Construction and case study of total factor evaluation index system of power generation enterprises

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Abstract. The electric power enterprises cannot cope with the current electric power system reform trend If they do not have enough competition abilities. Therefore, how to construct competitiveness evaluation system for power enterprises according to the characteristics of power market plays an important role in improving the scientific management level of electric power enterprises. This paper designs the evaluation system of total factor competitiveness of power generation enterprises, including market force, marketing force, development force, reliability, economy, flexibility, environmental protection. Analytic hierarchy process and fuzzy comprehensive evaluation method are used to determine the weight and the final evaluation basis.

1 The introduction

With the deepening of China's electric power system reform, power generation enterprises, especially the regional power generation enterprises with multi-source power, are facing the new normal of economy, new power transformation and the complex and changeable new situation of energy industry. How to cultivate and enhance the market competitiveness on the basis of inheritance, grasp the market opportunities, meet the challenges, and further enhance the status and influence of the industry will become a common issue for the power system industry. The competitive elements of power market of power generation enterprises should be oriented by low cost and high benefit, create the goal of maximizing economic benefit, realize efficient production, economic operation and benefit marketing, configure and perfect production and marketing system and evaluation mechanism, and help improve the overall competitiveness of enterprises in the market. In other words, we should try to achieve as much generating capacity as possible, as low cost as possible, and as high quotation as possible in the electricity market.

Therefore, the following factors should be taken into account when considering the competitive factors of power generation enterprises in the electricity market. (1) Profitability. The profitability of competitive elements is mainly reflected in reducing costs, improving quotations and creating profits, bringing considerable value and benefits to enterprises. (2) Economy. Multi-source power generation enterprises involve wind power, photovoltaic power, hydropower, thermal power and other forms of energy. Economic operation requires improving market competitiveness by optimizing economic operation mode, optimizing allocation of power generation resources and power structure, and optimizing maintenance arrangements. (3) Safe and reliable. Safety and stability of electric power production is the basic condition for power generation enterprises to create economic benefits. (4) High efficiency and energy saving. We promote the innovation of production technology and enhance the competitiveness by means of energy saving, consumption reduction and energy utilization efficiency. (5) Environmental protection. The competitiveness of power generation enterprises involving thermal power should highlight environmental factors, mainly in clean emission. At present, many research results have solved the problem of power generation enterprise competitiveness evaluation to a certain extent, but at the same time, due to the incomplete index system, the evaluation results lack of practicality and guidance. More often, power generation enterprises invest less in competitiveness evaluation, and often use the form of empirical judgment to identify the competitiveness, which may easily lead to problems such as incomplete consideration of factors and inaccurate judgment results, directly affecting the competitive decisions of power generation enterprises in the market. In view of this, this paper constructs the competitiveness evaluation system of total factor power generation enterprises, and determines the evaluation method, in order to play a practical role in the evaluation of power generation enterprises.

2 Construction of evaluation index of total factor competitiveness of power generation enterprises

Power generation enterprises involving multi-source power usually cover thermal power, hydropower, wind power, photovoltaic and other power generation systems.

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In the market environment, competitive factors mainly include: (1) Quantity. The quantity mainly reflects the competitiveness of power generation enterprises in the export of products and services. The main influencing factors include: electricity, heat, cold capacity and other products, as well as the factors that affect the output capacity of products, such as asset optimization, network structure, equipment capacity and fuel supply. Support services and customer service. (2) Price. The price mainly reflects the competitiveness of market quotation, and the main influencing factors include: supply and demand forecasting ability, market simulation, market price forecasting technology, quotation technology, policy and market research ability, etc. (3) Cost. The cost mainly reflects the cost competitiveness of external products of power generation enterprises, which mainly includes fixed cost and variable cost as well as related factors affecting cost, among which variable cost is the key factor of market competition.

Based on the quantity, price and cost as a starting point, this paper combines marketing work flow mechanism and core competitive factors of wind power, solar, hydropower, thermal power generating system, in the building of index, follows the scientific, comparable, growth, systematic, quantifiable indicators, such as design principles, to obtain objective and accurate evaluation results.

