Research on Optimization Method of Multi-regional Power Grid Investment Scale

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Abstract. Optimizing the scale of investment in multi-regional power grids is the basis for ensuring the benefits of power companies and can meet the urgent needs of power grid development. This article first takes the historical benefits of power grids, planning benefits, grid scale and development needs as indicators to establish a multi-regional grid investment scale optimization indicator system. Then this article establishes a multi-regional grid investment scale optimization model. According to the historical benefits of the region and the grid scale, the initial distribution model of the grid investment scale was established; the grid investment scale revised model was established according to the planning benefits and development needs. Finally, an example is used to verify the effectiveness and feasibility of the method proposed in this paper.

1. Introduction
At present, China's social development has entered a new stage, economic development has entered a new normal, and the reform of the power system has been intensified. Power grid development and investment management are facing unprecedented new situations and new requirements. Among them, maximizing investment benefits is the goal of investment decision-making. Therefore, in order to improve the lean level of investment management and control, it is very necessary to study the optimization method of multi-regional power grid investment scale.

At present, scholars at home and abroad have conducted a lot of researches on optimizing methods for the investment scale of power grids in multiple regions. Literature [1] focuses on the grid investment optimization method based on gray theory. The article first introduces the gray correlation analysis method, and then uses the gray correlation analysis method to calculate the correlation law between the investment amount and the selected indicators, uses an improved gray model to predict the selected grid investment indicators, and finally determines the grid investment through the predicted value Quota. Literature [2] uses fuzzy comprehensive evaluation method to evaluate the construction scale of regional power grid. This article establishes a fitness model of scale indicators relative to economic society, calculates the fitness coefficients of each indicator, uses subjective and objective comprehensive weighting method to determine the weight, and finally calculates the predicted value of power grid investment through the fuzzy comprehensive evaluation model.
Literature [3] combines investment scale, historical data, and key assumptions to establish an investment scale measurement function, and sets the asset-liability ratio, total profit and capital ratio as constraints. The final empirical results show that the model is effective and reasonable, and its evaluation and prediction results can objectively and truly reflect the investment situation of power companies. Literature [4] studies project investment decision-making methods from the perspective of project risk, and establishes a multi-objective mathematical model based on venture capital. The Markwitz model is used in this model to study portfolio strategies to ensure that the greatest returns can be obtained with the lowest risks. The greatest significance of this research is that it can guide investors to rationally allocate the investment amount among different projects. Literature [5] divides the investment decision model into a policy unknown stage and a policy known stage, and uses game theory to establish risk aversion investment decision models for these two stages. Literature [6] specifically analyzes the investment situation of a power grid company, takes the change trend of installed cost and fuel cost as the starting point, establishes an investment portfolio model based on the principle of minimum risk, and proposes an investment optimization plan for the power grid company through empirical research on the model. The above-mentioned research on the optimization of power grid investment scale rarely comprehensively considers the comprehensive investment benefits based on historical benefits, planning benefits, grid scale and development needs, and mainly focuses on the optimization of the investment portfolio of infrastructure projects or only the allocation of total investment based on grid planning benefits aspect. Therefore, the main research content of this article is based on the grid investment scale optimization model that considers the overall benefits of the entire process of grid development and the scale and development needs of the grid, which is more scientific and reasonable.

This paper analyzes and studies the benefits of the whole process of power grid development that runs through the two stages of history and planning, and establishes a method for optimizing the investment scale based on the level of benefit to provide reference for guiding the investment decisions of power grid companies. This article first takes the historical benefits of power grids, planning benefits, grid scale and development needs as indicators to establish a multi-regional grid investment scale optimization indicator system. Then, according to the historical benefits of the region and the scale of the power grid, the initial distribution model of the power grid investment scale is established; and the revised model of the power grid investment scale is established according to the planned benefits and development needs. Finally, an example is used to verify the effectiveness and feasibility of the proposed method.

### 2. Multi-regional grid investment scale optimization index system

This paper considers the influence of the comprehensive benefits of the entire process of power grid development on power grid investment. Among them, the comprehensive benefits of the entire process of power grid development include historical benefits and planning benefits. In addition, the distribution of power grid investment in multiple regions is also affected by the power grid scale and development needs of each region. In order to optimize the distribution of investment scale, this paper uses the historical benefits of power grids, planning benefits, grid scale and development needs as indicators to establish a multi-regional grid investment scale optimization index system, which can well represent the investment benefits of multi-regional power grids, as shown in the table 1.

| First-level index | Second-level index                                                                 |
|-------------------|-----------------------------------------------------------------------------------|
| Historical benefits |                                                                                   |
| Electricity Sales |                                                                                   |
| Power supply reliability rate |                                                                                       |
| Comprehensive voltage qualification rate |                                                                                     |
| Electricity replacement ratio |                                                                                         |
| Planning benefits  |                                                                                   |
| Average annual growth rate of line length |                                                                                  |
| Average annual growth rate of substation capacity |                                                                            |
The meaning and calculation formula of each indicator are as follows:

1. **Electricity sales**: refer to the electricity sales of the power grid within one year, and this indicator reflects the economic income status of the grid operation benefits.

