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The study of power grid emergency capacity evaluation method based on Fuzzy Analytic Hierarchy Process

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Abstract

When the power grid encountered the strong external force, there will be a large area of power failure phenomenon, and now the corresponding emergency response measures rarely. Based on this, this paper presents a method of evaluating the emergency capability of power grids based on the fuzzy analytic hierarchy process (AHP), which aims to study the level of emergency capability of current power grid and find its weak links to improve and improve the stability of power system. Firstly, based on the actual situation of China's power grid enterprises, determine the evaluation index system. Secondly, the corresponding index weights are calculated by the analytic hierarchy process. Finally, according to the weight distribution, the fuzzy evaluation of the power system emergency system is carried out to determine the emergency ability. And according to the actual situation of enterprises, carrying out the simulation, the results verify the validity of the proposed method.

Keywords: Fuzzy; analytic hierarchy process; grid; assessment

0 Introduction

Widespread power outages in the power grid have had a serious impact on economic, social and human life. So, to enhance power system deal with risk assessment level, to guarantee the safe and stable operation of power system, avoid blackouts and minimize losses after blackout is of great significance. In view of the research on power grid emergency capacity assessment, scholars at home and abroad have paid great attention. Literature [1] proposed a fuzzy comprehensive evaluation method to evaluate the risk of power system in large cities. Literature [2] in order to effectively reduce the power failure of power grid and effectively evaluate

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the emergency capacity of power grid, the index system was established and the fuzzy comprehensive evaluation method was adopted to comprehensively evaluate it. Literature [3] established the influence of factors on the scheduling and evaluated the electric power grid risk according to historical information and current operating conditions. Literature [4-6] based on the characteristics of urban power grid emergencies, it has constructed an evaluation index system of urban power grid emergency capability assessment and improved the emergency capacity of urban power grid. Literature [7] established the evaluation index of power grid emergency capability and put forward the research on the evaluation of power grid emergency capability level based on the entropy weight method. Literature [8] organized experts to discuss the emergency capability index system of power grid enterprises, reviewed and formulated relevant indicators system, which provided reliable theoretical support for the emergency assessment of power grid. Although has acquired the above research results, the emergency capability assessment of the power grid is still in its infancy stage. It is not realized to combine the establishment of the indicator system with the emergency assessment of the actual power grid and realize the research results of the theoretical connection. Based on the current research status, this paper builds a suitable evaluation index system according to the actual characteristics of China's power grid. And the fuzzy analytic hierarchy process is used to realize the numerical calculation and analysis of the index model of the theory. The theory is connected with practice and verified by simulation to verify the reliability of this scheme.

1. Evaluation system of power grid emergency management capability.

1.1EVALUATION INDEX SYSTEM

The emergency evaluation index of power grid needs to comprehensively consider the factors that affect the power failure of the power grid, which should fully reflect its overall characteristics.

The construction of the evaluation index system is mainly analyzed from the following aspects, as shown in FIG. 1 [9].

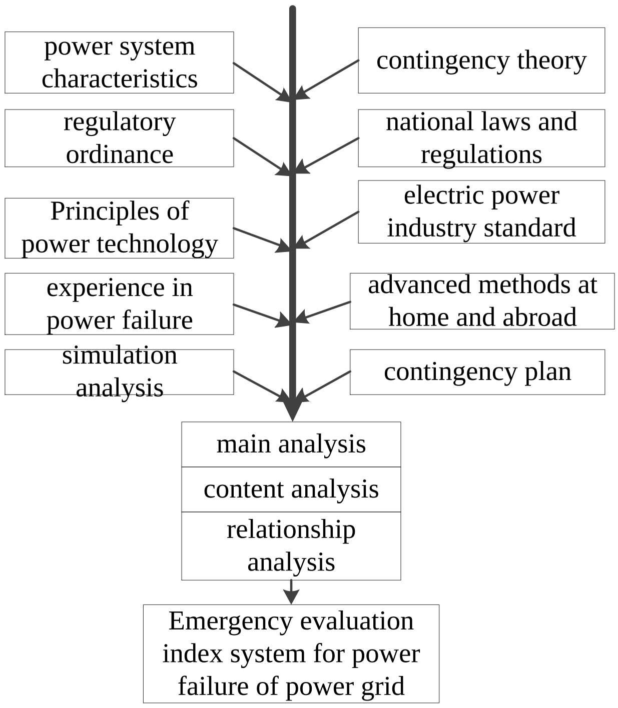

Fig1 Indicator system source

Combined with the current research results on the evaluation of power grid emergency capacity,