According to the above principles, after investigating specific power generation enterprises and consulting the opinions of many experts in the industry, the competitiveness evaluation will be finally determined from the seven aspects of market power, marketing power, development power, reliability, economy, flexibility and environmental protection, as shown in table 1.

Table 1. Total factor competitiveness evaluation index.

NO.	Index 1	Index 2
1	Market power(B1)	Market share (C11)
2		Priority generation capacity ratio (C12)
3		Base power ratio (C13)
4		Network structure (transport capacity) (C14)
5	Marketing force (B2)	Market share of electricity (C21)
6		Market price reduction rate (C22)
7		heating plan completion rate (C23)
8		Abandon wind, light and water rate (C24)
9		Heating charges recovery rate (C25)
10		Electricity charges recovery rate (C26)
11	Developme nt (B3)	Research funding(C31)
12		Sales growth rate (C32)
13		Unit life (C33)
14		Annual new authorized installed capacity (C34)
15		Clean energy installed capacity (C35)
16	Reliability (B4)	Equivalent availability coefficient (C41)
17		Unplanned outage factor (C42)
18		Planned generation completion rate (C43)
19		Maintenance quality (C44)
20	Economy (B5)	Marginal contribution per kilowatt hour (C51)
21		Marginal contribution of heating units (C52)
22		Power coal consumption (C53)
23		Integrated power utilization (C54)
24		Profit of transferred electric quantity (C55)
25		Profit from power generation rights trading (C56)
26	Flexibility (B6)	Peak shaving power supply ratio（C61)
27		AGC corresponding time（C62)
28		Peak and frequency modulation ability （C63)
29		Rotary reserve compensation（C64)
30	Environmen -tal protection (B7)	Penalty of environmental protection electricity price（C71)
31		Standard discharge rate（C72)
32		Environmental subsidies（C73)

3 Index weighting and competitiveness evaluation method

We need a set of scientific evaluation model and method to scientifically evaluate the core competitiveness of power generation enterprises according to the above index system. Through the evaluation, the real situation of the enterprise can be reflected truthfully. In this paper, fuzzy comprehensive evaluation method is applied, which is a widely used method and obtains good results in other fields. On the basis of competitiveness index system, the evaluation model of power generation enterprise competitiveness is constructed.

3.1 Determination of index weight

Reasonable weight determination plays a decisive role in comprehensive evaluation. Here, we use analytic hierarchy process (AHP) to determine the weight of indicators. AHP was proposed by American scholar T.L. Saaty in 1977. AHP method, the basic idea is to divide complex things into several orderly level, set up a description system features or characteristics of internal independent class hierarchy. According to the judgment of an objective thing, we construct the "comparative judgment matrix". Based on the maximum eigenvalue of the matrix and its corresponding eigenvector, and on the premise of passing the consistency test, the weight of relative importance order of each element in each level is determined; Through the analysis of each level, the analysis of the whole problem is derived, that is, the total ranking weight.

(1) Build hierarchical model.

The highest level refers to the purpose of the decision and the problem to be solved. The lowest level refers to alternatives when making decisions. The middle layer refers to the factors to be considered and the criteria for decision-making. For the two adjacent layers, the upper layer is called the target layer and the lower layer is called the factor layer.

(2) Construct judgment matrix.

The essence of the judgment matrix is a subjective judgment process, decision maker or relevant expert compare the relative importance of the factors related to this level in pairs. The judgment matrix has the following properties.

$$b_{ij} = 1/ b_{ij} \quad (1)$$

The scale method of judgment matrix element b_ij is as follows.

Table 2. Scaling method for matrix element b_{ij}

Factor i over factor j	Quantitative values
As important	1
A little important	3
More important	5
Highly important	7
Extremely important	9
Intermediate value of two adjacent judgments	2，4，6，8

(3) Calculate the characteristic roots λ_{max} of the judgment matrix.

The square root method is used here. The normalization of each component of the eigenvector is the weight value of the corresponding element of the same level for a factor of the upper level.

(4) Hierarchical ranking and consistency test of judgment matrix.

