Research on Evaluation Method of Grid Investment Benefit

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Abstract. As the overall investment in power grid increases yearly, how to improve the efficiency of power grid input-output has become a hot issue. This paper introduces a new grid input-output benefit evaluation method by looking for the corresponding relationship between grid stock asset investment, incremental asset investment and output benefit. Meanwhile, factors such as the time value of funds and the full life cycle cost have been taken into consideration. Based on the grid input-output benefit evaluation index system, a comprehensive evaluation model for grid input-output benefit is established in order to analyse the grid input-output benefit. The method overcomes the problem of non-corresponding between input and output in the traditional method and achieves to reflect the stock assets of the grid precisely.

1. Introduction

The development of the power grid has an important impact on power supply reliability and power quality. In recent years, the State Grid Corporation of China has attached great importance to the development of power grids. However, grid input-output benefit is still difficult to grasp. The assessment of grid input-output focuses on technology and safety assessments, which means the assessment of economics is insufficient. At the same time, grid analysis lacks of in-depth analysis and the effectiveness of grid investment needs to be reasonably evaluated. How to maximize the efficiency and grid input-output benefit has become a matter of great concern to decision-makers and managers at all levels of power grid enterprises. Therefore, it is urgent to construct an evaluation model of grid input-output benefit that comprehensively considers technology and economic evaluation.

Input-output benefit refers to the proportional relationship between input and achievement in a given period of time. Output benefit can be divided into enterprise economic benefit, national economic benefit and social benefit. The enterprise economic benefit refers to the economic benefit that a certain investment can bring. National economic benefit refers to the contribution of certain inputs to the effective growth of the national economy and structural optimization. Social benefit refers to the impact of certain inputs on social development, resources, ecology, environment, employment and distribution [1] [2] [3].

Foreign scholars' research on the evaluation of power grid input-output benefit involves engineering and technical issues such as power supply reliability, as well as financial aspects such as financing and risk in the power market. For example, some developed countries such as Britain, Norway, Canada and the United States have introduced competitive power generation market analysis in the power market reform [4]. The research on the evaluation of the power industry benefit is mainly
focused on the power generation, which includes the cost-benefit analysis of power generation enterprises, asset portfolio and risk management [5]. Reference [6] introduced the method on power market capacity planning and the risks on power market. Reference [7] proposed a method for loss evaluation and management in view of the loss of power revenue and the increase in overall cost and expenditure caused by non-technical losses in the operation of some national power grids. Reference [8] introduced the reliability and quality of power system and the cost of moderate system safety and reliability. This reference also analysed the power generation capacity and system power transmission capacity that is required to meet consumer demand levels.

Domestic scholars have also made significant contributions to the development of input-output benefit analysis techniques. The research on the input-output benefit evaluation of power grid involves power market evaluation, power grid planning evaluation, enterprise economic benefit evaluation and enterprise performance evaluation. Reference [9] introduced the concepts of market transmission service and the stability of the electricity market. Reference [10] introduced the engineering evaluation of power grid construction projects. Reference [11] introduced the performance evaluation indicators of grid enterprises under the premise of market reforms separated by the plant and the network. In terms of comprehensive evaluation, the input-output benefit of power grid involves power supply construction project evaluation and power grid planning evaluation. Reference [12] evaluated the investment risk of thermal power construction projects.

This paper introduces the evaluation indexes of grid input-output benefit and the calculation methods of them. The grid input evaluation indexes are picked by the full life cycle cost. The grid output benefits are divided into economic benefit and technical benefit. A comprehensive evaluation model of grid input-output benefit has been established in this paper. The comprehensive evaluation index of grid input-output efficiency can be obtained by combining the economic efficiency and the technical efficiency calculated through cost efficiency method. Finally, this paper picks two regions in similar development states for analysis and calculation.

2. Grid input-output evaluation index

According to the cost efficiency method, the grid input-output benefit refers to the ratio of the grid output benefit to the input cost of the grid in a given period of time. The input cost of the grid includes the following two points. One is the investment of existing asset of the power grid, which is also known as the investment of stock assets. This part of the cost is the investment of the built equipment of the grid and the trained human resources in this natural year. The other one is the input of the investment of incremental assets, which is the input cost of the new project in this natural year. The output benefit of the grid includes the following two points. One is the economic efficiency index of the power grid, which is measured by the economic benefit of electricity sales. The other one is the technical efficiency index of the power grid, which is the improvement of the equipment investment on the operation of the equipment and the quality of the power supply. Although the technical efficiency is difficult to quantify compared with the power sales benefit, it is an increase in asset investment which is of great significance to the power system.