the evaluation index requires rationality, practicability, representativeness, scientificity, universality and comprehensiveness and ease of operation. According to the above standards, the evaluation index system of emergency capacity of power grid enterprises is preliminarily constructed. Therefore, the indicators constructed in this paper include four levels of corresponding indicators, 12 secondary indicators and 38 tree indicators. Through

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the corresponding indicators in this direction, the corresponding indexes of the top level, level I and level ii are composed of the corresponding indicators, as shown in table 1 [11].

1.2 EVALUATION CRITERIA FOR EMERGENCY CAPABILITY

According to the characteristics of the power grid emergency accident emergency management ability, and the index system of power grid emergency, the emergency accident emergency ability is divided into four levels, the division standard is shown in table 2 [12].

2. Fuzzy analytic hierarchy process.

2.1ANALYTIC HIERARCHY PROCESS

Analytic hierarchy process (AHP) was proposed by T.L in the 1970s and is a systematic analysis method. AHP continuous decomposition evaluation targets are evaluated at all levels and the lowest level is used as the evaluation index. There are four steps to solve the problem by using the AHP method: the hierarchical model of the problem, the construction judgment matrix, the single layer weight calculation and the synthesis weight calculation.

2.1.1 Establish a hierarchical model of the problem. The hierarchical analytic hierarchy can be expressed as table 3.

Tab 1 Evaluation index of emergency capability of power grid enterprises

total indicator	level indicators	secondary indicators
The emergency capacity of power grid power failure A	Emergency preparedness for mitigation B1	construction of emergency organization systemC1
		construction of emergency command centerC2
		secondary system safety protectionC3
		preplan preparation standard and plan systemC4
	Power supply recovery readiness B2	emergency warning capacityC5
		emergency safeguard capacityC6
		training, publicity and actingC7
	Power supply recovery response capability B3	Event classification and emergency disposalC8
		emergency coordination mechanismC9
	Power supply recovery capability B4	power system black startC10
		accident investigationC11
		information reports and press releasesC12

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Tab 2 Emergency capability level

the level of emergency capability	Value C	Emergency capacity
excellent	85≤C	can well meet the needs of emergency rescue work and emergency preparedness
good	75≤C<85	can meet the needs of emergency rescue work and emergency preparedness
general	75≤C<85	cannot fully meet the needs of emergency rescue work and emergency preparedness
poor	C<65	cannot meet the needs of emergency rescue work and emergency preparedness

Tab 3 hierarchical structure of AHP

A				the target layer
B1	B2	……	Bm	primary index layer
C1	C2	……	Cm	secondary index layer
……	……	……	……	……
Z1	Z2	……	Zm	Z index layer

2.1.2 Construct decision matrix.

As shown in table 4, the judgment matrix represents the relationship between A factor and the next layer factor B1,B2 ,⋯, Bm. In this case, to determine the comparison judgment matrix A=(bij)m×m, we should compare the importance of B1,B2,…, Bm.

Tab 4 comparision matrix

A	B1	B2	……	Bm
B1	b11	b12	……	b1m
B2	b21	b22	……	b2m
……	……	……	……	
Bm	bm1	bm2	……	bmm

There are m elements in a layer: $X_1, X_2 \cdots X_n$, Construct an n-order judgment matrix: $Q=(q_{ij})_{n\times n}$, Where q_{ij} represents the ratio of element X_i to X_j about the importance of an element in the upper class.

The relative importance scale is proposed to determine the weight of element bij in the judgment matrix. The specific scale is determined as shown in table 5.

