PAPER • OPEN ACCESS

An Evaluation Method of Grid Operation Benefit based on Operation Data

View the article online for updates and enhancements.

An Evaluation Method of Grid Operation Benefit based on Operation Data

Yufang Liu[1,a], Qian Ma[1], Wenjuan Niu[2], Chen Wu[2], Yunyang Liu[3], Xinyue Wang[3]

[1] State Grid Jiangsu Electric Power Co, Ltd, 210024 Nanjing, China

[2] State Grid Jiangsu Economic Research Institute, 210008 Nanjing, China

[3]Beijing Tianhe Benan Electric Power Technology Co, Ltd, 102206 Beijing, China

[a] Corresponding author: author@e-mail.org

Abstract. With the rapid development of economy, more and more requirements are being made on the investment and operating efficiency of power grid. Therefore, it's necessary to establish an evaluation method of grid operation benefit based on operation data. This paper establishes a fuzzy comprehensive evaluation method to evaluate the operation benefit of power grid based on the improved variable weight theory. Firstly, a perfect index system is established, and the dimensionless calculation method in the efficacy coefficient method is introduced. Then the improved variable weight theory algorithm is studied. It makes more effective use of earned scores by introducing a non-const equilibrium coefficient, and the calculation process of the fuzzy comprehensive evaluation method is given. Finally, an example is illustrated to verify the feasibility and effectiveness of the proposed algorithm.

1..Introduction

With the rapid development of economy, the development and investment management work of power grid is facing unprecedented new situations and new demands. There is a general trend about the market strict supervision investment and carries out the investment accountability. Recently, under the limited investment expenditure but more and more extension and reconstruction demands of power network, it is necessary to strengthen the study of power grid investment benefit evaluation technology to provide the foundation for the power network investment optimization.

At present, the assessment of power network operation benefit at home and abroad mainly focuses on four aspects: economy, security, social benefit and environmental benefit, where the index system varies according to region. The indicators reduced according to the correlation analysis in [1], thus establish an effective and feasible overall indicator system for evaluation. Due to the different dimensions and attributes between each index, it needs to be processed. Reference [2] made the indicators consistent and unified to become extremely large indexes, and then made dimensionless so that each index could be written as a score. Finally, the index values are partitioned by normal distributions model to evaluate the power grid's operation benefit.

An overall evaluation model is needed after determining the index system. At present, the scholars at home and abroad generally use the method of weighting to develop the overall evaluation model. Reference [3] determined the weight through combining the subjective and objective methods. The former adopted the Analytic Hierarchy Process(AHP), and the latter adopted the entropy weight method(EWM). The weights obtained by the two methods are proportional to the final weights.

Reference [4] uses the Analytic Network Process(ANP) anti-entropy method to calculate the weight. The methods illustrated above only consider the influence of the importance of the index itself on the evaluation model, but do not consider the impact of the actual calculated index score on the overall evaluation.

This paper puts forward an evaluation method of power grid operation benefit based on the improved variable weight theory according to the scholars' study at home and abroad. The specific work has done in this paper are as follows: Firstly, establish the index system, including the economy and security of power grid operation, and the social benefit and environment benefit of power grid. Then, do the normalization processing according to the difference between index's attributes and dimensions. Moreover, a fuzzy comprehension evaluation model based on the improved variable weight theory is adopted in this paper to evaluate the operation benefit of power grid comprehensively. Finally, an example based on the model is illustrated in this paper to verify the feasibility and effectiveness of this model.

2.Index system

Existing level indicators of assessment indicator system of power network are generally divided into four aspects: economy, security, social benefit and environmental benefit. They also have secondary indicators and tertiary indicators, the total number of more than 30. The establishment of a perfect index system needs to meet four principles, which namely scientificity, systematicness, comprehensiveness and regional [5]. Under the condition that the above principles are satisfied, six indicators are selected to assess the operation benefit of power grid in this paper.

