Research on the Evaluation Model of Power Grid Performance Based on Analytic Hierarchy Process

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Abstract: Power grid performance study is an important tache for power supply companies, and it works important to improve the company development. It has an important meaning not only to advance and perfect the decision-making, also to support electric network reconstruction and benefit of investment. Along with the reform of economy system, market economy has more and more restriction to the investment. Besides, as the gradually growing of electric market, electric company will take more care of the network performance evaluation. Power network performance evaluation is the premise and foundation of overall economic efficiency analysis. Regarding on the appraisal to the power grid performances, it is helpful to appraisal its own management capability correctly and understand its own exists insufficiency, so it can discover the disparity and formulate the effective management developmental strategy. Power supply companies shall establish a scientific, practical and accurate performance evaluation model. The research on the selection indexes and assessment method should be able to fully reflect the current state, planning strategy and promoting development of the power grid. In this paper, based on the model of evaluation index system, we analyzed the performance of the grid and established the hierarchical structure model. This model has a classified hierarchical structure, it consist of power supply capability improving, voltage quality improving, reliability improving, etc. Most indexes of this model are quantitative which come from actual operation data, so as to make sure that the evaluation is objective. Using the analytic hierarchy process (AHP) to analyze the weight of index system in order to acquire the performance coefficients. These can objectively and factually reflect a power network production operation condition as well as its effect on the local power network. This paper has guiding significance and reference value for self evaluation by power supply companies and post-evaluation by third independent institution.

Keywords: power grid performance; evaluation model; analytic hierarchy process; influence coefficient

1.Introduce

In order to balance urban and rural development, promote and improve people's livelihood, and better serve the construction of a new socialist countryside，a new round of rural distribution network transformation and upgrading project was proposed by the party central committee and the state council in 2010，to meet the demand of "agriculture, rural areas and farmers" for electricity, promote rural economic development, and promote urban and rural economic and social integration[1].

In order to comprehensive assessment the grid performance in the investment effect of new round of rural distribution network transformation and upgrading project, selected in this paper, with the aid of expert experience, a set of generic retrofit upgrade project investment effect comprehensive evaluation index system, and to gather the network performance as the target layer, and the hierarchical structure of the power grid performance comprehensive evaluation model is established, using AHP (Analytic Hierarchy Process), the combination of qualitative and quantitative method, it is concluded that the influence of various factors coefficient (i.e., weight), and apply the results to the grid performance evaluation system, to achieve the desired effect, and can make up for the deficiency of the traditional method.

2.The research methods

2.1 Introduction of analytic hierarchy process（AHP）

Analytic hierarchy process (AHP) is the operational research, saaty (T.L.Saaty), a professor at the university of Pittsburgh in the early 1970s, for the study of the us department of defense, " Decide to electric power distribution according to the size of each industrial sector's contribution to the national welfare " subject, with the application of the theory of network system and multi-objective comprehensive evaluation method, a hierarchical weighted decision analysis method is proposed [2].

The characteristics of this method is to use less quantitative information to make decision of thinking process mathematically and provide easy decision method for multiple objectives, guidelines, or no structural characteristics of a complex decision problem, etc., which on the basis of in-depth analysis in the nature of the complex decision-making problems、influencing factors and internal relations. It is a model and method for making decisions on complex systems that are difficult to fully quantify.

This method was introduced to our country since 1982, due to its features which combine qualitative and quantitative to process all kinds of the characteristics of the decision factors, and the advantages of the system is flexible and concise, it has been quickly and widely recognized and applied in our country in the social and economic fields, such as project planning, resource allocation, ranking, policy making, conflict, performance evaluation, analysis of energy system, urban planning, economic management, scientific research evaluation [3].

Modeling with analytic hierarchy process can be generally carried out in the following four steps:

（1）Build a hierarchical model;

（2）Build judgment matrix of each layer;

（3）Sort individually in each layer and consistency check;

（4）Sort synthetically in all layers and consistency check.

2.2 Establish the hierarchical structure model

When applying AHP to analyze decision-making problems, the first step is to organize and stratify the problems and construct a hierarchical structure model. In this model, complex problems are decomposed into elements. These elements form several layers according to their attributes and relationships [4]. Elements at the upper level dominate elements at the lower level as criteria. These levels can be divided into three categories:

（1）Top layer: There is only one element in this hierarchy, which is generally the predetermined goal or ideal result of the analysis problem, so it is also called the target layer.

