Research on comprehensive performance evaluation technology of wind turbine based on Analytic Hierarchy Process

Xiangsheng Huang [1], Mingqiu Zhong [1], Ying Li [1] and Hongyuan Yang [2]

[1]Fujian Xinneng Offshore Wind Power R & D Center Co., Ltd., Fuzhou, China

[2]China General Certification Center, Beijing, China

916633859@qq.com

Abstract. High-power of the offshore wind turbine is in the early stage of development, then how to establish a scientific and impartial performance evaluation system of the offshore wind turbine becomes the key to the health development of the industry. This paper adopts the method of multi-level analysis and site testing, which can reduce the impact of human factors on evaluation to the most extent. A more reasonable judging criterion with the relative importance of different factors of the same criterion level is also put forward, which constructs a more scientific and fair evaluation system of the high-power offshore wind turbine.

1. Introduction

With the development of offshore wind power technology, the high-power wind turbine will gradually become an important direction for future development of offshore wind power in China [1]. However, since the offshore wind power is in the early stage of development, most of owners have not enough experience in the life cycle of the wind turbine maintenance, and have limited ability to recognize the comprehensive performance of the wind turbine. And the unit suppliers tend to improve the performance of the warranty period at the expense of higher maintenance costs and lower power generation at the end of equipment life. Therefore, scientific, fair and comprehensive performance evaluation system , which is an urgent need to solve the problem for wind farm owners developing offshore wind power, is the key to the wind turbine selection, and also is an important guarantee for the sustainable and healthy development of the wind power industry[2][3]. The comprehensive evaluation of the high-power offshore wind turbine is multi-objective, multi-criterion and multi-level system. How to use Analytic Hierarchy Process to construct evaluation system and determine the weight value of each criterion is the key of evaluation technology research [4][5].

2. Multi-level analysis model construction

2.1 Analytic Hierarchy Process

Based on the nature of the problem and the overall goal to be achieved, Analytic Hierarchy Process (AHP) forms a multi-level analysis structure model, which eventually makes the question ascribe to the determination of relative weights or the scheduling of relative priorities about the lowest level (decision-making schemes etc.) relative to the highest level (total goals) [6]. Mathematizing the decision-making process, AHP provides a simple decision method for solving the multi-objective and multi-criteria characteristics of complicated decision-making problems, to some extent, that reduces

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the risk of the decision makers simply based on experience [7]. However, when applying the tradional AHP to select unit, the relative importance of the evaluation factors of the criteria level and the relative merits of the candidate units for the scheme level are based on the intuitive judgment of evaluators, that lack of extensive investigation and statistical analysis of actual survey data or document data to support, which the analysis process of quantitative composition is insufficient. So APH should be improved in order to make the results more guiding significance.

2.2 Multi-level analysis model of offshore wind turbins

Applying the APH, first of all, the problem of the unit evaluation should be layered. Based on the nature of the problem and the overall goal to be achieved, the problem is decomposed into different evaluation factors, then according to the relationship between the evaluation factors and the subordinate relationships, the evaluation factors are aggregated at different levels to form a multi-level analysis structure model [7]. That the evaluation factors at each criterion level determine whether the structural model is reasonable or not, is the key to evaluation analysis. For the selection evaluation of offshore wind turbines, because of the limitation of the years of development, it is unrealistic to evaluate the performance indicators and data of a particular model over the entire life cycle of more than 20 years. Therefore, on the basis of site test verification and operation data of prototypes during the assessment period, the review of design documents of the unit, enterprise and unit technology, quality system and market performance aslo should be added to evaluate the comprehensive performance of the life expectancy of the unit. The multi-level analysis model of offshore wind turbines constructed by this paper is shown in figure 1. This comprehensive evaluation model was unanimously approved by the experts through internal and external meetings.

