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Research on the Reliability Allocation Method for a Wind Turbine Generator System Based on a Fuzzy Analytic Hierarchy Process Considering Multiple Factors

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ABSTRACT Given the current reliability allocation problem of wind turbine generator systems, based on the reliability allocation method of series systems, a reliability allocation model based on an improved fuzzy analytic hierarchy process (FAHP) is proposed. A three-scale standard is adopted to comprehensively consider six influencing factors, such as technical level, working environment and importance, by determining the comprehensive allocation weight combined with an improved FAHP and entropy weight method. In this way, the reliability allocation calculation model for a wind turbine generator system is developed for the reliability allocation of the wind turbine generator system. Using the method developed in this study and other methods for the reliability allocation of a wind turbine generator system as examples, the allocation results are compared and analyzed. The results show that this method not only is effective but also obtains lower allocation results than those of other studies, which verifies the rationality of the present method.

INDEX TERMS Fuzzy analytic hierarchy process, entropy weight method, reliability allocation, wind turbine generator system.

I. INTRODUCTION

With the increase in installed capacity, the reliability problem of wind turbine generator systems (WTGSs) has become increasingly prominent. Problems such as the aging of equipment, the degradation of the transmission system performance and the frequent failures and shutdowns of WTGSs have also emerged. Therefore, during production design, it is necessary to carry out repeated reliability prediction and allocation of the equipment and continuously improve and correct it until a reasonable technical scheme is designed.

Reliability allocation is a top-down and zero-integrating process, which means that the specified reliability indexes are reasonably allocated to each subsystem to meet the reliability requirements [1]. In the early stage of product design, there are few product reliability data, and it is possible that only the number of components is known. At this time, the equal apportionment technique can be used [2]. The allocation weights of the equal apportionment technique are determined by the number of subsystems, with the assumption that the subsystems are independent of each other, such that the reliability allocated to each subsystem is the same. If the designer can predict the failure rate of the subsystem based on empirical data, then a proportion allocation method, such as the Aeronautical Radio Inc. (ARINC) method [3], can be used. Neither the equal apportionment technique nor the ARINC method consider the actual system characteristics when reliability allocation occurs. On the basis of the above two methods, scholars have proposed the Advisory Group on Reliability of Electronic Equipment (AGREE) method, which takes into account the complexity and importance of subsystems [4]: the more complex a subsystem is, the higher its allocated failure rate, while the more important the subsystem is, the lower its allocated failure rate. The target feasibility algorithm uses the expert grading method (EGM) to determine the allocation weights by comprehensively considering the complexity, technical level, working environment and operation hours of the subsystems [5]. The above allocation methods have been widely used, and the factors to be considered when determining the allocation weights have become

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increasingly comprehensive; however, they all assume that each influencing factor is equally important and that the evaluation of factors is more subjective. Considering the above shortcomings, Chang *et al.* [6] proposed a reliability allocation weight of an ordered weighted average operator. In addition, Liaw *et al.* [7], based on the ME-OWA decision method, combined with the DEMATEL decision method, used different weights for each factor. In particular, Bona and Forcina [8] developed a new method based on the analytic hierarchy process (AHP). Although these methods have improved the defect of equal weight allocation for different components, Sriramdas *et al.* [9] believe that the main challenge now is to improve the subjectivity of traditional methods.

