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OPTIMAL DECISION-MAKING MODEL OF RELIABILITY DESIGN FOR PNS

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ABSTRACT

The power network system (PNS) is an important part of the power System, safety and reliability is ensured only by reliability optimized design. By analyzing the influential factors of reliability allocation, the method of fuzzy synthesis evaluation based on fuzzy mathematical theory was presented to carry through optimum allocation of power network system in this paper. Namely, appointed reliability index is distributed rationally to subsystem of PNS by defining factor set of reliability level and the weight of factors, and further defining synthesis decision-making based on attachment degree of every factor. Both reliability of whole system and economic benefit are ensured by the method, and design example is given . It provides a feasible method for reliability optimum design of power system.

Keywords: *Reliability Allocation, Power Network System(PNS), Fuzzy Synthesis Evaluation, Reliability Optimum Design*

1. INTRODUCTION

With the global economy develop continually, the large-scale grid interconnection become an inevitable trend in development of the power system. The power network can deliver electrical energy to the outside of the 100 to 1000Km, at the same time, partial failure can quickly spread to a large area or even the entire network system. Therefore, with the increasing of system size and complexity, to ensure safety and economic operation, chain reliability of the power system need be researched from the point of view of the overall network system.

Power network are composed of four parts, transformers, power transformation equipment, power transmission equipment, and distribution equipment of electric energy. Each parts also includes a lot of components, due to cost of the various parts, the original level of reliability, maintenance costs, complexity, and importance degree are different, they are not same to reliability requirements, in power network design, these factors must be considered comprehensively by optimizing selection[1]-[3]. Namely, admissible failure probability of the power network system is distributed reasonably to the various parts of the system by reliability optimization design and best reliability of each member is searched and obtained. Reliability allocation is important part of reliability design, it is essentially a question of engineering decisions, there are several common methods of reliability allocation such as equal allocation method, redistribution method, the complexity distribution method, AGREE allocation method, the prediction value method of system failure rate, engineering weighted allocation method, the relative failure rate distribution, setting allocation method, proportional distribution method[4]-[5].

There are a certain defects above the methods, they ignore some of the important factors that affect system reliability allocation or focus on one and two factors. Because of the power network system reliability allocation is an optimization problem, the factors that affect the reliability allocation include many uncertainty fuzzy factors, their boundaries are often vague, the traditional mathematical representations encountered substantial difficulties, uncertain reliability allocation becomes possible by the introduction of fuzzy mathematics. In this paper, reliability allocation optimal decision of the power network system is presented basis on fuzzy comprehensive evaluation, restrictive reliability index is reasonably allocated to every subsystem of power network system, so that the reliability of the entire system is guaranteed.

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Section 2 presents influencing factors of power network reliability allocation, the important factors that affect the reliability of the power network allocation are complexity, importance, cost and maintainability. In section 3, we presents fuzzy comprehensive evaluation method of reliability allocation, integrated decision and judgment are made according to a variety of factors. In section 4, we propose reliability allocation total process of power network system. Section 5 gives a conlusion to the whole paper, the parts reliability is calculated by fuzzy comprehensive evaluation method on the basis of analyzing comprehensively and evaluating influencing reliability factors. Both reliability and economic benefit are guaranteed by the method in the electricity network design, it has a larger significance for optimize design of the power network.

2. INFLUENCING FACTORS OF POWER NETWORK RELIABILITY ALLOCATION

Power network systems and their parts are series links, namely, if one parts fail, the entire system becomes ineffective, it's reliability block diagram shown in Figure 1, the system is made up of transformers, power transformation equipment, power transmission equipment and electric energy distribution equipment. The important factors that affect the reliability of the power network allocation are complexity, importance, cost and maintainability.

(1) The degree of importance. The effect of the failure of every parts on whole power network system is different, the greater influence the parts is and the higer importance is, its failure rate should be lower, its reliability should be distributed more highly.

(2) Complexity. The larger ratio of the number of the important components in every parts to the total number of components in the system is , the more complex the structure of the parts is. In general, the failure rate will be higher.

(3) Maintenance factor. The failure of the parts is easily maintained, the failure rate should be allocated highly, and difficult to repair, the failure rate is not high.

