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Expert System of Fault Diagnosis for Gear Box in Wind Turbine

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Abstract

Gear box is one of the key components in wind turbine. To make timely and accurate diagnosis for gear box, an expert system based on fault tree analysis is developed in this paper. Firstly, a fault tree model is established in accordance with the structural features of wind turbine gearbox. On basis of the fault tree model, qualitative analysis and quantitative analysis of the gearbox faults are carried out afterwards. Finally, a Web-oriented expert system is developed by C# on the .NET platform which will save the fault diagnosis time significantly and make the expert solution for the fault of gear box to achieve the precise and quick maintenance more effectively.

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Keywords: *expert system, fault diagnosis, industrial engineering, gear box, wind turbine;*

1. Introduction

Gear box is one of the key components in wind turbine and the fault of gear box will lead to wind turbine shut down inevitably. So what must be done is making timely and accurate diagnosis to gear box. However, due to rapid development of wind power industry, there is no fault diagnosis system specifically for wind turbine gearbox on the market in China. Currently, during the wind turbine gearbox fault diagnosis, workers generally analyze the phenomenon by rule of thumb. This fault diagnosis approach will spend more time and the accuracy is low. Statistics show that the determining time for the fault diagnosis takes up 70% to 90% of the total time, while the repair time takes up only about 10% to 30%[1].

Fault diagnosis systems have been successfully applied in many kinds of technical processes to improve operation reliability and safety. Wu introduced an expert system for fault diagnosis in internal combustion engines using wavelet packet transform and neural network[2]. Lei proposed a new multidimensional hybrid intelligent diagnosis method to identify different categories and levels of gear damage automatically[3]. Saravanan dealt with the effectiveness of wavelet-based features for fault diagnosis using support vector machines and proximal support vector machines[4]. In another paper, he introduced the use of decision tree for selecting best statistical features that discriminate the fault conditions of the gear box from the signals extracted and the decision tree was also used to generate the rules automatically from the feature set [5].

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Fault diagnosis systems are relatively new and are flourishing on a rapid scale in wind energy technology, especially for the development of large-scale wind turbines. Barszcz presents the application of the spectral kurtosis technique for detection of a tooth crack in the planetary gear of a wind turbine[6]. Tang presents a wind turbine fault diagnosis method based on the Morlet wavelet transformation and Wigner-Ville distribution[7]. Jiang applied a new denoising method based on adaptive Morletwavelet and singular value decomposition (SVD) to feature extraction for wind turbine vibration signals[8]. Hussain proposed a novel method for real time fault detection in gearboxes by using adaptive features extraction algorithm to deal with non-stationary faulty signals[9].

This paper applies the fault diagnosis system on wind turbine gear box, in order to make timely, accurate diagnosis for gear box and provide timely solutions. In this way, it can not only meet the requirements of rapid response to wind turbine fault diagnosis, but also prevent the emergence of human error, the valuable experience of experts can be retained to prevent lost, too.

Fault tree analysis is an intuitive, clear, logical, and applicable system compares to the relatively simple ones. The gear box of wind turbine has less hierarchical structure, so fault tree is used to analyze the component faults and express their reasons, and an expert system based on fault tree analysis is chosen to make diagnosis on wind turbine gear box in this paper.

2. Fault Tree of Gear Box in Wind Turbine

2.1. Fault Tree Analysis

Fault tree analysis is a graphical interpretation method which can refine the system fault causes from whole to part by dendrite progressively. It is also an important method of analyzing system reliability and safety. Fault tree is drawn through analyzing a variety of factors (including hardware, software, environment, human factors, etc.) which should cause system fault, refining system fault event from whole to part by dendrite progressively, identifying the cause of system fault, determining the probability of fault, and evaluating the important degree related to the cause[10]. Fault tree model is a behavior and qualitative causal model based on studying the structure and functional characteristics of fault. The top event is the event which is to be avoided firstly. The basic events are those can cause top event while the intermediate events are the nodes. Fault tree is a dendritic logic diagram which shows relevance between events by using logic gates. As shown in Fig. 1.

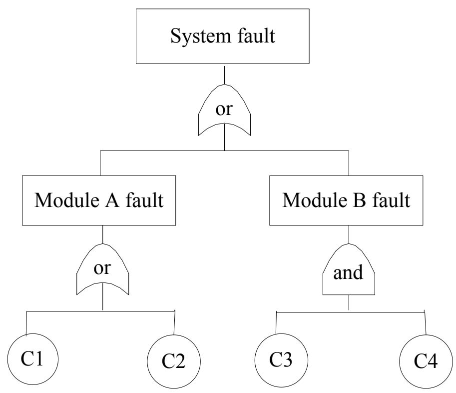

Fig.1 Fault tree diagram

In Fig. 1, the top event is system fault caused by intermediate events of component A fault or component B fault. Component A fault is caused by basic event of part 1 fault or part 2 fault. The basic events of part 3 fault and part 4 fault happen will cause the component B fault.

