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Layout Scheme Comparison of the Switching Station of Guoduo Hydroelectric Project Based on AHP-TOPSIS

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Abstract: The combination of AHP and TOPSIS can make the evaluation method easy to operate, and improve the objectivity and accuracy of the results. The mathematical model for the switching station scheme optimization was set up to choose an appropriate layout for the Guoduo hydropower station. Through the field survey and literature review, the expert questionnaire was finished. The weights of the index were calculated using the AHP method. Then the improved TOPSIS was employed for the index standardization and the sequencing calculation. The final option of layout 2 was obtained.

1. Introduction

Nowadays, with the massive integration of solar and wind energy in the current global energy sources, hydroelectric projects help maintain grid stability [1]. However, the investment period of a hydropower project is large and the environment is complex, and the switch station, as an important part of the hydropower project plant area, the rationality, safety and particularity of its arrangement greatly affect the quality switch station of hydropower project construction by accepting and distributing the electric energy generated by hydro-generator set. Because of the many factors that affect the comprehensive performance of the switch station design scheme, it is difficult to make an objective and reasonable evaluation of how to compare and select the switch station layout scheme scientifically and reasonably, which is of great practical significance for improving the quality, speeding up the progress and saving the cost.

The approximate ideal solution sorting method (TOPSIS) is a common method for multi-objective decision analysis of finite schemes. The method has been widely used in the comprehensive evaluation of industrial economic benefits because of its high flexibility. It can objectively evaluate the various multi-index options, and the evaluators' subjective preferences are also taken into account in the evaluation. However, it is difficult for TOPSIS to determine the weight of indicators. When the analytic hierarchy process (AHP) is used to construct the judgment matrix, the human factor often leads to the idealization of the judgment. Therefore, this paper intends to use AHP and TOPSIS evaluation methods to construct a comprehensive evaluation model of switch station layout optimization decision technology, taking the switch station of Guoduo Hydropower Station as an example.

2. Methodology

2.1 AHP method

Analytic hierarchy process (AHP) first presented by Saaty (1980), is a methodological approach which implies structuring criteria of multiple options into a system hierarchy [2], and then this method has been applied to many other fields: power planning, transportation research, American higher education industry prospect from 1985 to 2000, 1985 world oil price forecast and other major research projects. The AHP method combines qualitative and quantitative analysis of the multi-objective decision evaluation method. However, there will be many uncertain factors in the evaluation process, and for the method itself, when the step of constructing the judgment matrix is carried out, because of the strong subjectivity of the experts, there will also be a certain degree of uncertainty. Therefore, the use of this evaluation method alone is not conducive to the choice of switch station layout scheme.

2.2 TOPSIS method

TOPSIS is a comprehensive analysis method with multiple attributes [3-9]. The TOPSIS method holds that the optimal solution of a function should be at the point closest to the positive ideal point and the farthest from the negative ideal point, so this method focuses on calculating the positive ideal solution and the negative ideal solution of the evaluation problem. Finally, by calculating the relative closeness of each scheme to the ideal scheme, the scheme is sorted, and the most suitable scheme is selected.

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However, the relative weight of each index cannot be obtained accurately by using this method, which makes the error of the final result very large. Therefore, this paper considers the combination of the two methods to overcome the limitations of a single method, so that the final evaluation results are more reasonable and accurate.

3. Comprehensive evaluation model

In the selection of switch station position in hydropower station, there are many influencing factors involved in the decision target, and the influence degree between qualitative and quantitative factors is not easy to determine, so the method of the general mathematical model is difficult to solve effectively. Therefore, in this paper, the combination of FHP and TOPSIS (AHP-TOPSIS) is used to solve the problem of switch station layout. AHP-TOPSIS method combines the advantages of AHP and TOPSIS, and improves the scientific and reliable decision of switch station position selection. The AHP–TOPSIS model has been widely used in economics, management, and other fields with good results [10]. The method can be divided into the following two parts: the first part is to obtain the evaluation index system through a literature review, and then use AHP method to calculate the weight of the relevant indexes selected by switch station position comparison. The second part is to use TOPSIS method to sort the layout scheme under the condition of getting the weight of each index, and the first scheme is the optimal arrangement scheme.