2.1.3 Calculation of single-layer weight.

After the judgment matrix is established, an n-order decision matrix C.I. is constructed for nonzero eigenvalues of $\lambda_{\max}$.

$$C.I.=\frac{\lambda_{\max}-n}{n-1} \qquad (1)$$

Consistency index $R.I.(\text{Random Index})$, as shown in table 6:

Tab 5 scale of relative importance

qij	instruction
1	attribute xi is of the same importance as attribute xj
3	attribute xi is slightly more important than attribute xj
5	attribute xi is significantly more important than attribute xj
7	attribute xi is more important than attribute xj
9	attribute xi is more important than attribute xj
2,4,6,8, bottom	value in the above judgment. element xi and xj are compared to be judged bij, and the elements are compared to determine bji=1/bij

Tab 6 Mean random consistency index R.I.

n	1	2	3	4	5	6	7	8	9	10
R. I.	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

C. R. Determined by the following formula:

$$C.R.=\frac{C.I.}{R.I.} \qquad (2)$$

When the consistency ratio $C.I.<0.1$, it is considered within the permissible range. Otherwise, you need to reconstruct the judgment matrix.

2.1.4Calculation of synthetic weights.

The synthetic weight of all factors on the target layer in the calculation hierarchy model is called hierarchical total ordering. The ultimate problem of analytic hierarchy process is to find the synthesis weight of the underlying elements relative to the target. The calculation of synthetic weight is carried out from top to bottom.

The single layer weight of the second layer is the synthetic weight. The composition weight of the m elements of $k-1$ layer on the target layer is as follows:

$$\varepsilon^{(k-1)}=(\varepsilon_1^{k-1},\varepsilon_2^{k-1},\cdots\varepsilon_m^{k-1})^T \qquad (3)$$

The single layer weight of all n elements on the $k-1$ layer with respect to the jth element of the first layer is:

$$p_j^{(k)}=(p_{1j}^{(k)},p_{2j}^{(k)},\cdots,p_{nj}^{(k)},)^T, \qquad (4)$$

j=1,2…m

In this case, the power reuse of 0 which is not supported by the jth element of the $k-1$ layer.

Let $P^{(k)}=(p_1^{(k)},p_2^{(k)},\cdots p_m^{(k)})$ represent the single-layer weight matrix of layer k on the $k-1$ layer. The $k-1$ layer contains m elements. The composition weight of layer k element on the target layer can be calculated by the following formula:

$$\varepsilon^{(k)}=P^{(k)}\varepsilon^{(k-1)} \qquad (5)$$

or

$$\varepsilon_i^{(k)}=\sum_{j=1}^{m} p_{ij}^{(k)}\varepsilon_j^{(k-1)}, \qquad (6)$$

i=1,2,…,n

Assumed that the consistency index, random consistency index, and consistency ratio of the jth element of the $k-1$ layer are denoted as $C.I.^{(k)}$、$R.I.^{(k)}$和$C.R.^{(k)}$, $j=1,2,\ldots,m$, respectively.

Then, the comprehensive calculation of the k layer is as follows:

$$C.I.^{(k)}=(C.I._1^{(k)},C.I._2^{(k)},\cdots,C.I._n^{(k)},)w^{k-1} \qquad (7)$$

$$R.I.^{(k)}=(R.I._1^{(k)},R.I._1^{(k)},\cdots,\ R.I._n^{(k)})w^{(k-1)} \qquad (8)$$

$$C.R.^{(k)}=\frac{C.I.^{(k)}}{R.I.^{(k)}} \qquad (9)$$

If CR<0.1, it is accepted that the consistency of judgment matrix and single sort results is acceptable. Otherwise, you need to adjust the value of the judgment matrix element and recalculate.