(4) Cost. The cost of every parts of the power network system is different in the design and manufacturing process, their total costs are calculated according to the manufacturing materials, processing techniques.

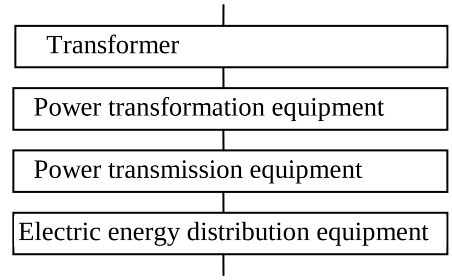

Figure1：Reliability block diagram of power network system

3. FUZZY COMPREHENSIVE EVALUATION METHOD OF RELIABILITY ALLOCATION

Comprehensive evaluation is also known as the integrated decision-making, any things and objects have a variety of attributes, so all aspects should be taken into account to make a rational decision-making in the course of the evaluation, namely, multiple factors must be taken into account. In the fuzzy environment, integrated decision and judgment are made according to a variety of factors, that is called fuzzy comprehensive evaluation [6].

1) To determine the alternative set. According to the composition of the power network and reliability block diagram, the alternative set is taken as $C=(c_1,\ c_2,\ c_3,\ c_4)$ = (transformer, the power transformation equipment, power transmission equipment, electric energy distribution equipment).

2) To determine factor set that affect the reliability level of every parts in the power network, they are the degree of importance, complexity and maintenance factors and cost. Therefore, factor set is $B=b_i=(b_1,b_2,b_3,b_4)$ = (degree of importance, complexity, cost, maintenance factors).

3) To determine the factors set of weight. Weight represents influencing degree of various factors on system reliability level, it reflects the status and role of various factors in the integrating decision and affects directly the results of the decision-making, it is often given by statistical methods or given empirically scores with several experts [7]. In this study, the weight value is given directly scores by the decimal system according to three experienced power system experts, the weight scores of four factors given by the three experts are shown in Table 1, they are taken average values.

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$$P_i = \frac{\sum_{j=1}^{3} P_{ij}}{3}$$

$$(i = 1,2,3,4;\ j = 1,2,3) \qquad (1)$$

Where P_i is the score of the i-th factor, P_{ij} is the score of the i-th factor given by the j-th expert, and then a_i is obtained by the normalization method.

$$a_i = \frac{P_i}{\sum_{i=1}^{4} P_i} \ (i = 1,2,3,4) \qquad (2)$$

The weight vector is obtain by table1.

$$A = (a_1, a_2, a_3, a_4) = (0.41,\ 0.19,\ 0.23,\ 0.17)$$

Where a_i is corresponding weight of the i-th factor b_i, $\sum_{i=1}^{4} a_i = 1$.

Table1: Three Experts on the Impact of the Factors Given score

No. 1	importance	Complexity	Cost	Maintainability
	4.0	1.5	2.5	2.0
No. 2	importance	Complexity	Cost	Maintainability
	4.5	2.0	2.0	1.5
No. 3	importance	Complexity	Cost	Maintainability
	3.8	2.2	2.5	1.5

4) To determine the membership degree of evrey parts to the various factors. Membership degree represents dependent degree of fuzzy relationship with a number between 0 to 1, selecting its value is related to subjective factors. To determine accurately membership degree of every parts to importance, complexity and maintenance factors and the cost, they are still given proper values by three experienced engineers, given values are shown in Table2, and then average value is obtained by (3).

$$D_{ij} = \frac{\sum_{k=1}^{3} D_{ijk}}{3} \qquad (3)$$

$$(i, j = 1,2,3,4;\ k = 1,2,3)$$

Where D_{ij} is the membership degree of the i-th parts to the j-th factors, D_{ijk} is given value of k-th experienced engineer for the i-th parts to the j-th factors. Let

$$r_{ij} = \frac{D_{ij}}{10}$$

r_{ij} is processed value of i-th parts to j-th factor, is shown in table 2. So a fuzzy mapping of alternative set to factor set is get $c_i \mapsto [r_{i1} \ \ r_{i2} \ \ r_{i3} \ \ r_{i4}]^T$, a fuzzy relation between B and C (fuzzy relation matrix) is constructed.

