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# The Application of Intelligent Fuzzy inference to the Fault Diagnosis in Pitch-controlled System

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**Abstract**

The purpose of this article is to develop a new method to diagnose faults in pitch-controlled system of wind turbine. To do this, Fuzzy inference techniques combining the actual performance of wind turbine generating units and the spot workers' as well as the experts' experiences were used and a model is developed to diagnose faults in pitch-controlled system. The fuzzy theory is used to solve uncertainty inference problem through the establishment of the fault tree. The diagnostic accuracy is raised and the confirmation time of fault is improved at the same time by this method.



*Keywords: fuzzy inference; pitch-controlled system; fault tree; fault diagnosis; wind turbine*

## 1. Introduction

The wind power is regarded as a key source in reducing energy consumption and carbon dioxide emissions. Therefore, at present the government policy and technical developments make wind energy running the lowest risk and taking advantage of most established technology among the renewable sources at present. However, the wind turbine is prone to multiple failures due to the poor environmental conditions where they work. Faults of wind turbine may cause the interruption of equipment working properly, increase economic costs, and even more threat to the live of operators in case faults are not predicted and treated timely. Therefore, it is of great significance to research the various fault reasons and accurate fault diagnosis of wind turbines.

Currently, the fault diagnosis research in wind turbines from abroad mainly focus on induction motor and gearbox as in [1-4]. These methods have been successfully applied for automated fault diagnosis and have achieved well economic result in practical applications. In china the fault diagnosis of wind turbine

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is not enormous, and most of current research works focus on vibration analysis and base on expert system to detect the fault of gearbox and other components prone to failure as shown in [5-6]. A method involved fuzzy inference proposed in reference [7] is easy to find the source of trouble. Unfortunately, the fault diagnosis accuracy depends on the membership function, while the current method for determining membership function is both empirical and subjective. In addition, the relationship between fault and the various sources of failures are difficult to be comprehensive understood and reflected directly by the fuzzy inference method.

we know that the number of faults occur in pitch-controlled system of wind turbine just followed the electrical system, and it also account for a large proportions of the longest machine halt time in parts and single failure longest downtime shown in [8] based on the statics obtained from Sweden, Finland and Germany. It is difficult to be described between fault mechanism and fault causes by mathematical models in the pitch-controlled system due to complexity and ambiguity. In view of this, the rules of fuzzy fault diagnosis  aimed at features of equipment fault in pitch-controlled system of wind turbine, combining the actual performance of wind turbine generating units and the spot workers' and the experts' experiencesbased on the fuzzy reasoning, are formed. The purpose is to identify the fault cause based on failure symptoms, and give some quantitative references to the maintenance staff s.

## 2. Establish Fault Diagnosis Model

### *2.1 The structure of fault tree*

Rule-based FT(fault tree) is chosen by knowledge in the source of knowledge .It is a graphic interpretation method that can put the reason of system fault formed from general to parts on the basis of arborization progressively refined, and draw the FT by analyzing the various factors which could cause system malfunction. The variable pitch system failures can be classified into several symptoms, For example: drive motor failure, pitch bearing failure, the master counter failure, limit switch failure; surface cleanliness fell, coating failure, loose bolts, poor lubrication, buffer wear, switch wiring disorders and so on. The fault tree is shown in Figure 1.

### *2.2 Fuzzy inference for fault diagnosis*

The essence of establishing fault mechanism intelligent inference is to diagnosis the failure of pitch system by drawing support from the experts` experiences and take a certain search strategy combines with fuzzy inference. Inference is divided into precise inference and fuzzy inference.

*1) Precise inference*

The fault location is determined through signs of phenomena observed, and then narrow the scope of the phenomenon according to some typical diagnosis till the final failure is identified.

