Research on the Calculation Method of Regional Grid Construction Efficiency and Power Demand under the Background of High Power Grid Complexity

Yan Zhang\textsuperscript{1}, Ya Zuo\textsuperscript{1}, Xiangping Li\textsuperscript{1}, Pengfei Fan\textsuperscript{2}, Shaoxiong Fang\textsuperscript{2,*} and Zelei Zhu\textsuperscript{2}

\textsuperscript{1} State Grid Xinjiang Electric Power Co., Ltd., China
\textsuperscript{2} China Electric Power Planning & Engineering Institute, Xicheng District, Beijing, China

\textsuperscript{*}Corresponding author e-mail: sxfang@eppei.com

Abstract. With the gradual development of power grid, the characteristics of power grid, such as regionalization, multi-dimensional and network complexity, have become more and more obvious. At the same time, the new round of power system reform has higher requirements for the development of power grid in all aspects. One of the key points of the reform is to achieve accurate investment in power grid, improve the efficiency of power grid construction and meet the demand of power grid construction. In this paper, the classic Analytic Hierarchy Process (AHP) is used, combined with the development situation of the power grid under the new requirements, the index system and model for the calculation of the construction efficiency and demand of the local and municipal power grid under the background of the highly complex development of the power grid are put forward. The model takes the time line of the power grid construction as the axis, through the pre-evaluation and post-evaluation of the power grid construction, the calculation of the construction situation of the regional power grid is completed. The efficiency and demand of power grid construction in different cities are analyzed. The example shows that the model can effectively identify the construction attributes of each region, reflect the construction requirements of the provincial power company system through different judgment matrix, and verify the final calculation results, optimize the construction and demand of the power grid system. The model effectively improves the operation efficiency of the power grid system, and realizes the ultimate goal of energy conservation and emission reduction.

Keywords: Grid, calculation, investment efficiency, investment demand.

1. Introduction
Electric energy is one of the most important forms of energy supply in modern society, as a transportation channel for electric energy, the development of grid is closely related to social and economic development. Grid construction should have a certain advancement to match economic development, and plays its supporting role. Moreover, with the deepening of power system reform and
the gradual maturity of grid construction, the investment of grid has gradually changed to lean, it shows that the grid development must fully consider various factors, the grid investment needs to evaluate the efficiency of grid investment and ensures that funds are fully utilized to maximize benefits.

In order to adapt to the requirements of new grid reform and meet the demand for grid investment in the new era, in recent years, based on the grid investment demand, many scholars have integrated the various methods and models, and conduct mechanism analysis or benefit evaluation for the grid investment from various aspects, a large number of research results are produced, which provide scientific advices for the development of lean investment of grid enterprises. In mechanism analysis, Yang Xiaoyan [1] studied the management problems of grid investment plan under the condition that grid construction environment changes, and proposed measures to deal with change; Hang Zubin [2] started from the efficiency of grid investment, analyzed how to control investment of grid construction from the level of grid enterprises and how to improve the investment benefit of grid; Zeng Ming [3] studied the investment benefit of micro-grid based on demand side response, and analyzed the impact of micro-grid investment on grid enterprises from investment and operation. In the research methods and practical problems, Wang Mianbin proposed a new risk assessment model for grid investment decision based on integrated analytical theory [4] and incremental method [5] two theoretical methods, which can effectively assess the problems of grid investment risk; Zhao Huiru [6] used financial management and other theories to construct a quantitative model to quantify the investment capacity of grid enterprises, and analyze investment planning issues based on this. In the impact of measures related to power system reform, Chen Li [7] and Ma Qian [8] analyzed the investment strategies of incremental distribution networks and the investment risk problem of grid enterprises based on the situation that China's incremental distribution business was gradually liberalized; You Weiyang [9], Huang Chenyang [10] and Long Yu [11] started from the reform of transmission and distribution price, and studied the efficiency and benefit evaluation of grid investment projects, provincial grid investment and dynamic investment development mechanism of power grid enterprises during the supervision period, etc.

In the actual situation, the impact of lean investment requirements on the provincial grid is mainly reflected in the determination of investment scale, investment time sequence determination, investment evaluation determination and investment allocation determination. In order to do good jobs in provincial grid investment plan and implement the spirit of power system reform, this paper uses the classical AHP to start from stock and increment, establishes the grid calculation model based on historical investment efficiency and investment demand in the future, this model is used to measure the investment allocation coefficient of regional grid, and provides scientific references for the annual investment of provincial grid allocation and various cities.