![fig1](image.png)
In order to make the input indexes correspond to the output indexes, peer-to-peer metric model should be used to select these indexes. Specifically, when we select the grid asset input indexes, the grid asset investment should be converted into the annual input of the evaluation year. Similarly, when we select the grid output benefit indexes, the output benefit should be converted into the annual output data of the evaluation year so that the input asset cost and output benefit are corresponding.

All in all, this paper divides the input investment indexes into two parts: the grid stock asset investment and the incremental asset investment. The output benefit indexes are divided into two parts: the technical benefit indexes and the economic benefit indexes. This paper also considers the time value of the asset, which is the correspondence between input and output over time.

2.1 Grid input evaluation index
The grid input evaluation indexes are determined by the full life cycle cost theory (LCC). Starting from the long-term economic benefits of the system, LCC theory comprehensively considers the whole process of feasibility study, procurement, installation, operation, overhaul and transformation of equipment and system. LCC theory pursues the lowest life cycle cost in the whole process, which makes the cost of the entire project life cycle more comprehensive and reasonable than the initial cost of the project considered by the traditional power grid planning.

Grid investment includes grid asset investment and grid project investment, which is the sum of grid stock asset investment and incremental asset investment. Based on the grid stock asset investment evaluation indexes and the project input evaluation indexes, the grid input evaluation indexes are determined as the annual average construction cost and the annual operation and maintenance cost of the grid asset. The annual average construction cost of the power grid is the sum of the annual average construction cost of the grid stock asset and the annual average construction cost of the incremental asset. The annual operating cost of the grid asset is the sum of the annual operating cost of the grid stock asset and the annual operating cost of the grid incremental asset. Grid input evaluation index are shown in table 1.

| LCC            | Grid asset cost                        | Grid investment evaluation index       | unit            |
|----------------|----------------------------------------|----------------------------------------|-----------------|
| Initial input cost | Original value of grid equipment assets | Annual average construction cost of power grid asset | Ten thousand yuan |
| Scrap disposal cost | Grid asset retirement disposal cost     |                                        |                 |
| Operation cost | Grid asset annual operating and maintenance cost | Annual average operating and maintenance cost of power grid assets | Ten thousand yuan |
| Maintenance cost |                                          |                                        |                 |

2.2 Grid output benefit evaluation index
The output benefit of the power grid is composed of the economic benefit and the technical benefit. When we conduct the grid output benefit analysis, comprehensive consideration of economic benefit and technical benefit can reflect the actual situation more realistically and make the benefit evaluation more reasonable.

The evaluation index of grid input-output economic benefit is the electricity sales revenue, which is composed of electricity price elements and electricity generation factors. The electricity price system includes the following three parts: electricity purchase price, transmission and distribution price and electricity sales price. The sales of electricity are fundamental to the survival and development of power grid management enterprise. Purchasing electricity and electricity sales should be comprehensively considered when we calculate the economic benefit of power grid.
The evaluation indexes of grid input-output technical benefit are the grid operation evaluation indexes, which are shown in table 2.

Table 2. Grid operation evaluation index

| Classification       | Grid operation index                                      | unit |
|----------------------|----------------------------------------------------------|------|
| Power supply capability | Average load rate at the maximum load time of the network | %    |
| Power quality        | Power supply reliability                                 | %    |
|                      | Comprehensive voltage pass rate                          | %    |
| Power supply economic | Average load rate at the level of the average load of the network | %    |
|                      | Comprehensive line loss rate                            | %    |

2.3 Index calculation method

1) Annual average construction cost of grid asset: the residual value of the fixed asset is converted into the present value at the same time as the original value of the fixed asset. The average annual construction cost is equal to the original value of fixed asset minus the residual value of fixed asset.

\[
C_0 = [D_0 - \frac{M}{(1+r)^n}] \times \frac{r(1+r)^n}{(1+r)^n - 1} \tag{1}
\]

Where \( M \) is the grid asset retirement disposal cost. \( r \) is the discount rate. In this paper, \( r=7\% \). \( D_0 \) is the original value of grid equipment asset, which is shown in equation (2).

\[
D_0 = D_n \times (1 + f)^n \tag{2}
\]

Where \( f \) is inflation rate. \( n \) is the operating life of the grid asset from the investment year to the evaluation year. \( D_n \) is the grid asset replacement value of the evaluation year, which is shown in equation (3).

\[
D_n = S \times P_n \tag{3}
\]

Where \( S \) is the size of equipment asset. \( P_n \) is equipment asset standard cost of the evaluation year.