3.1 Constructing evaluation system

The important premise of evaluating the layout of the switch station is to construct a reasonable evaluation index system, which is made by experts or through a literature search, and then modified according to the actual design situation of the switch station. In this paper, from the six aspects of project investment, layout condition, construction period, operation condition and environmental impact of switch station, as the evaluation index of the comprehensive performance of switch station, the evaluation index system is shown in Table 1.

Table 1. Evaluation index system

Principal criterion layer	Criterion layer
construction investment （X_1）	Civil investment (X_{11}) equipment investment (X_{12}) transportation costs (X_{13}) annual operating costs (X_{14})
Arrangement condition （X_2）	Civil structure arrangement (X_{21}) Mechanical and Electrical equipment arrangement (X_{22}) exit arrangement (X_{23}) Transportation and entrance Road layout (X_{24}) Station area drainage arrangement (X_{25})
Construction condition （X_3）	Structural complexity (X_{31}) Cross Construction influence (X_{32}) Construction Transportation conditions(X_{33}) Construction quality Assurance (X_{34})
construction period （X_4）	Construction preparation period (X_{41}) Civil structure Construction period (X_{42}) Mechanical and Electrical equipment installation period (X_{43})
Operating conditions （X_5）	Power station operator comfort (X_{51}) equipment heat dissipation (X_{52}) equipment maintenance management (X_{53}) later reconstruction and expansion conditions (X_{54})
environment effects （X_6）	Impact on the life of surrounding residents (X_{61}) switch station safety (X_{62}) plant area communication interference (X_{63}) flood control and pollution prevention conditions (X_{64}) meteorological conditions (X_{65})

From Table 1, we can see that the evaluation index system constructed in this paper is mainly the principal criterion layer, which is divided into the criterion layer. Among them, the target layer (switch station position arrangement comparison and selection) and six main criterion layers are regarded as the first level evaluation, and 25 indexes (sub-criterion layer) are regarded as the second level evaluation, so the index system in this paper is a two-level and three-layer comprehensive evaluation index system. Among the above indexes, it is difficult to quantify because many influencing factors are involved, so this paper considers using interval value to represent these indexes, so it constitutes the mixed multi-attribute decision making problem of target optimization.

3.2 AHP-based weighting index calculation

Step 1: Establishment of initial decision matrix. Let the scheme set $A = \{A1, A2, \ldots, Am\}$, a set of evaluation indicators composed of multiple evaluation indicators

$X = \{X1, X2, \ldots, Xn\}$. The scheme A_i, is measured according to X_j, and the attribute value of Ai with respect to X_j is interval number $\tilde{b}_{\mathrm{ij}} = [b^L{}_{ij}, b^U{}_{ij}]$, if $b^L{}_{ij} = b^U{}_{ij}$, then $\tilde{b}$ degenerates to real number, then the decision matrix is $\tilde{B} = (\tilde{b}_{ij})_{n\times m}$.

Step 2: Construct a standardized decision matrix. In actual multi-objective and multi-attribute decision making, there is no comparability due to the different dimensions between various schemes and indicators, so it is necessary to conduct dimensionless processing on these index values to convert the matrix into the same identity matrix. The calculation formula of the decision matrix is used in the following specification and the component normalization decision matrix $\tilde{C} = (\tilde{c}_{ij})_{n\times m}$ $(\tilde{c}_{ij} = [c^L{}_{ij}, c^U{}_{ij}])$.

$$c^L{}_{\mathrm{ij}} = {b^L{}_{ij}} \Big/ {\sqrt{\sum_{i=1}^{m} (b^U{}_{ij})^2}},\ c^U{}_{ij} = {b^U{}_{ij}} \Big/ {\sqrt{\sum_{i=1}^{m} (b^L{}_{ij})^2}} \tag{1}$$

Step 3: Determine index weight. Construct the comparison judgment matrix X-A. According to the 1-9 scale method in AHP method in table 1, the judgment matrix is constructed according to the value of the judgment matrix as shown in table 2.