2. Reform Background of Power System

A new round of power system reform has established "three decontrol, one independence and three enhancement" reform path, and forms "No. 9 Document" as the leader, "1+N" policy system supported by a series of supporting documents. This system covers and influences key policy and measures affecting grid investment, including formation mechanism of transmission and distribution price, power market construction, and distribution side reform, a series of reform policies put forward higher requirements for grid lean investment.

2.1. Reform of power transmission and distribution price.

The reform of power transmission and distribution price requires restoring attributes of electric power products, according to "permitted cost add reasonable income" principle, check and ratify the permitted total revenue of grid enterprises and the power transmission and distribution price at different voltage levels, and the government funds and cross-subsidies are clearly defined, and announced to the public for social supervision. Through the reform of power transmission and distribution price, the incentive and restraint mechanism for grid enterprises has been improved, the operation mode of grid enterprises has been reform, Promote the cost reduction and efficiency increase of enterprises. The pricing mechanism, adjustment mechanism and incentive constraints of power transmission and distribution
price have an impact on the investment planning, investment management and grid planning and construction of grid enterprises in many aspects.

2.2. Power market construction.
Power marketization is a major transformation of the operation mode of the power industry, which will inevitably have a significant impact on the power system, with the scale development of market transactions, the demand uncertainty of grid planning and investment planning increases, which affects the investment income of the transmission channel of West-East electricity transmission project. Moreover, the grid companies undertake the obligation of universal power supply service, and the persuasion way of its cost will affect the effectiveness of the guaranteed service investment of grid companies.

2.3. Placing power reform.
The main idea of the placement power reform is to orderly sell power sales to social capital, cultivate multipurpose market entities, encourage social capital to invest in power distribution business, and encourage the development of power distribution business in mixed ownership way. The reform will cause the grid enterprises to lose the "exclusive management" policy barrier, and the market competition suddenly aggravated, the grid enterprises will face all-round competition of local power and social capital in the power sales business and distribution business, which directly affect the management benefits of grid enterprises.

3. Introduction to AHP Method
Analytic Hierarchy Process (AHP) is a decision-making method that decomposes elements related to decision-making into goals, criteria and programs, and then conducts qualitative and quantitative analysis. This method is a hierarchical weight decision analysis method proposed by American operations researcher Thomas L. Saaty of University of Pittsburgh in the early 1970s with the theory of network system theory and multi-objective comprehensive evaluation method.

This method is used to solve the complex problem sorting and traditional subjective weight drawback; the system stratified analysis is used as a means to continuously decompose the total target of evaluation object, the weight of each layer is determined by pairwise comparison, and the combination weight of the lowest level target is weighted, the comprehensive index is obtained by weight, and the achievement condition of the target is evaluated according to size of the comprehensive index.

3.1. Characteristics and applicable scenarios of AHP method
The characteristics of AHP method is by conducting deep analysis for the nature, influencing factors and internal relationships of complex decision problems, use less quantitative information make decision-making process mathematics, thus providing a simple decision-making method for complex decision problems of multiple objectives, multiple criteria or no structural characteristics, it is specially suitable for occasions where the decision result is difficult to directly and accurately measure.

AHP is suitable for problem scenarios where the overall target is uncertain and the decomposed target levels are moderate. This method determines the weights hierarchically, calculates the comprehensive index by combining weights, reduces the deviation of traditional subjective weights, can objectively test the consistency of thinking standards, it is often combined with other evaluation methods to improve the accuracy and credibility of evaluation. However, in practical applications, since the consistency test is conducted within a certain probability range, constructing different judgment matrices in the effective range of consistency may result in different results. In order to make the evaluation result closest to the real situation, it is necessary to closely combine the actual conditions and construct a suitable judgment matrix under the condition of rich professional knowledge.

At present, AHP has been widely used in economic management planning, enterprise management, and talent forecasting.
3.2. Basic steps of the AHP method

(1) The hierarchical analysis model is constructed. Assume that the target layer is A, the corresponding criterion layer is B<sub>1</sub>, B<sub>2</sub> and B<sub>3</sub>, and the index layers are C<sub>1</sub>, C<sub>2</sub>, C<sub>3</sub>, C<sub>4</sub> and C<sub>5</sub>. After the hierarchical analysis structure is constructed, the problem analysis can be summed up as the priority problems of each index relative to target layer this overall goal.

