The Research of Doubly-fed Wind Turbine Gear Box of the Status of the Comprehensive Evaluation Method

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Abstract. Multiple indexes and multiple level comprehensive evaluations for wind power gear box focus more attention in recent days. Through the analysis of the state of wind turbine gearbox, fault hazard degree and other factors that is related with the internal temperature in gear box, environment temperature and the characteristics of wind speed, state evaluation index system of health indicators that is based on the current state of the age and the fault hazard health degree is established in this paper. Combined with the hazard matrix, current hazard degree is obtained. The effectiveness of adding health indicators is proved by examples.

1. Introduction

The running state of the gear box and its health is related with current performance[1]. The harm of gearbox's fault and protection measures is different in age. But in consideration of the fault hazard, other researches do not focus on difference under the degree of hazard fault in different stage in gearbox's life[2,3].

Multiple indexes and multiple level comprehensive evaluations for wind power gear box focus more attention in recent days. This chapter will attempt to seem present life gear box section and fault hazard as health indicators. Coupled with the performance of the gear box, the paper regards the combination of the two sections as index system of running evaluation state.

2. The state evaluation model of wind power gear box based on fuzzy comprehensive evaluation

2.1. The set of evaluation language and the establishment of the fuzzy judgments matrix

This chapter will divide state division of wind power gear box into 4 cases, that is good, general, attention, poor, namely: $L = $ [good, general, notice, poor] $= [l_1, l_2, l_3, l_4]$. Evaluating the condition of the gear box by using the evaluation index R_{ijk}, state of concentration is l_i ($i = 1,2,3,4$), its membership is v_{ij} ($j = 1,2,3,4$), you can set assemble membership $V_i = [v_{i1}\ v_{i2}\ v_{i3}\ v_{i4}]$, that represent R_{ijk} by the assessed results. All V_i constitute the evaluation matrix. R_{ijk} is the first evaluation index of the sub i item in the first j item. Such as to internal condition of sub project layer R_{11} as an example,

the evaluation matrix is shown in formula (1) and the limit values of evaluation indices is shown in Table 1.

$$V_{R_{11}} = \begin{bmatrix} V_{R_{111}} \\ V_{R_{112}} \end{bmatrix} = \begin{bmatrix} v_{11} & v_{12} & v_{13} & v_{14} \\ v_{21} & v_{22} & v_{23} & v_{24} \end{bmatrix} \qquad (1)$$

Table 1. Limit values of evaluation indices

number	Evaluation index	Designed operating limit	
		Upper limit value	lower limit value
1	Gearbox oil tank temperature R_{111} (℃)	80	0
2	Gearbox return oil temperature R_{112} (℃)	70	0
3	Gearbox bearing temperature R_{113} (℃)	90	0
4	Wind speed R_{121} (m/s)	25	3
5	Environment temperature R_{122} (℃)	50	-20
6	Age of current gear R_{211} (year)	20	0
7	Hazard degree of gear R_{212}	10	1
8	Age of current shaft R_{221} (year)	20	0
9	Hazard degree of shaft R_{222}	10	1
10	Age of current bearing R_{231} (year)	20	0
11	Hazard degree of bearing R_{232}	10	1

2.2. The processing of fuzzy operator and evaluation index

The expression of fuzzy comprehensive evaluation is $B = A_R \circ V_R$, in which the generalized fuzzy operator is $\circ$, the weight is A_R. Dynamic state change obviously in the process of running gear box. So this chapter selects the weighted average type fuzzy operator M, $b_j = \sum_{i=1}^{m} a_i v_{ij}$ (j = 1, 2…). According to the principle of maximum membership degree, the final select $b_{max} = \max$ and corresponding l_i (i= 1, 2…) as the evaluation results[4,5].

Determining the membership function of each index and the weight of each evaluation index is the key of the state evaluation model, and then the two factors are analysed concretely.

