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Health assessment and management of wind turbine blade based on the fatigue test data

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ABSTRACT

With the quality problem becoming increasingly prominent, it is necessary to assess and manage the health condition of the wind turbine blade. The health degree is defined and calculated by the Grey Relation (GR) model to assess the health condition of the wind turbine blade quantitatively. The availability, reliability and artificial test result are taken as three indexes of the health degree. The availability is defined according to the stiffness degradation affected by the environmental temperature. Based on the health assessment results, after determining the decision objectives and the management strategies, the weights of the decision objectives and the health management decision are determined by the Analytic Hierarchy Process and Fuzzy (AHP-Fuzzy) decision method. This process is shown in a practical example of the 3 MW wind turbine blade. As a result, an approach and a certain theoretical guidance for the health assessment and management of wind turbine blade are proposed.

1. Introduction

Wind turbine blade is the key component that converts wind energy into mechanical energy and finally drives the generator to generate electric power. In recent years, with the increasing wind power capacity, the size of wind turbine blade has increased rapidly. At the same time, the problem of its quality has become increasingly prominent [1]. Hence, it is necessary to research the health assessment and management of the wind turbine blade.

For wind turbine blade, its performance is gradually degrading, which may not be described only by the simple and ambiguous approaches that seem not accurate enough. Therefore, it is necessary to quantify the indicators of the health assessment. Some methods are used in health assessment. Miao et al. [2] presented a health evaluation method using comblet filtering and exponentially weighted moving average, and proposed a new health condition indicator. Several researchers [3–5] had given the health evaluation method with some other methods. However, some indicators that characterizing the health condition are difficult to be measured directly [6]. They are non-quantitative indicators. Compared with the above methods, the GR model can be used to analyze some quantitative and non-quantitative indicators together. Using the GR model, Patil [7] achieved the close tolerance and good surface by considering several indicators. Therefore, the GR model can be used to assess the health condition of the wind turbine blade.

The purpose of health assessment is to acquire the health condition and make some management decisions. Health management is a multi-objective decision problem. The methods such as Multidimensional Utility Mergence, AHP, Entropy Weight, Fuzzy, etc. are widely used. Several researchers [8–11] had tried to apply these methods to identify the weight of the indexes and propose an approach for some multiple objective decision cases. Amidst these above methods, the AHP is the most suitable method to identify the weights of the objectives as well as the Fuzzy decision method is the most suitable method to find the optimal decision. Obviously, the combination of the AHP and the Fuzzy decision method is a good choice. Zhou et al. [12] proposed a method to select the optimal mode of wind turbine. Some other researchers [13–15] had solved the mode selection and the multi-objective decision by AHP and Fuzzy. Therefore, the health management of the wind turbine blade can be carried out by combining the two methods, which is called the AHP - Fuzzy decision method.

At present, it is difficult to collect the health condition data (internal defects, surface quality, stiffness, etc.) of the wind turbine blade in service directly. In order to overcome the difficulties of collecting operational data, the full-scale fatigue test is an alternative access to get the basic data [16,17]. The service life of the wind turbine blade mainly depends on its fatigue life. The full-scale fatigue test is used to simulate the fatigue properties of the blade within its whole life cycle. All kinds of data (stiffness, defects, vibration, stress and strain, etc.) collected in the fatigue test can be used to describe the health condition of the blade on different test times. Thus, facing the difficulties of collecting data in service, it is reasonable to assess and manage the health condition by the full-scale fatigue test of the wind turbine blade.

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In summary, the 3 MW wind turbine blade is taken as an example of the health assessment and management. The health degree is calculated by the Grey Relation (GR) model to quantify the indicators of the health assessment. Based on the health assessment results, the health management decision is made by the AHP-Fuzzy decision method.

According to the above analysis, the health assessment based on the GR model is presented in Section 2, and the health management decision based on the AHP-Fuzzy decision method is presented in Section 3. A practical example is shown in Section 4. Several conclusions are listed in Section 5. A flowchart of the method is shown in Fig. 1 to illustrate the mind in this paper.

2. Health assessment based on the GR model

Due to the gradual performance degradation, the residual performance level of the wind turbine blade could be measured quantitatively by comparing the health indexes with their initial values. So the relation degree (means the proximity) between the health indexes and their initial values is defined as the health degree of the wind turbine blade. The health degree can be used to assess the health condition quantitatively. This process meets the characteristics of the Grey Relation (GR) model.

2.1. Indexes of the health assessment

The availability is a measurement for the ability of a system or component to work properly during certain time [18]. For the wind turbine blade, availability is the essential precondition to measure its work condition, as well as to assess other performances. Thus, the availability can be selected as the first index in the health assessment of the wind turbine blade.