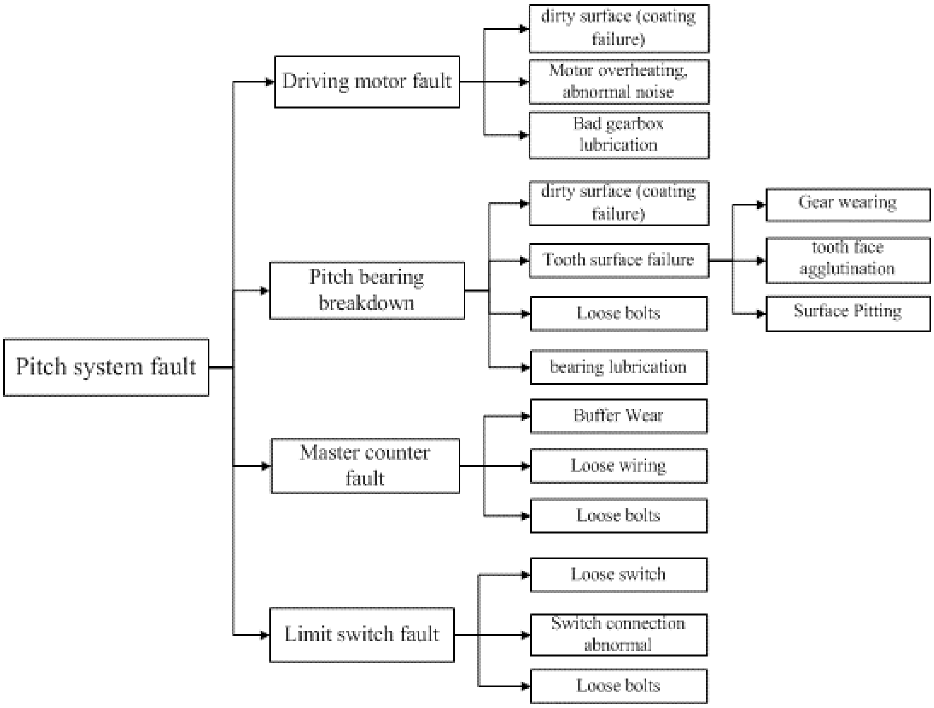


Figure.1 Fault tree based on rules in pitched-system

Rule-based FT is used to carry on precise inference in the intelligent fuzzy system as shown in [9]. It uses a search strategy combined with depth-first and breadth-first. Inference is only started within a knowledge source so as to save computer memory space and improve the efficiency of inference, namely, depth-first search is expanded. While in the interior of knowledge source, breadth-first search in which they are matched according to rules layer by layer is adopted, and we can search out the fault reasons corresponding with fault phenomena at the bottom.

*2) Fuzzy inference*

The relationship between symptoms and fault reasons is described by fuzzy fault diagnosis method which uses membership functions and fuzzy relation matrix in fuzzy set theory, and it obtains membership functions of symptoms through membership functions of fault reasons as in [10]. The fuzzy fault diagnosis model is established as following steps:

*(a)* Fault indication vector space is set. a set$\{x_1,x_2,x_3,\ldots x_i\ldots,x_m\}$ is consisted of all fault phenomena which could happen in system. Where $X_i$ is possible fault phenomenon, m is the total number of symptoms.

*(b)* Fault reasons vector space is set, a set $\{y_1,y_2,y_3,\ldots y_j\ldots,y_n\}$ is consisted of all possible fault reasons in system. Where $y_j$ is possible fault reason, n is the tot number of fault reasons.

The fuzzy fault symptom vector is constituted by the membership $\mu_{x_i}$ of each element $X_i$:

$$X = [\mu_{x_1}, \mu_{x_2}, \Lambda\ \mu_{xm}]$$

The fuzzy reason vector is constituted by the membership $\mu_{y_j}$ of each element $y_j$:

$$Y = [\mu_{y_1}, \mu_{y_2}, \mathrm{L}\ \mu_{yn}]$$

Then there is a certain fuzzy relation R between X and Y universe of fuzzy sets,

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nn} \end{bmatrix} = \left[ r_{ij} \right]_{m \times n}$$

where $0 \le r_{ij} \le 1, 0 \le i \le m, 0 \le j \le n$.

