Comprehensive Evaluation of Power Grid Security and Benefit Based on BWM Entropy Weight TOPSIS Method

Lang Zhao¹, a, Hui Li¹, Zhidong Wang¹, Dong Peng¹, Yawei Xue¹ and Xin Ai²
¹State Grid Economic and Technological Research Institute Co., Ltd., Beijing 102209, China;
²School of Electrical and Electronic Engineering, North China Electric Power University, Beijing 102206, China;
a zhaolang@chinasperi.sgcc.com.cn

Abstract. With the gradual integration of various forms of energy, the energy utilization rate has increased and it also brings great challenges to grid evaluation. Therefore, the use of scientific and reasonable comprehensive evaluation method can provide effective help for the development of power grid. In order to solve the problem that the traditional single evaluation method is used in the comprehensive evaluation of power grid, resulting in too strong subjective awareness and lack of evaluation of the objective original data itself and uneven weight distribution, this paper proposes that Nash equilibrium solution is introduced into BWM entropy weight as the goal of coordination and optimization. In the method, the comprehensive weight is calculated, and the distance between the selected scheme and the ideal scheme is sorted by TOPSIS. This method combines all the information of objective data to balance the subjective and objective weight. Through this method, 16 indicators of safety and benefit in 25 provinces in 2017 of State Grid Economic Research Institute are analyzed, and the feasibility of this method is verified.

1. Introduction
At present, many comprehensive evaluation methods have been put forward for power quality and power safety [1]. Comprehensive evaluation research on power grid development mostly focuses on power supply quality [2], sustainable development [3] and intelligent development [4].

In this paper, a comprehensive evaluation method based on BWM-entropy weight-TOPSIS is proposed based on the index system established in reference. Firstly, a comprehensive evaluation index system of power grid safety and benefit is established, which takes into account the basic attributes of power grid planning and the needs of power customers themselves. Secondly, BWM method and entropy weight method are used to determine subjective and objective weights, game theory is combined with the calculation of comprehensive weights, NASH equilibrium is taken as the coordinated optimization goal, and TOPSIS method is used to calculate the distance between the selected scheme and the ideal scheme for comprehensive evaluation. Finally, this method is used to analyze 16 indicators of safety and benefit from the data returned by State Grid Economic Research Institute in 2017, and the comprehensive evaluation of safety and benefit of power grids in each province verifies the feasibility of this method. It can be seen that the comprehensive weight obtained by Nash equilibrium solution is more reasonable than that obtained by weighted average in the past.
The influence of the change of some evaluation indexes on the overall evaluation results is demonstrated by using the index sensitivity analysis method, and relevant improvement measures are put forward.

2. Comprehensive evaluation index system of power grid safety and benefit

2.1. Indicator selection principle
This paper follows the following principles when screening indicators [5].
(1) Consistency principle: the selected indicators should be consistent with the evaluation objectives, and the key indicators with representativeness should be selected to reflect the development status and future development capability of the power grid through calculation;
(2) Hierarchy principle: The comprehensive evaluation system of power grid is a complex system, which should be hierarchical and look clearer when constructing the index system;
(3) Independence principle: different indicators in the system should have a strong relationship and the indicators at the same level should not repeat each other;
(4) Comparability principle: the selected indicators can intuitively show some characteristics in the development process of power grid, and can be compared with each other.

2.2. Establishment of index system
According to the actual situation of 25 provinces in China [6], this paper constructs an index system from two aspects of power grid security and benefit. In order to make the evaluation clearer and easier to realize, the indicators are divided into four layers, namely, target layer, category layer, primary index layer and secondary index layer, that is, the final evaluation target is power grid safety and efficiency. The specific 16 indicators are divided into power grid safety and power grid efficiency, and the final comprehensive evaluation index system is obtained from three aspects (see Table 1).