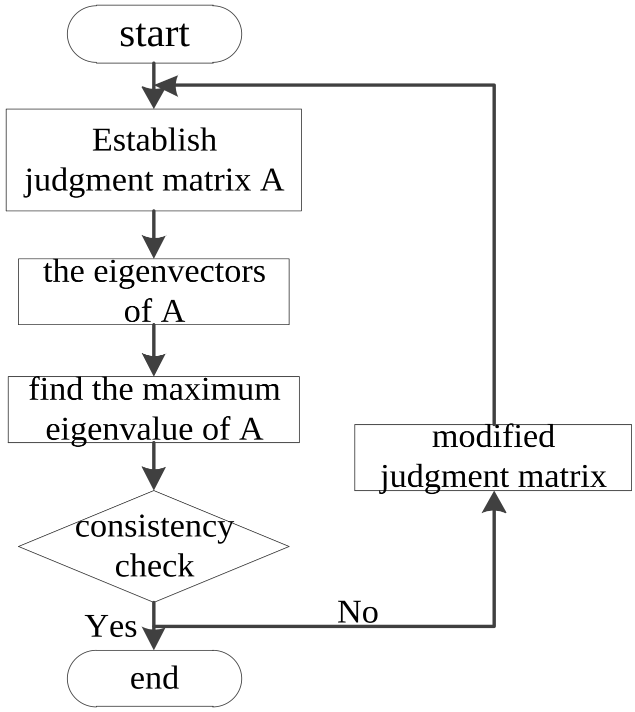

Fig 2 flow chart of AHP

2.2 FUZZY EVALUATION METHOD

The flowchart of the fuzzy evaluation method is shown in figure 3

E represents the difference between the predicted value and the expected value, and u represents the current value. Define fuzzy control rules by table 7. Among them, NB: is the deviation of direction big. NM: the deviation in the negative direction. NS: it is a small deviation in the negative direction. ZO: it's close to 0. PS: it's a small deviation in the positive direction. PM: the deviation in the positive direction. PB: it is a deviation in the positive direction.

Table 7 the table of fuzzy control rule

e u	NB	NM	ZO	PM	PB
PB	1	0	0	0	0
PM	0	1	0	0	0
ZO	0	0	1	0	0
NM	0	0	0	1	0
NB	0	0	0	0	1

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3 Example simulation

3.1CALCULATION EXAMPLE SIMULATION CALCULATION

In this paper, the evaluation of emergency management ability of a municipal power grid enterprise in 2015 was selected, and the opinions of 30 experts in relevant fields were consulted as the basis for evaluation. The basic situation of the power grid enterprise is as follows: the enterprise is a power supply enterprise with a total power supply of 14,000 square kilometers and 2.1 million users. There are 18 220kv substations,63 6kv substations, 135main transformers, total capacity 665.85 million kva. It contains 61 220kv power lines, with a total length of 1209 kilometer,249 66kv transmission lines, total length of 2455.77 km, 10kv distribution line 2388 km, 10kv cable line 1385 km, distribution transformer 9384, total capacity 331.01 million kva[13].

According to the basic information of the enterprise and the selected index system, use the analytic hierarchy process (AHP) to calculate each index weight of the enterprise, and use the fuzzy evaluation method for power grid emergency ability of modeling.

First, the weights of the four primary indexes are calculated as follows:

