Advances in Economics, Business and Management Research, volume 91
1st International Symposium on Economic Development and Management Innovation (EDMI 2019)

Research on Evaluation Method of Power Grid Scale based on Grey Correlation Analysis

Hui Li[1, a], Zifa Liu[2, b], Yunyang Liu[2, c], Zhidong Wang[1, d], Lang Zhao[1, e]
[1]State Grid Economic and Technological Research Institute CO.LTD Beijing, China
[2]North China Electric Power University Beijing, China
[a]2330183130@qq.com, [b]tjubluesky@163.com, [c]hdliuyy@163.com, [d]yd1711@126.com, [e]154776804@qq.com

Abstract. At present, the power grid planning and management department has been lacking a scientific quantitative assessment method for the overall scale of power grid construction, making it difficult to accurately grasp and determine the overall size of the power grid construction and the priority of construction projects. Based on this, a method for evaluating the scale of power grid construction is proposed in this paper. The method uses the gray correlation analysis principle to establish the scale index fitness model and calculates the fitness index of the scale index. The comprehensive evaluation model is used to establish the comprehensive evaluation model to obtain the comprehensive scale. Taking the regional power grid construction planning as an example, the case test is carried out to verify the rationality and reliability of the proposed method.

Keywords: power grid scale; evaluation method; grey correlation analysis.

1. Introduction

In the actual project construction investment, if the investment scale is too large, the power grid construction will far exceed the needs of the national economy and social development, which will inevitably result in waste of funds and excess resources. If the scale of investment is too small, it will restrict the national economic and social development and will not achieve the expected investment benefits. Therefore, it is an important issue in the construction of regional power grids, and is also an inevitable requirement for regional power grid construction under the conditions of power market that how to properly grasp the scale and capital investment of regional power grid construction, scientific evaluation and control of regional power grid construction scale [1].

With the gradual development and popularization of power grid planning theory, there are more and more evaluation methods for power grid construction projects. In recent years, there have been some research results in the optimization methods and decision-making methods in project evaluation. Ref [2] applies the fuzzy multi-objective comprehensive evaluation decision theory in the decision-making of the recent construction project of power grid planning. Ref [3] theoretically supports expert decision-making and establishes a human-computer cooperation decision-making method, which not only utilizes the advantages of mathematical optimization and expert decision-making, but also overcomes the limitations of both, systematically processing quantitative and multiple uncertainties. Based on qualitative factors, a comprehensive evaluation decision for urban power grid planning based on interval analytic hierarchy process is proposed. In Ref [4], through the analytic hierarchy process, the urban medium voltage distribution network was evaluated from the aspects of technical rationality, safety, power supply quality and reliability, and a comprehensive evaluation system for urban distribution network is established. Ref [5] uses statistical principles and statistical analysis methods to assess the scale of regional high-voltage distribution network construction. The paper establishes an index system for evaluating the scale of 110kV high-voltage distribution network construction. Based on partial correlation analysis, it analyzes and reveals the correlation law between various influencing factors and scale indicators. In Ref [6], using the optimization principle, an optimized mathematical model is established to assess the construction scale of the regional high-voltage distribution network under the conditions of given power supply area and maximum power load level.

Compared to existing literature, contributions of this work include: (1) A method for judging the scale of power grid construction based on grey correlation analysis is proposed. (2) calculate the fitness index of the scale index, and use the comprehensive evaluation model to obtain the evaluation scale of the comprehensive scale. (3) An example test is carried out with a regional power grid construction plan to verify its rationality, feasibility and effectiveness.

2. Evaluation Index System of Grid Construction Scale

2.1 Basic Principles for the Establishment of an Indicator System

Whether the indicator system is scientific and reasonable is directly related to the quality of grid scale assessment. To this end, the indicator system must contain scientifically, objectively, reasonably and as comprehensively as possible the factors that reflect the factors affecting the development of the scale of the power grid and the scale factor representing the size of the regional power grid construction. Therefore, we must first follow certain established principles:

- Purposeful: The index system should be designed around the goal of grid construction scale assessment, and it should be composed of typical indicators representing the various components of the grid construction scale, reflecting the scale of the grid construction in multiple directions and multiple angles.
- Scientific: The formulation of the indicator system and the choice of indicators must have a scientific basis. Only by adhering to the principle of science, the information obtained is reliable and objective, and the results of the evaluation are credible.
- Systematic: The indicator system should include many aspects of the grid size, making it a system.
- Operable: The design requirements of the indicators are clear and well defined, and data can be collected conveniently.
- Outstanding: The choice of indicators should be comprehensive, but it should be distinguished from the primary and secondary, and the indicators that play a major role in the evaluation results should be highlighted.