Table 1. Comprehensive evaluation index of power grid

| Target layer | Category level | Primary index | Secondary index |
|--------------|----------------|---------------|-----------------|
| Security and benefit of power grid | Power grid Safety | Structure Safety | Pass rate of 500-N-1 (%) |
| | | | Passing rate of N-2 of 500- double circuit line on the same tower (%) |
| | | | 220-N-1 pass rate (%) |
| | | | Pass rate of N-2 of 220- double circuit line on the same tower (%) |
| | Risk Hidden danger | | 220- major accident hazards (pieces) |
| | | | 220- general accident hazards (pieces) |
| | Short circuit capacity | | 500kV short circuit current-exceeding switch |
| | | | Interrupting capacity 80%- Bus node ratio (%) |
| | | | 220kV short circuit current-exceeding switch |
| | | | Interrupting capacity 80%- Bus node ratio (%) |
| | Growth Benefit | | Annual growth rate of maximum power load (%) |
| | Environmental benefits | | Annual growth rate of electricity consumption in the whole society (%) |
| | Economic benefit | | Annual growth rate of electricity sales (%) |
| | | Renewable energy generation capacity (10,000 kWh) | |
| | | Save standard coal (tons) | |
| | | Power supply load of unit power grid assets (kW/10,000 yuan) | |
| | | Electricity sales of unit grid assets (kwh/yuan) | |
| | | Sales revenue of unit power grid assets (yuan) | |
3. Comprehensive evaluation model of BWM-entropy weight-TOPSIS

3.1. Best-worst method (BWM) to calculate subjective weight

In the past multi-index decision-making problems, the most commonly used method is Analytic Hierarchy Process (AHP), which compares any two indexes with each other to get the evaluation matrix of the indexes, which needs to be compared twice and finally gets data. The process is complex and the comparison times are many, which will lead to some mistakes by experts and high error rate.

3.2. Entropy weight method to calculate objective weight

Entropy weight method is an objective weighting method, which determines the weight of each index according to the amount of information contained in the index. In the multi-index decision-making problem, the greater the information content of an index, the greater its change degree, the smaller its entropy value, the greater its role in scheme evaluation, and the greater its weight, so as to avoid the influence of subjective factors and make the calculated weight more reliable.

3.3. BWM-entropy weight comprehensive weight method based on game theory

Many scholars calculate the combination weights which comprehensively consider subjective and objective weights by weighted averaging, but the mutual influence between subjective and objective weights is great and the rationality is poor. By introducing game theory, NASH equilibrium is regarded as an optimization goal of coordinating subjective and objective weights, and a balance point is found between different weights, so that the deviation between the final comprehensive weight and each basic weight is minimized as much as possible, and then a more reasonable comprehensive weight is obtained.

3.4. Comprehensive evaluation model of BWM-entropy weight-TOPSIS

The basic principle of this method is to sort and select the best according to the calculated distance between each selected scheme and the optimal solution and the worst solution. If the evaluation object is closest to the optimal solution and farthest from the worst solution, then the selected scheme is the best one; On the contrary, it is the worst plan. TOPSIS method can be used to evaluate and select multiple alternatives through a large number of indicators.

4. Case analysis

In this paper, according to the diagnostic feedback data of the State Grid Economic Research Institute of 25 provinces in 2017 as the original data, 16 indicators are selected from the aspects of power grid safety and efficiency to evaluate through the above methods and evaluation system.

4.1. Calculation of weights

(1) For the calculation of subjective weights, three experts scored one by one, and the subjective weights of each index were calculated by BWM method and AHP method respectively, and the consistency test was carried out to prove that the judgment matrix was effective. at the same time, the consistency ratios obtained by the two methods were compared. as shown in Table 2, it can be seen that although the ratio values of the two methods are not much different, the results calculated by BWM method are closer to 0.1 and have higher reliability.

| Table 2. Consistency ratio comparison table |
|--------------------------------------------|
| Calculation of subjective weight method    | AHP         | BWM         |
| Expert 1 consistency ratio                 | 0.00018334  | 0.00014032  |
| Expert 2 consistency ratio                 | 0.00017452  | 0.00013116  |
| Expert 3 consistency ratio                 | 0.00017857  | 0.00013441  |
\( \omega_j = [0.048, 0.038, 0.051, 0.047, 0.04, 0.06, 0.01, 0.092, 0.056, 0.056, 0.017, 0.094, 0.051, 0.052, 0.049] \)

(2) Through entropy weight method, objective weight values of 16 indexes can be obtained:
\( \omega_j = [0.045, 0.051, 0.041, 0.04, 0.043, 0.038, 0.056, 0.066, 0.058, 0.06, 0.073, 0.018, 0.11, 0.054, 0.1, 0.056] \)

(3) Considering the game theory model, the NASH equilibrium solutions of subjective and objective weights are obtained by \( g_1^* = 0.63, g_2^* = 0.37 \). According to the combination weight formula, calculate the combination weight value of each index:
\( \omega_j = [0.057, 0.056, 0.047, 0.052, 0.084, 0.058, 0.053, 0.063, 0.062, 0.107, 0.1, 0.052, 0.07, 0.052] \)