In the full-scale fatigue test of wind turbine blade, the stiffness degradation is taken as the evidence to determine whether the ability of the blade meets the normal requirement [16,19]. So, the availability of the blade is defined as the holding quantity of the stiffness in the full-scale fatigue test of wind turbine blade.

$$A(k) = \frac{S(k)}{S(0)} \tag{1}$$

where k denotes the test number, $S(k)$ denotes the residual stiffness on k test times, $S(0)$ denotes the initial stiffness on 0 test times, $A(k)$ denotes the availability on k test times.

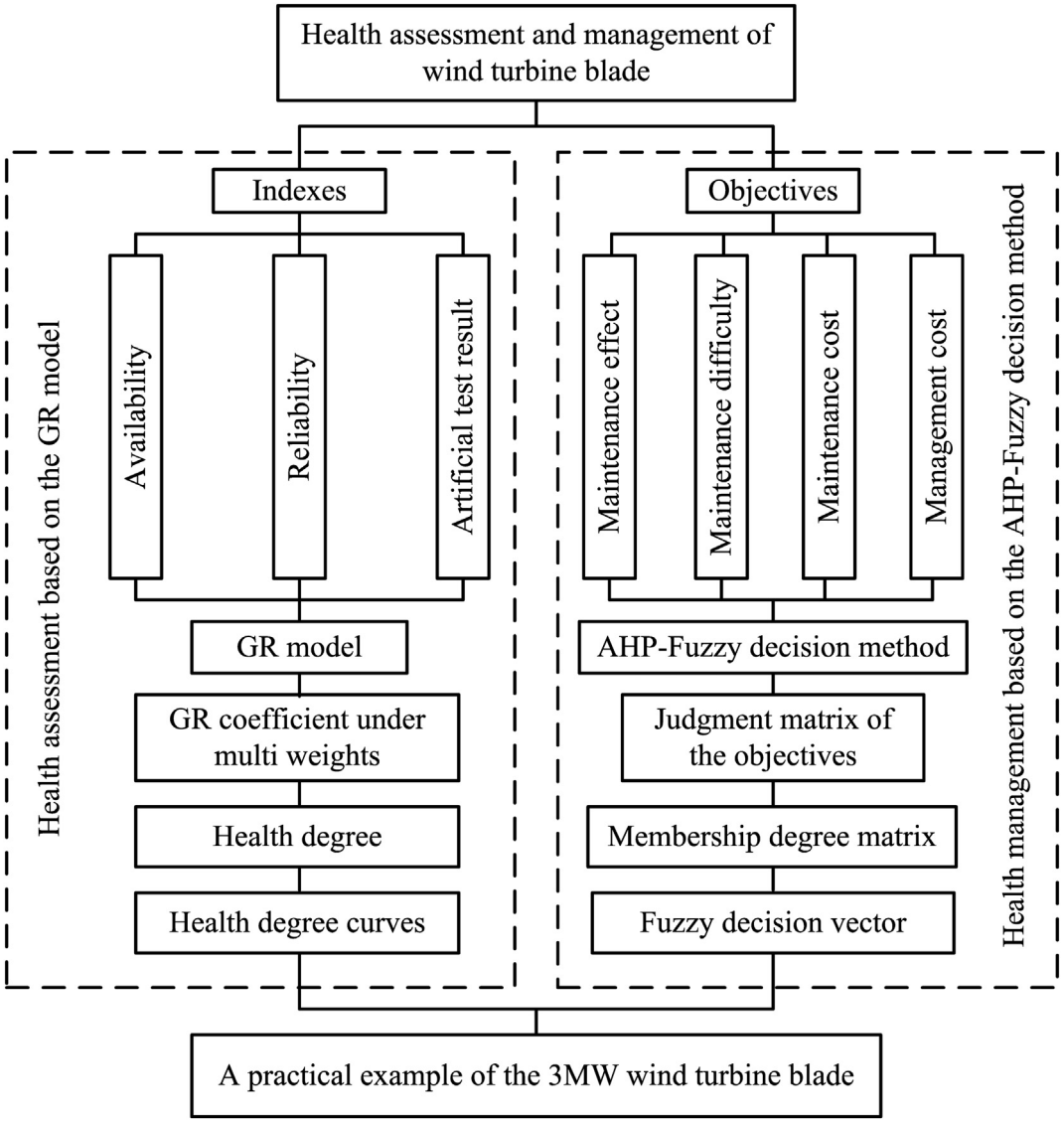

Fig. 1. Flowchart of the method in this paper.

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