2. **Power supply reliability rate**: directly reflects the power supply safety and reliability of the grid system. As shown in the formula (1).

   \[ R_s = \left(1 - \frac{T_o}{T_a}\right) \times 100\% \]

   Among them, \( R_s \) is the power supply reliability rate, \( T_o \) is the average power outage time of users, and \( T_a \) is the total time of the statistical period.

3. **Comprehensive voltage qualification rate**: reflects the power quality of the power grid and the stable operation of the power grid. As shown in the formula (2).

   \[ R_v = \frac{N_i}{N} \]

   Among them, \( R_v \) is the comprehensive voltage qualification rate, \( N_i \) is the qualified number of main network monitoring points, and \( N \) is the main network voltage monitoring points.

4. **Average annual growth rate of line length**: refers to the average annual growth rate of the line scale under a specific voltage level during the planning year. As shown in the formula (3).

   \[ s_L = \frac{\sum \Delta L}{nL_0} \times 100\% \]

   In the formula, \( \Delta L \) is the line scale growth in one year; \( n \) is the number of planning years; \( L_0 \) is the line scale at the beginning of the planning.

5. **Average annual growth rate of substation capacity**: is the same as the average annual growth rate of line length. It refers to the average annual growth rate of transformer capacity during the planned year. As shown in the formula (4).

   \[ s_S = \frac{\sum \Delta S}{nS_0} \times 100\% \]

   In the formula, \( \Delta S \) is the increase in transformer capacity within one year; \( n \) is the number of planning years; \( S_0 \) is the transformer capacity at the beginning of the plan.

6. **Utilization efficiency of power transmission and distribution equipment**: such as transformers and lines refers to the utilization rate of the equipment after project investment. The calculation formula is shown in formula (5).

   \[ k = \frac{\sum S_{aw} \times t_i}{S_r \times 8760} \]

   In the formula, \( S_{aw} \) is the equipment usage in time \( t_i \), the transformer is the transformer capacity, and the line is the tidal current power; \( S_r \) is the rated capacity of the equipment.

7. **Scale of newly installed capacity**: represents the demand for installed capacity in a region, which is affected by various factors such as safety, reliability, and economy, and is often determined by relevant departments. The scale of load growth characterizes the demand brought about by the load growth of the regional power grid, and the specific value is obtained by the relevant load forecasting method.

### 3. Optimization model of multi-regional power grid investment scale

Based on the multi-regional grid investment scale optimization index system established above, an
investment scale optimization model that considers the entire process of grid development is established.

3.1. Initial Distribution Model of Grid Investment Scale

The initial distribution model of power grid investment scale firstly optimizes the index system based on the scale of power grid investment in multiple regions, integrates the historical benefits of the region and the scale of power grids, and establishes an index system for the initial distribution of power grid investment scale. Then, according to the fuzzy comprehensive evaluation method, a comprehensive quantitative evaluation of the established initial allocation index system of the grid investment scale is carried out. Finally, an initial distribution model of the grid investment scale based on the evaluation results is established, and the investment scale constraint distribution of the grids in various regions is carried out.

3.1.1. Initial allocation index system of grid investment scale

According to the optimized indicator system, the indicators that characterize historical benefits and grid scale are selected to form the initial allocation indicator system of grid investment scale, as shown in the table 2.

### Table 2. Initial allocation index system of power grid investment scale

| First-level index       | Second-level index                  |
|-------------------------|-------------------------------------|
| Historical benefits     | Electricity Sales                   |
|                         | Power supply reliability rate       |
|                         | Comprehensive voltage qualification rate |
|                         | Electricity replacement ratio       |
| Grid size               | Unit transformer capacity supports electricity load |
|                         | Supporting electricity load per unit line length |

3.1.2. Comprehensive quantitative evaluation

The quantitative evaluation of the initial allocation index system of the grid investment scale is carried out, and the evaluation method is as follows.