2.1 Economic indexes

2.1.1 Unit investment additional supply load

Unit investment additional supply load refers to the additional supply load corresponding to the unit investment of power network in the period of statistic. The computational formula is shown in (1):

$$\Delta P_{load} = \frac{P_{Ln} - P_{Ln-1}}{M} \qquad (1)$$

Where ΔP_{load} represents the unit investment additional supply load, kw; P_{Ln} represents the maximum load for n-th, kw; P_{Ln-1} represents the maximum load for (n-1)-th, kw; M represents the investment of power network last year, which unit is 10000 RMB.

2.1.2 Grid loss rate

Grid loss rate refers to the proportion of power loss in the process of transmission of electric energy, the computational formula is shown in (2):

$$\eta_{netloss} = \frac{P_{in} - P_{out}}{P_{in}} \qquad (2)$$

Where $\eta_{netloss}$ represents the loss rate of network; P_{in} represents the active power input from the power grid;

P_{out} represents the output power.

2.2 Security indexes

2.2.1 Voltage qualification rate

Voltage qualification rate refers to the ratio of qualified voltage in all monitored nodes, the computational formula is shown in (3):

$$\eta_v = \frac{n_s}{n_a} \qquad (3)$$

Where η_v represents voltage qualification rate; n_s represents the number of nodes with acceptable voltage in monitoring point. n_a represents the number of all monitored nodes.

2.2.2 Satisfaction rate of N-1 criterion

Satisfaction rate of N-1 criterion refers to the fraction of all components that satisfy the N-1 criterion, the computational formula is shown in (4):

$$\eta_{N\text{-}1} = \frac{n_{N\text{-}1}}{n_{total}} \qquad (4)$$

where $\eta_{N\text{-}1}$ represents satisfaction rate of N-1 criterion; $n_{N\text{-}1}$ represents the number of components that satisfy the N-1 criterion.

2.3 Social benefits indexes

Social benefits indexes refer to the evaluation indicators that the impact of operation of power grid on society, and the representative public satisfaction index is selected as such indicator, the data can be quantified by the number of complaints, reports, suggestions and praises generated by the power grid during its operation and by the form of statistical questionnaire, the computational formula is shown in (5):

$$\eta_{ps} = \frac{n_s}{n_a} \times 100\% \qquad (5)$$

where η_{ps} represents public satisfaction; n_s represents the number of satisfied users; n_a represents the number of all users.

2.4 Environmental performance indexes

Environmental performance indexes refer to the evaluation indicators that the impact of operation of power grid on environment, and what stands out is the reduction of carbon dioxide emissions. With the increasingly capacity of new energy generation connected to the grid, the carbon dioxide emissions are falling, and the computational formula is shown in (6):

$$M_{CO_2} = E_{new} \times a \qquad (6)$$

where M_{CO_2} represents the reduction of carbon dioxide emissions, which unit is 10000ton; E_{new} represents the capacity of renewable energy sources connected to the grid, which unit is 100million KWh; a represents the carbon dioxide emissions-reducing factor, which unit is 10000ton per 100 million KWh, generally value 9.97.
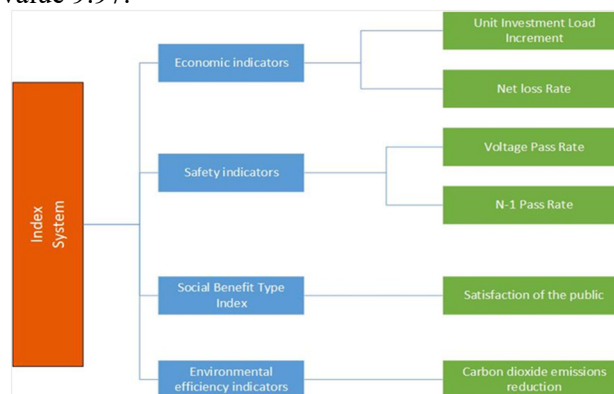

Figure 1. Evaluation Index System of Power Grid Operating Efficiency

2.5 Evaluation index system of power grid operating efficiency

According to the operating status of power grid, appropriate and representative indicators are selected

to build the evaluation index system of power grid operating efficiency in this paper. For convenience, the frame diagram of index system is illustrated in Figure 1.