In recent years, many scholars have improved the above methods according to the characteristics of WTGSs. Zhou and Li [10] established a reliability allocation model based on the historical fault maintenance data of permanent magnetic direct-drive wind turbines in four years and the allocation principle of the fault frequency and average fault maintenance time of each component. They rationally allocated the reliability index of the ten components of the wind turbine system. The system reliability test allocation results are reasonable, and the reliability allocation method for the wind turbines is simplified. Guo [11] used the failure rate as the reliability index and comprehensively considered the allocation principle at the technical level for complexity and importance. In this study, the traditional expert scoring method is improved and the fuzzy comprehensive scoring method is established to carry out the reliability distribution of the seven components of the wind turbine. The failure rate of the entire system and the mean time without failure are tested to meet the requirements of the wind turbine system. This study provides theoretical support for the initial design and reliability improvement design of the system. Rajeevan *et al.* [12] adopted the weighted factor method, assumed that the subsystems were independent but the failure rate remained unchanged, and established the reliability allocation method to improve the availability of the wind energy system from 97.86% to 98%. Chen *et al.* [13] used the mean time between failures (MTBF) and the mean maintenance time (MTTR) as reliability indicators, adopted the fuzzy set theory to analyze the operation data of wind turbines, and combined with the expert scoring method, established the fuzzy reliability evaluation model. Through analysis and verification, the generating capacity of the entire turbine with high reliability is also high, which conforms to the actual operation situation of the wind turbines. This paper deals with the assignment process to improve the subjectivity of the expert grading method.

Based on the above research on the reliability distribution method of WTGSs, combined with the service operation mechanism of WTGSs, this paper considers the factors affecting the reliability of WTGSs as comprehensively as possible; In the case of considering many factors, to solve the problem that the expert's judgment is too subjective, a comprehensive weight calculation method is proposed by an improved fuzzy analytic hierarchy process (FAHP) combined with the entropy weight method. The reliability allocation model of WTGS is established. Finally, the reliability allocation of WTGS is taken as an example to verify the rationality and effectiveness of the proposed method. This reasonable reliability allocation method provides a basis for product designers to improve and determine the technical scheme, providing a reference for analyzing the weak links of the reliability of each component of WTGSs.

II. PRELIMINARIES

In this section, the definition and knowledge of the traditional FAHP are introduced to compare with the traditional FAHP.

The FAHP combines the AHP and the fuzzy analysis method, making good use of the quantitative and qualitative indicators of the products [14]. According to the traditional AHP, before determining the judgment matrix, experts need to judge the importance of each influencing factor according to the evaluation scale. The commonly used scaling methods are the reciprocity scale and the complementarity scale [15]; the reciprocity scale method is not introduced much in this paper.

The specific evaluation criteria of the complementarity scaling method are shown in Table 1.

TABLE 1. Evaluation criteria of the complementarity scaling method.

0.1-0.9 scale	0-1 scale	0-2 scale	-2-2 scale	Qualitative description
0.1	0	0	-2	i is definitely less important than j.
0.3	0	0	-1	i is obviously less important than j.
0.5	0.5	1	0	i is just as important as j.
0.7	1	2	1	i is obviously more important than j.
0.9	1	2	2	i is absolutely more important than j.

The complementarity scaling method is not only helpful for experts to make reasonable judgments, but also helpful for decision makers to understand those judgments. To make the experts' evaluation results more consistent, this paper adopts the 0-1 three scale method, simplifies the scale method, and performs a quantitative analysis of the importance of each influencing factor.

The core of FAHP is the establishment of a fuzzy consistency matrix through pairwise comparisons of influencing factors. According to the definition of a fuzzy consistency matrix, if the matrix $A = (a_{ij})_{n\times n}$ satisfies: $0 \leq a_{ij} \leq 1$, $(i, j = 1, 2, \cdots, n)$, then A is called fuzzy matrix. If the fuzzy matrix $A = (a_{ij})_{n\times n}$, for $\forall i, j, k$, satisfies: $a_{ij} = a_{ik} - a_{jk} + 0.5$, A is called the fuzzy consistency matrix. Since the literature [16] has proven that the fuzzy consistency matrix is robust, there is no need to carry out a consistency test in this study.

III. RELIABILITY ALLOCATION MODEL OF A WTGS CONSIDERING MULTIPLE FACTORS

The purpose of reliability research is to increase the product lifecycle and reduce the frequency of failures, and large and complex mechanical equipment such as a WTGS is no exception. Regardless of the technical level, the working environment or the system complexity, many factors will significantly impact the reliability of WTGSs [17]. On the basis of the comprehensive consideration of the influences of the technical level, the working environment, the task situation, the cost, the complexity and the importance on the reliability of a WTGS system, the reliability allocation of the system indexes from top to bottom is performed, which will not only provide designers and installers with a more reasonable design and installation plan but also enable the product to achieve high reliability within the scope of cost control in the early stages of design.