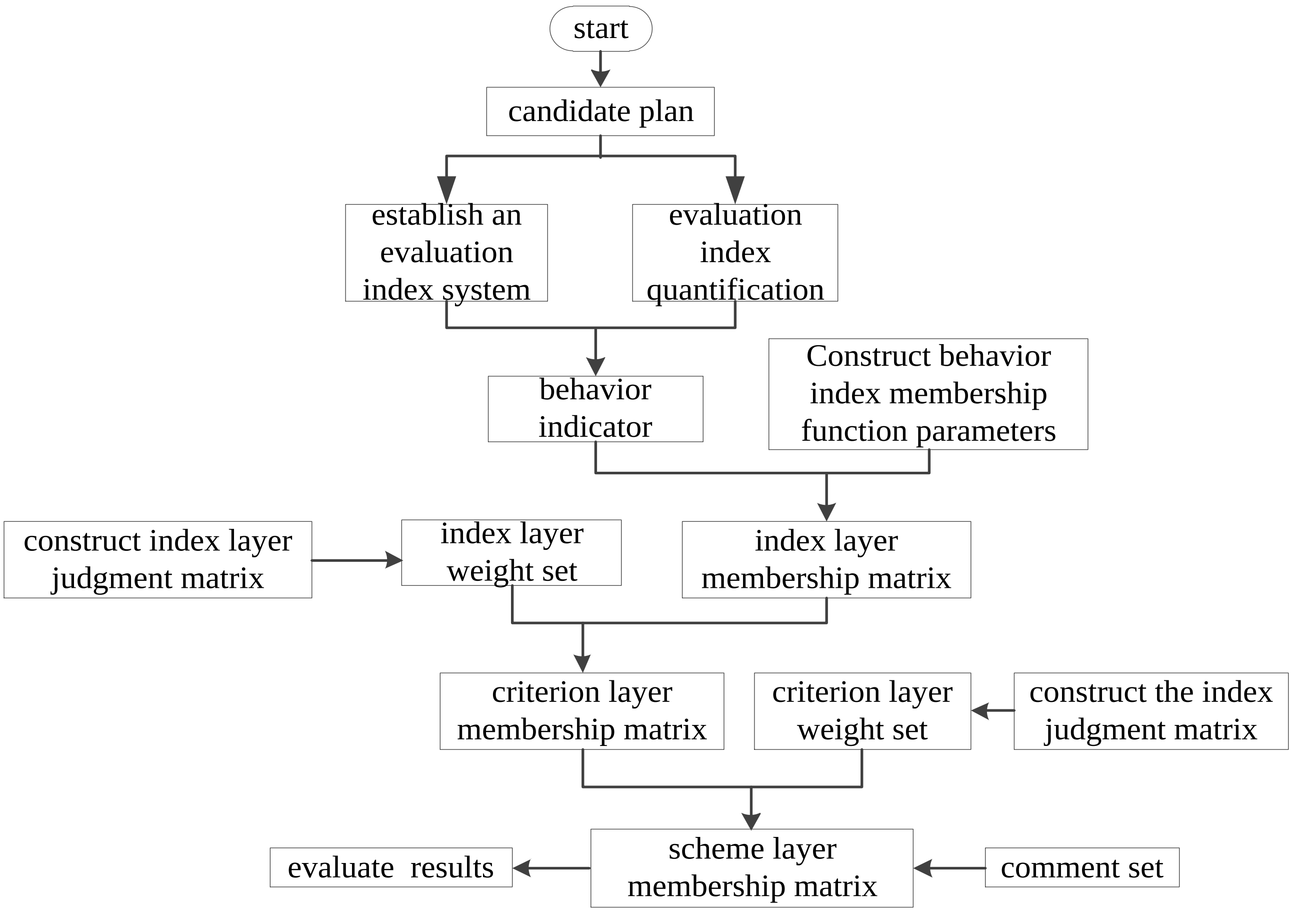

Fig 3 Comprehensive assessment process

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$$X_A = \begin{bmatrix} [1,1] & \left[\frac{1}{2},1\right] & \left[\frac{1}{3},\frac{1}{2}\right] & \left[\frac{1}{3},\frac{1}{2}\right] \\ [1,2] & [1,1] & \left[\frac{1}{3},\frac{1}{2}\right] & \left[\frac{1}{2},1\right] \\ [2,3] & [2,3] & [1,1] & [1,2] \\ [2,3] & [1,2] & \left[\frac{1}{2},1\right] & [1,1] \end{bmatrix} \quad (10)$$

$$W_A = [0.13705, 0.18305, 0.38945, 0.29045] \quad (11)$$

The secondary measures are B1, B2, B3, B4.

$$X_{B_1} = \begin{bmatrix} [1,1] & [3,4] & [4,5] & [3,4] \\ \left[\frac{1}{4},\frac{1}{3}\right] & [1,1] & [2,3] & [1,3] \\ \left[\frac{1}{5},\frac{1}{4}\right] & \left[\frac{1}{3},\frac{1}{2}\right] & [1,1] & [1,2] \\ \left[\frac{1}{4},\frac{1}{3}\right] & \left[\frac{1}{3},1\right] & \left[\frac{1}{2},1\right] & [1,1] \end{bmatrix} \quad (12)$$

$$W_{B_1} = [0.54380, 0.21210, 0.12045, 0.12355]$$

$$X_{B_2} = \begin{bmatrix} [1,1] & \left[\frac{1}{2},1\right] & \left[\frac{1}{3},\frac{1}{2}\right] \\ [1,2] & [1,1] & \left[\frac{1}{2},1\right] \\ [2,3] & [1,2] & [1,1] \end{bmatrix} \quad (13)$$

$$W_{B_2} = [0.21165, 0.31225, 0.4761] \quad (14)$$

$$X_{B_3} = \begin{bmatrix} [1,1] & \left[\frac{1}{4},\frac{1}{3}\right] \\ [3,4] & [1,1] \end{bmatrix} \quad (15)$$