1. **Index score**: First, calculate the value of each index according to the calculation method of each index. Then, according to the satisfactory value and the disallowed value of each index, through the function coefficient method [7], each index of each area is scored, and the score value of each index of each area is obtained. The efficacy coefficient method is divided into four rules according to the nature of the index, extremely small (the smaller the index value, the higher the score), the extremely large (the larger the index value, the higher the score), and the stable type (the closer the index value is to a fixed satisfaction value) the higher the score) and interval type (the more the index value tends to a certain interval, the higher the score).

2. **Determine the satisfactory value and the disallowed value of each index**: Electricity sales, power supply reliability, comprehensive voltage qualification rate and electric energy substitution ratio are very large indicators. The satisfactory value is the maximum value in all regions, and the value is not allowed to be 0; the unit substation capacity supports the electricity load and the unit line length supports The electric load is a very large index. The satisfactory value is the maximum value of each region, and the minimum value of each region is not allowed.

3. **Calculate the comprehensive evaluation results of the historical benefits of each region and the grid scale**: The comprehensive evaluation result is obtained by multiplying the index score value and the index weight. The calculation formula is formula (6).

\[
\gamma_i^d = \sum_j x_{ij}w_j
\]
In the formula, $y_i^A$ is the comprehensive evaluation result of the region $A$; $x_i$ is the score value of the index $i$; $w_i$ is the weight of the index $i$.

3.1.3. Initial distribution model of power grid investment scale

The initial distribution model of the power grid investment scale is based on the comprehensive evaluation results to allocate the power grid investment scale of each region under the conditions of the total investment of the specific power grid. The calculation formula is formula (7).

$$M^A = \frac{Q}{\sum_A y_i^A}$$

In the formula, $M^A$ is the upper limit of the investment amount initially allocated by the region $A$; $Q$ is the total investment in the power grid.

After obtaining the upper limit of the investment amount initially allocated in each region, further allocate the upper limit of the investment amount of the transmission grid and distribution network in the region. In this paper, according to the historical investment ratio of the regional transmission grid and distribution network, the upper limit of the investment in the regional transmission grid and distribution network is allocated.

3.2. Modified Model of Power Grid Investment Scale

After the above-mentioned initial distribution model of grid investment scale, the upper limit of the initial investment amount in each region is calculated. Taking into account the difference in investment scale and development direction between transmission grids and distribution grids, this section will revise the distribution of investment scales in transmission grids in various regions based on the results of the initial distribution, based on planning benefits and development needs; based on development needs, revise the distribution of investment scale in distribution networks in various regions.

3.2.1. The revised index system of power grid investment scale

According to the optimized indicator system, select indicators that characterize planning benefits and development needs to form a grid investment scale correction indicator system, as shown in the table 3.

| First-level index          | Second-level index                  |
|---------------------------|-------------------------------------|
| Planning benefits         | Average annual growth rate of line length |
|                           | Average annual growth rate of substation capacity |
|                           | Transformer utilization             |
|                           | Line utilization                    |
| Development demand        | Scale of newly installed capacity   |
|                           | Load growth scale                   |

Determine the satisfactory value and the disallowed value of each index score. The four indicators, the average annual growth rate of line length, the average annual growth rate of substation capacity, the utilization rate of transformers, and the utilization rate of lines, are very large indicators. The satisfactory value is the maximum value of each region, and the value is not allowed to be 0; newly installed capacity Scale and load growth scale represent development needs, which are very large indicators. The satisfaction value is the maximum value of each region, and the value is not allowed to be 0.

3.2.2. Modified model of grid investment scale

The specific steps of the revised model to revise the upper limit of the investment in the transmission grid and distribution network in each region are as follows.
(1) Calculate the comprehensive score $X$ of all pending projects of the transmission grid (distribution network) in each region;
(2) According to the value $X$, sort the regions from largest to smallest;
(3) Find the center value $X_{\text{center}}$. First calculate the average value $\bar{X}$ of each area, and take the smallest absolute value of the difference between each area and the average value as the center value $X_{\text{center}}$;
(4) Determination of the ratio of upward or downward adjustment. For areas $X$ greater than the central value, the upper limit of the investment amount will be raised. For areas $X$ less than the central value, the upper limit of the investment amount will be lowered. The correction ratio calculation formulas are formula(8) and formula (9).

\[ r_u = \frac{X_A - X_{\text{center}}}{X_{\text{max}} - X_{\text{center}}} \quad r_{\text{upmax}} \]
\[ r_d = \frac{X_A - X_{\text{center}}}{X_{\text{center}} - X_{\text{min}}} \quad r_{\text{downmax}} \]  

In the formula, $r_u$ is the ratio of regional $A$ upward or downward adjustment; $X_{\text{max}}$ and $X_{\text{min}}$ is the maximum and minimum value of investment benefits in all regions; $r_{\text{upmax}}$ and $r_{\text{downmax}}$ is the maximum value of upward and downward ratio. For the transmission grid, the value is the sum of the weights of investment benefits and development demand indicators. The larger the value, the greater the impact of investment benefits and development needs on the distribution of the upper limit of the investment amount, and the maximum value of the increase or decrease ratio will be the largest. For the distribution network, the value is the ratio of the weight of the development demand index to the sum of the weights of the development demand, historical benefit and regional scale.