The influences of factors such as the technical level, the working environment and the task situation on a WTGS are mostly judged through qualitative and quantitative analyses of existing reliability information, such as the fault and maintenance data of the WTGS. As most of these data have fuzzy uncertainties, they cannot be analyzed by single mathematical theories such as traditional probability theory and fuzzy mathematics [18]. Therefore, a reliability allocation model is established based on the FAHP to carry out the reliability allocation of a WTGS in the early stages of design through comprehensively considering the influence of the above-mentioned factors. The specific process is shown in Fig. 1.

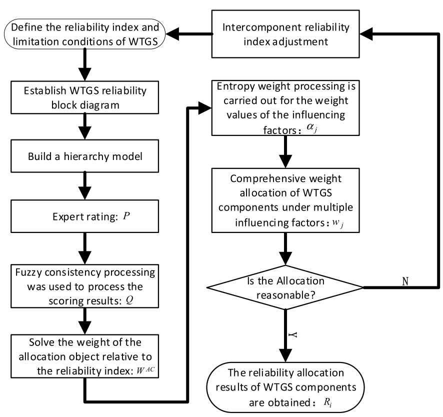

FIGURE 1. WTGS reliability allocation flow chart.

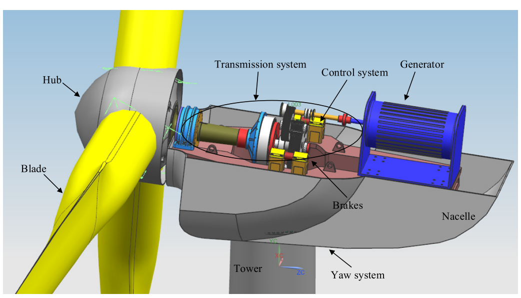

FIGURE 2. Structural diagram of the WTGSs.

A. RELIABILITY MODELING OF WTGS

A WTGS comprises complex equipment that converts wind energy into mechanical energy and then converts mechanical energy into electric energy, with the overall structure shown in Fig. 2. According to their function, WTGSs can be categorized as blade and hub systems, transmission systems, generator systems, yaw systems, and tower and control systems. Through the Failure Mode, Effects and Criticality Analysis(FMECA) of the key components of the WTGSs [19], once a key subsystem has failed, it will lead to the shutdown and overhaul of the entire machine or to overall failure. Therefore, the use of the series logic relation is suitable for expressing the failure logic relation between the subsystems of a WTGS, as shown in Fig. 3.

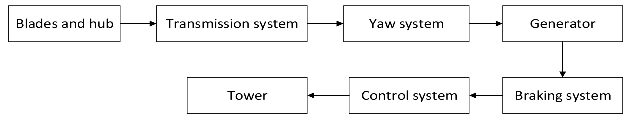

FIGURE 3. Reliability block diagram of a WTGSs.

B. RELIABILITY ALLOCATION MODEL OF A WTGS BASED ON THE IMPROVED FAHP

1) HIERARCHICAL MODEL OF THE WTGS RELIABILITY ALLOCATION

Due to the fuzziness, uncertainty and complexity of the equipment information in complex systems, traditional reliability allocation methods cannot be applied. To solve these problems, Huang *et al.* [20] proposed the use of fuzzy set theory to explore the reliability allocation method when considering multiple factors in mechanical systems. Bona *et al.* [21] developed a new reliability allocation method based on the AHP. Karczmarek *et al.* [22] proposed a comprehensive analysis method that combines fuzzy theory with the AHP. The traditional FAHP is a multi-objective decision analysis method that combines qualitative and quantitative analyses but lacks the necessary reliability data [23]. Using a nine-scale method to establish a judgment matrix requires not only a large number of calculations but also multiple evaluations by experts, which makes it difficult to ensure the consistency of the method. For a WTGS, not only is the structure complex but the operating environment is also harsh; therefore, traditional reliability allocation methods can no longer be applied. Therefore, in this paper, an improved FAHP [24] is adopted with a three-scale method to compare and analyze the influencing factors in pairs, which not only is a simple and clear approach but also makes it easier for experts to reach agreement in terms of their scores, greatly reducing the difficulty and workload involved in the calculations and ensuring the consistency of the evaluation.