2.2 Power Grid Scale Indicator System

There are many measurement indicators reflecting the scale of regional power grid construction, which are closely related to each other and have great interaction and influence. In the establishment of the evaluation index system, attentions must be paid to the relationship between micro and macro, local and overall, individual targeting and universal adaptability. In order to extract a scientific and reasonable evaluation index system from a large number of optional indicators, after a large number of on-site investigations and comparative analysis, combined with expert opinions, using the basic idea of Analytic Hierarchy Process (AHP), the scale index of power grid construction is established as TABLE 1[7].

Table 1. Power Grid Scale Indicator System

	Indicators (under the same voltage level)	*Number*
Power grid scale indicator system	Total substation capacity	U1
	Total number of transformers	U2
	Total length of grid lines	U3
	Total number of grid lines	U4

2.3 Power Grid Scale Influence Factor Indicator System

The fundamental purpose of power grid construction is to meet the demand for electricity consumption in regional social and economic development. The impact of economic development on the scale of power grid construction is mainly reflected in the total national economy and various industrial structures; social development is mainly reflected in population, urbanization rate, and per capita disposable income. This paper selects three core categories of economic development, social development, and power development. These three categories of indicators comprehensively reflect the set of influencing factors affecting the scale of power grid construction [8]. The indicator system of influencing factors is shown in TABLE 2.

Table 2. Power Grid Scale Influence Factor Indicator System

	influence factor Indicators		***Number***
Power grid scale influence factor indicator system	Economic development indicators	GDP	F 1
	Social development indicators	Total population of the region	F 2
		Urbanization rate	F 3
		Per capita disposable income	F 4
	Electric development indicators	Electricity consumption in the whole society	F 5
		Maximum load	F 6

The quantitative calculation of the indicator is as follows:

1) GDP: Gross domestic product, which is the gross domestic product, indicates the total value of the market value of all final products and services provided in the economy of a country or region within a certain period of time (one quarter or one year). The indicator that measures the comprehensive level of economic development of a country or region is also the most important indicator.

2) Total population of the region: Population refers to the sum of living individuals within a certain period of time and within a certain area. The total population of the region refers to the total number of people in the region at 24 o'clock on December 31 each year.

3) Urbanization rate: The urbanization rate refers to the percentage of urban population in a country or region as a percentage of its total population.

$$R_u = \frac{P_{non-agricultural}}{P_{total}} \times 100\% \tag{1}$$

where R_u represents urbanization rate; $P_{non\text{-}agricultural}$ represents regional non-agricultural population; P_{total} represents regional total population

4) Per capita disposable income: Per capita disposable income refers to the sum of household consumption and final non-obligatory expenditures and savings, that is, the income that households can use for discretion. It is the most important and most commonly used indicator for measuring household income levels and living standards.

5) Electricity consumption in the whole society: The electricity consumption in the whole society is an important economic indicator in the electricity market. It includes the first, second and third industries and the electricity consumption of urban and rural residents. It reflects the total scale and total level of electricity consumption in a certain period of time. It generally reflects the situation of electricity demand and the law of change in a region.

6) Maximum load: The maximum load indicator is an important indicator for carrying out load characteristics analysis and power planning, and it reflects the level of power demand in a region. Generally, the maximum power load of the whole society is adopted.

3. Evaluation Method of Power Grid Scale based on Grey Correlation Analysis

To achieve a quantitative assessment for the scale of regional power grid construction, it is first necessary to establish a complete and systematic indicator system (including “scale factor set U” and “influence factor set F”), and then association analysis method is used to scientifically reveal the inherent objective between related indicators. Correlate the law and establish a scientific and reasonable comprehensive evaluation model to achieve an objective quantitative assessment of the grid scale.

3.1 Index Actual Development Speed Calculation Model

The average rate of development is used to indicate the extent to which things develop on a mean-period basis over a longer period of time. In this paper, the "development coefficient method" is used to calculate the average development speed of the influencing factors. The calculation formula is as follows [9]:

$$v_{act} = \frac{\frac{1}{m}\sum_{i=1}^{m} a_i \sum_{i=1}^{m} b_i - \sum_{i=1}^{m}(a_i b_i)}{\frac{1}{m}(\sum_{i=1}^{m} b_i)^2 - \sum_{i=1}^{m}(b_i)^2} \tag{2}$$

In the formula, the original sequence A= $\{a_0, a_1, ..., a_i, ..., a_m\}$ is appropriately processed to obtain the cumulative generation sequence B= $\{b_0, b_1, ..., b_i, ..., b_m\}$. The characteristic of the development coefficient method is that the original sequence is accumulated in the calculation, which can reduce the randomness volatility of the original sequence change, and strengthen its regularity.

