \leq \) \( j \) \( \leq \) \( n \)), the expected values of \( w_{kj} \) and \( w_{pj} \) can be calculated according to equation (9).

\[
\begin{align*}
E(w_{kj}) &= \frac{\sum_{j=1}^{y} w_{kj}}{y} \\
E(w_{pj}) &= \frac{\sum_{p=j+1}^{g} w_{pj}}{g-y}
\end{align*}
\]

(9)

Using equation (9), the important coefficients \( \alpha_j \) and \( \beta_j \) of the subjective and objective weights of each index can be calculated according to equation (10).

\[
\begin{align*}
\alpha_j &= \frac{E(w_{kj})}{E(w_{kj}) + E(w_{pj})} \\
\beta_j &= \frac{E(w_{pj})}{E(w_{kj}) + E(w_{pj})}
\end{align*}
\]

(10)

For the evaluation index in the multi-index decision matrix, it can be regarded as taking \( m \) samples from the two populations respectively, and the basic idea of moment estimation is also adopted, we can get:
For each evaluation index $c_j (1 \leq j \leq n)$, we hope that $H(w_j)$ is as small as possible. Therefore, the optimization model shown in equation (12) can be transformed into:

$$
\min H = \{H(w_1), H(w_2), \ldots, H(w_n)\}
$$

s.t. $\sum_{j=1}^{n} w_j = 1$

$0 \leq w_j \leq 1, (1 \leq j \leq n)$

(12)

To solve equation (12), the linear weighting method with equal weights is used to transform the multi-objective optimal model into the single-objective optimization model shown in equation (13):

$$
\min H = \frac{n}{\sum_{j=1}^{n} a_j} \sum_{k=1}^{\frac{n}{2}} \left( w_j - w_k \right)^2 + \frac{n}{\sum_{j=1}^{n} \beta_j} \sum_{p=1}^{\frac{n}{2}} \left( w_j - w_p \right)^2
$$

s.t. $\sum_{j=1}^{n} w_j = 1$

$0 \leq w_j \leq 1, (1 \leq j \leq n)$

(13)

Without considering the constraint condition $0 \leq w_j \leq 1$, the Lagrange function is established by the Lagrange multiplier method:

$$
I = \sum_{j=1}^{n} a_j \left( w_j - w_k \right)^2 + \sum_{j=1}^{n} \beta_j \left( w_j - w_p \right)^2 + \lambda \left( \sum_{j=1}^{n} w_j - 1 \right)
$$

(14)

From the knowledge of calculus, we can get:
Combining equation (15) with \( \sum_{j=1}^{n} w_j = 1 \), the weight of each attribute can be obtained as follows:

\[
\begin{align*}
\frac{\partial f}{\partial w_j} &= 2\alpha \sum_{k=1}^{\gamma} (w_j - w_{kj})^2 + 2\beta \sum_{p=1}^{\delta} (w_j - w_{pj}) + g\lambda = 0 \\
\Rightarrow w_j &= \frac{2\alpha \sum_{k=1}^{\gamma} w_{kj} + 2\beta \sum_{p=1}^{\delta} w_{pj} - g\lambda}{2q} \\
\end{align*}
\]

(15)

3.3. Improved grey relational analysis method based on moment estimation theory

Through the above analysis, the specific steps for determining the optimal plan of substation placement planning based on the moment estimation theory weighting and the improved grey relational analysis optimization method are as follows:

- Establishing an evaluation index system for the location of substation;
- Determining the plan for comparison and selection of substation locations;
- Based on steps 1 and 2, calculating the attribute value of the evaluation index of each comparison plan to form a decision matrix for the optimal selection of the substation location;
- Determining the subjective weights and the objective weights of the evaluation index system of substation location;
- Determining the optimal combination weight of each evaluation index of the substation location based on moment estimation theory;
- Based on the known substation evaluation index weights, the optimal site of the substation is recommended by using the improved grey relational analysis method.

The process of substation locating base on improved grey relational analysis using weight determining by moment estimation theory is shown in Figure 2.
4. Case study

4.1. Phnom Penh power grid's newly added substation locating comparison plan

This paper takes the location of the GS011 230kV substation in Phnom Penh as an example. Due to the rapid economic development in the region, the scale of the new economic development zone has continued to expand, various industries have developed vigorously, and the electricity demand has increased rapidly. Besides, according to the Phnom Penh development plan, the preferential policies for the region will be increased in the next few years to attract more capital investment and vigorously develop the region, thereby driving the development of the entire city. Moreover, relevant forecasts in the next few years, the peak load in this area will increase significantly, and the substation itself will no longer be able to meet the demand in terms of power supply and stability. In this case, it is imperative to build a new substation.

