Comprehensive Evaluation Index System for Screening and Sequencing Power Transmission Grid Planning Projects

Hongsheng Zhao¹, Hengwei Liu²*, Dahai You² and Xiongguang Zhao¹

ABSTRACT

As provincial Power Grid Corp launches medium and short term transmission grid planning, projects which are involved in these planning need to be screened and sequenced. Traditional screening and sequencing methods that depend on personal experience are lack of quantitative evaluation. Based on this, this paper presents a set of comprehensive evaluation index system, which is suitable for various planning projects to be evaluated under the same standard. The evaluation index system comprehensively evaluate the transmission grid planning projects from five aspects that is safety and reliability, economy and efficiency, coordination flexibility, social benefits and risk controllability. It provides an objective basis and reference for screening and sequencing the projects. There are several new index such as transmission capacity insufficient rate, substation capacity ratio, and so on. These new index make it more scientific to evaluate the urgency, coordination and output level of the projects. This research apply an overview method that is combination weighting of Analytic Hierarchy Process (AHP)-Entropy to make a comprehensive evaluation for the projects. The results of practical case analysis show that the proposed index system is reasonable and effective.

Keywords: power transmission grid planning, comprehensive evaluation, Analytic Hierarchy Process-Entropy weight combination method

INTRODUCTION

The medium and short term planning of provincial power grid companies is related to the collaborative construction of several transmission grid planning projects. Under the constraints of conditions such as funds and construction resources, screening and sequencing the planning projects are necessarily needed. At present, the reference index of screening and sequencing to the projects is relatively simple, and lack of unified standards, which depends

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too much on the personal experience of experts. And screening and sequencing results vary from different people, so there may be a lot of differences. The features of screening and sequencing in the grid planning projects are the multi-objective, multi-criteria and multi-foundation. If relying solely on subjective judgment and assessment, the objectivity and rationality of the results will be difficult to ensure. It may lead to the repetition and blindness of the power grid construction process. Therefore, there is a need for a multi-dimensional and all aspects evaluation index system to assess numbers of planning projects under the same set of standards to provide objective basis and reference for screening and sequencing work in future project construction.

At present, the research on the evaluation index system of transmission grid focuses on the comparison between multi-schemes of single transmission grid planning project. There are some researches based on the evaluation index of one aspect of power grid. Reference 1 puts forward the evaluation index of grid planning based on reliability evaluation. Reference 2 puts forward the evaluation and optimization of the economic scheme for the transmission grid planning projects. Reference 3 puts up a consideration about the impact about the construction of the grid project on the environment, and illustrates the establishment of environmental evaluation index to assess the power grid planning and construction projects. Reference 4 has a thought about the risk evaluation along with prevention and control countermeasures of project construction. At the same time, there are many studies on the comprehensive evaluation index system of transmission grid. However, due to the different objectives such as the purpose, size and location of the planning project, the current single-project multi-schemes evaluation index system can’t be used as a criterion for assessing the planning projects. And the research which is suitable for the comprehensive evaluation index system to the screening and sequencing of the projects is relatively scarce.

For that reason, this paper establishes a comprehensive evaluation index system that is suitable for the transmission grid construction projects by considering the balance between safety and economy, environment and new energy transportation, and the adaptation level of future economic development and grid changes. The system can more scientifically assess the necessity, urgency and financial level of grid planning projects and can comprehensively measure the impact of planning projects on grid development and the ability to adapt to uncertainties.

The rest of this article is as follows: The Third part introduces the evaluation index system of the grid planning project proposed in this paper and elaborates each index in detail. The Fourth part uses the comprehensive evaluation method to support the assessment of the index system rationality. The Fifth section is numerical simulation. The Sixth part is the conclusion and prospect.

COMPREHENSIVE EVALUATION INDEX SYSTEM OF TRANSMISSION GRID PLANNING

Through the study of the characteristics of transmission grid planning projects, five aspects of numerous index can be created. Safety and reliability, cost-effectiveness, coordination and flexibility, social benefits and risk control.

Safety and Reliability Index

Demonstrate the necessary degree of project construction through urgency index. The safety index is to measure the safety and reliability of the project itself.