(2) The judgment matrix is constructed. The judgment matrix represents the comparison of relative importance between the related factors of level and upper level factor, the judgment matrix is the basic information of AHP and the important basis for calculating the relative importance. In this step, we need to determine which is more important under the criterion B<sub>K</sub>, C<sub>i</sub> or C<sub>j</sub>, this requires the assignment of importance, the source or basis of the assignment can be directly provided by the decision-maker, or determined by the dialogue between the decision-maker and the analyst, or obtained by the analyst through some kind of technical consultation, or determined by other appropriate ways. Generally, the judgment matrix should be given independently by experts who are familiar with the problems. For matrix C containing element C<sub>ij</sub>, the judgment matrix assignment is generally shown in Table.1.

| serial number | importance level | C<sub>ij</sub> assignment |
|---------------|------------------|--------------------------|
| 1             | i, j two elements are equally important | 1                        |
| 2             | i is slightly more important than j    | 3                        |
| 3             | i is obviously more important than j   | 5                        |
| 4             | i is intensively more important than j | 7                        |
| 5             | i is extremely important than j        | 9                        |
| 6             | i is less important than j             | 1/3                      |
| 7             | i is obviously more un important than j| 1/5                      |
| 8             | i is strongly less important than j    | 1/7                      |
| 9             | i is extremely more unimportant than j | 1/9                      |

(3) Consistency test of judgment matrix. It is very important to apply the analytic hierarchy process to maintain the consistency of judgmental thinking, the consistency of the so-called judgmental thinking means that when experts judge the importance of indicators, the judgments are coordinated and there is no contradictory result. Inconsistency in the conditions of multi-level judgment is extremely easy to occur, so in order to ensure the rationality of the results, it is necessary to carry out consistency for the judgment matrix. When the judgment matrix does not have approving consistency, the judgment matrix needs to be adjusted.

(4) Hierarchical single sorting. The relative importance of a certain level of factors relative to a factor in the upper level is calculated, this sorting calculation is called hierarchical single sorting. Specifically speaking, the hierarchical single sorting is based on the judgment matrix to calculate the weight of importance order of the elements related to elements in the upper layer according to the judgment matrix. In theory, the problem of hierarchical single sorting can be attributed to the problem of calculating the largest characteristic root of the judgment matrix and its feature vector.

(5) Total hierarchical sorting. The layer-by-layer hierarchy is calculated step by step from top to bottom, then the relative importance or ranking value of relative advantages and disadvantages of the lowest level factor (index level) relative to the highest level (target level), namely total hierarchical sorting.

3.3. Advantages and disadvantages of AHP method

As a traditional mathematical evaluation method, AHP has the characteristics of simplicity, systematization and less data. These characteristics make AHP widely used since it was put forward. However, the shortcomings of AHP are obvious, for example, the subjective judgment of experts has a great impact on the results, and when there are many indicators, the data statistics grow rapidly.
4. Index System Construction

Index system is the basis of comprehensive evaluation; the principles of index system construction include comprehensiveness, purpose, simplicity, independence, hierarchy and feasibility. In order to objectively and comprehensively evaluate the efficiency and demand in grid investment, based on the six principles of index system construction, this paper establishes the index system of grid investment calculation based on the efficiency and demand of power grid investment.

4.1. Calculation of regional historical investment efficiency

Investment efficiency indicators measure the effectiveness problem of regional grid investment from the angle of historical investment, due to the particularity of grid investment, the investment in the previous year often cannot directly reflect the benefits in the same year, when evaluating grid investment efficiency, the past 3-5 years is more appropriate as an evaluation period. The investment efficiency measurement indicators are shown in Fig.1; the second-level indicators are input-output indicators and grid structure improvement indicators, the third-level indicators are return on equity, household allocation capacity increase, distribution network contact rate improvement, and the improvement indicators of average section number in the medium voltage line. The return on equity measures the return rate problem of the grid capital investment from the angle of grid assets; the household average distribution capacity improvement index measures the reliability of users' electricity consumption from the angle of distribution network users; The improvement of line connection rate of distribution network evaluates the effectiveness of grid investment from the aspect of distribution network frame; the improvement of average section number in medium voltage lines measures the effectiveness of distribution network investment from distribution network structure. These four three-level indexes are used to measure the investment efficiency of power grid; we can evaluate the historical investment efficiency of grid from all links of power grid.