（2）Middle layer: This level includes the intermediate links which is involved to achieve the goal, it can be composed of several layers, including the required standards, standards, also known as the criterion layer.

（3）Bottom layer: this layer includes various measures, decision plans, etc. that are available to choose for the purpose of achieving the goals, and is therefore called the measures layer or the program layer.

The number of levels in a hierarchical structure is related to the complexity of the problem and the level of detail to be analyzed, The general number of levels is not limited. The number of elements at each level is generally no more than nine, it is because too many elements of dominance can make it difficult to compare and judge.2.3 Construct a judgment matrix.

2.3 Establish judgment matrices

Hierarchical structure reflects the relationship between the factors, but the proportion of each criterion in the target measure at the rule layer is not necessarily the same, they all have the certain proportion in the mind of the decision makers.

The study of power grid performance is very professional, the respondents are required to make professional judgment when you're doing a pairwise comparison, so using the expert investigation method, therefore, ask manager and specialist who work at the power grid construction and operation maintenance and respectively to compare indicators of two different levels, finally determine the important degree of each index factor.

As to how to determine the value of a_{ij}, Saaty suggest referring to the Numbers 1~9 and their inverse as scales. The following table lists the meanings of scale 1 to 9.

Table 2-1 Scale and its meaning

Scale	Meaning
1	It means that the two factors are of equal importance compared to each other
3	It means that the former is slightly more important than the latter
5	It means that the former is significantly more important than the latter
7	It means that the former is highly important than the latter
9	It means that the former is extremely important than the latter
2,4,6,8	It means the intermediate value of the above adjoining judgment
reciprocal	If the ratio of factor i to factor j is a_{ij}, so the ratio of factor i to factor j is $a_{ji}=1/a_{ij}$

2.4 Sort at a single level

Judgment matrix A corresponding to eigenvector W of the largest eigen value λ_{max}, is the sort weights of the relative importance of factors on a level corresponding to the above level, this process known as hierarchical single sort.

The AHP method is used to analyze the factors and their relations. The key is to find the maximum eigen value and eigenvector of each judgment matrix. The specific steps are as follows:

（1）Normalize the judgment matrix column vectors

$$\overline{A_i} = \frac{A_i}{\sum_{j=1}^{n} A_i} \qquad (2\text{-}1)$$

（2）Calculate the geometric average value of each element of the judgment matrix：

$$\overline{W_i} = \sqrt[\frac{1}{n}]{\prod_{j=1}^{n} \overline{a_{ij}}} \qquad (2\text{-}2)$$

Among them i=1,2,3,4,5……n， $\overline{W} = \left[\overline{W}_1, \cdots, \overline{W}_n\right]^T$

（3）Normalized eigenvectors：

$$W_i = \frac{\overline{W_i}}{\sum_{j=1}^{n} \overline{W_i}} \qquad (2\text{-}3)$$

That's the eigenvector；

（4）Calculate the maximum eigenvalue：

$$\lambda_{max} = \sum_{i=1}^{n} \frac{(AW)_i}{nW_i} \qquad (2\text{-}4)$$

2.5 Consistency check

AHP is the approach for making the relative rational choice under fuzzy situation; however, this approach is unavoidable in judging the matrix consistency test, the judgment matrix can be used for sorting only if it through the consistency test. The steps of consistency test of judgment matrix are as follows:

（1）Calculate the consistency index CI :

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad (2\text{-}5)$$

（2）Find the corresponding average random consistency index RI. To $n = 1, \cdots, 9$， The RI values given by Saaty are shown in the following table：

Table 2-2 RI value of judgment matrix

n	1	2	3	4	5
RI	0	0	0.58	0.90	1.12
n	6	7	8	9	
RI	1.24	1.32	1.41	1.45	

（3）Calculate the consistency ratio CR

$$CR = \frac{CI}{RI} \quad (2\text{-}6)$$

When $CR < 0.10$,it is considered that the consistency of judgment matrix is acceptable, otherwise the judgment matrix should be appropriately corrected.