The allocation hierarchy modeling of a WTGS is carried out based on the structure of the FAHP and the characteristics of the three-scale method used. For a WTGS, the reliability indexes of the entire system make up the target layer, the subjective and objective factors that affect the reliability allocation make up the criterion layer, and the subsystems make up the object layer. The reliability allocation hierarchical model of the WTGS in this study is shown in Fig. 4.

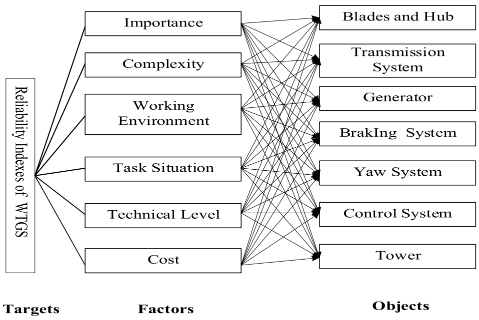

FIGURE 4. **Reliability allocation hierarchical structure diagram of the WTGSs.**

2) ALLOCATION WEIGHT CALCULATION MODEL BASED ON THE IMPROVED FAHP

Because different factors have different degrees of influence on a WTGS, they are difficult to detect directly with instruments. Therefore, through the experience and judgment of wind turbine experts, the reliability of the entire system and subsystems under the influence of different factors is objectively evaluated as much as possible, and then, the reliability allocation weights of the entire machine for each subsystem are obtained.

First, through expert evaluation, a priority judgment matrix P is established as follows:

$$P = (p_{ij})_{n\times n} = \begin{cases} 0 & a < b \\ 0.5 & a = b \\ 1 & a > b, \end{cases} \tag{1}$$

where p_{ij} refers to the results of the comparisons among judgment indexes through the use of the three-scale method; a and b denote the relative importance of the pairwise comparison between rows and columns, respectively; and n is the number of indexes to be analyzed.

The fuzzy consistency judgment matrix $Q = (q_{ij})_{n\times n}$ is obtained by transforming the priority judgment matrix. The transformation process is as follows:

$$\begin{cases} q_i = \sum_{i=1}^{n} p_{ij},\ q_j = \sum_{j=1}^{n} p_{ij} \\ q_{ij} = \dfrac{q_i - q_j}{2n} + 0.5. \end{cases} \tag{2}$$

The fuzzy consistency judgment matrix Q is a normalized rank aggregation. The row sum vector of the matrix is obtained as follows:

$$l_i = \sum_{i=1}^{n} q_{ij} - 0.5, \tag{3}$$

where l_i refers to the relative importance of element i in the allocation hierarchy model relative to the upper level.

The sum of the elements (excluding diagonal elements) is as follows:

$$\sum_{i=1}^{n} l_i = \frac{n(n-1)}{2}. \tag{4}$$

By the normalization conversion of l_i, the allocated weight values of the reliability indexes to the criterion layer in the FAHP are obtained as follows:

$$W^{AB} = (w_i^{AB})_{1\times n} = \frac{l_i}{\sum_{i=1}^{n} l_i} = \frac{2l_i}{n(n-1)}. \tag{5}$$

Similarly, the allocation weight W_j^{BC} of a single element of the object layer relative to the criterion layer is obtained as follows:

$$W_j^{BC} = (w_j^{BC})_{1\times m} = (w_1^{BC}, w_2^{BC}, \cdots w_m^{BC}), \tag{6}$$

where m refers to the number of object layers.

By repeating the above calculations, the allocation weights of different factors for each allocated object are obtained as follows:

$$W^{BC} = (w_{11}^{BC}, \cdots, w_{ij}^{BC}, \cdots, w_{nm}^{BC}), \tag{7}$$

where $i = 1, 2, \cdots, n$ refers to the number of factors in the middle layer, and $j = 1, 2, \cdots, m$ refers to the number of subsystems in the object layer.