2.3. Determine the weight of assessment indicators at all levels

2.3.1. Determination of constant weight. According to the analytic hierarchy process to calculate the weight. Ask 5 experts (1,2, 3, 5, 4) to determine the relative importance of each assessment indicator

paired comparison. It can be arbitrarily taken between the number of 1~9. The judgment matrix established by each expert is as follows:

$$P = \frac{\sum_{i=1}^{n} P_{E_i}}{n} \tag{2}$$

Where, P_{E_i} —the judgment matrix determined by the i expert; n —the number of experts.

Table 2 is the constant weight of each level of the 2MW wind turbine gearbox. According to the gear box inspection record, the engineering design and the failure statistics data, the constant weight of the different sub items is selected based on the above.

Table 2. Constant weights value of evaluation index

Item	$A_R^{(0)}$	Sub items	$A_{R_{iij}}^{(0)}$	$A_{R_{ijk}}^{(0)}$
R_1	0.7253	R_{11}	0.6437	[0.3733，0.2009，0.4258]
		R_{12}	0.3563	[0.8869，0.1131]
R_2	0.3563	R_{21}	0.61	[0.4832，0.5168]
		R_{22}	0.12	[0.4832，0.5168]
		R_{23}	0.27	[0.4832，0.5168]

2.3.2. Handling variable weight. The deterioration of the assessment indicators will be changed with unit operating conditions changing[6]. In this chapter, it uses the balanced function to improve the evaluation index of each layer. The variable weight is calculated by using the following formula:

$$A_{R_{ijk}}(g_{R_{ij1}}, \cdots, g_{R_{ijd}}) = A_{R_{ijk}}^{(0)} (1 - g_{R_{igk}})^{\delta-1} / \sum_{s=1}^{d} A_{R_{ijs}^{(0)}} (1 - g_{R_{ijs}})^{\delta-1} \tag{3}$$

Where, $A_{R_{ijk}}^{(0)}$ and $A_{R_{ijk}}$ are the regular and variable weight of the first k index of the j sub item of the first i project respectively. d is the number of evaluation indicators in the sub item layer. δ is the variable weight coefficient, take $\delta = -1$. $g_{R_{ijk}}$ indicates the degree of deterioration of the evaluation index R_{ijk}.

As shown in Figure1. The deterioration degree is calculated first, and once the deterioration degree of a single evaluation index is $g > 0.9$, that is, the result of the evaluation is "very poor" ". Otherwise, the state can be evaluated by changing the weight and evaluation matrix, which can improve the accuracy of the evaluation results. For example, when the gear box performance index of R_1 in $R_{111} = 60.2\ ℃$, $R_{112} = 34.3\ ℃$ and $R_{113} = 49.9\ ℃$, according to the type of before ,it gets the deterioration degree $g_{R_{111}} = 0.7525 < 0.9$, $g_{R_{112}} = 0.49 < 0.9$ and $g_{R_{113}} = 0.5544 < 0.9$, it should evaluate the current state by changing the weights and evaluation matrix.
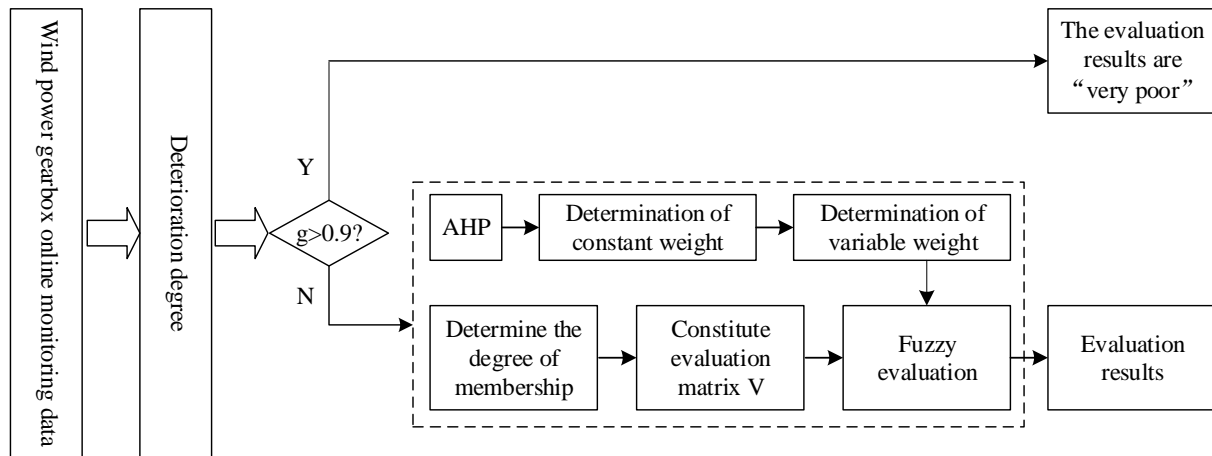
Figure1. Flow chart of the fuzzy synthetic evaluation.