(5) Revise the upper limit of the investment amount and normalize the revised investment distribution ratio. The calculation formula is formula (10).

\[ R_{d,j} = \frac{M_{d,j}}{\sum_{A} M_{d,j} (1 + r_u)} \]  

In the formula, $R_{d,j}$ is the normalized distribution ratio of the investment scale of the regional $A$ transmission grid (distribution network); $M_{d,j}^A$ is the upper limit of the initial distribution investment of the regional $A$ transmission grid (distribution network).

(6) Calculate the upper limit of investment in each region, the calculation formula is formula(11).

\[ M_{d,j} = R_{d,j} \sum_{A} M_{d,j}^A \]  

In the formula, $M_{d,j}$ is the upper limit of investment in the transmission grid (distribution network) in each region.

### 4. Empirical analysis of power grid companies in typical provinces

4.1. Basic Information of Typical Empirical Evidence

Select the four regions of A, B, C, and D in Province A to do an empirical analysis on the optimization of the investment scale of long regions. The total investment is 25 billion yuan. The basic information of each region is shown in the table 4.

| Region | Power supply reliability rate (%) | Comprehensive voltage qualification rate (%) | Electric energy substitution ratio (%) | Electricity sales (MVAh) | Load growth scale (MW) |
|--------|-------------------------------------|-------------------------------------------|--------------------------------------|------------------------|-----------------------|
| A      | 99.8202                             | 99.934                                    | 3.590312                            | 285.9118               | 843.703               |
4.2. Analysis of Typical Empirical Results

According to the distribution model of the upper limit of power grid investment, the upper limit of power grid investment in each region is calculated, and the results are shown in the table 6.

Table 6: Upper limit of power grid investment by region

| Region | Initial distribution result (100 million yuan) | Final distribution result (100 million yuan) |
|--------|-----------------------------------------------|-----------------------------------------------|
|        | Distribution grid | Transmission grid | Distribution grid | Transmission grid |
| A      | 50.17524          | 10.64371          | 36.74084          | 8.072838          |
| B      | 52.19702          | 8.092931          | 49.45219          | 3.266987          |
| C      | 53.13917          | 15.07377          | 75.47116          | 22.05142          |

According to the distribution model of the upper limit of power grid investment, the upper limit of power grid investment in each region is calculated, and the results are shown in the table 6.
It can be seen from Table 5 that among the initial distribution results based on the historical benefits and scale of the regional power grid, the upper limit of the investment scale of the transmission and distribution network in C is the largest. According to Table 3, the indicators that affect historical benefits and the scale of the power grid are all better in place C. Therefore, in the initial allocation results, place C has the largest investment limit. According to Table 3, it can be seen that the planning benefit indicators and development demand indicators of C land are higher. Therefore, the upper limit of the investment scale of C land is adjusted upward, and the other areas are adjusted downward accordingly.

5. Conclusion
In order to solve the problem of optimizing the distribution of grid investment scale in different regions, this paper uses grid historical benefits, planning benefits, grid scale and development needs as indicators to establish a multi-regional grid investment scale optimization indicator system. Then, under the condition of the total investment scale, a multi-regional investment scale allocation model and calculation method considering the whole process of power grid development are proposed. The model is divided into two parts to allocate the upper limit of the investment amount. First, according to the established multi-regional grid investment scale optimization indicator system, this article comprehensively evaluates the historical benefits and grid scales of each region, and uses this as a basis to initially allocate the upper limit of the investment; then this article optimizes the indicators based on the established multi-regional grid investment scale. The system comprehensively evaluates the development needs and investment benefits of each region, and uses this as a basis to revise the upper limit of the investment amount, optimizes the allocation of the upper limit of the investment amount in each region, and then realizes the optimal allocation of investment scale. Finally, the analysis of a typical power grid company example verifies the effectiveness and feasibility of the method proposed in this paper. The method proposed in this paper can effectively solve the problem of multi-regional grid investment scale allocation, and the results obtained are of reference significance and provide a new idea for multi-regional grid planning.

Acknowledgement
This work has been supported by the Science and Technology Project of SGCC"Research on lean investment optimization method based on benefit analysis of the whole process of power grid”.

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