According to the above evaluation index system, the indexes of the main criterion layer, namely the first-level indexes, are:

$X=(X_1, X_2, X_3, X_4, X_5, X_6, X_7)$;

Sub-criteria layer indicators, namely secondary indicators are:

$X_1=(X_{11}, X_{12}, X_{13}, X_{14})$,
$X_2=(X_{21}, X_{22}, X_{23}, X_{24}, X_{25}, X_{26})$,
$X_3=(X_{31}, X_{32}, X_{33}, X_{34}, X_{35})$,
$X_4=(X_{41}, X_{42}, X_{43}, X_{44})$,
$X_5= (X_{51}, X_{52}, X_{53}, X_{54}, X_{55}, X_{56})$,
$X_6=(X_{61}, X_{62}, X_{63}, X_{64})$,
$X_7=(X_{71}, X_{72}, X_{73})$,

Let the weight of principal criterion layer B to target layer A be set as B1, B2, B3, B4, B5, B6, B7 respectively, and $\sum^{7}_{i=1}B_i=1$, the corresponding weight matrix is B= (B1, B2, B3, B4, B5, B6, B7) . The weight of sub-criterion layer C to the main criterion layer B is W1, W2, W3, W4, W5, W6, W7 respectively, and

$\sum^{7}_{i=1}W_i=1$, The corresponding weight matrix is:

$W_1=(W_{11}, W_{12}, W_{13}, W_{14})$,
$W_2=(W_{21}, W_{22}, W_{23}, W_{24}, W_{25}, W_{26})$,
$W_3=(W_{31}, W_{32}, W_{33}, W_{34}, W_{35})$,
$W_4=(W_{41}, W_{42}, W_{43}, W_{44})$,
$W_5=(W_{51}, W_{52}, W_{53}, W_{54}, W_{55}, W_{56})$,
$W_6=(W_{61}, W_{62}, W_{63}, W_{64})$,
$W_7=(W_{71}, W_{72}, W_{73})$,

If hierarchical ordering can be confirmed, consistency test is required. Where, the unique non-zero characteristic root of n-order uniform matrix is n; The maximum characteristic root of n-order positive reciprocal matrix A, if and only if λ=n, A is an uniform matrix. Consistency indicators are defined as:

$$CI =(\lambda-n)/(n-1) \quad (2)$$

CI=0, complete consistency; CI is close to 0, with satisfactory consistency; The larger CI is, the more serious the inconsistency is. To measure the size of CI, random consistency index RI is introduced:

$$RI= (CI_1+CI_2+...+ CI_n)/n \quad (3)$$

In general, the higher the order of matrix, the higher the probability of consistent random deviation.

$$CR=CI/RI \quad (4)$$

If CR<0.1, it is considered that the hierarchical ordering has a satisfactory consistency; otherwise, it is necessary to adjust and modify the judgment matrix of this level until the overall ordering of the hierarchy reaches a satisfactory consistency.

(5) The total weight conclusion is drawn.

3.2 Competitiveness evaluation method

(1) Determine the set of judgment comments.

For the above-mentioned evaluation index system, according to the concept of enterprise competitiveness, the following comment set is adopted: *Y= (Y1, Y2, Y3,*

Y4, Y5) = {Strong, Secondary Strong, Medium, Weak, Poor}.

(2) Establish fuzzy evaluation matrix.

Fuzzy evaluation matrix *Ai* (I =1,2,3,4,5,6,7) is established for each evaluation index Xi in the main criteria layer. By considering the classification factor index Xij in layer C, the degree of its subordination to the t-th evaluation Yt is judged to be r_{ijt}, and Xi's fuzzy evaluation matrix Ri can be obtained. For example,

$$R_1=\begin{bmatrix} r_{111} & r_{112} & r_{113} & r_{114} & r_{115} \\ r_{121} & r_{122} & r_{123} & r_{124} & r_{125} \\ r_{131} & r_{132} & r_{133} & r_{134} & r_{135} \\ r_{141} & r_{142} & r_{143} & r_{144} & r_{145} \end{bmatrix}$$

Now we can determine the fuzzy comprehensive discriminant set Ai of the first-level indicators. We use Ai=Wi○Ri (I =1,2,3,4,5,6,7) to obtain the comprehensive fuzzy discriminant set Ai= (ai1, ai2, ai3, ai4, ai5).