2.2. Fault Tree of Gear Box in Wind Turbine

From the current structural characteristics of gear box in wind turbine and its actual fault conditions, faults usually occur in parts such as gears, shafts, bearings and box. But in order to perfect the fault tree, fastener fault and oil seal fault are added to the fault tree. In the fault tree of gear box, wind turbine gear box fault is the top event; the intermediate events include gear fault, shaft fault, bearing fault, the box fault, fasteners fault, seals fault and other events which can be further refined; the damage of parts or improper operation is taken as the basic event. As fault of any component of the gear box will cause a system fault, the main logical relationship between the fault is "or". The final fault tree is shown in Figure 2(M stands for intermediate event, while C stands for basic event).

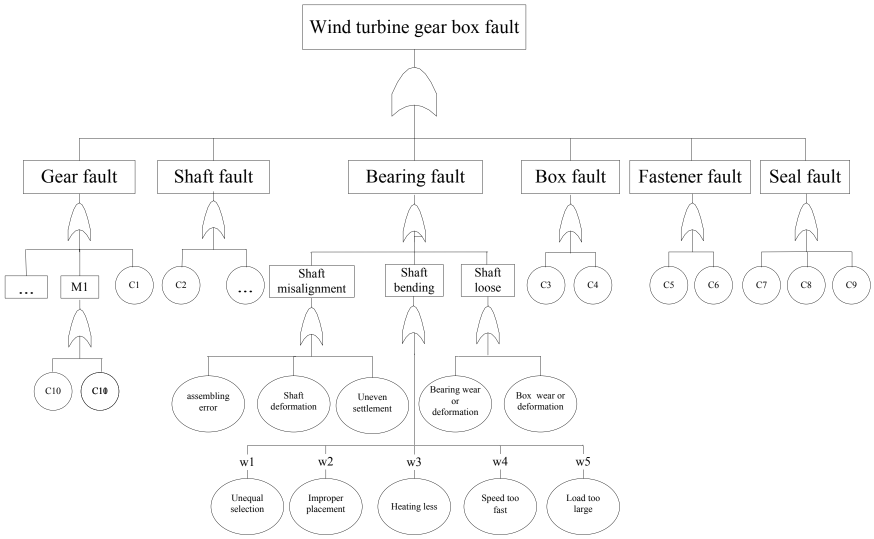

Fig.2 Wind turbine gear box fault tree diagram

In order to get an extended fault tree, auxiliary information including the weight and solution of fault is added to each basic event. Fig.2 only shows corresponding weight of intermediate event M3. The relationship of weights is:

$$\sum_{i=1}^{5} \omega_i = 1 \qquad (1)$$

In which, ω_i stands for the corresponding weight of basic event C.

Finally the diagnostic knowledge base is obtained by using production rules to put the fault tree information into knowledge base [11]. According to the diagnostic knowledge base, not only the specific locations and causes of fault can be obtained, but also the reference solution can be given by experts.

3. Fault Analysis Based on Fault Tree

3.1. Qualitative Analysis

The task of qualitative analysis is to identify the possible causes of system top event fault, or to find out the minimal cut sets of the fault tree [12]. The method of finding the minimum cut set is mainly upstream and downstream. According to logical relationship between faults of gear box in wind turbine, this paper adopts downstream. The idea of downstream is: according to the two adjacent terms in the fault tree, logic "or" gate increases the number of cut sets and logic "and" gate increases the capacity of the cut set [13]. Starting from the top event, the cut sets of fault tree is obtained by replacing the previous events into the next level event, writing event vertically when meeting "or" gate, until the gates are all converted into the top event. Fig. 3 shows the minimal cut sets are gotten by qualitative analysis which take the gearbox fault, axis fault and axis bending as the main line.

The minimal cut sets of other components fault can be obtained by the same method. Due to the structural characteristics of gear box, the resulting cut sets are all the minimal cut sets, which are {C1},{C2},{C3},{C4},{C5},{C6},{C7},{...}. Minimal cut sets are independent of each other.

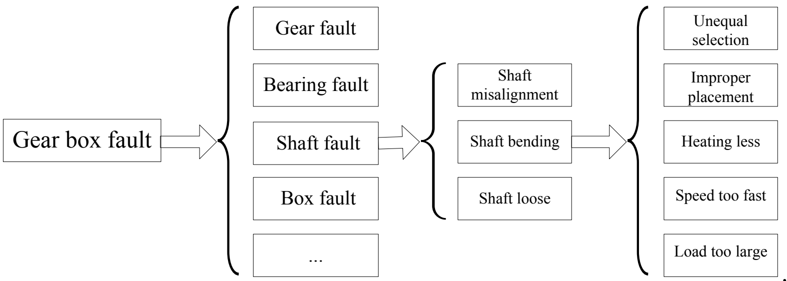

Fig.3 Qualitative analysis of gear box fault

3.2. Quantitative analysis

After obtaining all minimal cut sets, if there is enough data which can support inferring probability of each basic event, the further quantitative analysis can be made [14]. The main purpose of quantitative analysis is to find the characteristic quantities of the top event (such as the top event probability and system reliability) and the importance of the basic event, which can determine the weaknesses in the system.