$$W_{B_3} = [0.22500 \quad 0.77500] \quad (16)$$

$$X_{B_4} = \begin{bmatrix} [1,1] & [4,5] & [3,4] \\ \left[\frac{1}{5},\frac{1}{4}\right] & [1,1] & \left[\frac{1}{3},\frac{1}{2}\right] \\ \left[\frac{1}{4},\frac{1}{3}\right] & [2,3] & [1,1] \end{bmatrix} \quad (17)$$

$$W_{B_4} = [0.64885 \quad 0.11700 \quad 0.23410] \quad (18)$$

The fuzzy evaluation method is used to evaluate the above calculation. Set the evaluation set:

$$V = \{v_i\}(i = 1,2,3,4,5) = \left\{\begin{matrix}\text{excellent, good,} \\ \text{medium, poor, very poor}\end{matrix}\right\}.$$

And assign them separately:

$$F = (f_i)^T (100 \quad 75 \quad 50 \quad 25 \quad 0)^T, i = 1,2,3,4,5$$

According to the fuzzy evaluation set, calculated and normalized the second-level index, and obtained the relation of membership degree, then constructed the fuzzy evaluation mathematical model of the power grid, as shown below.

$$\begin{bmatrix} R_{C_1} \\ R_{C_2} \\ R_{C_3} \\ R_{C_4} \\ R_{C_5} \\ R_{C_6} \\ R_{C_7} \\ R_{C_8} \\ R_{C_9} \\ R_{C_{10}} \\ R_{C_{11}} \\ R_{C_{12}} \end{bmatrix} = \begin{bmatrix} 0.0 & 0.2 & 0.6 & 0.2 & 0.0 \\ 0.2 & 0.4 & 0.2 & 0.2 & 0.0 \\ 0.6 & 0.3 & 0.05 & 0.05 & 0.0 \\ 0.0 & 0.2 & 0.7 & 0.1 & 0.0 \\ 0.5 & 0.5 & 0.0 & 0.0 & 0.0 \\ 0.55 & 0.35 & 0.1 & 0.0 & 0.0 \\ 0.3 & 0.5 & 0.15 & 0.05 & 0.0 \\ 0.0 & 0.2 & 0.4 & 0.3 & 0.1 \\ 0.45 & 0.25 & 0.2 & 0.1 & 0.0 \\ 0.5 & 0.3 & 0.2 & 0.0 & 0.0 \\ 0.0 & 0.2 & 0.45 & 0.35 & 0.0 \\ 0.5 & 0.25 & 0.25 & 0.0 & 0.0 \end{bmatrix} \quad (19)$$

$$R_{B_1} = W_{B_1} * \begin{bmatrix} R_{C_1} \\ R_{C_2} \\ R_{C_3} \\ R_{C_4} \end{bmatrix} \quad (20)$$
$$= [0.1147 \quad 0.2544 \quad 0.4612 \quad 0.1696 \quad 0.0000]$$

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$$R_{B_2} = W_{B_2} * \begin{bmatrix} R_{C_5} \\ R_{C_6} \\ R_{C_7} \end{bmatrix} \quad (21)$$
$$= \begin{bmatrix} 0.4203 & 0.4531 & 0.1026 & 0.0238 & 0.0000 \end{bmatrix}$$

$$R_{B_3} = W_{B_3} * \begin{bmatrix} R_{C_8} \\ R_{C_9} \end{bmatrix} \quad (22)$$
$$= \begin{bmatrix} 0.3488 & 0.2388 & 0.2450 & 0.1450 & 0.0225 \end{bmatrix}$$

$$R_{B_4} = W_{B_4} * \begin{bmatrix} R_{C_{10}} \\ R_{C_{11}} \\ R_{C_{12}} \end{bmatrix} \quad (23)$$
$$= \begin{bmatrix} 0.4415 & 0.2766 & 0.2409 & 0.0410 & 0.0000 \end{bmatrix}$$

$$R_A = W_A * \begin{bmatrix} R_{B_1} \\ R_{B_2} \\ R_{B_3} \\ R_{B_4} \end{bmatrix} \quad (24)$$
$$= \begin{bmatrix} 0.3568 & 0.2911 & 0.2474 & 0.0960 & 0.0088 \end{bmatrix}$$

