Power grid operation and maintenance investment allocation based on gridded information entropy multiple attribute evaluation Optimization Technology Research

Min Yu¹, Fuyan Liu¹, Jie Shen², Jinpeng Liu³*
¹ Economic and Technological Research Institute, State Grid Zhejiang Power Co., Ltd., Hangzhou 310000, China;
² State Grid Zhejiang Power Co., Ltd., Hangzhou 310000, China;
³ School of Economics and Management, North China Electric Power University, Beijing 102206, China.
*Corresponding author’s e-mail: juzen123@163.com

Abstract. Under the new situation, China's power grid enterprises will face a situation of limited funding for operation and maintenance and increasing pressure on cost control. Therefore, further improving the scientificity of grid operation and maintenance investment allocation is of great significance to the operation and development of grid companies. Based on the problems of current operation and maintenance input allocation, this paper proposes a grid operation information entropy multi-attribute evaluation-based optimization technology for power network operation and maintenance input allocation, and combines empirical analysis to verify the scientific rationality of the allocation technology. The optimization technology can provide support for grid operation and maintenance investment decision-making and enterprise lean management.

1. Introduction
The scientific and reasonable allocation of operation and maintenance investment is an important guarantee for the safe and stable operation of power grid enterprises. However, the current operation and maintenance investment decisions of power grid enterprises are mainly allocated according to the input scale of subordinate units over the years, which not only cannot guarantee an effective return on investment for grid investment, but also causes a waste of resources. Therefore, combining the development situation of China's electric power system reform and the trend of grid management, it is of great research value to propose scientific and reasonable operation and maintenance investment fund allocation and optimization technology.

Xuan Juqin et al.[1] introduced the concept of gridization and proposed a grid-based distribution network management strategy to achieve grid-based management of the entire business of the distribution network. Chen Shuxin[2] discussed the principles of grid planning and put forward scientific grid division principles and division basis. Chen Haoming et al.[3] analyzed the main problems of current operation and maintenance management with the distribution network as the research object. Wei Pu et al.[4] pointed out that the development of the power grid needs to pay more attention to input-output benefits, and suggested that the operation and maintenance input funds should be tilted to projects or units with good output benefits. Xu Jialong[5] and others established a strategic model for grid equipment
operation and maintenance fund investment under the influence of multiple factors such as economy, technology, risk, and benefit to support grid companies' precise investment.

2. Model construction
Based on the development trend of grid-based management, this paper fully considers the main purpose and principles of asset investment, and constructs two-stage operation and maintenance investment allocation optimization technology of basic allocation and adjustment allocation. The model building process is shown in Figure 1.

As shown in the figure above, the process of model building mainly includes the following steps:
(1) Grid attribute analysis, statistics of the original asset value and operating index data of different grids, and the original asset value is used as the basis for calculating the allocation ratio of each grid operation and maintenance input.
(2) Construct a multi-attribute evaluation index system as a calculation support for adjusting the ratio.
(3) Use the entropy weight method to calculate the objective weight of the evaluation index system.
(4) The weight of the distribution ratio according to the asset scale and the comprehensive evaluation of the distribution ratio based on comprehensive multi-dimensional attributes each account for 0.5, and the final distribution ratio is comprehensively obtained by linear weighting.

2.1. Index normalization processing method
In order to solve the impact of different dimensions of the index data on the evaluation results, it is necessary to perform dimensionless processing on the index data.
A positive indicator means that the larger the indicator value, the more the operation and maintenance investment amount is allocated. For example, the proportion of heavy loads in substations, the duration of power outages for customers, and the electricity sales revenue per unit asset. The processing method is as follows:

\[
x_{ij}^* = \frac{x_{ij}}{\max_{i,j} x_{ij}} (1 \leq i \leq n, 1 \leq j \leq m)
\]

Reverse indicators means that the larger the indicator value, the less the operation and maintenance investment amount is allocated. For example, the reliability of power supply, etc., the processing method is as follows:

\[
x_{ij}^* = 0.1 + \frac{\max_{i,j} x_{ij} - x_{ij}}{0.9 (1 \leq i \leq n, 1 \leq j \leq m)}
\]

In the formula: \( n \) represents the number of evaluation objects, that is, the number of grids; \( m \) represents the number of indicators of each evaluation object; \( x_{ij} \) is the index value, and \( x_{ij}^* \) is the processed result.