2) Annual operating and maintenance cost of grid asset:

\[
C_i = C_{10} + C_{11} + C_{12} \tag{4}
\]

Where \( C_{10} \) is self-operated material cost. \( C_{11} \) is the outsourcing material cost. \( C_{12} \) is the outsourcing repair cost.

3) Electricity sales benefit:

\[
EP_s = S_w \times P_w - S_u \times P_u \tag{5}
\]

Where \( S_w \) is the electricity sales. \( P_w \) is the electricity price. \( S_u \) is the purchased electricity. \( P_u \) is the price of purchased electricity.

4) Load ratio:

\[
R_s = \frac{\sum S_{\alpha}}{P_{\text{max}}} \tag{6}
\]

Where \( \sum S_{\alpha} \) is the sum of the capacity of the main transformer of the substation. \( P_{\text{max}} \) is the maximum load of the grid.

5) Average load rate of the line at the maximum load time of the network:

\[
R_{\text{line}} = \frac{\sum R_{L,i}}{n} \tag{7}
\]

Where \( n \) is the number of lines. \( R_{L,i} \) is the load rate of line \( i \).

6) Power supply reliability:
Where $T_a$ is user average power outage time. $T_c$ is the user average power cut time. $T$ is the total time.

7) Comprehensive voltage pass rate:

$$V(\%) = \left(1 - \frac{t_0}{T}\right) \times 100\%$$

Where $t_0$ is the time when the voltage exceeds the allowable voltage deviation range. $T$ is the total time.

8) Average load rate at the level of the average load of the network:

$$R_{la} = \frac{P_a}{P_c} \times 100\%$$

Where $P_a$ is the average annual power of the line. $P_c$ is the continuous transmission of power throughout the year.

9) Comprehensive line loss rate:

$$R_{loss} = \frac{L_s}{P_{tot}} \times 100\%$$

Where $L_s$ is statistical line loss, which is the total power lost during the process of transmission, substation, and distribution of the system. $P_{tot}$ is power supply, which is equal to the total power generation of all power plants in the system minus the power consumption of the plant.

3. Comprehensive evaluation model for grid input-output benefit

3.1 Comprehensive evaluation methods

During the process of comprehensive evaluation, the most important task is to determine the weight of each index for the evaluation target. The comprehensive evaluation is divided into subjective comprehensive evaluation methods and objective comprehensive evaluation methods. Although the objective evaluation method is sufficiently objective and fair, this kind of methods ignore the meaning of the evaluation index of the system. Besides, there are many ways for subjective evaluation methods to minimize the impact of human preferences. Therefore, this paper intends to use Analytic Network Process (ANP), which belongs to subjective evaluation method.

ANP is a multi-scheme or multi-objective decision-making method that performs quantitative analysis of non-quantitative time and subjective judgment in the decision-making process. It decomposes the elements that are relevant to decision-making into goals, criteria and programs. On this basis, it also conducts qualitative and quantitative analysis.

3.2 Evaluation index of grid input-output economic cost efficiency value

This paper evaluates the input-output benefit of the power grid through the cost efficiency method. Cost efficiency (CE) refers to the ratio of the output benefit to the investment cost. For the comprehensive evaluation model of grid input-output benefit constructed in this paper, cost efficiency method is used to calculate the value of economic cost efficiency $CE_e$ and technical cost efficiency $CE_t$ separately. We can obtain the comprehensive cost efficiency after using the ANP to obtain the weights of $CE_e$ and $CE_t$.

The specific steps for calculating the economic cost efficiency are as follows.

1) The annual investment cost of the power grid includes the annual average construction cost of the grid asset and the annual operation and maintenance cost of the grid asset, which is shown in equation (12).

$$C = C_0 + C_1$$ (12)
2) The output economic benefit of grid is the electricity sales benefit $EP$, shown in equation (5).

3) Equation (13) shows the input-output economic benefit:

$$B_E = \frac{EP}{C} \quad (13)$$

4) Grid economic benefit evaluation index: the grid input-output economic benefit is not uniform with the dimension of the input-output technical benefit. So the results of the $CE_e$ and $CE_T$ cannot be directly summed. In this paper, the ratio of the economic benefit value to the regional average economic benefit value should be calculated, which is defined as $P_E$. The corresponding relationship between $CE_e$ and $P_E$ is shown in table 3.

### 3.3 Evaluation index of grid input-output technical cost efficiency value

The specific steps for calculating the technical cost efficiency are as follows.

1) The annual investment cost of the power grid is shown in equation (12).