At the same time, the comprehensive weight is also calculated by using the commonly used method of solving the optimal combination weight by Lagrange multiplier method, which is as follows:
Set the optimal combination weight as \( \omega_j (j = 1, 2, \ldots, n) \), if the optimal combination weight \( \omega_j^* \) and \( \omega_j^s \) are as close as possible, according to the principle of minimum discrimination information, establish the following objective function:
\[
\min F = \sum_{j=1}^{n} \omega_j \left( \ln \frac{\omega_j^*}{\omega_j} \right) + \sum_{j=1}^{n} \omega_j \left( \ln \frac{\omega_j}{\omega_j^s} \right)
\]

The optimal combination weight is obtained by Lagrange multiplier method:
\[
\omega_j = \frac{\omega_j^s \omega_j^*}{\sum_{j=1}^{n} \omega_j^s \omega_j^*}
\]

| Table 3. Comprehensive Weight Comparison Table |
|-----------------------------------------------|
| Indicators | Equilibrium solution with Nash consideration | Lagrange multiplier method for solution |
|-------------|------------------------------------------------|---------------------------------------|
| Pass rate of 500-N-1 (%) | 0.057 | 0.052 |
| Passing rate of N-2 of 500- double circuit line on the same tower (%) | 0.056 | 0.05 |
| 220- general accident hazards (pieces) | 0.052 | 0.049 |
| Annual growth rate of electricity sales (%) | 0.062 | 0.057 |
| Renewable energy generation capacity (10,000 kWh) | 0.107 | 0.096 |
| Electricity sales of unit grid assets (kWh/Yuan) | 0.07 | 0.068 |

In view of too many calculated data, six indexes are selected and the comprehensive weights calculated by the two methods are compared (see Table 3). Through calculation and the above table, it can be seen that the calculation results of the two methods are similar, but the comprehensive weight obtained by Nash equilibrium solution is less affected by subjective and objective weights, and the results are more reasonable.

4.2. Calculation of score evaluation value based on TOPSIS method
The relative fitting degree of each evaluated object can be calculated by using the weighted normalized index matrix:
\[
C = [0.042, 0.023, 0.046, 0.053, 0.041, 0.055, 0.038, 0.028, 0.047, 0.024, 0.01, 0.049, 0.032, 0.037, 0.026, 0.07, 0.012, 0.05, 0.034, 0.056, 0.043, 0.046, 0.035, 0.061, 0.053]
\]

According to the method mentioned in this paper, the final score and ranking of safety and benefit evaluation are made for a total of 16 indicators in 25 provinces (see Table 4).
After calculation, combined with the original data, the comprehensive weight obtained and the final ranking of scores, it can be seen that province A strictly controls all aspects in terms of power grid safety and benefits, and has never had any hidden dangers of accidents. The electricity sales of unit power grid assets are also in the forefront, so it has the highest score. However, the lower-ranked areas are mostly due to the massive access of new energy power generation equipment, which cannot guarantee the power quality and meet the power demand, resulting in lower scores.

| Area | Comprehensive score | Rank | Area | Comprehensive score | Rank |
|------|---------------------|------|------|---------------------|------|
| A    | 0.07                | 1    | N    | 0.04                | 14   |
| B    | 0.061               | 2    | O    | 0.038               | 15   |
| C    | 0.056               | 3    | P    | 0.037               | 16   |
| D    | 0.055               | 4    | Q    | 0.035               | 17   |
| E    | 0.053               | 5    | R    | 0.034               | 18   |
| F    | 0.053               | 6    | S    | 0.032               | 19   |
| G    | 0.05                | 7    | T    | 0.028               | 20   |
| H    | 0.049               | 8    | U    | 0.026               | 21   |
| I    | 0.047               | 9    | V    | 0.024               | 22   |
| J    | 0.046               | 10   | W    | 0.023               | 23   |
| K    | 0.046               | 11   | X    | 0.012               | 24   |
| L    | 0.043               | 12   | Y    | 0.01                | 25   |
| M    | 0.042               | 13   | -    | -                   | -    |

5. Sensitivity analysis

According to the original data of each index in 2017, taking A province as an example, the index value changed from -50% to +50%, and the relationship between comprehensive evaluation value and main index was observed by single index sensitivity analysis and multi-index combination sensitivity analysis.