（1）URGENCY
1) Transmission capacity insufficient rate. The urgency of the transmission line project is measured by calculating the proportion of the transmission capacity that meets the planned annual demand exceeds the limit transmission power.

2) Capacity-load ratio before project construction. The greater the difference between the index and the reasonable value range defined by the "Urban Electricity Planning Guidelines", the stronger the urgency of the transformer substation to be built in the area.

3) Substation load rate. Load rate refers to the ratio of apparent power (kVA) to substation capacity of substation load. The higher the load rates of the substation, the stronger the urgency of the substation to be built.

4) Load property. Power load can be divided into three grades, in which the first level load is the most important. The higher the load level of the project, the higher the urgency of construction.

(2) SAFETY

5) N-1 and N-2 pass rate. Evaluate the safety of power supply and the ability to prevent large area blackout.

6) Short circuit current level. The index reflects the rationality and coordination of short-circuit current in the planning project.

7) Thermal stability Margin. In order to measure the distance between the line flow and the thermal stability limit transmission power in the current operating mode, define the thermal stability margin:

\[ K_s = \frac{S_{\text{max}} - S}{S_{\text{max}}} \]  

(1)

Where \( S \) represents transmission apparent power under current operating mode; \( S_{\text{max}} \) represents thermal stability limit transmission power.

8) Capacity-load ratio after project construction. The index is to estimate the capacity-load ratio of the relevant area after the construction of the project.

Economy and Efficiency Index

Technical and economic evaluation is to highlight the economic operation of the project. Financial evaluation is to assess the project's construction economy.

(1) TECHNICAL AND ECONOMIC EVALUATION

1) Equipment utilization. The index is a technical and economic index reflecting the working condition and production efficiency of the equipment.

2) Line loss rate. The index reflects the proportion of the loss of electric energy in the transmission process, so as to evaluate the operation economy of the project.

3) The reliability benefit of unit investment. Reliability benefit refers to the benefits brought by improving power supply reliability through power grid project construction. With the expansion of the scale of power grid, the structure of power grid is stronger and the social outage cost is reduced. So the reliability benefit of the grid can be characterized by the grid loss of the planning grid relative to the initial grid reduction. The reliability benefit of unit investment can be used to reflect the benefits of investment output and also to make comparability between different projects.

\[ \text{The reliability benefit of unit investment} = \frac{B_i}{C_{\text{all}}} = \frac{L_{\text{cut}0} - L_{\text{cut}}}{C_{\text{all}}} \]  

(2)

Where, \( B_i \) is the reliability benefit of power grid; \( L_{\text{cut}0} \) is the social outage cost of initial grid; \( L_{\text{cut}} \) is the social outage cost of planning grid. The social outage cost can be solved based on \( EENS \) of the reliability index.
Where, $L_{cut}$ is the social outage cost; $EENS_{sys}$ is systematic $EENS$; $p_d$ is the outage loss per unit quantity of electricity.

4) Annual cost of unit electricity. The concept of annual cost was proposed in 7. With the index "Annual cost of unit electricity", the projects of different power supply can be compared.

5) Unit investment to increase sales of electricity. The index refers that the electricity sales increased through the implementation of the planning project, and the amount of income then increases. Also the index reflects the unit investment output value, reflecting the economic benefits of investment.

(2) FINANCIAL EVALUATION

6) NPVR. The index is the ratio of the net present value of the project to the present value of the original investment.

7) IRR. Internal rate of return. For details, see the reference 8.

**Coordination and Flexibility Index**

The coordination is manifested as the coordination between the economic and the reliability of the planning project. Measuring the coordination of each voltage level and adapting to the development of the project is the key point of the evaluation of this kind of index.

(1) COORDINATION AMONG DIFFERENT VOLTAGE LEVELS OF POWER GRID

1) Substation capacity ratio. The index refers to the capacity ratio of each voltage class substation. The index reflects the capacity coordination of each voltage class substation, and represents the degree of coordinated development of each voltage level grid.