Under the regional development situation, to cooperate with the development plan of the city, it is necessary to build a new 230kV substation. The planned capacity of the proposed substation is 2×200MVA, and a total of 16 circuits of various voltage levels are planned. The commissioning of the
new substation will greatly improve the power supply capacity of the area, and rationally optimize the grid layout in the area, which has a positive role in promoting local economic development. The new substation can also relieve the power supply pressure of the power grid, strengthen the power grid structure, solve the problems encountered in the system planning of Phnom Penh city, and ensure the safe and stable operation of Phnom Penh power system. Consequently, the work of the new substation needs to be carried out in time. According to the situation of the power grid and through in-depth inspections and on-site surveys, three sites were selected in different places. In this paper, Plan I, Plan II, and Plan III are used as representatives and it has advantages and disadvantages.

4.2. Optimal selection of new substation location in Phnom Penh power system

Using the evaluation index system and evaluation method of the substation location proposed in this paper to compare and choose the alternative to make the optimal decision. In this paper, qualitative indices are described by selected evaluation sets and turned into quantitative indices. Evaluation sets \{1, 2, 3, 4, 5, 6\} are selected to represent 6 grades of very poor, poor, slightly poor, slightly better, better and very good.

Calculating the evaluation index values of each comparison and selection plan, and form a judgment group of experts to obtain the evaluation grades of each index including security, economy, environment and operation, and form a decision matrix. Due to space limitations, the evaluation index value calculation and normalization process of each comparison plan will not be described in detail. After normalizing the indexes, the index values of each alternative in Table 1 form the decision matrix, where \(m = 3\) and \(n = 15\).

| Index               | Plan I          | Plan II         | Plan III         |
|---------------------|-----------------|-----------------|------------------|
| Flood C1            | 1               | 0.8333          | 1                |
| Geology C2          | 1               | 0.6             | 0.8              |
| Location C3         | 1               | 0.5             | 0.6667           |
| Demolition C4       | 0.5             | 1               | 0.8333           |
| Land C5             | 1               | 0.8333          | 0.5              |
| Earthwork C6        | 1               | 0.4             | 1                |
| Grid layout C7      | 1               | 0.6667          | 0.3333           |
| Construction C8     | 0.8             | 0.8             | 1                |
| Local planning C9   | 1               | 0.8             | 0.6              |
| Electromagnetic C10 | 1               | 0.4             | 0.8              |
| Domestic garbage C11| 0.5             | 0.8333          | 1                |
| Pollution C12       | 0.6             | 0.8             | 1                |
| Living condition C13| 0.5             | 0.8333          | 1                |
| Transportation C14  | 1               | 0.4             | 0.8              |
4.2.1. **Calculating optimal combination weight.** This paper chooses the analytic hierarchy process (AHP) method [19] and the G1 method [20] to calculate the subjective weight of each evaluation index, and the calculation results are as follows:

\[
W_{AHP} = (0.3065, 0.1063, 0.0737, 0.0319, 0.0982, 0.0319, 0.1411, 0.0132, 0.0634, 0.0357, 0.0116, 0.0206, 0.0132, 0.0206, 0.0323);
\]

\[
W_{G1} = (0.2337, 0.0927, 0.1298, 0.0398, 0.0637, 0.0332, 0.0892, 0.0276, 0.0625, 0.0447, 0.0233, 0.0279, 0.0320, 0.0384, 0.0615).
\]

The mean square deviation method [21] and entropy weight method [22] are used to calculate the objective weight of each evaluation index, and the calculation results are as follows:

\[
W_{MSM} = (0.0269, 0.0559, 0.0712, 0.0712, 0.0969, 0.0932, 0.0323, 0.0559, 0.0854, 0.0712, 0.0559, 0.0712, 0.0854, 0.0559);
\]

\[
W_{EWM} = (0.0062, 0.0371, 0.0717, 0.0664, 0.0664, 0.1241, 0.1537, 0.0102, 0.0371, 0.1100, 0.0664, 0.0371, 0.0664, 0.1100, 0.0371).
\]

Then using equation (10) to calculate the relative importance of the subjective weight of each evaluation index as: \( \alpha_1 = 0.9422, \alpha_2 = 0.6814, \alpha_3 = 0.5874, \alpha_4 = 0.3425, \alpha_5 = 0.5405, \alpha_6 = 0.2274, \alpha_7 = 0.4825, \alpha_8 = 0.4902, \alpha_9 = 0.5751, \alpha_{10} = 0.2913, \alpha_{11} = 0.2020, \alpha_{12} = 0.3426, \alpha_{13} = 0.2473, \alpha_{14} = 0.2321, \alpha_{15} = 0.5020. \)

According to equation (10), the relative importance of the objective weight of each evaluation index is calculated as: \( \beta_1 = 0.0578, \beta_2 = 0.3186, \beta_3 = 0.4126, \beta_4 = 0.6575, \beta_5 = 0.4595, \beta_6 = 0.7726, \beta_7 = 0.5175, \beta_8 = 0.5098, \beta_9 = 0.4249, \beta_{10} = 0.7087, \beta_{11} = 0.7980, \beta_{12} = 0.6574, \beta_{13} = 0.7527, \beta_{14} = 0.7679, \beta_{15} = 0.4980. \)