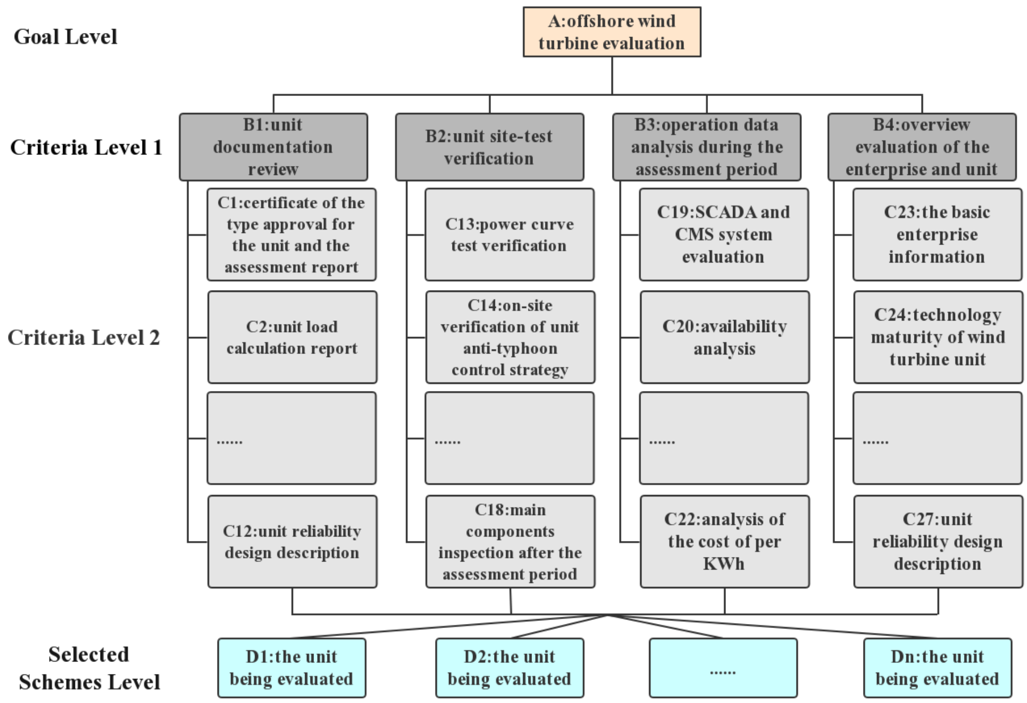

Figure1. Analytic Hierarchy Process model of the offshore wind turbine

3. The basic calculation principle of weight value of the evaluation factor

3.1 Construct of judgment matrix

After establishing the multi-level analysis model, another key technical link of the comprehensive evaluation model is to determine the weight value of each evaluation factor through the judgment matrix. In general, the judgment matrix is constructed according to comparing the the importance of each evaluation factor at the same level, which the comparion takes the above level factor as the evaluation goal. Assuming that the factor B_k in the level B is related to the evaluation factors C_1, C_2, …, C_n in the next level, then the constructed judgment matrix $C=\left(C_{\text{ij}}\right)_{n\times n}$ is shown in figure 2.

B_{k}	C_1	C_2	$\cdots$	C_{n}
C_1	C_{11}	C_{12}	$\cdots$	$C_{1\text{n}}$
C_2	C_{21}	C_{22}	$\cdots$	C_{2n}
$\vdots$	$\vdots$	$\vdots$	$\cdots$	$\vdots$
C_{n}	$C_{\text{n}1}$	C_{n2}	$\cdots$	C_{nn}

Figure2. Judgment matrix

In figure 2, C_{ij} is the scale value of the evaluation factor, which indicates the importance of the evaluation factor C_{i} with respect to the evaluation factor C_{j}. The judgment matrix C is a positive reciprocal matrix and has the following properties:

（1） $C_{\text{ij}}>0$

（2） $C_{\text{ij}}=\dfrac{1}{C_{\text{ji}}}$ ， $\left(i\neq j\right)$

（3） $C_{\text{ii}}=1$ ， $\left(i=1,2,\cdots,n\right)$

3.2 Weight vector

The judgment matrix $C=\left(C_{\text{ij}}\right)_{n\times n}$ satisfies the following condition [6][7][8]:

$$\left(C-\lambda E\right)\overline{W}=0 \tag{1}$$

Where: $\overline{W}$ is the eigenvector of the judgment matrix C; λ is the eigenvalue of the judgment matrix C; E is an identity matrix.

For the judgment matrix C, according to the matrix theory [6], there is a unique non-zero maximum eigenvalue with corresponding the eigenvector. When the judgment matrix C has consistency, the eigenvector corresponding to the maximum eigenvalue can be normalized and used as a weight vector, and each element value of the weight vector is the weight value of each evaluation factor.

The process of the judgment matrix C constructed shows that there is the following equation for any of the i, j, k:

$$C_{\text{ij}}\cdot C_{\text{jk}}=C_{\text{ik}} \tag{2}$$

That is, the judgment matrix C is a consistency matrix, so the judgment matrix C can be constructed by the above method to calculate the weight value of each evaluation factor.

4. The scale value of evaluation factors determined by expert survey method

The scale value obtained by judging the relative importance of evaluation factors of the same criterion level is the direct basis for calculating weight values and is the key to the accuracy of the comprehensive evaluation model. This paper applys the 1 to 9 scale method to judge the importance of the factors of the same criteria level relative to the above criterion level[7][9], shown in table 1.