3.Evaluation method of power grid operation benefit based on the improved variable weight theory

3.1 Improved variable weight theory
Variable weight theory is used to solve the situation that the grade of each indicator deviates from the central value excessively, when the grade is too large or too small, it need variable weight theory to reduce the impact on the general evaluation results, and achieve better general evaluation by reducing the weight. The calculation formula of variable weight which introduce the balanced function is given in [6]:

$$w_j' = \frac{w_j\left(x_j\right)^{T-1}}{\sum\limits_{l=1}^{m} w_l\left(x_l\right)^{T-1}} \tag{7}$$

where w_j represents the weight before the weight change; x_j represents the score of j-index; T represents the equalizing coefficient, $T \in \left(0,1\right]$.

All the existing variable weight theory set the equilibrium coefficient as a constant, and did not consider the impacts of the different abnormal degree of grade on the overall evaluation, and this article has made improvement about it. In this paper, the mean of all indicators is normal value, and all indicator grades that deviate from the mean are abnormal, which needs special handing to reduce the impact on the overall evaluation. The more the index grade deviates from the mean, the smaller the equilibrium coefficient should be; the closer the index grade is to the mean, the larger the equilibrium coefficient should be. The specific calculation formula is shown in (8):

$$T_{ij} = \begin{cases} \dfrac{\sum\limits_{j=1}^{m} x_{ij}\Big/m}{x_{ij}} & ,\sum\limits_{j=1}^{m} x_{ij}\Big/m < x_{ij} \\[4mm] \dfrac{x_{ij}}{\sum\limits_{j=1}^{m} x_{ij}\Big/m} & ,\sum\limits_{j=1}^{m} x_{ij}\Big/m \geq x_{ij} \end{cases} \tag{8}$$

where, T_{ij} represents the equilibrium coefficient of j-th target of the i-th project; m represents index number; x_{ij} represents the grade of j-th index of the i-th project.

3.2 Fuzzy comprehensive evaluation method based on the improved variable weight theory
The comprehensive evaluation method can be multi-level or single-level either, generally speaking, the multi-level comprehensive evaluation can be divided into multiple single-level evaluation problems. Therefore, this paper focuses on the single-level fuzzy comprehensive evaluation method, and the specific steps are as follows:
    1)Determine alternatives set
    First, determine the existing grid operation and planning scheme, then divide according to different permeability of distributed power or different new-type load sizes. The scheme set expressed by A={A1，A2,…，Ai,...An}, where n represents the number of schemes.
    2)Determine index set
    According to the indexes used above, establish a set of indexes and expressed by X={X1,X2,…,Xj,...,Xm}, where m represents the number of indexes.

3)Index score

First, calculate each index value according to the operation data, and then, the evaluation indexes are treated dimensionless with the efficacy coefficient method[7] ,which is shown in (9):

$$x_{ij} = c + \frac{x'_{ij} - m_j}{M_j - m_j} d \qquad (9)$$

where x_{ij} represents the dimensionless score of j-th index of i-th scheme; x'_{ij} represents the calculated value of j-th index of i-th scheme; M_j and m_j represents the satisfaction value and disallowed value of j-th index; c and d are constants, generally value $c = 60$ and $d = 40$.

4)Determine the weight of each index

Using the consistent matrix method of analytic hierarchy process to generate the judgment matrix B.

$$B = \begin{bmatrix} b_{11} & b_{12} & ... & b_{1m} \\ b_{21} & b_{22} & ... & b_{2m} \\ ... & ... & ... & ... \\ b_{m1} & b_{m2} & ... & b_{mm} \end{bmatrix} \qquad (10)$$

Where, b_{ij} represents the significance of i-th index compared with j-th, its value can be determined according to the method in Table 1.