3. Hierarchical analysis of grid performance

3.1 Establishment of AHP model

By analyzing the history, current situation and statistical data of power grid construction and operation at home and abroad, the hierarchical structure model of power grid performance is established, as shown in table 3-1:

Table 3-1 Hierarchical structure model of power grid performance

The target layer	The restriction factor layer	The index layer
Grid performance（A）	The grid structure（B1）	Dual power ratio of 35kV and above substation（C11）
		N-1 pass rate of 35kV and above substations（C12）
		N-1 pass rate of 10（20）kV line（C13）
		Contact ratio of 10（20）kV trunk line（C14）
		Power supply radius qualified rate of 10（20）kV trunk line（C15）
	The power supply ability（B2）	The annual growth rate of transformer capacity（C21）
		The average annual growth rate of distribution transformer capacity（C22）
		Distribution transformer capacity per household（C23）
		Ratio of heavy load, overload distribution transformer（C24）
		Ratio of heavy load, overload distribution line（C25）
		Capacity-load ratio of 110（66）kV substation（C26）
		Capacity-load ratio of 35kV substation 35kV（C27）
	y of power supply（B3）	Reliability power rate（RS-3）（C31）
		Integrated voltage pass rate（C32）
		Resident voltage pass rate（C33）
	Equipment level（B4）	Application ratio of load regulating main transformer in 35kV and above substations（C41）
		Application ratio of S7 and below high energy consumption transformer（C42）
		Insulation rate of 10kV and below overhead lines（C43）
		Reactive power compensation installation rate of 100kVA and below distribution transformer（C44）
	Science and technology progress（B5）	Optical cable communication coverage of substations（C51）
		Unattended ratio of substations（C52）
		Comprehensive monitoring system coverage of distribution transformer（C53）
		Resident remote meter reading coverage（C54）

3.2 Form a comparison matrix

Relevant experts are invited to conduct a paired comparison of the importance of each sub-layer factor to the upper layer factor, and the comparison matrix (also known as judgment matrix) is obtained, as shown in table 3-2 to table 3-7:

Table 3-2

A—B	B1	B2	B3	B4	B5
B1	1	3	2	3	1/5
B2	1/3	1	1/3	2	1/5
B3	1/2	3	1	2	1/3
B4	1/3	1/2	1/2	1	1/2
B5	5	5	3	2	1

Table 3-3

B1—C1	C11	C12	C13	C14	C15
C11	1	3	3	3	5
C12	1/3	1	1/3	1/3	1/3
C13	1/3	2	1	2	4
C14	1/3	1/2	1/2	1	2
C15	1/5	3	1/4	1/2	1

Table 3-4

B2—C2	C21	C22	C23	C24	C25	C26	C27
C21	1	3	3	5	5	7	5
C22	1/3	1	1	3	3	5	3
C23	1/3	1	1	3	3	5	3
C24	1/5	1/3	1/3	1	1	3	1
C25	1/5	1/3	1/3	1	1	3	1
C26	1/7	1/5	1/5	1/3	1/3	1	1/3
C27	1/5	1/3	1/3	1	1	3	1

Table 3-5

B3—C3	C31	C32	C33
C31	1	5	3
C32	1/5	1	1/3

Table 3-6

B4—C4	C41	C42	C43	C44
C41	1	1/3	1	7
C42	3	1	3	9
C43	1	1/3	1	3
C44	1/7	1/9	1/3	1

Table 3-7

B5—C5	C51	C52	C53	C54
C51	1	1/5	1/3	3
C52	5	1	3	3
C53	3	1/3	1	1/3
C54	1/3	1/3	3	1

3.3 Determination of influence coefficient (weight) by AHP

According to equations 2-1 to 2-4, the influence coefficients (weights) of each index are calculated as follows:

Each index's weight of power grid performance (A) is: W_A=[0.21，0.09，0.16，0.10，0.44]^T

Each index's weight of the grid structure（B1） is: W_{B1}=[0.43，0.08，0.25，0.12，0.12]^T

Each index's weight of the power supply ability（B2）is: W_{B2}=[0.38，0.18，0.18，0.07，0.07，0.03，0.07]^T