Finally, according to equation (11), the importance coefficients of subjective weight and objective weight can be calculated as: \( \alpha = 0.4458, \beta = 0.5542. \)

Substituting the subjective weight, objective weight and the above calculating importance coefficients \( \alpha \) and \( \beta \) of the subjective weight and objective weight into the solution of equation (16), the optimal combination weight vector of each evaluation index can be obtained as: \( w = (0.0981, 0.0684, 0.0758, 0.0604, 0.0704, 0.0712, 0.0932, 0.0438, 0.0603, 0.0694, 0.0563, 0.0516, 0.0574, 0.0670, 0.0567). \) They represent the weight of flood, geology, geographic location, demolition compensation, land occupation, earthwork, power grid layout, construction conditions, local planning, electromagnetic radiation, domestic garbage, operational pollution, living conditions, transportation and line connecting conditions. Comparing the above weight vectors, it can be seen that the weight assignments obtained by subjective weighting and objective weighting are quite different from each other, while the difference between the weighting values obtained based on the optimal combination of moment estimation theory is smaller, and the weighting results are more reasonable.
4.2.2. Using improved grey relational analysis method to calculate the correlation degree. After the optimal combination weight of each evaluation index is obtained, the alternatives are compared and selected through the improved grey relational analysis method, and the best plan is recommended. The results show the alternative and the most correlation degree of the optimal ideal is\( \gamma = (0.0616, 0.0400, 0.0476) \). Among them, \( \gamma_1, \gamma_2 \) and \( \gamma_3 \) are the correlation degrees between the sample of Plan I, Plan II and Plan III with the ideal location, respectively. From the principle of maximum membership degree, the improved grey relational analysis method of substation locating based on the optimal combination weight results show that Plan I, Plan III and Plan II are consistent with the actual situation, so it is preferred to recommend Plan I as the optimal site for the new substation in Phnom Penh.

4.3. Comparison of evaluation methods

To illustrate the feasibility of the evaluation method, the traditional analytic hierarchy process (AHP) is used to compare with the improved grey relational analysis (IGRA) in this paper. Table 2 shows the ranking results of the evaluation of the above alternatives by the traditional analytic hierarchy process.

| Alternatives | AHP     | Ranking | IGRA     | Ranking |
|--------------|---------|---------|----------|---------|
| Plan I       | 0.4043  | 1       | 0.0616   | 1       |
| Plan II      | 0.2936  | 3       | 0.0400   | 3       |
| Plan III     | 0.3021  | 2       | 0.0476   | 2       |

It can be seen from Table 2 that the most optimal results obtained by the improved grey relational analysis method based on moment estimation theory determining weight are consistent with the results of using the analytic hierarchy process, which demonstrates the effectiveness and feasibility of the optimization evaluation method proposed in this paper. However, in terms of weight assignment, the analytic hierarchy process (AHP) can simplify complex problems to obtain index weights, there is strong subjectivity in the weighting process, but the improved grey relational analysis (IGRA) comprehensively considers the subjective and objective weights of the evaluation indexes, and uses the optimal combination weighting method based on the moment estimation theory to determine the optimal combination weights of each index, so that the weighting results are more reasonable. In terms of the evaluation method, the AHP method uses the comprehensive synthesis of index values, and the obtained evaluation results only retain the meaning of the macro target layer, so there will be difficulties in delimitation in qualitative evaluation. But the IGRA method combines the grey relational analysis method with the cosine sorting method, which integrates the information of “distance” and “angle”, can not only make up for the incomparability of alternatives with the same distance in grey relational analysis, but also make up for the incomparability of alternatives with the same angle in cosine sorting method, making the evaluation results more scientific, objective, and convenient for practical operation. It can be seen that the evaluation method in this paper is superior to the analytic hierarchy process in terms of weight assignment and evaluation methods, which not only reduces subjectivity but also improves the credibility of the evaluation method results. Therefore, the
method proposed in this paper is effective and feasible and has certain advantages over the analytic hierarchy process.

5. Conclusions

With the development of the power system, the optimal planning of substation locations is of great significance to the establishment of a reasonable and reliable power system. This paper establishes a set of evaluation index system suitable for optimal allocation of the substation. Based on the theory of moment estimation, an improved grey relational analysis method based on optimal combination weighting is proposed. This method combines the grey relational analysis method and the cosine sorting method, which comprehensively considers the information of “distance” and “angle”, which can be more accurately evaluate each alternative. The site selection of the new substation in Phnom Penh was evaluated using the evaluation index system and evaluation method studied, and the optimal location for the new substation in Phnom Penh was recommended. The research results show that the rationality of the proposed evaluation index system and the evaluation method are effective and feasible in actual engineering. At the same time, the research results of this paper have a strong theoretical and practical guidance for scientific substation locating planning and have certain engineering application value.

6. References

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