Table1. The definition of scale value

No.	Level of relative importance	Scale value
1	i evaluation factor is as important as j evaluation factor	1
2	i evaluation factor is slightly important than j evaluation factor	3
3	i evaluation factor is obviously important than j evaluation factor	5
4	i evaluation factor is mightily important than j evaluation factor	7
5	i evaluation factor is extremely important than j evaluation factor	9
6	i evaluation factor is slightly unimportant than j evaluation factor	1/3
7	i evaluation factor is obviously unimportant than j evaluation factor	1/5
8	i evaluation factor is mightily unimportant than j evaluation factor	1/7
9	i evaluation factor is extremely unimportant than j evaluation factor	1/9
10	the scale values corresponding to the intermediate state between the above judgments	2,4, 6, 8, 1/2, 1/4, 1/6, 1/8

In addition to the reasonable choice of expert consultants, it is necessary to have a deeper understanding of the connotation of the relative importance of the evaluation facrors. For example, "cost" and "scenery" are important evaluation factors for selecting travel destinations. When determining the scale value of relative importance, if only from the factors themselves to understand the importance, tending to think of the two equally important, so the scale value is "1". Cost is relatively easy to compare, while everyone’s perception of the scenery does not have a uniform scale, thus evaluating the scenery is not easy to be fair and accurate. Therefore, it is more reasonable to set the scale value of "cost" as "2" compared with "scenery". Similarly, "live" and " diet " are also a travel destination choice. In general, “living” is slightly more important than “diet” (ie, the scale value of “living” is “3”). However, the standard of living conditions is consistent, dietary habits and preferences are difficult to unify. So for choosing a travel destination, the weight of "live" should be larger than that of " diet ". When the expert judges, the scale value of the relative importance of “living” set as “ 4" is more scientific.

This paper collects survey questionnaires to collect experts' judgments on the relative importances of different evaluation factors at the same criterion level in each subdivided field. The essence of expert consultations is to transform the profound knowledge and rich experience into useful information, and the survey questionnaire fully explained the importance of evaluation factors to the experts, including the importance of this evaluation factor relative to the evaluation goal of the above level and the operability, fairness of the evaluation factors themselves. The weight value, calculated by the judgment matrix which established by the scale values obtained by survey questionnaires of experts, is more reasonable.

5. The weight value of each evaluation factor determined by expert survey method

In this paper, 26 effective questionnaires were collected, including 9 experts from the host manufacturers, 9 experts from the testing and certification organizations, 4 experts from the wind farm owners, 5 experts from the operation and maintenance, and 3 from the research institutes. After statistical analysis, the judgment matrix is constructed according to the chapter 2, then the eigenvalues of the judgment matrix are established. After the consistency verification, the weight values of evaluation factors of each criterion level are obtained, shown in table 2.

Table2. The calculation results of weight values of evaluation factors

Evaluation factors of the criteria level 1	Weight values of evaluation factors of criteria level 1	Evaluation factors of the criteria level 2	Weight values of evaluation factors of criteria level 2
Unit documentation review	0.318	Certificate of the type approval for the unit and the assessment report	0.197
		Unit Load Calculation Report	0.109
		Site-specific load calculation report	0.096
		tower strength calculation report of the specific site	0.092
		Matching descriptions of environment conditions for specific sites of the unit and main components	0.061
		Description of the unit's anti-typhoon strategy	0.054
		Load testing and simulation comparison reports	0.088
		Power curve test report	0.076
		Safety and function test report	0.067
		Blade type test report	0.055
		Gear box or transmission chain test report	0.059
		Unit reliability design description	0.046
Unit site-test verification	0.388	Power curve test verification	0.241
		On-site verification of unit anti-typhoon control strategy	0.185
		Unit environmental adaptability test verification	0.132
		Load test and simulation comparison during typhoon	0.197
		Subsystem check after the assessment period	0.117
		Main components inspection after the assessment period	0.128
Operation data analysis during the assessment period	0.242	SCADA and CMS system evaluation	0.175
		Availability analysis	0.220
		Fault statistics and analysis	0.184
		Components replacement statistics and impact analysis	0.181
		Analysis of the cost of per KWh	0.133
Overview evaluation of the enterprise and unit	0.052	The basic enterprise information	0.259
		Technology maturity of wind turbine unit.	0.294
		Wind turbine market performance evaluation	0.227
		Wind turbine historical operation	0.221

6. Conclusion

The traditional AHP method directly evaluates the relative advantages and disadvantages of selected schemes from the bottom-level evaluation factors, and finally obtains the relative merits of the each scheme relative to the total goal. The comparison, judgment and calculation of the results of the traditional AHP method are crude, and the subjective factor has a great influence on the whole process, which make it difficult for the decision maker to accept the result. This paper establishes a reasonable multi-level analysis model for the offshore wind turbine, and formulates detail evaluation factors for second criterion level. Through the site test verification and document review, each evaluation factor is accurately scored, and then the comprehensive performance score of each unit is calculated by means of weighted sum according to the weight values of evaluation factors of the two criteria levels (ie, table 2). The score quantifies the comprehensive performance of the unit, making the evaluation process more objective and fair, and the evaluation result is clear at a glance.

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