Each index's weight of quality of power supply（B3） is: W_{B3}=[0.64，0.11，0.26]^T

Each index's weight of equipment level（B4） is: W_{B4}=[0.22，0.55，0.18，0.05]^T

Each index's weight of science and technology progress（B5） is: W_{B5}=[0.17，0.47，0.17，0.19]^T

3.4 Consistency check

According to the formula, the maximum eigen values corresponding to the above eigenvectors are：

λ_{max}=[5.42，5.25，7.41，3.04，4.12，5.11]^T

According to formula 2-5 to 2-6：

CR=[0.094，0.056，0.052，0.031，0.044，0.025]^T

CR was all less than 0.1, all six judgment matrices passed the consistency test.

3.5 Total ranking of the layers

According to the principle of AHP, the components of the characteristic vectors of each judgment matrix are the influence coefficient (weight) of the layer factors relative to the upper layer factors. The influence coefficient of layer C on layer A can be calculated by the combination of corresponding weights, and the results are shown in table 3-8.

4. Conclusion

（1）In the process of comprehensive evaluation of power grid performance by AHP method, the number of influencing factors (indicators) can be increased or deleted dynamically according to the actual situation, so as to ensure the comprehensiveness and accuracy of the evaluation.

（2）In the process of constructing the judgment matrix, it fully reflects the opinions and Suggestions of decision makers and experts, enhances the effectiveness of decision making, and makes the construction of power grid and the optimization of power grid structure more scientific.

（3）In the performance evaluation of power grid, it is the key point to select the evaluation analysis method reasonably. In this paper, analytic hierarchy process (AHP) is used to analyze the performance indicators of power grid. Through analysis and research, it can be obtained that AHP is an effective and operable method in the practical application of power grid performance evaluation and grade division and can be well applied to power grid performance evaluation.

（4）In the process of power grid construction and network structure optimization, decision makers should take into full account various influencing factors, according to the weight of comprehensive indicators obtained by AHP analysis, implement power grid construction projects in a targeted way, and improve the scientific nature of power grid planning and construction.

Table 3-8 Total ranking of grid performance evaluation model

The target layer	The weight	The restriction factor layer	The weight	The index layer	Total ranking
Grid performance（A）	0.21	The grid structure（B1）	0.43	Dual power ratio of 35kV and above substation（C11）	0.090
			0.08	N-1 pass rate of 35kV and above substations（C12）	0.017
			0.25	Pass rate of 10（20）kV line（C13）	0.053
			0.12	Contact ratio of 10（20）kV trunk line（C14）	0.025
			0.12	Power supply radius qualified rate of 10（20）kV trunk line（C15）	0.025
	0.09	The power supply ability（B2）	0.38	The annual growth rate of transformer capacity（C21）	0.034
			0.18	The average annual growth rate of distribution transformer capacity（C22）	0.016
			0.18	Distribution transformer capacity per household（C23）	0.016
			0.07	Ratio of heavy load, overload distribution transformer（C24）	0.006
			0.07	Ratio of heavy load, overload distribution line（C25）	0.006
			0.03	Capacity-load ratio of 110（66）kV substation（C26）	0.002
			0.07	Capacity-load ratio of 35kV substation 35kV（C27）	0.006
	0.16	Quality of power supply（B3）	0.64	Reliability power rate（RS-3）（C31）	0.102
			0.11	Integrated voltage pass rate（C32）	0.018
			0.26	Resident voltage pass rate（C33）	0.042
	0.10	Equipment level（B4）	0.22	Application ratio of load regulating main transformer in 35kV and above substations（C41）	0.022
			0.55	Application ratio of S7 and below high energy consumption transformer（C42）	0.055
			0.18	Insulation rate of 10kV and below overhead lines（C43）	0.018
			0.05	Reactive power compensation installation rate of 100kVA and below distribution transformer（C44）	0.005
	0.44	Science and technology progress（B5）	0.17	Optical cable communication coverage of substations（C51）	0.075
			0.47	Unattended ratio of substations（C52）	0.207
			0.17	Comprehensive monitoring system coverage of distribution transformer（C53）	0.075
			0.19	Resident remote meter reading coverage（C54）	0.084

5.References

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