![Fig.1 Indicator system of investment efficiency](image)

4.2. Calculation of regional investment demand in the future

The investment demand index measures the real demand of power grid for investment from the angle of grid demand in the future, for regions with large demand, investment should be inclined to meet local demand, however, the investment demand of grid is a demand prediction problem and a evaluation problem before investment, so how to comprehensively and truly evaluate all aspects of grid demand, and minimize the error with the actual situation is the key to the calculation of investment demand. The investment demand measurement indicators are shown in Fig.2, the second-level indicators include the assets, regional social, economic conditions, grid structure and load conditions, the third-level indicators include the debt to asset ratio, regional GDP development, power policy driving conditions, the average load rate of line transformer, power supply reliability and load prediction six indexes. Among them, the debt to asset ratio can measure the condition of project under construction of grid companies; the
development condition of regional GDP can measure the power demand development from the angle of economic development; the driving condition indicator of power policy is to analyse the demand for grid projects required by the policy; the average load ratio of line transformer measures whether the current facilities of grid match the demand for power load; the reliability of power supply is to measure the grid demand from the users' angle; the load forecasting situation is to measure the grid investment demand based on the predicted future power demand development.

![Indicator system of investment demand](image)

**Fig.2 Indicator system of investment demand**

4.3. *Impact of decision preferences on indicator weight*

For the current grid investment planning, the subjective factor judgment is still the main judgment method, based on the efficiency measurement and demand measurement in the investment decision, although it provides a more scientific and reliable investment decision basis to some extent, however, due to differences in regional decision makers and regional development attributes, the focus of grid investment development measurement among regions is different. The difference of investment focus can be reflected by the judgment matrix in AHP, considering from the first-level indicators, when regional decision makers prefer grid investment need to meet the grid demand, then the weight of the investment demand should be set higher than the investment efficiency; otherwise, it is lower. Considering from the second-level indicators, when the regional decision makers think that the grid investment should meet the grid and load demand, then the judgment matrix should reflect the more important characteristics of the grid and load indicators than the other two indicators. In summary, the judgment matrix reflects the decision-making preferences of regional grid development, which will further affect the evaluation results of investment decision.

On the other hand, since the judgment matrix is extremely important in the evaluation process and belongs to subjective judgment, the expert who determines the judgment matrix should have strong ability to judge the grid investment, moreover, when experts form the judgment matrix, they should be independently judge and reduce the impact of each other, try to make the results more objective and comprehensive.

5. **Model Calculation**

Based on Yaahp software, this paper builds a regional structure determination model of grid investment based on investment efficiency and investment demand, the model construction is shown in Fig.3, and the relevant judgment matrix is improved and constructed. Through the evaluation and analysis of six regions, the relevant conclusions are obtained.
This paper studies the change of regional investment analysis coefficient when the assessment weight of investment efficiency and investment demand change continuously, among them, when the investment efficiency weight is 0 and the investment demand weight is 1, it shows that the investment decision does not consider the investment efficiency problem, only plan the grid investment planning for the future demand of the grid, which will cause the investment efficiency of the future grid cannot to be guaranteed, when the investment efficiency weight is 1 and the investment demand weight is 0, it shows that the grid investment only looks at the investment efficiency of the regional grid in the past years, and does not consider the future investment demand, this can ensure the investment efficiency, but may not meet the power growth demand of some regions.

The calculation results are shown in Table 2, brackets in different situations show the weight of investment efficiency and investment demand, respectively, and in which case 1 only considers investment demand and case 6 only considers investment efficiency.

Table 2 Calculation results of regional investment distribution in six cases

| region | case 1 | case 2 | case 3 | case 4 | case 5 | case 6 |
|--------|--------|--------|--------|--------|--------|--------|
| 1      | 0.2017 | 0.1880 | 0.1743 | 0.1606 | 0.1469 | 0.1332 |
| 2      | 0.1110 | 0.1219 | 0.1328 | 0.1437 | 0.1546 | 0.1655 |
| 3      | 0.1851 | 0.1792 | 0.1735 | 0.1674 | 0.1615 | 0.1555 |
| 4      | 0.1765 | 0.1854 | 0.1943 | 0.2032 | 0.2121 | 0.2209 |
| 5      | 0.1465 | 0.1392 | 0.1318 | 0.1245 | 0.1171 | 0.1098 |
| 6      | 0.1791 | 0.1863 | 0.1935 | 0.2007 | 0.2079 | 0.2151 |

The calculation results show that as the weights of efficiency and demand indicators change, the regional investment distribution coefficient also has continuous linear change; it is due to the fact that AHP is a linear evaluation method. As the investment efficiency weight increases from 0 to 1, the investment distribution coefficients in regions 1, 3 and 5 show a decreasing trend, and the investment distribution coefficients in regions 2, 4 and 6 show an increasing trend, it shows that when decision makers pay more attention to the future demand of the grid, then the more funds allocated in regions 2, 4 and 6, and when the policy makers more value the historical investment efficiency of the grid, the more funds allocated in regions 1, 3 and 5.