2) Score of grid output technical benefit evaluation index: in this paper, we calculate all the indexes involved in the technical benefit according to the method discussed in the previous chapter. After obtaining the calculation results of the indexes, the various indexes should be processed separately. For economic benefit index and cost, there is only a single index and does not involve a comprehensive evaluation. So the index can be used directly. For the technical benefit evaluation indexes, there are multiple evaluation indexes and the dimensions of the indexes are different. The indexes can’t be comprehensively evaluated. Therefore, the value of each index should be converted into the corresponding scoring function so as to achieve comprehensive evaluation of index of different dimensions. The full score of each index is 100 points. All the technical benefit indexes are divided into benefit-type indexes, cost-type indexes and intermediate-type indexes. In the process of scoring, appropriate scoring strategies are adopted for the different indexes.

3) Weight of grid output technical benefit evaluation index: in order to synthesize the scores of the indexes, it is required to take the weight that correspond to each index. In this paper, ANP is used to calculate the weight.

4) Equation (14) shows the comprehensive score of technical benefit evaluation index.

$$F_T = \sum_{i=1}^{n} y_i w_i \quad (14)$$

Where $y_i$ is the score of the evaluation index $i$, $w_i$ is the weight of the evaluation index $i$.

5) Equation (15) shows the input-output technical benefit:

$$B_T = \frac{F_T}{C} \quad (15)$$

6) Similarly, $p_T$ is the ratio of the technical benefit value to the regional average technical benefit value. The corresponding relationship between $CE_T$ and $p_T$ is the same as the relationship between $CE_e$ and $P_E$, which is shown in table 3.

| $P_E$ ($p_T$) | $[2, +\infty)$ | 1.5 | 1 | 0.8 | 0.5 |
|--------------|----------------|-----|---|-----|-----|
| $CE_e$ ($CE_T$) | 100 | 80 | 60 | 40 | 20 |

### 3.4 Comprehensive evaluation index of grid input-output cost efficiency

The evaluation index of grid input-output economic cost efficiency value and the evaluation index of input-output technical cost efficiency value are weighted through ANP. Equation (16) shows the comprehensive evaluation index of grid input-output cost efficiency.

$$CE = w_1 \cdot CE_T + w_2 \cdot CE_e \quad (16)$$

Where $w_1$, $w_2$ are the weight of $CE_e$ and $CE_T$. 

6
4. Case study
According to the comprehensive evaluation model of input-output benefit, the grid input-output benefit of two regions are analysed to determine the better performance by comparing the comprehensive evaluation index of grid input-output cost efficiency value of the two regions. The relevant actual data are shown in Table 4.

Table 4. The actual data of the two regions

|                      | Region A         | Region B         |
|----------------------|------------------|------------------|
| Electricity sales (kw·h) | 5.734*10^9     | 7.556*10^9     |
| Electricity price (yuan/kw·h) | 0.62            | 0.62            |
| Purchased electricity (kw·h) | 6.969*10^9     | 9.371*10^9     |
| Purchase price (yuan/kw·h) | 0.374           | 0.374           |
| The sum of the capacity of the main transformer of the substation (MVA) | 1734            | 2411            |
| Maximum load on the grid (MVA) | 1097            | 1468            |
| Number of lines | 279              | 319              |
| Total load rate of the line (%) | 76.1            | 74.9            |
| User average power outage time (h) | 7.16            | 6.56            |
| User average power cut time (h) | 1.243           | 1.117           |
| The time when the voltage exceeds the allowable voltage deviation range (h) | 21.7            | 16.5            |
| Total time(h) | 8760             | 8760             |
| The average annual power of the line (MW) | 570.28          | 600.05          |
| the continuous transmission of power throughout the year (MW) | 756.44          | 820.97          |
| Statistical line loss(MW) | 1.94*10^9       | 2.37*10^9       |
| Power supply(MW) | 6.97*10^9       | 9.461*10^9      |
| The grid asset replacement value of the evaluation year (billion yuan) | 12.7963         | 16.3348         |
| Inflation rate (%) | 4.704            | 4.704            |
| Operating life of the grid asset (years) | 11              | 14              |
| the grid asset retirement disposal cost (billion yuan) | 0.32            | 0.47            |
| The discount rate (%) | 7                | 7                |
| Annual operating and maintenance cost of grid asset (billion yuan) | 0.67            | 0.79            |

The results of grid output benefit evaluation indexes can be calculated through equation (6)-(11), which are shown in Table 5.

