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The Influence Mechanism of Power Grid Operation Comprehensive Value from Perspective of Sustainable Energy Development

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Abstract: Safe operation and sustainable construction of a power system can promote economic development and technological progress. A good grid operation system can improve the operation efficiency and input-output efficiency of the whole power system. An index system was built to list criteria of impacting on power grid operation comprehensive value from perspective of investment based on the value creation. A factor analysis method was applied to recognized key criteria. An entropy method was introduced to sort the importance of the key criteria. Based on Chinese data from 2004 to 2017, an empirical study was preformed to verify the framework and explained the impact of key criteria on the power grid operation value. A series of investment strategies and technical means were proposed to improve the power system operation according to the empirical research results.

Keywords: Power grid operation, Comprehensive value, Influence criteria, Factor analysis, Entropy method.

1. Introduction

Electric power industry is the basic industry of national economy. Sustained and stable power grid operation can generate certain value to guarantee the balanced development of economy and society in China [1]. Thus, to grasp the mechanism of impacting on the power grid operation comprehensive value is one of the key points to improve the efficiency of power grid operation and ensure the sustainable development of the whole power system and the energy industry.

According to Adam Smith, value creation refers to the process in which an enterprise or an industry invest certain resources to achieve the highest possible return, or devote the lowest resources to achieve certain return. Continuous value creation, as a basic economic behavior, promotes economic development and social progress, and ensures all industries sustainable improvement [2]. Traditional value creation is only limited to the economic profits generated by enterprises or industries. But their investment and other economic behaviors can not only bring economic returns, but also promote social development, technological progress and ecological environment improvement.

Due to the change of national macroeconomic regulation and control, scale expansion and technology upgrading of power grid become increasingly complex. Power grid development involves many aspects,



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including in power grid infrastructure construction, production technical innovation, non-production technical innovation, marketing projects, technical research and development, management consulting, education and training etc. According to the sustainability theory, sustainable development should be measured through economic, social and environmental dimensions [3]. Thus, the comprehensive value of large power grid construction and operation will be measured from the three perspectives of economic, social and environmental.

In this paper, a reasonable index system will be established to measure the comprehensive value of large power grid operation. A factor analysis method is introduced to select key criteria based on historical data of Chinese power grid construction and operation. An entropy method is applied to research on the importance of the key criteria on the operation value. According to these research results, effective strategies will be proposed to improve the input-output value of the power system operation value.

2. Establishment of an Index System for Power grid Operation Value

Based on the value creation theory and the sustainability theory, power grid investment, conduction and operation can generate enormous value in the perspectives of economic, social and environmental. Thus, the evaluation index system is established by an economical and financial criterion, a social development criterion and an eco-environmental criterion.

(1) Economical and financial criterion. Power grid operation can bring economic benefits for investors and promote economic balanced development of infrastructure [4]. Some sub-criteria are selected to reflect the economical and financial effects of impacting the value, including investment amount of power grid, power supply growth per investment unit, ratio of power line loss, elasticity coefficient of power consumption, lending rate.

(2) Social development criterion. A strong power network can produce certain social value, such as improvement of electrification level, reduction of urban-rural differences and improvement of residential life quality. Specially, investment in rural power grid construction and transformation is of great significance for promoting social equity [5]. Some sub-criteria are chosen to describe the impact of the investment on the social values, including power growth rate of electricity consumption per capita, electricity consumption per capita, growth rate of per capita household electricity consumption, the proportion of rural people with access to electricity, comparison of the main household appliances in urban and rural households, comparison of per capita electricity consumption in urban and rural households.