2.2. Calculation method of indicator weight
Entropy was first introduced into information theory by Shen Nong, and has been widely used in engineering, socio-economic and other fields. The basic idea of entropy weight method is to determine
the objective weight according to the size of the index variability. The calculation steps for determining
the index weight by the entropy weight method are as follows:

1. Index data normalization
   Suppose given $k$ indicators: $X_1, X_2, ..., X_k$, where $X_i = \{x_{i1}, x_{i2}, ..., x_{in}\}$.
   (1) Index data normalization
   Assume that the values of the index data after normalization by formulas (1) and (2) are: $Y_1, Y_2, ..., Y_k$,
   then:
   \[
   Y_{ij} = \frac{x_{ij} - \min(x_i)}{\max(x_i) - \min(x_i)}
   \]

   (2) Find the information entropy of each index
   According to the definition of information entropy in information theory, the information entropy of
   a set of data is:
   \[
   E_j = -\ln(n)^{-1} \sum_{i=1}^{n} p_{ij} \ln p_{ij}
   \]
   Among them, $p_{ij} = Y_{ij}/\sum_{i=1}^{n} Y_{ij}$.
   (3) Determine the weight of each indicator
   According to the calculation formula of information entropy, the information entropy of each
   indicator is calculated as $E_1, E_2, ..., E_k$. Calculate the weight of each indicator through information
   entropy:
   \[
   W_i = \frac{1 - E_i}{k - \sum E_i} (i = 1, 2, ..., k)
   \]

2.3. Calculation method of adjustment ratio
This paper uses the linear weighted summation method for comprehensive evaluation, that is:
\[
F_i = \sum_{j=1}^{m} w_{ij} x_{ij}
\]
In the formula: $w_{ij}(i = 1, 2, ..., n; j = 1, 2, ..., m)$ is the weight of the indicator, and $x_{ij}$
is the standardized data of the indicator.
\[
F_i^* = \frac{F_i}{\sum F_i}
\]
In the formula: $F_i^*$ is the adjustment ratio, and $\sum_{j=1}^{m} F_i$ is the sum of the comprehensive evaluation
results.

2.4. Calculation method of distribution ratio
The above obtains the adjustment ratio of each grid. If the investment amount of the operation and
maintenance investment plan for the year is $Q$, then the investment amount $Q_i$ allocated to each grid is:
\[
Q_i = 0.5 * \frac{F_i}{\sum F_i} * Q + 0.5 * \frac{V_i}{\sum V_i} * Q
\]
Where $V_i$ is the asset size of the grid.

3. Construction of multidimensional comprehensive evaluation system
Take "reliability, security, economy, and coordination" as the "four performances", consider it as an
important factor to measure operation and maintenance investment, comprehensively consider the
relevant principles of operation and maintenance investment, and the preferred indicators can fully
reflect the physical structure of the power grid. The operating characteristics, operating efficiency level,
asset health level, and network structure level are used to evaluate the urgent needs of operation and maintenance inputs. The evaluation index system is shown in Table 1 below.

| First indicators                      | Secondary indicators                                      |
|---------------------------------------|-----------------------------------------------------------|
| Operating efficiency level            | Unit asset sales                                          |
|                                       | Line loss rate                                            |
| Asset health                          | Average operating life of main transformer                |
|                                       | Line average operating life                              |
|                                       | Equipment defect rate                                     |
|                                       | Equipment failure rate                                    |
|                                       | User average outage time                                  |
| Power supply safety and reliability   | Power supply reliability                                  |
|                                       | Comprehensive voltage qualification rate                   |
|                                       | Line heavy load ratio                                     |
| Network structure level               | Overload ratio of main transformer                        |
|                                       | Line contact rate                                         |

### 4. Empirical analysis

Six grids in a certain area were selected as the subject of empirical research. The planned operation and maintenance investment cost of the six grids was 80 million yuan. The relevant index data are shown in Table 2 below.