Table 1. Meaning of elements in judgement matrix B

Value	Meaning
1	Indicator b_i is equally important to indicator b_j
3	Indicator b_i is slightly more important than indicator b_j
5	Indicator b_i is important relative to indicator b_j
7	Indicator b_i is much more important than indicator b_j
9	Indicator b_i is absolutely important relative to indicator b_j
2/4/6/8	The compromise value of the importance of indicator b_i relative to indicator b_j
The reciprocal of the value	If the ratio of significance of indicator i to indicator j is b_{ij}, then the ratio of importance of indicator j to indicator i is $b_{ji} = 1/b_{ij}$

Then according to the square root method to calculate the index weight preliminary, the calculation formula is shown in (11):

$$W_i = \frac{\left(\prod\limits_{j=1}^{m} b_{ij}\right)^{\frac{1}{m}}}{\sum\limits_{i=1}^{m}\left(\prod\limits_{j=1}^{m} b_{ij}\right)^{\frac{1}{m}}} (i, j = 1, 2, \ldots, \text{m}) \qquad (11)$$

Afterwards, the final weight of each index is determined according to the variable theory, which expressed by $W_i = \{w_{i1}, w_{i2}, \ldots, w_{im}\}$.

5)Comprehensive grade of calculation scheme

The calculation formula is shown in (12):

$$P_i = \sum_{j=1}^{m} w_{ij} x_{ij} \qquad (12)$$

Where P_i represents the comprehensive grade of i-th scheme.

6)Determine the fuzzy comprehensive evaluation results based on the maximum membership principle

The membership degree of each scheme is calculated, and then the grade of this scheme is determined according to the membership degree. In regard to the calculation of the membership degree, the improved triangular distribution[8] is used shown as Figure 2.
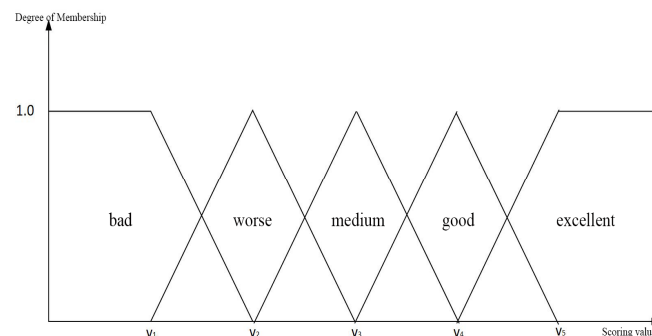

Figure 2. The membership distribution

where $v_k \left(k = 1, 2, 3, 4, 5\right)$ represents the boundary value of the fuzzy decomposition interval, in order to embody its generalized, the values in this paper are 10,30,50,70,90.

According to this method, the classification results are shown in Table 2.

Table 2. Graded interval

Grade	Bad	Worse	Medium	Good	Excellent
Score	[0,20]	[20,40]	[40,60]	[60,80]	[80-100]

For the multi-level comprehensive evaluation, it only needs to use the single-level comprehensive evaluation for each level that can obtain the highest-level comprehensive evaluation results.

4.Case study

In order to verify the feasibility of the proposed model, the operation data of A1, A2 and A3 are adopted in this paper, and the calculation results of indexes are shown in the following Table 3.

Table 3. Calculation results of indexes

Indexes	A1	A2	A3
Unit investment additional supply load （B1）,KW/10000RMb	0.56	0.71	0.65
Grid loss rate（B2）	4.23%	3.13%	2.89%
Voltage qualification rate（B3）	99.25%	99.59%	99.35%
Satisfaction rate of N-1 criterion（B4）	94.5%	98.6%	96.1%
public satisfaction（B5）	82%	89%	88%
reduction of carbon dioxide emissions （B6）,10000ton	560	650	790

Table 4. The satisfaction value and disallowed value

Index	Satisfaction value	Disallowed value
B1	1	0
B2	0%	5.2%
B3	100%	98.5%
B4	100%	0%
B5	100%	50%
B6	1000	0

The index scores of the three schemes were calculated according to the efficacy coefficient method as shown in Table 5.