3. The calculation of example

The paper evaluates the statement of the segmental operation monitoring data of the wind turbine gearbox from December 21 to December 22, 2014 (table 2), compared with evaluation results of no consideration of gearbox health indicators and analyzes its actual operating results. The comparison of evaluation results is shown in table 4. According to the degree of deviation of operating data of evaluation index and normal value, each set of data in the table 3 is analyzed: the second, third sets of temperature data are in the normal operating range, criticality calculated by the second set of vibration data and the current age are also in the normal range; some evaluation indicators in the fourth set of data will reach the allowable limits, but do not affect the unit to continue to run，for example ,the temperature of gearbox oil bath R_{111} is 68.1℃, the temperature of box bearing R_{113} is 62.5℃；the criticality of gear R_{212} and bearing R_{232} are all in the period of performance degradation, so the criticality increasing is the main reason of the statement of "caution"; the deteriorative degree of evaluation index R_{113} got in the fifth set of data $g_{R_{113}} > 0.9$,through membership determination and evaluation matrix to calculate the final evaluation result is $B = \begin{bmatrix} 0 & 0 & 0 & 1 \end{bmatrix}$, the result is "worst". This shows that evaluation results are in keeping with the analysis of actual operation data, that is the main reason for the "worst" that is the gearbox bearing temperature is close to the limit of 90 ℃.

Table 3. Monitoring temperature, wind speed, temperature surroundings data of a 2 MW grid wind power gearbox

number	Evaluation index	Online monitoring data					
		Data 1	Data 2	Data 3	Data 4	Data 5	Data 6
1	Gearbox oil tank temperature R_{21} (℃)	52.1	49.7	59.2	68.1	68.9	10.2
2	Gearbox return oil temperature R_{22} (℃)	35.0	29.1	39.6	33.4	45.8	38.5
3	Gearbox bearing temperature R_{23} (℃)	61.5	56.7	59.3	62.5	50.7	80.2
4	Wind speed (m/s)	10.6	11.2	9.9	11.4	11.4	11.5
5	Environment temperature (℃)	18.5	16.7	21.4	33.3	34.1	6.9

Table 4. Evaluate results

State evaluation results	Corresponding number of monitoring data				
	2	3	4	5	6
Calculation results without considering health index	[0.5106, 0.2165, 0.2304, 0.0325]	[0.4793, 0.3155, 0.1804, 0.0248]	[0.2897, 0.2911, 0.2058, 0.2134]	[0.2454, 0.2904, 0.2235, 0.2407]	[0.6325, 0.1865, 0.1452, 0.0388]
Evaluation results without considering health index	Good	Good	General	General	Good
Calculation results of considering health index	[0.4962, 0.2836, 0.1980, 0.0422]	[0.325, 0.396, 0.276, 0.003]	[0.1695, 0.1694, 0.3769, 0.2842]	[0.061, 0, 0.834, 0.105]	[0.039, 0, 0.205, 0.756]
Evaluation results of considering health index	Good	General	Notice	Notice	Poor

4. Conclusion

In this paper, by analysing the state of wind power gearbox is related to the fault criticality and the age of wind turbine, and the internal temperature, environment temperature and wind speed characteristics, it constructs a state evaluation index system, which use the current age and the fault criticality as health index. The fuzzy comprehensive evaluation is used to evaluate the fault degree of the gearbox, and combined with the criticality matrix, the current criticality of gear box can be obtained. The example shows that the evaluation model is more significant after adding health index.

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