Table 2. comparison scale of risk factors

Meaning	Scale
equal importance	1
a little more important	3
Obvious importance	5
Strong importance	7
Extremely important	9
median	2、4、6、8
Inverse comparison (j ratio I)	count backwards

And the maximum characteristic value and the consistency check of the matrix are calculated. According to formula (2),

the maximum Eigen root $\lambda_{\max}$ of judgment matrix is calculated, and the C_I value of judgment matrix X-A is calculated according to formula (3).

$$\lambda\max = \sum_1^4 \frac{(B\varpi)\ i}{n\varpi_i} \tag{2}$$

$$C_I = (\lambda\max - n)/(n-1) \tag{3}$$

$$C_R = C_I/R_I \tag{4}$$

Where $\lambda_{\max}$ is the maximum characteristic value and C_I is the test index. R_I is average random consistency index, n is matrix order, and omega is the index weight set. When $C_R \leq 0.1$, the consistency of X-A matrix is considered acceptable; otherwise, appropriate modifications shall be made to the judgment matrix until it meets the requirements.

Table 3. average random consistency index values

n	1	2	3	4	5	6	7	8	9
R_I	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.46

3.3 TOPSIS-based program ranking

After the above AHP method is used to determine the weight of each evaluation index, then the TOPSIS method is used to determine the scheme ranking of the switch station position. Generally speaking, for the position of switch station, its evaluation index includes quantitative and qualitative. By using TOPSIS method, it is necessary to quantify the qualitative index, and the relationship between the qualitative index rating term and the standard value is shown in Table 4.

Table 4. Qualitative index importance scale table.

Meaning	Scale
Better	(0,2)
Poor	(2,4)
General	(4,6)
Better	(6,8)
Very good	(8,10)

First, establishment of a weighted normalized decision matrix. construction weighted normalization matrix:

$$\tilde{D} = \{\tilde{d}_{\mathrm{ij}}\}_{n\times m} = \begin{bmatrix} \varpi_1.c_{11} & \varpi_2.c_{12} & \cdots & \varpi_n.c_{1n} \\ \varpi_1.c_{21} & \varpi_2.c_{22} & \cdots & \varpi_n.c_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \varpi_1.c_{m1} & \varpi_2.c_{m2} & .. & \varpi_n.c_{mn} \end{bmatrix} \tag{5}$$

Then, calculate the sticker progress of the object. The positive and negative ideal points U_j, V_j may be determined by the equations (6) and (7), where $\tilde{u}_j = [u_j{}^L, u_j{}^U](j \in N)$, $\tilde{v}_j = [v_j{}^L, v_j{}^U](j \in N)$.

$$u_j{}^L = max\, d_{ij}{}^L, u_j{}^U = max\, d_{ij}{}^U \tag{6}$$

$$v_j{}^L = max\, d_{ij}{}^L, v_j{}^U = max\, d_{ij}{}^U \tag{7}$$

$$D_i{}^+ = \sum_{j=1}^{n} \left| \left(d_{ij}{}^L - u_j{}^L\right) + \left(d_{i_j}{}^U - u_j{}^U\right) \right| i \in M \tag{8}$$

$$D_i{}^- = \sum_{j=1}^{n} \left| \left(d_{ij}{}^L - v_j{}^L\right) + \left(d_{ij}{}^U - v_j{}^U\right) \right| i \in M \tag{9}$$

$$S_i{}^* = \frac{D_i-}{D_i{}^+ + D_i{}^-} i \in M \tag{10}$$

The distance from the target to the positive ideal point is $D_i{}^+$, the distance from the negative ideal point to the negative ideal point is $D_i{}^-$, and the relative sticker progress is $S_i{}^*$. The greater the relative closeness value is, the greater the superiority of the scheme is.