Table 5. Index score

Score	A1	A2	A3
B1	82.4	88.4	86
B2	67.46	75.92	77.77
B3	80	89.07	82.67
B4	97.8	99.44	98.44
B5	85.6	91.2	90.4
B6	82.4	86	91.6

In order to confirm the weight of each index preliminary, firstly, generate the judgment matrix as shown in Table 6.

Table 6. Index judgment matrix

Index category	B1	B2	B3	B4	B5	B6
B1	1	1/5	1/7	1/5	1	1/3
B2	5	1	1/3	1/2	5	3
B3	7	3	1	3	6	4
B4	5	2	1/3	1	4	3
B5	1	1/5	1/6	1/4	1	1/3
B6	3	1/3	1/4	1/3	3	1

Combined with the weight and variable weight theory obtained preliminarily, the final weight can be calculated and the results are shown in Table 7.

Table 7. Index final weight

Weight	B1	B2	B3	B4	B5	B6
A1	0.149	0.201	0.152	0.186	0.164	0.148
A2	0.151	0.192	0.152	0.178	0.166	0.161
A3	0.159	0.181	0.157	0.175	0.163	0.164

The final score of each scheme can be obtained by the final weight, and the results are shown in Table 8.

Table 8. Scheme final score

Scheme	A1	A2	A3
Score （Grade）	82.4228 （Excellent）	88.1623 （Excellent）	87.8055 （Excellent）

It can be seen from the table that scheme A2 is optimal, followed by A3, and finally A1. It can also be seen from the original indexes calculation results that the indicators of A2 and A3 are superior to those of A1, and the calculation results of the arithmetic in this paper are same as this conclusion, which shows that the evaluation method proposed in this paper is feasible. In addition, the pros and cons of A2 and A3 are also compared according to the arithmetic, which is difficult to see directly from the indexes data, demonstrating the effectiveness of the arithmetic.

5.Conclusion

According to the operation data of power grid, a fuzzy comprehensive evaluation method was adopted to evaluate the operation benefit of power grid based on the improved variable weight theory in this paper. The following conclusions can be drawn from the study in this paper. Firstly, to evaluate the operation benefit of a network, it should select the indexes from multiple aspects and establish a thorough index system. Secondly, by introducing the variable equilibrium coefficient to the improved variable theory, the score can be effectively used for comprehensive evaluation, and the final weight obtained is more practical. What's more, the result of the initial weight obtained by using the judgment matrix in analytic hierarchy process, is relatively objective and universal. Finally, the evaluation arithmetic proposed in this paper has been verified by an example, which shows its excellent feasibility and effectiveness.

References

[1] L. Shengli. Study and application of investment benefit evaluation and decision model of distribution network (2017)
[2] L. Jia. Study on the analysis model of wind power development impact on power grid operation (2016)
[3] H. Puyu, Y. Xiaobao, D. Ying, et al. Applied research of improved ELECTRE-Ⅲ algorithm in the comprehensive evaluation of provincial grid efficiency and efficiency. Smart Power, **46(8)**, 52-59 (2018)
[4] R. Ming. Study on optimization model of distribution network investment decision based on engineering attribute and its application (2017)
[5] T. Zihao. Development and application of power network development diagnosis system with comprehensive evaluation of various indexes (2018)
[6] L. Wenqi. Equilibrium function and its application in variable weight synthesis. SETP, **17(4)**, 58-64 (1997)
[7] Z. Lixu, W. Pnegde. Application of efficiency coefficient method in comprehensive evaluation of enterprise economic benefit. JDU, **11(10)**, 5-8 (2012)
[8] S. Renjie, C. Yuming. Fuzzy comprehensive evaluation method of the relay protection state based on variable weight coefficient. PSPC, **44(3)**, 46-50 (2016)