$$R = \begin{bmatrix} r_{11} & r_{21} & r_{31} & r_{41} \\ r_{12} & r_{22} & r_{32} & r_{42} \\ r_{13} & r_{23} & r_{33} & r_{43} \\ r_{14} & r_{24} & r_{34} & r_{44} \end{bmatrix} = \begin{bmatrix} 0.850 & 0.883 & 0.850 & 0.917 \\ 0.767 & 0.817 & 0.617 & 0.867 \\ 0.750 & 0.200 & 0.867 & 0.417 \\ 0.633 & 0.767 & 0.550 & 0.817 \end{bmatrix}$$

Rows represent the degree of importance, complexity, cost and maintainability respectively, and columns represent transformers, the power transformation device, power transmission device and electric energy distribution equipment respectively in the above matrixs.

Table2: Given Score Value on the Influencing Factors by Experienced Engineers

	b1	b2	b3	b4
C1	8.0	9.0	9.0	9.5
C2	7.5	8.5	6.0	9.0
C3	7.0	2.0	8.5	4.5
C4	6.0	7.5	6.0	8.5

	b1	b2	b3	b4
C1	8.5	9.0	8.5	9.0
C2	7.0	8.0	5.5	9.0
C3	7.5	2.5	9.0	4.0
C4	6.5	7.0	5.5	8.0

	b1	b2	b3	b4
C1	9.0	8.5	8.0	9.0
C2	8.5	8.0	7.0	8.0
C3	8.0	1.5	8.5	4.0
C4	6.5	8.5	5.0	8.0

C1, C2, C3 and C4 represent transformer, the power transformation equipment, power

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transmission equipment and electric energy distribution equipment respectively in the above tables.

5) In accordance with the principle of fuzzy transformation [8], fuzzy decision is made, the triad (C, B, R) constitutes a fuzzy comprehensive evaluation model, fuzzy set E is obtained by integrating judge.

$$E = a \circ R = (a_1, a_2, a_3, a_4) \circ \begin{pmatrix} r_{11} & r_{21} & r_{31} & r_{41} \\ r_{12} & r_{22} & r_{32} & r_{42} \\ r_{13} & r_{23} & r_{33} & r_{43} \\ r_{14} & r_{24} & r_{34} & r_{44} \end{pmatrix}$$

$$= (e_1, e_2, e_3, e_4) \qquad (4)$$

Where $\circ$ is fuzzy operators, there are different models of computation as using different fuzzy operators. There are four fuzzy comprehensive evaluation model [9]:

Model 1: $M(\wedge,\vee): b_j = \bigvee_{i=1}^{m} (a_i \wedge r_{ij})$

Model 2: $M(\cdot,\vee): b_j = \bigvee_{i=1}^{m} (a_i \cdot r_{ij})$

Model 3: $M(\cdot,\oplus): b_j = \sum_{i=1}^{m} (a_i \cdot r_{ij})$

Model 4: $M(\wedge,\oplus): b_j = \sum_{i=1}^{m} (a_i \wedge r_{ij})$

The model 3 is used in order to make the evaluation results more reasonable and reliable[10], fuzzy decision is made according to the above data.

$$E = a \circ R =$$

$$\begin{bmatrix} 0.41 & 0.19 & 0.23 & 0.17 \end{bmatrix} \begin{bmatrix} 0.850 & 0.883 & 0.850 & 0.917 \\ 0.767 & 0.817 & 0.617 & 0.867 \\ 0.750 & 0.200 & 0.867 & 0.417 \\ 0.633 & 0.767 & 0.550 & 0.817 \end{bmatrix}$$

=(0.8677, 0.7590, 0.6158, 0.6706)

Decision-making result E reflects the degree and level that the various parts depend on required reliability as comprehensive consideration on all factors that affect the power network reliability.