It can be seen from the table 5 that the indexes of power quality in region A and region B have high scores, while the scores on line capacity of the two regions are low. Therefore, the two regions are supposed to build new lines on the basis of maintaining the quality of power supply to improve grid transmission capacity.
Table 5. The results of grid output benefit evaluation index

| Grid output benefit evaluation index | Region A   | Region B   |
|-------------------------------------|------------|------------|
| Load ratio                          | 87.8174    | 91.2452    |
| Average load rate at the maximum load time of the network | 54.7054    | 59.8160    |
| Power supply reliability            | 100        | 100        |
| Comprehensive voltage pass rate     | 99.76      | 99.82      |
| Average load rate at the level of the average load of the network | 35.1247    | 38.4114    |
| Comprehensive line loss rate        | 76.7719    | 79.7298    |

The weight of grid output benefit evaluation indexes is shown in table 6.

Table 6. The weight of grid output benefit evaluation index

| Grid output benefit evaluation index | Weight |
|-------------------------------------|--------|
| Load ratio                          | 0.198  |
| Average load rate at the maximum load time of the network | 0.114  |
| Power supply reliability            | 0.267  |
| Comprehensive voltage pass rate     | 0.215  |
| Average load rate at the level of the average load of the network | 0.076  |
| Comprehensive line loss rate        | 0.130  |

Comprehensive score of technical benefit evaluation index is shown in table 7.

Table 7. Comprehensive score of technical benefit evaluation index

| Region | Region A | Region B |
|--------|----------|----------|
| $F_T$  | 84.4225  | 86.3310  |

$P_E$ and $P_T$ can be calculated due to the input-output economy and technical benefit values of the two regions. The evaluation index of grid input-output economic and technical cost efficiency value can be obtained through table 3. Table 8 shows the evaluation index of grid input-output cost efficiency of the two region.

Table 8. The evaluation index of grid input-output cost efficiency of the two region

| Region | Region A | Region B |
|--------|----------|----------|
| $CE_E$ | 65.2688  | 73.8920  |
| $CE_T$ | 70.3564  | 69.2869  |
| CE     | 67.8126  | 71.5894  |

Therefore, the score of the evaluation index of grid input-output cost efficiency in region B is higher than that in region A, which means the input-output benefit of the power grid in region B is better than that in region A.

5. Conclusion
This paper constructs an evaluation index system for grid input-output benefit. Combined with the grid input-output benefit evaluation index, the calculation method of grid input cost and the comprehensive evaluation method of grid output benefit is proposed. A comprehensive evaluation model for grid input-output benefit is established through the cost efficiency method. Based on the model, comprehensive evaluation index of grid input-output cost efficiency can be calculated so as to analyze the grid input-output benefit, which can optimize the investment structure of the grid and improve the investment benefit of the grid.
References

[1] X. Y. Hu. Research on Cost Management of Substation Project Based on Life Cycle Theory. (2015)

[2] H. F. Su. Research on Theory and Method of Life Cycle Management of Power Distribution System Planning. (2012)

[3] B. F. Ren. Research on Method and Application of System Comprehensive Evaluation. (2010)

[4] X. J. Ruan. Research on Comprehensive Evaluation of Technology and Economy of New Energy Vehicles and Its Development Strategy. (2010)

[5] Y. Luo, Y. L. Li. Comprehensive Decision-making of Transmission Network Planning Scheme Based on Entropy Weight Method and Grey Relational Analysis. P. S. T. 37, 77-81 (2013)

[6] K. Zhou. Comprehensive Evaluation of Wind and Light Energy Storage Power Station Projects. (2015)

[7] X. H. Li, L. Zhang, X. Y. Li, etc. Research on Current State Grid Evaluation Method Based on Analytic Hierarchy Process. P. S. P. C. 36, 57-61 (2008)

[8] J. Xiao, C. S. Wang, M. Zhou. Comprehensive Evaluation Decision of Urban Power Network Planning Based on Interval Analytic Hierarchy Process. Proceedings of the CSEE 04, 54-61 (2004)

[9] S. Ouyang, Y. L. Shi. Improved Entropy Weight Method and Its Application in Power Quality Assessment. A. E. P. S. 37 156-159+164 (2013)

[10] H. R. Hai, D. Han, Y. J. Liu, etc. Smart Grid Evaluation Based on Anti-entropy Weight Method. P. S. P. C. 40 24-29 (2012)

[11] M. Wu. Research on Efficiency Evaluation of Agricultural Enterprises in China Based on Data Envelopment Method. (2012)

[12] H. B. Zhang, Z. L. W, F. Ge, etc. Research on Evaluation System of Distribution Automation Construction Based on SMART Criterion. P. S. T. 40, 2192-2198 (2016)