Therefore, the allocation weight of the WTGS reliability indexes to each subsystem is as follows:

$$W^{AC} = W^{AB} \times W^{BC}. \tag{8}$$

C. COMPREHENSIVE ALLOCATION WEIGHT MODEL BASED ON THE IMPROVED FAHP AND THE EWM

In terms of the involved factors, evaluations and judgments are made as objectively as possible when determining the allocation weight via the FAHP; however, the uncertainty and fuzziness of the information cause experts to evaluate them with subjective feelings. The EWM [25] is an evaluation method used to determine the weight based on the amount of information contained in each factor. The basic idea behind this method is to determine the objective weight according to the size of the index variability, thus avoiding focusing only on the subjective judgment of decision makers and making the above-mentioned allocation weight vector more objective. Therefore, a weight calculation method combining the EWM and the improved FAHP is proposed to make the allocation results more reasonable and credible.

After experts have judged the relative influence degree of multiple factors of the WTGS, combined with the FAHP in Section 3, the priority relation judgment matrix, W^{BC}, of each subsystem is obtained. After normalizing the rank aggregation, the priority judgment matrix is obtained as follows:

$$V = (v_{ij})_{m\times n}, \tag{9}$$

where v_{ij} is the normalized value of w_{ij}^{BC}, m is the number of WTGS subsystems, and n is the number of factors.

Through the EWM, the entropy weight value of the evaluation indexes is calculated with formula (10), which determines the entropy weights of multiple factors in the WTGS as follows:

$$\begin{cases} f_{ij} = v_{ij} \Big/ \sum_{i=1}^{m} v_{ij} \\ e_j = \dfrac{1}{\ln m} \sum_{i=1}^{m} (f_{ij} \ln f_{ij}). \end{cases} \tag{10}$$

The difference coefficient, D_i [26], is introduced to describe the entropy weights of the factors by considering the calculation principle and properties of the EWM as follows:

$$D_j = 1 - e_j, \tag{11}$$

where $j = 1, 2, \cdots, m$. Therefore, the entropy weight of each factor α_j is obtained as follows:

$$\alpha_j = D_j \Big/ \sum_{j=1}^{m} D_j. \tag{12}$$

Finally, the comprehensive allocation weight of the subsystems is obtained by considering the influence of various factors according to formula (13) as follows:

$$w_j = \frac{W^{AC} \cdot \alpha_j}{\sum_{j=1}^{m} W^{AC} \cdot \alpha_j}. \tag{13}$$

D. RELIABILITY ALLOCATION WEIGHT MODEL OF THE WTGS

According to the reliability theory of mechanical systems, the failure rate, $\lambda_i = P(X_i \leq t)$, of mechanical systems refers to the frequency of failure during their lifetime, where X_i is the rated life of the systems. In the early stage of product design, through the comprehensive consideration of the influence of multiple factors, a reliability allocation method considering this influence is established to obtain the reliability expression of the WTGS as follows:

$$R_i = P(X_i > t) = 1 - \frac{\lambda}{w_j} \Big/ \sum_{j=1}^{m} \frac{1}{w_j}. \tag{14}$$

IV. CASE VERIFICATION AND COMPARATIVE ANALYSIS

A. RELIABILITY ALLOCATION WEIGHT CALCULATION OF THE WTGS CONSIDERING THE INFLUENCE OF MULTIPLE FACTORS

Combined with the reliability allocation hierarchy model of the WTGS shown in Fig. 4, wind power experts evaluate the six influencing factors of the WTGS and then establish the priority judgment matrix P according to formula (1) as follows:

$$P = \begin{bmatrix} 0.5 & 0 & 1 & 1 & 1 & 1 \\ 1 & 0.5 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0.5 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0.5 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0.5 & 1 \\ 0 & 0 & 1 & 1 & 0 & 0.5 \end{bmatrix} \tag{15}$$