2) Substation coordination factor. The index is the variance of substation load rate, which reflects the discrete degree of the substation load rate. The closer the value is to 0, the better load distribution matching of substation, the smaller the difference of operation between substation and the better coordination.

\[
C_S = \frac{1}{N_S} \sum_{i=1}^{N_S} (S_i - \bar{S})^2
\]

Where, $C_S$ is substation coordination factor; $S_i$ is $i$-th substation load rate; $\bar{S}$ is the average load rate of substation; $N_S$ is the total number of substations.

3) Line coordination factor. The index refers to the variance of the load rate of each line in the power grid, reflecting the equilibrium degree of the line power flow in the grid operation. The closer the value of 0 indicating that the average power flow of the grid, the grid operation of the higher security and economy.

\[
C_L = \frac{1}{N_L} \sum_{i=1}^{N_L} (L_i - \bar{L})^2
\]

Where, $C_L$ is line coordination factor; $L_i$ is the load rate of the $i$-th line; $\bar{L}$ is the average load rate of line; $N_L$ is the total number of lines.

(2) EXTENDED MARGIN

4) Substation expansion margin. The index indicates the ratio of the sum of the expandable capacity to the total capacity of the substation at a voltage level in the statistical year.
Social Benefits Index

From the traditional resource consumption situation and the new energy grid-connected emission reduction benefits to comprehensive evaluation.

(1) LAND RESOURCE CONSUMPTION
1) Capacitance area of unit power supply and transmission. The index is used to evaluate the area of the power supply and transmission capacity of the substation project and the line project. Among them, the concept of power supply for project refers to the substation capacity, for the line project refers to the thermal stability limit transmission capacity of the line.

(2) BENEFITS OF NEW ENERGY GRID-CONNECTION
2) Reducing the standard coal quantity consumed by fossil energy. The index reduces the amount of fossil energy consumption by reducing the amount of fossil energy generation after the new energy grid connected, reflecting the function and role of new energy in the development of low carbon economy.

Risk Controllable Index

This paper emphasizes the risk of new energy transmission, in line with the current development of mainstream demand.

(1) TECHNOLOGY RISK
1) New energy delivery satisfaction rate. The large-scale and rapid development of new energy is out of line with the development plan of local power grid and power supply, so the shortage of power transmission capacity will enhance the risk of large-scale wind power and Photovoltaic power curtailment.

COMBINATION WEIGHTING EVALUATION METHOD

After obtaining the data of each index, this paper uses the combination weighting evaluation method to calculate the weight of each index, and the two parts are combined to get the final comprehensive evaluation results.

Classification and Pre-processing of Index Data

Each index's critical choice is different, and the obtained data can’t be visually defined, so it is necessary to classify the evaluation index according to different attributes. In this study, the evaluation index is divided into cost type (the smaller the attribute value the better), benefit type (the greater the attribute value, the better), Interval type (the attribute value falls within the best of a range), and for some qualitative indicators to take sub-scoring, sub-scoring criteria need to combine expert experience. Standardized processing of indexes with different attributes 9, make it a value of the interval [0,1], the greater the better.

Research on Combination Weighting Evaluation Method of Index

Through the comparison and research of different index weighting methods, this paper proposes the combination of Analytical Hierarchy Process-Entropy weight, in which the subjective features and objective features are combined, is taken as the calculation method to evaluate the weight of the index.
Analytic Hierarchy Process, AHP 10 combines quantitative and qualitative analysis, and transforms complex multi-objective decision problem into the results of multiple levels and factors. This method quantifies the subjective judgment relationship between the indexes by means of the 1-9 scale method proposed by Satty, constructs the quantity judgment matrix and makes consistency test. Then the eigenvector corresponding to the largest feature root is obtained, which is standardized as the weight vector.

As an objective and practical weighting method, entropy weight method is the method of judging the weight of the index by using the amount of information contained in the entropy of different indexes.