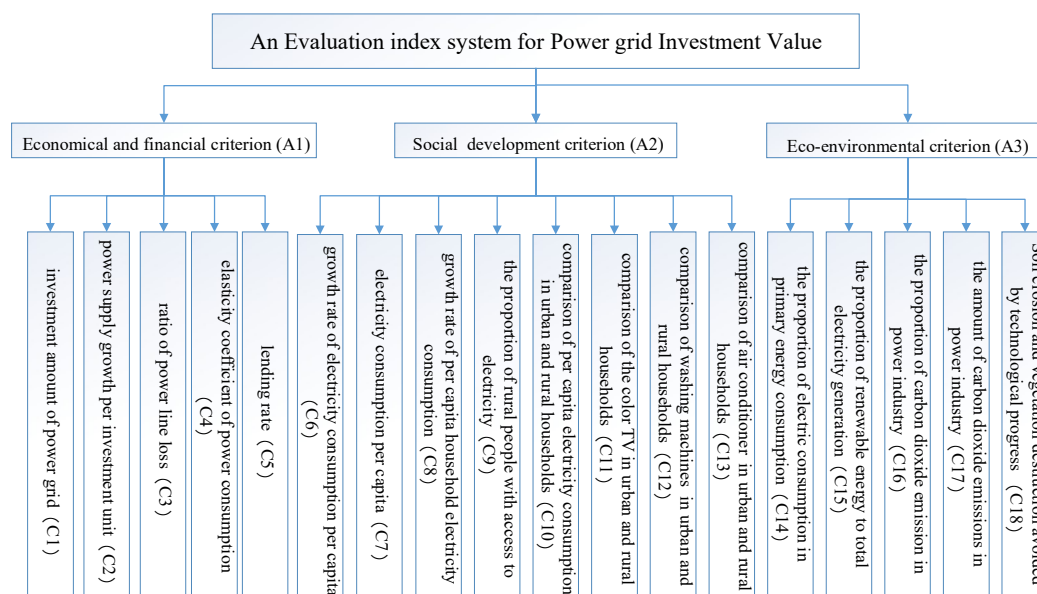


Figure 1. An evaluation index system of the power grid comprehensive value

(3) Eco-environmental criterion. There is a large amount of renewable energy available in the western part of China, while the electricity load is mainly concentrated in the eastern part. Construction and operation of large-scale long-distance transmission network can promote clean energy absorption and reduce greenhouse gas emissions. There are some sub-criteria to impact the environmental values, including the proportion of electric consumption in primary energy consumption, the proportion of renewable energy to total electricity generation, the amount of carbon dioxide emissions in power industry, the proportion of carbon monoxide emissions in power industry, soil erosion and vegetation destruction avoided by technological progress. Figure 1 shows the evaluation index system.

3. Methods and Research Framework

3.1. The factor analysis method

Factor analysis method, developed by Charles Edward Spearman, is a multivariate statistical analysis method that converts multiple variables into a few irrelevant comprehensive indicators. Based on dimension reduction processing, variables with strong correlations can be grouped together to simplify the complexity of variable analysis in different categories. A few indicators that can reflect the main information of other observation variables can be regarded as factors [6].

The method is be introduced to classify the many criteria that affect the whole value of power grid operation into a few common factors that reflect all variable information, as shown in:

$$X_i = a_{i1}F_1 + a_{i2}F_2 + \cdots + a_{ij}F_j + \cdots a_{im}F_m + \varepsilon_i \quad (1)$$

where X_i is i th variable, F_j is j th common factor, a_{ij} is a factor loading, ε_i refers to the variable information that cannot be contained by common factors. $i=1,2,\cdots,p$ and $j=1,2,\cdots,m$. p is the total number of the all variables, m is the total number of the all common factors.

3.2. The entropy method

The entropy method, introduced in to the information theory by Shannon, was applied to rank the importance of many criteria [7]. Suppose there are m key sub-criteria counted and n evaluation alternatives, an initial decision matrix X is:

$$X = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1n} \\ c_{21} & c_{22} & \cdots & c_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ c_{m1} & c_{m2} & \cdots & c_{mn} \end{bmatrix} \quad (2)$$

Step 1: normalize the initial decision matrix using the linear scaling transformation, as is:

$$R = (d_{ij})_{m \times n} \quad (3)$$

where d_{ij} is the data of the j alternative on the i sub-criterion, and $d_{ij} \in [0,1]$.