| Indicator name                          | unit                     | Grid 1     | Grid 2     | Grid 3     | Grid 4     | Grid 5     | Grid 6     |
|----------------------------------------|--------------------------|------------|------------|------------|------------|------------|------------|
| Original value of fixed assets         | 100 million yuan         | 25.24      | 19.34      | 21.23      | 27.23      | 30.22      | 17.32      |
| Unit Asset Sales                       | Billion kWh / Billion yuan | 4.37      | 2.85      | 2.68      | 4.06      | 2.67      | 2.73      |
| Line loss rate                         | %                        | 2.29      | 2.58      | 3.38      | 2.66      | 2.56      | 3.08      |
| Average operating life of main transformer | year                   | 6.75      | 5.21      | 8.91      | 8.6       | 7.93      | 7         |
| Line average operating life            | %                        | 8.81      | 7.05      | 8.92      | 10.25     | 8.56      | 7.54      |
| Equipment defect rate                  | %                        | 20.31     | 30.52     | 25.23     | 12.31     | 15.23     | 15.27     |
| Equipment failure rate                 | %                        | 12.12     | 14.21     | 15.23     | 15.23     | 15.68     | 17.23     |
| User average outage time               | hour                    | 2.29      | 0.86      | 3.38      | 0.61      | 1.83      | 2.03      |
| Power supply reliability               | %                        | 99.9083   | 99.9077   | 99.9135   | 99.9796   | 99.8886   | 99.8954   |
| Comprehensive voltage qualification rate | %                      | 99.9970   | 99.9982   | 99.9988   | 99.9960   | 99.9965   | 99.9976   |
| Line heavy load ratio                  | %                        | 4.6       | 3.07      | 4.52      | 6.24      | 6.3       | 3.43      |
| Overload ratio of main transformer     | %                        | 2.31      | 2.45      | 3.12      | 1.49      | 2.76      | 1.57      |
| Line contact rate                      | %                        | 35.24     | 32.21     | 31.24     | 32.52     | 30.14     | 34.51     |

Combined with the calculation formula of distribution ratio, the following results are obtained.
Table 3. Operation and maintenance investment allocation results.

| Project name | Grid 1 | Grid 2 | Grid 3 | Grid 4 | Grid 5 | Grid 6 |
|--------------|--------|--------|--------|--------|--------|--------|
| Base ratio   | 17.95% | 13.76% | 15.10% | 19.37% | 21.50% | 12.32% |
| Adjustment ratio | 19.80% | 17.68% | 17.91% | 17.71% | 25.00% | 15.47% |
| Distribution ratio | 18.88% | 15.72% | 16.51% | 18.54% | 23.25% | 13.90% |

The specific situation of the distribution amount of each grid is shown in Figure 2 below.

Figure 2. operation and maintenance investment allocation results.

5. Conclusion

Based on the current situation of China’s power system reform and development, combined with the current development needs of power grid operation and maintenance investment allocation, this paper proposes grid power information entropy multi-attribute evaluation-based optimization techniques for grid operation and maintenance investment allocation. This technology takes the gridded asset size as the basis for calculating the operation and maintenance input base ratio, and combines the multi-attribute comprehensive evaluation results as the basis for adjusting the ratio calculation. Finally, the basic allocation scale and the adjustment allocation scale are weighted by a ratio of 0.5 each. Thus, the actual input allocation scale of the grid is obtained. The research content of this paper can solve the practical problems of current operation and maintenance investment allocation, and assist in supporting the grid company’s capital investment decision.

References

[1] Xuan Juqin, Jiang Mingshui, Liu Pengfei. Discussion on Optimization of Distribution Network Management System Based on Grid [J]. Electrical Engineering Technology, 2020 (01): 101-102 + 105.
[2] Chen Shuxin. Analysis on grid planning method of distribution network and its application [J]. Communications World, 2019, 26 (10): 201-202.
[3] Chen Haoming, Zhang Shengrong, Ruan Pinghong, Xu Shiping. Model innovation of power grid maintenance operation and maintenance management [J]. Science and Technology Innovation Herald, 2019, 16 (21): 168-169.
[4] Wei Wei, Li Xuyang, Liu Qiming. Physical assets evaluation and management suggestions for power grids [J]. Communications World, 2019, 26 (12): 269-270.
[5] Xu Jialong, Yu Min. Suggestions on the management of capital investment in the operation and maintenance of power grid equipment suitable for the reform of the power system [J]. Enterprise Management, 2016 (S1): 90-91.