The evaluation scores are:

$$\begin{bmatrix} Z_{C_1} \\ Z_{C_2} \\ Z_{C_3} \\ Z_{C_4} \\ Z_{C_5} \\ Z_{C_6} \\ Z_{C_7} \\ Z_{C_8} \\ Z_{C_9} \\ Z_{C_{10}} \\ Z_{C_{11}} \\ Z_{C_{12}} \end{bmatrix} = \begin{bmatrix} R_{C_1} \\ R_{C_2} \\ R_{C_3} \\ R_{C_4} \\ R_{C_5} \\ R_{C_6} \\ R_{C_7} \\ R_{C_8} \\ R_{C_9} \\ R_{C_{10}} \\ R_{C_{11}} \\ R_{C_{12}} \end{bmatrix} \begin{bmatrix} 100 & 75 & 50 & 25 & 0 \end{bmatrix}^T \quad (25)$$

$$=[50\ 65\ 86.25\ 52.5\ 87.5\ 86.25\ 76.25\ 42.5\ 76.25\ 82.5\ 46.25\ 81.25]^T$$

Similarly, the score of the first-level indicators is calculated:

$$\begin{bmatrix} Z_{B_1} \\ Z_{B_2} \\ Z_{B_3} \\ Z_{B_4} \end{bmatrix} = \begin{bmatrix} R_{B_1} \\ R_{B_2} \\ R_{B_3} \\ R_{B_4} \end{bmatrix} \begin{bmatrix} 100 & 75 & 50 & 25 & 0 \end{bmatrix}^T \quad (26)$$
$$= \begin{bmatrix} 57.87 & 81.7375 & 68.6650 & 77.9650 \end{bmatrix}$$

$$Z_A = R_A * \begin{bmatrix} 100 & 75 & 50 & 25 & 0 \end{bmatrix}^T = 72.2825 \quad (27)$$

3.2 ANALYSIS OF SIMULATION RESULTS

Compared with other simulation algorithms, the algorithm proposed in this paper has high reliability in evaluating power grid emergency capability. After the evaluation and calculation of the emergency capability of the above fuzzy analytic hierarchy process, and the suggestions of the experts, the following conclusions can be obtained in combination with the practical situation of the enterprise:

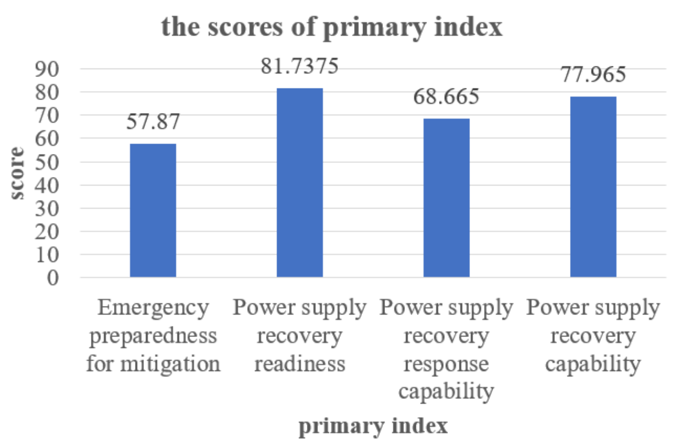

Fig 4 the scores of primary index

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The B1 and B3 scores of the first level index are lower, which is reflected in the poor response ability and response ability of emergency prevention.

ZC1, ZC2, ZC4, ZC8, ZC11S scores of the second level index are lower. Index analysis: the emergency organization system construction, the construction of emergency command center, plan formulation of standard system and plan, indices such as event classification and emergency treatment of accident investigation ability is bad, and we should strengthen the construction of the corresponding indicators.

4. Summarizes

Based on the basic situation of power grid in China, fully considered the grid emergency index, and accorded to the relevant expert advice, based on the fuzzy analytic hierarchy process (AHP), the comprehensive evaluation of power grid emergency capability is carried out. By using the method of analytic hierarchy process, the index of experts is calculated. Through modeling method of fuzzy evaluation: adopting the membership function of rating system, calculating the indicators of the final evaluation score. The application of this method provides new ideas and new methods for the calculation of the power grid emergency capacity and the capability assessment. The validity of this method is verified by a practical simulation test. This method is of great significance to guide the emergency capability assessment of China's power grid enterprises.

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