5.1. Single index sensitivity analysis

Select 3 indicators from 16 indicators of safety and benefit to do single-indicator sensitivity analysis, and get the sensitivity analysis curve shown in Figure 1. The change of slope of each index curve can reflect the influence of the index on comprehensive evaluation. The greater the change of slope, the greater the influence of the table representing the index on comprehensive evaluation value, etc.

![Figure 1. Sensitivity of Safety and Benefit Index](image1)

![Figure 2. Sensitivity of Combinations](image2)

It can be seen from Figure 1 that the absolute value of the slope of the 500-N-1 pass rate curve is the largest, which is gradually reduced from the original data in 2017 to -50%, and the comprehensive evaluation value is reduced from 3.53 to 2.994; Gradually increased to +50%, and the comprehensive evaluation value decreased from 3.53 to 3.36. Therefore, when the index value remains unchanged or increases by +10%, the corresponding comprehensive evaluation value is the largest.
5.2. Sensitivity analysis of multi-index combination
The indexes with linkage relationship are selected for combination in the aspects of power grid safety and benefit, as shown in Table 5, and six groups of index combinations are given. The sensitivity analysis curve of multi-index combination is shown in Figure 2. It can be seen from the curve change trend in the figure that combination 5 has the greatest impact on the comprehensive evaluation results, keeping unchanged or increasing the new energy access by 10%. Followed by combination 1 and combination 2, their changes are also obvious. Properly increasing the passing rate of 10%N-1 and N-2 can improve the security of power grid. Combination 4 has little influence and the curve tends to be flat. However, the combination 6 showed fluctuation and changed forward, and the comprehensive benefits could be improved by increasing or decreasing by 10%.

Table 5 Multi-index Sensitivity Analysis Combination

| Combination | Indicators |
|-------------|------------|
| 1           | 500-N-1 pass rate and 500-N-2 pass rate of double-circuit lines on the same tower |
| 2           | Pass rate of 220-N-1 and pass rate of 220- double-circuit line on the same tower N-2 |
| 3           | 500kV short-circuit current-exceeding switch interrupting capacity by 80%- bus node proportion, 220kV short-circuit current-exceeding switch interrupting capacity by 80%- bus node proportion |
| 4           | Annual growth rate of maximum electricity load, annual growth rate of electricity consumption of the whole society and annual growth rate of electricity sales |
| 5           | Renewable energy generation and standard coal saving |
| 6           | Power supply load of unit grid assets, electricity sales of unit grid assets and income from electricity sales of unit grid assets |

6. Conclusion
BWM-entropy weight method improves the tedious process of calculating subjective weight in traditional AHP method and reduces the risk of inconsistency. At the same time, combined with objective weights, the internal information of the original data is fused, and more reliable comprehensive weights are obtained by NASH equilibrium solution, which improves the problem of great influence between subjective and objective weights in the weighted averaging combination weights used in the past, and makes the final evaluation results more scientific and accurate. Using the obtained distance to solve the relative fitting degree between index samples and ideal samples, and realizing the comprehensive evaluation of power grid safety and benefit by sorting the fitting degree. The results show that this method can not only effectively evaluate the power grid safety and benefits, but also objectively reflect the overall closeness of each indicator in the scheme to the ideal scheme, which is an effective comprehensive evaluation method.

Acknowledgment
This paper was supported by the science and technology project of State Grid Corporation of China 5102-201956310A-0-0-00, “Research on Intelligent Diagnosis Analysis and Comprehensive Decision Technology of Power Grid Development Based on Data Driven”.

References
[1] Li H Z, Guo S, Tang H, et al. 2013 Comprehensive evaluation on power quality based on improved matter-element extension model with variable weight Power System Technology 37 92-98
[2] Watson N R. 2016 Power-quality management in New Zealand IEEE Transactions on Power Delivery 31 1963-970
[3] IqtiyaniIlham N, Hasanuzzaman M, Hosennuzzaman M. 2017 European smart grid prospects policies and challenges Renewable and Sustainable Energy Reviews 67 776-790
[4] Zhang Y, Chen W, Gao W J. 2017 A survey on the development status and challenges of smart grids in main driver countries Renewable and Sustainable Energy Reviews 79 137-147
[5] Luo Y and Li Y L. 2013 Comprehensive decision-making of transmission network planning based on entropy weight and grey relational analysis *Power System Technology* 37 77-81.

[6] Wand X D, Liu J Y, Liu Y B, et al. 2019 Typical load curve shape clustering algorithm based on adaptive piece wise aggregation approximation *Automation of Electric Power Systems*, 43 110-121