3.2 Grey Correlation Analysis

The basic idea of grey correlation analysis is to judge the closeness for the geometrical shape of the sequence curve. In this paper, the scale factor set $U=\{U_i\}=\{U_1, U_2, \ldots, U_I\}$, the i-th scale factor corresponds to the time series $U_l=\{u_l(1), u_l(2), \ldots, ui(\mathrm{n})\}$ (i = 1,2, … ,I); influencing factors are sets: $F=\{F_j\}=\{F_1, F_2, \ldots, F_J\}$, the j-th influencing factor corresponds to the time series $F_j=\{f_j(1), f_j(2), \ldots, f_j(\mathrm{n})\}$,($j$=1,2,…,$J$); n is the length of the sequence. The calculation formula of the influence factor on the gray correlation degree r (U_i , F_j) is as follows[10]:

$$r[u_i(k), f_j(k)] = \frac{\min_j \min_k |u_i'(k) - f_j'(k)| + \rho \max_j \max_k |u_i'(k) - f_j'(k)|}{|u_i'(k) - f_j'(k)| + \rho \max_j \max_k |u_i'(k) - f_j'(k)|} \tag{3}$$

Where ρ represents the resolution coefficient. $u_i'(k)$ and $f_j'(k)$ are numerical maps of $u_i(k)$ and $f_j(k)$ respectively. The grey correlation degree describes the relationship between each impact factor and the change and development of each scale evaluation factor. The ranking result of the correlation degree reflects the primary and secondary status of each influencing factor. From the above formula, the magnitude of the gray correlation degree of the influencing factors to each scale factor can be calculated, and sorted according to the size, and the sorting result $p_{i,j}$ is obtained. According to the following formula, $p_{i,j}$ is transformed into $q_{i,j}$, which represents the influence weight of the grid influence factor fj on the development of the scale factor.

$$q_{i,j} = p_{i,j} \Big/ \sum_{i=1} p_{i,j} \tag{4}$$

3.3 Index Ideal Development Speed Calculation Model

The ideal speed of development of scale indicators can be determined by the following formula [11]:

$$v_{ideal} = \sum_{i=1}^{6} q_{i,j} v_{act} \tag{5}$$

where v_{act} represents the ideal development speed of the scale indicator; v_{ideal} represents the actual development speed of the impact factor indicator.

After obtaining the ideal development speed of the scale indicator, comparing the actual development speed of the scale indicator with the ideal development speed can achieve an assessment of the reasonableness of the single scale indicator. The "fitness coefficient" f_{ui} is defined as follows [12]:

$$f_{ui} = \frac{v_{act}}{v_{ideal}} \tag{6}$$

where f_{ui} is the fitness coefficient. When f_{ui} =1, it indicates that the development of scale factor u_i is most suitable for national economic and social development; when f_{ui} <1, it indicates that the development of scale factor is lagging; when f_{ui} >1, it indicates that its development is advanced.

4. Case Study

This paper takes the area of a certain city in the province as the research object, and tests the validity of the proposed method and the correctness of the model. Case analysis is carried out using the grid size reached by a regional power grid.

The main indicators reflecting the national economic and social development and the main indicators of the development scale of the regional power grid construction are shown in Table 3 and Table 4, respectively.

Table 3. Indicator raw data

Years	F1	F2	F3	F4	F5	F6
2012	21.48	4856	31.7	4907	5.62	1306
2013	24.76	4875	32.3	5304	5.81	1458
2014	28.11	4889	32.7	5852	6.12	1695
2015	31.25	4896	33.1	6261	6.35	1911
2016	34.19	4901	33.3	6586	6.46	2056
2017	37.08	4902	33.9	6907	6.61	2267
2018	39.66	4905	34.1	7204	6.75	2258

In the above table, F1 represents GDP (billion yuan); F2 represents total population of the region (thousand); F3 represents the urbanization rate (%); F4 represents per capita disposable income (yuan); F5 represents electricity consumption (billion kWh); F6 represents the maximum load (MW).

Table 4. the main indicators of the regional 220kV power grid construction SCALE

Years	U1	U2	U3	U4
2012	2567	48	56.5	72
2013	2759	52	59.7	76
2014	3095	55	63.1	81
2015	3374	56	66.8	84
2016	3814	60	69.7	88
2017	4115	63	71.1	90
2018	4449	65	72.6	92

In Table 4, U1 represents total substation capacity (kMVA); U2 represents total number of transformers; U3 represents total length of grid lines (thousand km); U4 represents total number of grid lines.

The examples were tested using the evaluation model of the grey correlation analysis method. The evaluation results are shown in Table 5.