The fuzzy consistency judgment matrix, Q, of the factors is as in the following formula (16):

$$Q = \begin{bmatrix} 0.5000 & 0.4167 & 0.7500 & 0.8333 & 0.5833 & 0.6667 \\ 0.5833 & 0.5000 & 0.8333 & 0.9167 & 0.6667 & 0.7500 \\ 0.2500 & 0.1667 & 0.5000 & 0.5833 & 0.3333 & 0.4167 \\ 0.1667 & 0.0833 & 0.4167 & 0.5000 & 0.2500 & 0.3333 \\ 0.4167 & 0.3333 & 0.6667 & 0.7500 & 0.5000 & 0.5833 \\ 0.3333 & 0.2500 & 0.5833 & 0.6667 & 0.4167 & 0.5000 \end{bmatrix} \tag{16}$$

The allocation weight, W^{AB}, of each influencing factor relative to the reliability of the entire system is calculated using formulas (3) ~ (5) as follows:

$$W^{AB} = [\,0.2167\ 0.2500\ 0.1167\ 0.08333\ 0.1833\ 0.1500\,] \tag{17}$$

Similarly, wind power experts evaluate the influence degree of a factor on each subsystem of the WTGS. Moreover, the priority judgment matrix of each subsystem considering a certain factor is obtained. Through normalization transformation according to formula (2) and repeated calculation according to formulas (3) ~ (5), the comprehensive weight values of each subsystem considering the influence of different factors are obtained, as shown in Table 2.

Table 2 is then converted into the matrix form of formula (7), and formula (8) is used to calculate the reliability allocation weights of the subsystems relative to the entire WTGS as follows:

$$\begin{aligned} W^{AC} &= W^{AB} \times W^{BC} \\ &= [\,0.1321\ 0.1591\ 0.1516\ 0.1433\ 0.1151\ 0.1067\ 0.1921\,] \end{aligned} \tag{18}$$

B. ALLOCATION WEIGHT CACULATION OF THE WTGS

Through formulas (9) ~ (13), the difference coefficients, entropy weights and allocation weight values of the WTGS subsystems are calculated as shown in Table 3.

If the reliability of the WTGS is 0.95, then the cumulative failure rate is $\lambda_i = 0.05$. According to formula (14), the allocated reliability of the subsystems is calculated with the following results:

$$\begin{aligned} &R_i = \\ &[\,0.9922\ 0.9934\ 0.9928\ 0.9939\ 0.9937\ 0.9899\ 0.9940\,] \end{aligned} \tag{19}$$

where $i = 1, 2, \cdots, 7$.

C. DISCUSSION

1) The series logic reliability allocation model is adopted in this paper. The actual reliability of the WTGS is as follows:

$$R_S = \prod_{i=1}^{7} R_i = 0.9509 > 0.95 \tag{20}$$

which meets the reliability allocation criteria.

TABLE 2. The comprehensive weights of the subsystems considering different factors.

	B.H.	Tra	Gen	Bra	Yaw	Con	Tow
T.L.	0.1190	0.0952	0.1667	0.0714	0.1905	0.1429	0.2143
W.E.	0.1905	0.1667	0.1429	0.1990	0.0714	0.0952	0.2143
T.S.	0.0952	0.1905	0.1429	0.1667	0.0714	0.1190	0.2143
Com	0.0952	0.1429	0.1667	0.2143	0.0714	0.1190	0.1905
I	0.1190	0.1667	0.1905	0.2143	0.0714	0.0952	0.1429
Cos	0.1190	0.2143	0.0952	0.1429	0.1905	0.0714	0.1667

In the table, B.H. = Blades and hub, Tra = Transmission system, Gen = Generator, Bra = Braking system, Yaw = Yaw system, Con = Control system, Tow = Tower, T.L. = Technical level, W.E. = Working environment, T.S. = Task situation, Com = Complexity, Imp = Importance, and Cos = Cost.

TABLE 3. The difference coefficients, the entropy weights and the allocation weights of the subsystems.