Step 2: Define the entropy of the i sub-criterion, as is:

$$H_i = -k \sum_{j=1}^n f_{ij} \ln f_{ij} \quad (4)$$

where $f_{ij} = d_{ij} / \sum_{j=1}^n d_{ij}$, $k = 1/\ln n$ and suppose, if $f_{ij} = 0$, $\ln f_{ij} = 0$

Step 3: Compute the entropy weight of the i sub-criterion, as is:

$$w_i = \frac{1 - H_i}{m - \sum_{i=1}^m H_i} \quad (5)$$

3.3. The framework of proposed analysis model

The framework of the proposed model of researching on the influence mechanism of the power grid operation comprehensive value involves the following three phases.

Phase 1: Eliminate some sub-criteria with weak correlation based on a Delphi method and form a significant index system.

Phase 2: Reflect the correlation among significant sub-criteria according to the factor analysis method. A series of key sub-criteria can be extracted scientifically based on the correlations.

Phase 3: Rank the importance of the key sub-criteria based on the entropy method. Some strategies can be proposed to input-output benefit of the power grid operation.

4. Empirical Analysis

4.1. Describe the data and recognize the significant sub-criteria

China has experienced a period of rapid development of an electric power industry. Large-scale investment and operation in power grid promotes the sustainable development of the power industry. According to Figure 1, a series of sub-criteria data were collected from 2004 to 2017. Except C18, other data of the sub-criteria were obtained from the world bank database and the statistical yearbooks of China. An expert group from government departments, research institutions and electricity utilities were formed to recognize the significant sub-criteria. Besides, C18 data were obtained in the form of expert ratings. The degree of C18 are measured on a scale of 0 to 10. 0 means there is no impact, 10 means there is very significant impact. According to the Delphi method and the expert group's opinions, some sub-criteria with weak influence were eliminated, involving in C5, C6, C11, C16, C17, C18. The others are regarded as the significant sub-criteria.

4.2. Extract the key sub-criteria of impacting the comprehensive operation values

Factor analysis of the 12 significant sub-criteria data were performed by using SPSS 22.0 software. First, a series of raw data is standardized to eliminate dimensional differences. Second, KMO and Bartlett tests were performed to verify the feasibility of this method. The KMO statistic is 0.637, which is greater than the minimum standard 0.6. And the P value of Bartlett spherical test is 0.000, which is less than 0.001. The results reflect that it is suitable to perform factor analysis. Third, based on the principal component method, the common factors with cumulative variance contribution over 90% are selected. According to the software output, the first three common factors were extracted, and their cumulative variance contribution was 94.275%. Fourth, the initial factor load array is rotated by using orthogonal rotation with maximum variance to highlight the correlation between the common factors and the significant sub-criteria. Table 1 shows the factorial load matrix after rotation.

Table 1. The factorial load matrix after rotation

Sub-criteria	Common factor 1	Common factor 2	Common factor 3
C3	0.916	0.288	-0.042
C13	0.905	0.242	0.308
C14	0.898	0.309	0.303
C10	0.889	0.296	0.335
C2	0.878	0.393	0.094
C4	0.237	0.912	0.263
C8	0.29	0.201	0.888
C7	-0.88	-0.243	-0.397
C15	-0.716	-0.250	0.508
C12	-0.792	-0.263	0.439
C9	-0.850	-0.332	0.323
C1	-0.893	-0.328	-0.237
Contribution of variance	79.29%	8.76%	6.28%

According to the Table 1, contribution of variance for the common factor 1 is 79.29%, which means that the factor contains more than 70% of the data information about the value of the power grid operation. The C3, C13, C14, C10, C2 have larger load values in the common factor 1 than that in the other common factors. Thus, the common factor 1 can reflect the comprehensive impact indicators of economic, social and environmental values from power grid operation. In the common factor 2, the load value of C4 is significantly higher than others. C8 has a various large load value in the common factor 3. Thus, C4 and C8 can reflect most information of common factor 2 and common factor 3 respectively and should be regarded as key sub-criteria. Based on the above analysis, C3, C13, C14, C10, C2, C4 and C8 should be considered as key sub-criteria.