6) The allocation of power network system reliability. The decision results reflect the relative high and low degree of reliability requirements for the various parts of the power network. Therefore,

$$F = 1 - E = (f_1, f_2, f_3, f_4) =$$

$$(0.1323, 0.2410, 0.3842, 0.3294)$$

Namely, F reflect transformer, power transformation equipment, power transmission equipment, electric energy distribution equipment should be the level of relative failure rate. F is normalized, Then

$$F = (f_1, f_2, f_3, f_4)$$

$$= (0.1323, 0.2410, 0.3842, 0.3294)$$

Taking f_1, f_2, f_3, f_4 as relative failure rate of transformer, power transformation equipment, power transmission equipment, electric energy distribution equipment respectively, because the power network system is a series system, the reliability of various parts are obtained according to the relative failure rate by(5).

$$R_i = R_s^{\,f_i} \qquad (5)$$

Where R_s is requiring reliability of a power network system. If requiring reliability of the system $R_s = 0.96$, the reliability of transformer, power transformation equipment, power transmission equipment, electric energy distribution equipment are calculated by (5), they are 0.9946, 0.9902, 0.9844, 0.9866 respectively.

7) Component reliability allocation. For the power network system, each parts is made up of many components, the failure rate of each component is different, the relative failure rate method is used in order to distribute reasonably reliability to every component, the relative failure rate method makes allowable failure rate of every unit of system is is proportional to prediction failure rate value of the unit and reliability of subsystem is distributed according to this principle.

Let the reliability of the parts is R_C , corresponding failure probability is Fc.

$$F_{C_i} = \frac{F_i}{\sum_{i=1}^{n} F_i} F_C \approx \frac{\lambda_i}{\sum_{i=1}^{n} \lambda_i} F_C \qquad (6)$$

The reliability of each component is calculated by(7).

$$R_{C_i} = 1 - F_{C_i} \qquad (7)$$

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4. RELIABILITY ALLOCATION TOTAL PROCESS OF PNS

The structure of optimal reliability allocation of the power network system based on multi-level method is shown in Figure 3-4, the allocated structure shown in Figure 3, flow chart shown in Figure4.

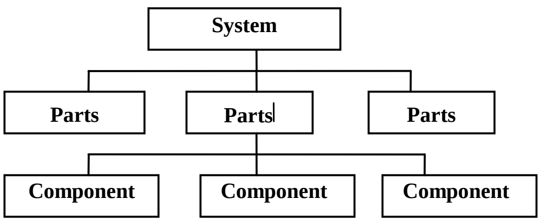

Figure3: Reliability Allocation Structure of Power Network System

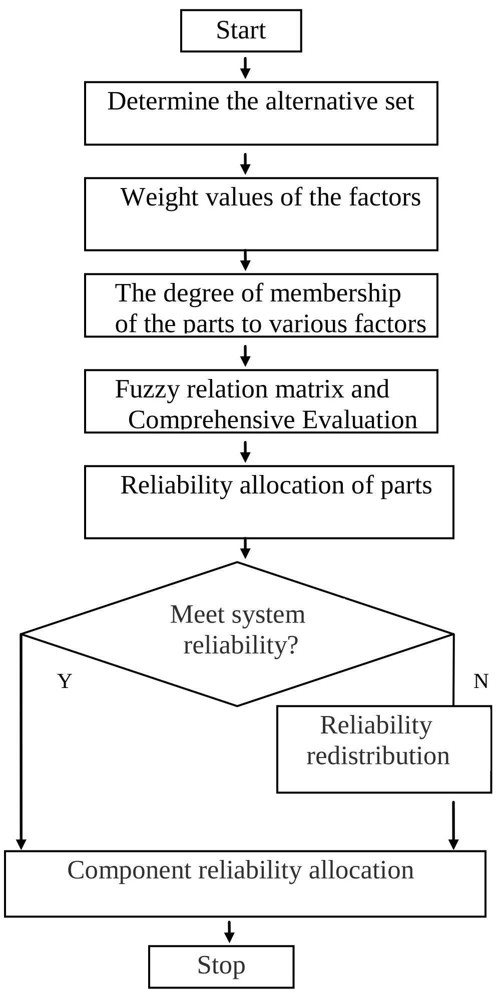

Figure4: Reliability Allocation Flow Chart of Power Network System

5. CONCLUSION

Reliability allocation method of the parts and the components of the power network system is built in this paper, the parts reliability is calculated by fuzzy comprehensive evaluation method on the basis of analyzing comprehensively and evaluating influencing reliability factors. Both reliability and economic benefit are guaranteed by the method in the electricity network design, it has a larger significance for optimize design of the electricity network.

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