	B.H.	Tra	Gen	Bra	Yaw	Con	Tow
D_j	0.0951	0.0937	0.0898	0.1091	0.1403	0.0911	0.0848
α_j	0.1352	0.1331	0.1276	0.1550	0.1993	0.1294	0.1204
w_j	0.1271	0.1508	0.1377	0.1581	0.1633	0.0983	0.1647

2) According to the working principle of the key components of the WTGS, the tower is the structure that supports the nacelle of the entire machine. Once the structure fails, the wind turbine will collapse. Therefore, the structure should be given the highest reliability when conducting reliability allocation. The average cumulative failure rates of the WTGS components in Table 4 [27] show that the control system has the highest value, followed by that of the blades, and then the drive train/gears, yaw system, generator, brakes, and others have middle values. The structures have lower values. The results of WTGS reliability allocation from the method proposed in this paper show that the reliability order of the subsystems from large to small is as follows: the tower, the braking system, the yaw system, the transmission system, the generator system, the blades and hub system, and the control system, which is basically consistent with the actual failure situation of WTGS components, verifying the rationality of the method used in this study.
3) The method in this paper is compared with those proposed by other scholars. Zhou and Li [10] proposed a reliability allocation model for WTGSs based on the number of failures and mean time needed for repairs, and Zhang 17] proposed a reliability allocation model for WTGSs based on the AGREE method. The methods in the above two papers and this paper are used to allocate the reliability of the seven subsystems in this paper. The results are shown in Fig. 5.

The data in Fig. 5 show that the three methods have consistent results for WTGS reliability allocation. The control system and the tower have the lowest and highest allocated reliability, respectively. At the same time, the results of allocated reliability using this paper's method are lower than those using the methods of Zhang and Zhou.

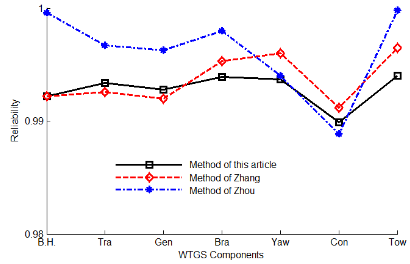

FIGURE 5. Reliability allocation results of the WTGS subsystems using different methods.

TABLE 4. Comparison of cumulative failure rate trends of the WTGS components.

Components	Average cumulative failure rate [27]	Cumulative failure rate by the proposed method
Control system	0.2856	0.0101
Blades/Pitch	0.2752	0.0078
Drive train/Gears	0.1325	0.0066
Yaw system	0.1130	0.0063
Brakes	0.0761	0.0061
Generator	0.0743	0.0072
Structure	0.0468	0.0060

V. CONCLUSION

In this paper, the reliability modeling of WTGSs is carried out by AHP based on a three-scale standard under the influence of multiple factors, such as the technical level, the working environment, the task situation, the importance, the complexity and the cost. The fuzzy consistency and other information processing are carried out on the expert score value, and the entropy weight processing is carried out on the reliability index of each component under different influencing factors by combining with the entropy weight method principle. The entropy weight value of each subsystem of the WTGS is first obtained, and then the reliability of each subsystem of WTGS under the influence of multiple factors is obtained.

In this paper, the three-scale standard is simplified, which makes it easier for experts to judge the influence of various factors on the subsystem of the WTGS. Fuzzy consistency processing is also carried out according to the results of the expert evaluations, such that the entire reliability allocation process eliminates the work of consistency inspection. More importantly, because of the subjectivity of the experts' judgment, to make the allocation result more objective, the reliability allocation weight of each factor is processed according to the principle of the entropy weight method, and the reliability allocation of the WTGS is carried out using comprehensive weights to make the distribution result closer to the objective.

The reliability allocation method of WTGSs in this paper not only improves the subjectivity of the allocation results, but also reduces the reliability values allocated to each subsystem. In this way, the allocation result is not only more reasonable, but also reduces the manufacturing and maintenance cost of the WTGS, improving the overall economic benefits. However, the reliability allocation model in this paper simplifies the failure logic of the system, which considers only the series systems. In addition, this paper considers only the reliability allocation between the entire system and the key subsystems. To consider the reliability allocation of the parts of these subsystems, it is necessary to analyze the actual relation between the influencing factors and the failure logic.

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