1) Calculate the probability of top event

The probability of occurrence of top event with "and" gate can be calculated by following formula:

$$p(x) = \bigcap_{i=1}^{n} p(x_i) = \prod_{i=1}^{n} p(x_i) \tag{2}$$

The probability of occurrence of top event with "or" gate can be calculated by following formula:

$$p(x) = \bigcup_{i=1}^{n} p(x_i) = 1 - \prod_{i=1}^{n} [1 - p(x_i)] \tag{3}$$

In which, p(x) is probability of the fault tree top event, p(xi) is probability of the i-th minimal cut set of fault tree, n is the total number of fault tree minimal cut set.

2) Importance analysis of basic event

Importance analysis is to analyze the contribution of fault, which occurred in the minimal cut sets of a component, to the probability of top event. Probability importance degree of basic event describes the extent of probability change of top event caused by the probability change of i-th basic event fault, which is expressed by the formula as follow:

$$I_i(x) = \frac{\partial p(x)}{\partial p(x_i)}, i = 1 \ldots n \tag{4}$$

Ii(x) is probability importance degree of i-th basic event, p(x) is probability of the tree top event fault, p(xi) is probability of the i-th minimal cut set of fault tree, n is the amount of minimal cut set in the fault tree.

4. Expert System of Fault Diagnosis

On the basis of fault tree analysis for gear box, a Web-oriented expert system for fault diagnosis of gear box is developed. The system is designed to have three grades, including symptoms page, fault causes page, solutions page.

After entering the system, the default page is a symptoms page. As shown in Fig. 4.

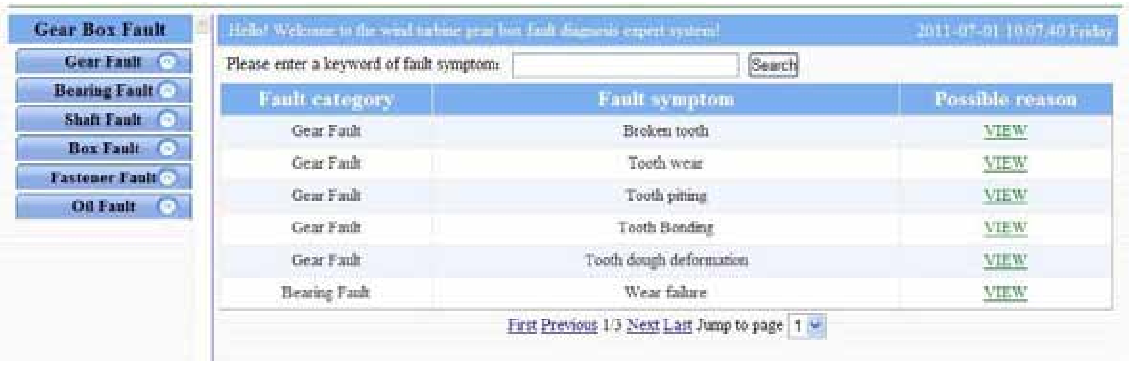

Fig.4 Qualitative analysis of gear box fault

This system is developed by C# on the .NET platform. The overall framework of the system is as shown in Fig. 4. According to the structural of the gear box, the left side of page is made to accordion style, in which the six components fault of gear box are defined to the category name; the right side of the page defaults symptoms page, in which the previous column of symptoms column displays corresponding fault category and the next column links possible causes.

1) To query fault symptom

In the symptoms page, the user can query page by page or do fuzzy query by writing keywords in the search box, and click the “search” button to get the results you want.

2) To query reason of fault

The user can get corresponding possible causes of fault symptom by clicking on the details link of possible cause column in the above list. They can also directly click on the corresponding fault symptom in accordion structure to get a list of corresponding reasons.

The query result is ordered by the weight of reason and the reason whose weight is large is sorted in the top of the list.

3) To query solution of fault

After getting the list of fault reason, the user can click on the details link of solution column to get the recommended solution given by expert. Recommended solution will be ordered from top to bottom, if there are multiple. Maintenance staff can choose different solutions according to the circumstances.

5. Conclusion

Gear box is one of the key components of wind turbine, whose fault will directly affects the safety and the operation of the overall wind turbine. This paper develops an expert system of fault diagnosis for gearbox in wind turbine based on fault tree analysis. With the gradual accumulation of fault and repair instance about wind turbine gear box, the expert system based on fault tree analysis will play a better role in the fault diagnosis of wind turbine gear box.

Acknowledgements

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