1) Standardized evaluation matrix according to certain rules as

\[ x = [x_{ij}]_{n \times m} \]

2) Calculate the entropy value of index \( J \).

\[ H_j = -k \sum_{i=1}^{n} p_{ij} \ln p_{ij} \]  

(6)

3) Entropy weight for calculating index \( J \).

\[ \sigma_j = \frac{1 - H_j}{m - \sum_{j=1}^{m} H_j} \]  

(7)

The combination of Entropy method and Analytic Hierarchy Process makes the weight not only contain the information of the data itself, but also reflect the subjective judgment of the experts. The combination weight is expressed as:

\[ \psi = \alpha \omega_j + (1 - \alpha) \sigma_j \]  

(8)

Where \( \omega_j \) is the weight obtained by analytic hierarchy process (AHP); \( \sigma_j \) is the weight of entropy weight calculation; the value of \( \alpha \) depends on the correlation between \( \omega_j \) and \( \sigma_j \), and \( 0 \leq \alpha \leq 1 \), according to the Kendall correlation coefficient11, this paper takes \( \alpha = 0.7 \).

Results Analysis

In this paper, the standardized processing of the index data multiplied by 100 to get the standardized score of each index, and then multiplied with the corresponding weight, the data obtained is the score of each item. This result can be used as an important reference for projects screening and sequencing.

NUMERICAL SIMULATIONS

Take three power transmission projects (Two 220kV power transmission project, a 500kV power transmission project) that are involved in a provincial planning circle for analysis and assessment objects. First, we use the Analytic Hierarchy Process-Entropy weight combination method to determine the secondary index weight of five primary indexes, which are safety and reliability, economy and efficiency, coordination flexibility, social benefits and risk controllability. Through the standardized score results obtained by the secondary index data score, then through the secondary indexes step by step integration and finally get the scores of each project.

\[ P_i^{(n)} = \sum_{j=1}^{n} p_{ij}^{(n)} w_j^{(n)}, i = 1, 2, \cdots m \]  

(9)

Where, \( m \) is the number of projects; \( P_i^{(n)} \) is the project \( I \) score on the \( k \) layer index; \( n \) is the
subordinate index of a certain index in layer $k$; $w_j^{(n)}$ is the index weight of the subordinate index $j$ in the $k$-1 layer; $p_{ij}^{(n)}$ is the project $I$ on sub index $j$ project score.

Taking the safety and reliability index system as an example, the results of the indexes standardization of each project are shown in Table I.

<table>
<thead>
<tr>
<th>Evaluation index</th>
<th>Index attribute</th>
<th>Standardized scoring result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety and reliability index</td>
<td>Transmission capacity shortage rate</td>
<td>Benefit type</td>
</tr>
<tr>
<td></td>
<td>Capacity-load ratio before project construction</td>
<td>Interval type</td>
</tr>
<tr>
<td></td>
<td>Substation load rate</td>
<td>Benefit type sub-scoring</td>
</tr>
<tr>
<td></td>
<td>Load property</td>
<td>Benefit type</td>
</tr>
<tr>
<td></td>
<td>N-1 pass rate</td>
<td>Benefit type</td>
</tr>
<tr>
<td></td>
<td>N-2 pass rate</td>
<td>Benefit type sub-scoring</td>
</tr>
<tr>
<td></td>
<td>Short circuit current level</td>
<td>Benefit type sub-scoring</td>
</tr>
<tr>
<td></td>
<td>Thermal stability margin</td>
<td>Interval type</td>
</tr>
<tr>
<td></td>
<td>Capacity-load ratio after project construction</td>
<td>Interval type</td>
</tr>
</tbody>
</table>

We use the Analytic Hierarchy Process-Entropy Weight Combination Method to determine the secondary index weight of safety and reliability evaluation index system, as shown in Table II.

According to the weight of the secondary indexes, the scores of the project 1, the project 2 and the project 3 are 97.07, 81.45 and 86.89 respectively according to the scores of the secondary indexes.

Taking this as an example, we can draw the weight and score of the project in safety and reliability, economy and efficiency, coordination flexibility, social benefits and risk controllability as shown in Table II.
### Table II. Indexes weight in safety and reliability.