3.4 Evaluation of objects

$$F = W \times S \tag{11}$$

F is the comprehensive evaluation result, A is the closeness value of each index in the second stage of the evaluation system, and $S = \{S_1{}^*, S_2{}^*, \ldots, S_m{}^*\}$ is the first-level attribute weight. And finally, determining the optimal scheme by comparing the size of the $W = \{w_1, w_2, \ldots, w_m\}$.

4. Case study

According to the examination opinion of the electrical access system scheme of the power station, combined with the scale of the power station and the overall layout of the hub, the switching station layout scheme of the plant area is further studied and compared according to the installed scale of Zajuguodo Hydropower Station in Tibet. There are three options for the layout of switch stations in the plant area of Guoduo Hydropower Station, which requires that a scheme be selected scientifically for construction. AHP-TOPSIS method is used to evaluate the comprehensive performance of the four schemes. The program arrangements are as follows:

Scheme 1 (F1): the switch station is arranged close to the main factory building, 4 main transformers are arranged indoors, and 1 contact transformer is placed on the platform between factories and dams.

Scheme 2 (F2): the switch station is close to the dam arrangement, and 5 transformers are placed on the platform between the switch station and the main factory building;

Scheme 3 (F3): the switch station is close to the main factory building, 4 main transformers are arranged side by side in the factory dam platform, and one contact transformer is arranged vertically at the right end of the factory dam platform.

Scheme 4 (F4): the switch station is arranged next to the left side of the main factory building, and 5 transformers are arranged on the excavation platform of the left slope of the main factory building.

The factors considered in the scheme are civil structure layout, electrical equipment arrangement, civil investment, mechanical and electrical equipment investment, heating and ventilation, construction difficulty, construction safety, construction period, operation cost, operation comfort, transportation, consideration of development, maintenance and maintenance, etc.

Because the process of the six performance algorithms in the principal criterion layer is exactly the same, this paper only gives the detailed calculation process of the evaluation of four indexes of engineering investment in the main criterion layer.

Step 1: The initial decision matrix of project investment is established as shown in Table 5.

Table 5. Initial decision matrix

	X_{11}	X_{12}	X_{13}	X_{14}
F1	[6,7]	[8,9]	[7,8]	[4,5]
F2	[7,8]	[8,9]	[5,6]	[6,7]
F3	[7,8]	[7,8]	[6,7]	[4,5]
F4	[2,3]	[3,4]	[6,7]	[8,9]

Step 2: Build the standardized decision matrix as follows:

Table 6. Standardized decision matrix

	X_{11}	X_{12}	X_{13}	X_{14}
F1	[0.440,0.596]	[0.514,0.660]	[0.497,0.662]	[0.298,0.435]
F2	[0.513,0.681]	[0.514,0.660]	[0.355,0.497]	[0.447,0.609]
F3	[0.513,0.681]	[0.450,0.587]	[0.426,0.579]	[0.298,0.435]
F4	[0.147,0.256]	[0.193,0.293]	[0.426,0.579]	[0.596,0.783]

Step 3: Determination of secondary index weights. Firstly, a comparative judgment matrix was constructed. The experts are invited to evaluate and score according to Table 2 and the various influencing factors on site, as shown in Table 7. Then the judgment matrix is correlated (normalized), as shown in Table 8.

Table 7. Comparison judgment matrix

	X_{11}	X_{12}	X_{13}	X_{14}
X_{11}	1	2	5	5
X_{12}	1/2	1	2	5
X_{13}	1/5	1/2	1	2
X_{14}	1/5	1/5	1/2	1

Table 8. Normalized comparison judgment matrix

	X_{11}	X_{12}	X_{13}	X_{14}
X_{11}	0.526	0.541	0.588	0.385
X_{12}	0.263	0.270	0.235	0.385
X_{13}	0.105	0.135	0.118	0.154
X_{14}	0.105	0.054	0.059	0.077

The weight of engineering investment index in the main criterion layer is obtained $\omega_j=(\omega 1\ ,\omega 2,\omega 3,\omega 4,)=(0.51,0.288,0.128,0.074)$. and the maximum characteristic root of the judgment matrix is further judged, and finally the consistency test is performed.

$$\lambda_{\max}=\sum_1^4\frac{(X\varpi)_i}{4^*\varpi_i}=4.067$$

From formula, $C_I=(4.067\leq 4)\ /\ (4\leq 1)=0.022$. According to $n\geq 4$, $R_I=0.9$, gets $C_R=C_I/R_I=0.022/0.90=0.025<0.1$ in table 3, so the consistency of judgment matrix meets the requirements, then the index weight of secondary project investment $W_1=(0.51, 0.288, 0.128, 0.074)$.