Table 5. the main indicators of the regional 220kV power grid construction SCALE

Years	U1	U2	U3	U4
v_{act}	1.625	1.384	1.378	1.412
v_{ideal}	1.524	1.412	1.408	1.415
f_{ui}	1.066	0.980	0.978	0.997

Table 5 shows the results of the gray scale correlation analysis method for the comprehensive scale of 220kV voltage level, the overall size of the regional power grid and the suitability of each scale factor. The assessment results show that the overall size of the grid in the region is basically coordinated with the development of the local national economy. From the evaluation results of various scale factors, the 220kV substation capacity is advanced, which indicates that the substation capacity of the region can meet the load demand of the region; the distribution capacity and the number of distribution transformers are not coordinated, indicating that the distribution network construction In the distribution transformer, it is necessary to use a small capacity, short radius, dense point of power supply; and a major factor affecting the distribution scale is that the line length of the medium voltage distribution network is too small, resulting in a greater impact on the overall scale. It reflects that the line is a relatively weak link in the construction of the power grid, and it is necessary to strengthen the construction and transformation of the distribution network.

5. Conclusion

The quantitative assessment of the construction scale of the power grid is a new topic in the power grid planning and construction management work that is proposed along with the continuous deepening of the power market reform, and is a macro evaluation of the power grid development planning.

At present, the grid planning and management department has been lacking a scientific quantitative assessment method for the overall scale of power grid construction, making it difficult to accurately grasp and determine the overall size of the distribution network construction and construction project priorities. This paper has carried out the following research work in this context.:

(1) Introduced the basic principles for the establishment of evaluation indicators. On this basis, a complete and comprehensive evaluation index system for the scale of regional power grid construction was established. The indicator system consists of an indicator “scale factor set” that reflects the scale of power grid construction and various social and economic development indicators “influence factors set” that affect the development of power grid scale.

(2) The statistical analysis methods in the grid construction scale assessment method were studied separately. The general idea, method implementation and comprehensive evaluation model of the statistical analysis method for grid construction scale evaluation are summarized.

(3) Propose an evaluation method for the scale of regional power grid construction. The method uses the principle of grey relational analysis to establish the fitness model of scale indicators for national economic and social development and calculates the fitness index of scale indicators. The fuzzy comprehensive evaluation model is established by weighted comprehensive evaluation principle to obtain the evaluation scale of comprehensive scale. Taking a regional power grid construction planning as an example, the example test is carried out. The evaluation conclusion is consistent with the actual scale of the power grid, which indicates that the proposed method is adaptable and can achieve a comprehensive quantitative objective assessment of the scale of the regional power grid construction.

Acknowledgments

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”.

References

[1]. Cai Bin, Wu Subong, Wang Shiming et al. Grid online security and stability analysis and early warning system. Power Grid Technology, 2007, 31(2): 36-41.

[2]. Wu Li, Wu Jie, Zhou Lerong et al. Fuzzy multi-objective comprehensive evaluation decision-making for power transmission and transformation projects. Power System Technology, 1999, 23(3): 19-22.

[3]. Xiao Jun, Wang Chengshan, Zhou Min. Decision-making of comprehensive evaluation of urban power grid planning based on interval analytic hierarchy process. Chinese Journal of Electrical Engineering, 2004, 24(4): 50-57.

[4]. Xiao Jun, Gao Haixia, Ge Shaoyun et al. Evaluation method and case study of medium voltage distribution network in urban city. Electric network technology, 2005, 29(20): 77-81.

[5]. Li Xinran, Liu Yanghua, Zhu Xiangyou et al. Evaluation index system for the construction scale of high voltage distribution network and its application. Journal of China Electrical Engineering, 2006, 26(17): 18-24.

[6]. Li Xinran, Li Peiqiang, Zhu Xiangyou, et al. Evaluation of the scale of high-voltage distribution network construction based on the optimization principle. Automation of Power Systems, 2007, 31(4): 45-50.

[7]. Lin Feng. Methods of Statistical Analysis of Economics. Beijing: Social Sciences Academic Press, 2003, 52-68.

[8]. Li Xinran, Ouyang Li, Zhu Xiangyou, etc. Application of GRA in the scale assessment of regional power grid construction. Journal of Electric Power Science and Technology, 2007, 22(1): 61-66.

[9]. Si Zhiyuan. Research on the content and evaluation index of large-scale power grid construction scale adaptation [D]. North China Electric Power University, 2013.

[10]. Shang Jingan. Research on coordination evaluation of power system planning plant network [D]. North China Electric Power University (Beijing), 2010.

[11]. Peng Guorong. Research on fuzzy comprehensive assessment method for regional power grid construction scale [D]. Hunan University, 2008.

[12]. Li Xinran, Zhu Xiangyou, Li Peiqiang, Ouyang Li, Peng Guorong.Study on Comprehensive Evaluation Method of Regional Power Grid Construction Scale[J]. Journal of Hunan University (Natural Science),2008(02):61-65.