<table>
<thead>
<tr>
<th>Evaluation index</th>
<th>Primary index</th>
<th>Secondary index</th>
<th>Weight of AHP</th>
<th>Weight of entropy weight method</th>
<th>Combinaton weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety and reliability index</td>
<td>Transmission capacity shortage rate</td>
<td></td>
<td>0.1348</td>
<td>0.0961</td>
<td>0.12319</td>
</tr>
<tr>
<td></td>
<td>Capacity-load ratio before project construction</td>
<td></td>
<td>0.1056</td>
<td>0.1341</td>
<td>0.11415</td>
</tr>
<tr>
<td></td>
<td>Substation load rate</td>
<td></td>
<td>0.0626</td>
<td>0.0037</td>
<td>0.04493</td>
</tr>
<tr>
<td></td>
<td>Load property</td>
<td></td>
<td>0.1542</td>
<td>0.4714</td>
<td>0.24936</td>
</tr>
<tr>
<td></td>
<td>N-1 pass rate</td>
<td></td>
<td>0.2463</td>
<td>0.0258</td>
<td>0.18015</td>
</tr>
<tr>
<td></td>
<td>N-2 pass rate</td>
<td></td>
<td>0.1326</td>
<td>0.0340</td>
<td>0.10302</td>
</tr>
<tr>
<td></td>
<td>Short circuit current level</td>
<td></td>
<td>0.0584</td>
<td>0.1173</td>
<td>0.07607</td>
</tr>
<tr>
<td></td>
<td>Thermal stability margin</td>
<td></td>
<td>0.0409</td>
<td>0.0629</td>
<td>0.0475</td>
</tr>
<tr>
<td></td>
<td>Capacity-load ratio after project construction</td>
<td></td>
<td>0.0646</td>
<td>0.0547</td>
<td>0.06163</td>
</tr>
</tbody>
</table>

### Table III. The weight and score of the primary indexes.

<table>
<thead>
<tr>
<th>Primary index</th>
<th>Secondary index</th>
<th>Index score</th>
<th>Project 1</th>
<th>Project 2</th>
<th>Project 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety and reliability</td>
<td></td>
<td></td>
<td>0.3969</td>
<td>97.07</td>
<td>81.54</td>
</tr>
<tr>
<td>Economy and efficiency</td>
<td></td>
<td></td>
<td>0.2276</td>
<td>75.81</td>
<td>90.60</td>
</tr>
<tr>
<td>Coordination flexibility</td>
<td></td>
<td></td>
<td>0.201</td>
<td>99.04</td>
<td>61.70</td>
</tr>
<tr>
<td>Social benefits</td>
<td></td>
<td></td>
<td>0.1026</td>
<td>66.56</td>
<td>98.01</td>
</tr>
<tr>
<td>Risk controllability</td>
<td></td>
<td></td>
<td>0.0719</td>
<td>86.56</td>
<td>80.95</td>
</tr>
</tbody>
</table>

According to the process of Synthetic operator and upward integration, regarding combination weight as the weight of each index, along with the scores of each item to the primary index included in the overall target, some results can be figured out, towards the overall target, the scores of project 1, project 2 and project 3 are 88.74, 81.26 and 83.26, respectively. The total score of the evaluation results is sequenced as project 1> project 3> project 2. From the total score can be seen, the comprehensive evaluation index system proposed in this study can scientifically and reasonably evaluate the planning of the project, and it can be intuitively quantified to get the sequence of the projects, improve the scientific and rigorous of screening and sequencing of the planning projects.
CONCLUSION

This paper puts forward a set of comprehensive evaluation index system which can be used in the evaluation of projects, starts from the characteristics of the development of power grid planning, and compares the multi-dimensional and all aspects of the comparison between the transmission grid planning projects in safety and reliability, economy and efficiency, coordination flexibility, social benefits and risk controllability. This system meets the needs of the development of the new situation, and provides more scientific and rigorous standards for project screening and sequencing. The results show that the index system is scientific, reasonable, flexible and comprehensive consideration of all kinds of construction projects. It is a comprehensive evaluation standard which is worth promoting.

REFERENCES

1. Han Hui, Research of Power System Planning Based on Reliability Assessment [D], Zhejiang University. (2013).
8. XuChengbin, Chen Qi, Comparative Study on IRRs for Financial Analysis of Investment Project [J], Energy Technology and Economics. 1, 6(2011).