Step 4: determine the attribute weight of the main criterion layer. Repeated step 3 can be used to calculate the layout conditions, construction period, operation conditions and environmental impact index weights of the main standard layer respectively. From this, we get the total weight of the first level attribute $W_{总}=(0.455, 0.250, 0.215, 0.095, 0.105, 0.070)$.The weighted canonical decision matrix is established, and the results of formula (5) and step 2 are obtained:

Table 9. Weighted Normalized decision Matrix

	X_{11}	X_{12}	X_{13}	X_{14}
F1	[0.224,0.304]	[0.148,0.190]	[0.064,0.085]	[0.033,0.045]
F2	[0.262,0.133]	[0.148,0.190]	[0.045,0.064]	[0.021,0.034]
F3	[0.262,0.133]	[0.130,0.169]	[0.055,0.074]	[0.022,0.032]
F4	[0.038,0.019]	[0.056,0.084]	[0.055,0.074]	[0.044,0.058]

Step 5: calculate the Posting progress of the object. According to formula (6), (7), (8), (9) and (10), the distance from the target to the ideal point minus the ideal point and the relative closeness degree are calculated:

$\tilde{u}_j=\{[0.262,0.133],[0.148,0.190],[0.064,0.085],[0.044,\ 0.058]\}$

$\tilde{v}_j=\{[0.038,\ 0.019],[0.056,0.084],[0.045,\ 0.064],[0.021,0.034]\}$

$D_1^+=0.205\quad D_2^+=0.237\quad D_3^+=0.08\quad D_4^+=0.119$

$D_1^-=1.147\quad D_2^-=0.555\quad D_3^-=0.08\quad D_4^-=0.069$

$S_1{}^*=0.848\quad S_2{}^*=0.701\quad S_3{}^*=0.5\quad S_4{}^*=0.367$

Step 6: Using the same method to calculate the relative sticking progress of each index in the sub-standard layer, the matrix S is formed.

$$S=\begin{bmatrix}0.748 & 0.701 & 0.500 & 0.367\\ 0.504 & 0.850 & 0.764 & 0.600\\ 0.405 & 0.650 & 0.835 & 0.307\\ 0.319 & 0.677 & 0.750 & 0.585\\ 0.400 & 0.385 & 0.656 & 0.550\\ 0.322 & 0.495 & 0.505 & 0.532\end{bmatrix}$$

Step 7: determine the comprehensive evaluation value. $F=W\times S$ =(0.648,0.811,0.774.0.48), so the priority of the fourth scheme is F2>F3>F1>F4.

The above figures show that the comprehensive performance evaluation value of scheme 2 is the largest, which indicates that the design of switch station should be close to the layout of the main factory building, 4 main transformers should be arranged indoors, and 1 contact transformer should be placed in the plant and dam platform. Therefore, this scheme should be selected as the design and construction scheme of switch station.

5. Conclusion

In this paper, the mixed TOPSIS method is used to make a decision on the selection of the construction location of the switch station of Zatuguoduo Hydropower Station in Tibet. On the premise of analyzing and constructing the evaluation index system, the weight of each index is calculated by AHP method, and then the priority of four alternative schemes is determined by TOPSIS method, and the second scheme is the optimal arrangement scheme, which provides a reference for the selection of switch station position. Combined with the advantages of these two methods, making full use of the information of each scheme, the mathematical calculation is simple and the conclusion is reliable, which is especially suitable for this kind of qualitative evaluation.

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