The nature which change in investment distribution in these regions is different attributes of each region, for regions 1, 3 and 5, their regional investment efficiency is higher, but their investment demand is relatively low, and the efficiency of region 1 is the highest, therefore, when only considering the investment efficiency, the investment allocation coefficient of the region 1 is the highest; relatively speaking, The grid demand attributes of regions 2, 4 and 6 are more obvious than their investment...
efficiency attributes, among them, the demand for power grid in region 4 is the largest, the next is region 6.

The research results also confirm the fact that investment efficiency and investment demand are not mutually exclusive, for example, region 5 has the highest investment when only considering investment efficiency, it shows that its investment demand is very low, but regions 4 and 6 as the two region with the highest investment demand, under the case 1, their investment distribution coefficient is still higher than the region 5, it shows that the investment efficiency and investment demand of the regions 4 and 6 are higher than those of the region 5.

6. Conclusion
This paper studies the problem of capital allocation calculation in grid investment area under the requirement of power system reform for grid lean investment, and proposes an evaluation model covering historical investment efficiency calculation and future grid demand calculation based on AHP. Moreover, through an example, the regional grid investment allocation is calculated fully and objectively from efficiency and demand two aspects, and the practicability of the model is verified, the calculation results show that the grid investment allocations are different are different in the case of efficiency emphasis and demand emphasis, this is because the investment efficiency and investment demand of different regions are different from each other, and how to determine the weight of the two types of indicators in decision-making is more depends on the consideration direction of decision makers.

References
[1] Yang Xiaoyan, Management of Power Grid Investment Plan Based on the Change of Power Grid Construction Environment, Technology Wind. 2017(12): 196.
[2] Hang Zubin, Strengthen the Investment Control of Power Grid Construction, Modern Economic Information. 2010(01): 46.
[3] Zeng Ming, Ma Shaoyin, Liu Yang, Chen Yingjie, et al, Investment Cost-benefit Analysis of Regional Micro grid Based on Demand-side Response, Water Resource and Power. 2012, 30(7): 190–193.
[4] Wang Mianbin, Tan Zhongfu, Zhang Liying, Cai Chengkai, et al, Power Grid Investment Risk Evaluation Model Based on Set-pair Analysis Theory in Power Market, Proceedings of the CSEE. 2010, 30(19): 91–99.
[5] Wang Mianbin, Tan Zhongfu, Zhang Rong, Wang Chengwen, Cao Fucheng, Li Xiaojun, et al, Risk Evaluation Model of the Power Grid Investment Based on Increment Principle, Transactions Of China Electrotechnical Society, 2006, 21(9): 18–24.
[6] Zhao Huiru, Fu Liwen, et al, Quantitative Analysis of Investment Capacity for Electric Power Enterprises, Water Resources and Power. 2012, 30(4): 191–194.
[7] Chen Li, Wang Beibei, Huang Junhui, Tan Jian, Lin Kaiying, et al, Asset Investment Strategy Adapting Default Service of Incremental Distribution Network for Grid Companies, Automation of Electric Power Systems. 2018, 42 (20): 38–44.
[8] Ma Qian, Wang Chen, Li Yang, Wang Zhe, Zhou Lei, et al, Investment Risk Analysis of Power Grid Enterprises Under Incremental Distribution Businesses Opening, Electric Power Construction. 2017, 38(9): 139–144.
[9] You Weiyang, Wang Xiuna, Efficiency and Benefit Evaluation of Grid Investment Project under the Transmission and Distribution Price Supervision, Electric Power Science and Engineering. 2018, 34(12): 43–48.
[10] Huang Chenyang, Yan Zheng, Yang Huoming, Han Dong, Yun Jingyang, Yang Jianlin, Impacts of TDP Reform on Investment of Provincial Power Grid and Its Dynamic Evaluation Method, Power System Technology. 2018, 42(10): 3292–3297.
[11] Long Yu, Hu Wei, Ma Qian, Tan Jinjing, Li Yang, et al, Whole-cycle Dynamic Investment and Development Mechanism of Power Grid Enterprises at Transmission and Distribution Price, Proceedings of the CSU-EPSA. 2019, 31(8): 143–150.