4.3. Rank the importance of the key sub-criteria

First, the initial decision matrix X was established by collecting these sub-criteria values. The normalized decision matrix can be computed. Then, the entropies of the key sub-criteria were calculated, as shown in Table 2. The final weights can be computed according to Equation (5), as listed in Table 2. The importance of the key sub-criteria can be ranked based on the weights. The ranking results were indicated in Table 2. The larger the weight of a sub-criterion is, the more important it is.

Table 2. Entropies and final weights of the key sub-criteria

Sub-criteria	C3	C13	C14	C10	C2	C4	C8
Entropies	0.937	0.957	0.914	0.958	0.922	0.929	0.877
Weights	0.124	0.085	0.17	0.083	0.155	0.14	0.243
Ranking	5	6	2	7	3	4	1

According to Table 2, C8 has a largest weight and can be considered as the most importance criteria affecting social values of power grid operation directly. Per capita household electric consumption can reflect to the social development and people's living standard to a certain extent. In order to promote residents' energy availability and social justice, the investment and construction of electric power infrastructure should be implemented effectively and continuously. C14 referring to the proportion of electric consumption in primary energy consumption, is the second most importance criteria and can influence on the environmental values. China is gradually promoting electricity substitution to reduce fossil energy consumption and pollutant emissions, which can drive up the increasing proportion of electric consumption. For instance, promotion of electric vehicles in some cities can effectively reduce emissions of fuel-consuming vehicle exhaust. Efficiency of power grid operation is the basis of implementing electricity substitution. Except for C8 and C14, C2 is more importance than other sub-criteria and may influence on the economic values of the power grid operation. The sub-criterion reflects the promote grid operation efficiency and can be considered to influence operation strategies for the next year. C4 and C3, directly impacting on the environmental values, are the fourth and fifth most important criteria respectively. C4 reflects overall relationship between electricity consumption and economic development. Economic growth and industrial restructuring can affect a development trend of electricity consumption, and then impact on the decision in next operational management period. C3 can reflect the power infrastructure construction status and technical level. Hight ratio of power line loss may lead to poor power supply quality and shows an urgent need for conducting strong power grid. C10 and C13 shows the influence of urban-rural difference on power consumption. Power grid investment and construction should be focus on poor rural resident to ensure all people to enjoy electricity equally and enjoy the improvement of life quality brought by social development.

4.4. Propose investment strategies and technology means

Based on the above key sub-criteria and their influence to the whole value, appropriate strategies are proposed to improve comprehensive input-output benefit.

- Pay close attention to industrial structure adjustment policy and change trend, forecast power demand reasonably, establish demand-oriented grid investment.

- There is still much room for improvement in residential electricity consumption. Construction and development of power grid should pay due attention to residential electricity consumption.
- There should be some unrequited investment and operation for poor rural residents in remote areas in order to achieve the equalization of energy supply.
- In the face of energy conservation and emission reduction, the operation decision makers should take into account the impact of electric energy substitution and renewable energy development

5. Conclusion

To the influence mechanism of power grid operation comprehensive value, an index system was built from the three perspectives of economic, social and environmental. A research framework was proposed based on the factor analysis and the entropy method. Empirical research results show seven sub-criteria can impact on the comprehensive value significantly, including C3, C13, C14, C10, C2, C4 and C8. C8 is the most important sub-criterion, following by C14, C2, C4 etc. Four strategies were put forward based the above research results.

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