$\underline{A}_1=W_1\circ R_1=(a_{11}, a_{12}, a_{13}, a_{14}, a_{15})$,

$\underline{A}_2=W_2\circ R_2=(a_{21}, a_{22}, a_{23}, a_{24}, a_{25})$,

$\underline{A}_3=W_3\circ R_3=(a_{31}, a_{32}, a_{33}, a_{34}, a_{35})$,

$\underline{A}_4=W_4\circ R_4=(a_{41}, a_{42}, a_{43}, a_{44}, a_{45})$,

$\underline{A}_5=W_5\circ R_5=(a_{51}, a_{52}, a_{53}, a_{54}, a_{55})$,

$\underline{A}_6=W_6\circ R_6=(a_{61}, a_{62}, a_{63}, a_{64}, a_{65})$,

$\underline{A}_7=W_7\circ R_7=(a_{71}, a_{72}, a_{73}, a_{74}, a_{75})$.

$\underline{A}=(\underline{A}_1, \underline{A}_2, \underline{A}_3, \underline{A}_4, \underline{A}_5, \underline{A}_6, \underline{A}_7)^T$

Finally determine the fuzzy evaluation matrix of the evaluation object:

$$E= B\circ\underline{A}=(e_1, e_2, e_3, e_4, e_5) \quad (5)$$

$$e_i'=e_i/\sum e_i \quad (i=1,2,3,4,5) \quad (6)$$

$$E' =(e_1', e_2', e_3', e_4', e_5') \quad (7)$$

ei 'corresponds to the previous comment element Yi respectively. From the perspective of probability, the probability in conformity of this ability and enterprise competitiveness is e_i'. According to the maximum membership principle in fuzzy mathematics, the core competitiveness of enterprises is evaluated.

4 A case study on total factor competitiveness of W company

W company is mainly engaged in hydropower, thermal power, new energy and coal development, which is an integrated energy enterprise. The total installed power capacity of the company is 13.245 million kW, including 8.695 million kW of hydropower, 4.5 million kW of thermal power and 50,000 kW of new energy.

4.1 Using the analytic hierarchy process (AHP) to weight the index

By constructing the judgment matrix and hierarchy single sort, the hierarchy total sort and consistency test are completed.

Table 3. Total hierarchical ordering.

B / c	B1	B2	B3	B4	B5	B6	B7	C-level ordering
	0.379	0.167	0.0976	0.057	0.233	0.04	0.026	
c1	0.643							0.2437
c2	0.048							0.0182
c3	0.101							0.0383
c4	0.208							0.0788
c5		0.491						0.0820
c6		0.222						0.0370
c7		0.093						0.0156
c8		0.093						0.0156
c9		0.050						0.0084
c10		0.050						0.0084
c11			0.233					0.0228
c12			0.526					0.0514
c13			0.070					0.0068
c14			0.041					0.0040
c15			0.129					0.0126
c16				0.275				0.0157
c17				0.138				0.0079
c18				0.512				0.0292
c19				0.074				0.0042
c20					0.486			0.1133
c21					0.122			0.0285
c22					0.225			0.0524
c23					0.037			0.0087
c24					0.065			0.0151
c25					0.065			0.0151
c26						0.400		0.0160
c27						0.200		0.0080
c28						0.200		0.0080
c29						0.200		0.0080
c30							0.200	0.0052
c31							0.600	0.0156
c32							0.200	0.0052

Consistency test of c-level total ranking is shown in table 4.

Table 4. Total hierarchical ordering.

B / C	B1	B2	B3	B4	B5	B6	B7	index
	0.379	0.167	0.098	0.057	0.233	0.04	0.026	
CI	0.058	0.009	0.019	0.004	0.015	0	0	0.029
RI	0.9	1.24	1.24	0.9	1.24	0.9	0.58	1.045

CR=CI/RI=0.029/1.045=0.028<0.1, so the consistency of the overall ranking at level C is satisfactory.

4.2 Fuzzy comprehensive evaluation and analysis

Through questionnaire analysis and data processing, the fuzzy comprehensive analysis and evaluation of the core competitiveness of the independent power generation enterprise is conducted as follows:

(1) It is known that the weight vector of the sub-criteria layer to the principal criteria layer is:

$W_1=(W_{11},W_{12},W_{13},W_{14})$=(0.643,0.048,0.101,0.208);

$W_2=(W_{21},W_{22},W_{23},W_{24},W_{25},W_{26})$=(0.491,0.222,0.093, 0.093,0.005,0.005);

$W_3=(W_{31},W_{32},W_{33},W_{34},W_{35})$=(0.233,0.526,0.07, 0.041,0.129);

$W_4=(W_{41},W_{42},W_{43},W_{44})$=(0.275,0.138,0.512,0.074);

$W_5=(W_{51},W_{52},W_{53},W_{54},W_{55},W_{56})$=(0.486,0.122,0.225, 0.037,0.065,0.065);

$W_6=(W_{61},W_{62},W_{63},W_{64})$=(0.4,0.2,0.2,0.2);

$W_7=(W_{71},W_{72},W_{73})$=(0.2,0.6,0.2).

(2) The weight vector of the principal criterion layer to the target layer is:

$B=(B_1,B_2,B_3,B_4,B_5,B_6,B_7)$=(0.379,0.167,0.0976,0.057, 0.233,0.04,0.026).

(3) The following comment set is adopted: $Y=(Y1, Y2, Y3, Y4, Y5)$ = {Strong, Secondary Strong, Medium, Weak, Poor}.

(4) Through expert investigation and analysis, the membership degree of indicator Xij to Y under factor index Xi of C-layer is sorted out, and the fuzzy evaluation matrix Ri of Xi is obtained.

(5) Determine the membership degree of each index in the principal criterion layer to Y, so as to obtain the fuzzy matrix A of X.

$\underline{A}_1=W_1\circ R_1$=(0.317,0.494,0.147,0.042,0),

$\underline{A}_2=W_2\circ R_2$=(0.186,0.359,0.203,0.119,0.042),

$\underline{A}_3=W_3\circ R_3$=(0.211,0.363,0.208,0.133,0.084),

$\underline{A}_4=W_4\circ R_4$=(0.138,0.512,0.322,0.018,0.01),

$\underline{A}_5=W_5\circ R_5$=(0.003,0.128,0.483,0.315,0.072),

$\underline{A}_6=W_6\circ R_6$=(0.174,0.4,0.222,0.198,0),

$\underline{A}_7=W_7\circ R_7$=(0.468,0.386,0.106,0.04,0).

$\underline{A}=(\underline{A}_1,\underline{A}_2,\underline{A}_3,\underline{A}_4,\underline{A}_5,\underline{A}_6,\underline{A}_7)^T$

(6) The degree of subordination of the comment set Y to the total factor competitiveness of power generation enterprises

$E=B\circ A$=(0.199,0.368,0.252,0.132,0.033).

Normalization is carried out:

$\sum_{i=1}^{5} e_i$=0.984，

$e_i'=e_i/\sum e_i$ (i=1,2,3,4,5)

$E'=(e_1', e_2', e_3', e_4', e_5')$= (0.202,0.374,0.256,0.134,0.034)

Where, e_i' respectively corresponds to the previous comment set element Yi.

(7) From the above calculation results, it can be shown that: 20.2% of the assurance that the power generation enterprise competitiveness is strong, 37.4% of the assurance that the power generation enterprise competitiveness is strong, 25.6% of the assurance that the power generation enterprise competitiveness is general, 13.4% of the assurance that the power generation enterprise competitiveness is weak, 3.4% of the assurance that the power generation enterprise competitiveness is weak. According to the principle of maximum membership, we can judge the competitiveness of the enterprise is strong.

5 Conclusion

The evaluation of the competitiveness of power generation enterprises is a concept with wide coverage and complex content. In view of the multi-source power enterprises under the environment of power market, it is necessary to analyze the objective facts of enterprises based on scientific methods, take the market as the entry point, and measure them reasonably.

This study focuses on the analysis of the power market elements of power generation enterprises, namely, from the seven aspects of enterprise market power, marketing power, development power, reliability, economy, flexibility and environmental protection to evaluate the sustainable development ability and market competitiveness of enterprises. We have integrated the domestic and foreign evaluation indexes, and introduced the relevant indexes in the power marketing, which is more conducive to the enterprise to clarify the advantages and disadvantages in the strategic planning.

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