If the fuzzy symptom vector X and the fuzzy relationship matrix R is known, the vector of fuzzy reason Y can be determined. The relation between them is:

$$Y = XOR \Leftrightarrow \mu_{v} = \sum_{i=1}^{m} x_i \times r_{ij}, \; j = 1,2,3 \cdots n,$$

"O" is arithmetic operator, $\sum_{i=1}^{m} r_{ij} = 1$

Some $\mu_{y_j}$ may be a little small due to the operator we used, and there is no sign to say the j fault happened by this method. This influence can be eliminated by pre-setting threshold vector,

$$\lambda = [\lambda_1, \lambda_2, \lambda_3 \cdots \lambda_m]$$

When $\mu_{y_j} > \lambda_j$ ( $j = 1,2,\cdots m$ ), we can view that fault j does occur, or else $y_j$ do not happen.

## 3. Application Example

There are four common fault symptoms in pitch system as shown in Fig.1. Universe of a symptom set is: U= [drive motor failure, pitch bearing failure, the master counter failure, limit switch failure]. Universe of a fault reason set is: V= [dirty surface (coating failure), poor lubrication, switch loose, abrasion, abnormal wiring, bolts loose].

Fuzzy relationship matrix R, as shown in table 1, is obtained by taking advice from experts and the spot workers, accessing to relevant books, combining with analyzing the actual performance of wind turbine generating units and the operational mechanism of pitched-system.

Table1. Fault diagnosis matrix of pitch system

| Reason / Symptom | Surface dirty | Poor lubrication | Switch loose | Wear and tear | Connection exception | Loose bolts |
|---|---|---|---|---|---|---|
| **Drive motor fault** | 0.20 | 0.30 | 0.00 | 0.43 | 0.00 | 0.07 |
| **Pitch bearing fault** | 0.10 | 0.20 | 0.00 | 0.40 | 0.00 | 0.30 |
| **Master cabinet Fault** | 0.05 | 0.07 | 0.00 | 0.11 | 0.40 | 0.37 |
| **limit switch fault** | 0.05 | 0.00 | 0.30 | 0.00 | 0.40 | 0.25 |

The fault reasons are needed to be detailing due to the complexity of fault reasons and symptoms in pitched-system so that it can make a good correspondence with symptom and facilitate the spot workers to locate fault position quickly. Therefore, combined with FT in Fig.1, fault reasons d(abrasion) are divided into: motor overheating (abnormal noise), tooth surface failure, buffer wear.

The detailing fault reasons are correspondence with symptoms 1, 2, 3 respectively. Similarly, fault reasons e(abnormal wiring) are divided into : loose wiring and switch wiring anomalies, they are correspondence with symptoms 3, 4 respectively.

Supposing that fault symptoms in pitched-system are $X_2$, $X_3$, and take symptoms of membership vector:

$$X=[0,0.8,0.75,0]$$

Fault membership can be obtained:

$$Y = X \bullet R = \begin{bmatrix} 0 \\ 0.8 \\ 0.75 \\ 0 \end{bmatrix}^T \bullet \begin{bmatrix} 0.20 & 0.30 & 0.0 & 0.43 & 0.0 & 0.07 \\ 0.10 & 0.20 & 0.0 & 0.40 & 0.0 & 0.30 \\ 0.05 & 0.07 & 0.0 & 0.11 & 0.4 & 0.37 \\ 0.05 & 0.00 & 0.3 & 0.00 & 0.4 & 0.25 \end{bmatrix}$$

$$=[0.1175,0.2125,0,0.4025,0.3000,0.5175]$$

Taken threshold vector in this case

$$\lambda=[0.2,0.6,0.4,0.4,0.5,0.5]$$

Based on the above theory and data, and made comparison with threshold vector $\lambda$

$$y_1=0.1175<\lambda_1, y_2=0.2125<\lambda_2, y_3=0<\lambda_3,$$

$$y_4=0.4025>\lambda_4, y_5=0.3<\lambda_5, y_6=0.5175>\lambda_6$$

The reasons of fault symptoms happened above during the running of pitched-system can be deemed to $y_4$ and $y_6$ ,which are caused by wear and tear and loose bolt. According to the principle of maximum membership, $y_4$=0.4025< $y_6$=0.5175, so the fault reason results from loose bolt.

The failure analysis above is based on sub-domain of universe of fault discourse. A reasonable fault procedure is needed to diagnose as shown in [11] if we want to locate the symptom of fault point listed in the FT, the diagnostic flowchart selected in this paper is shown in Fig.2.This process has returned automatically and re-check features, which provides a basis for deciding the accuracy of fault point.

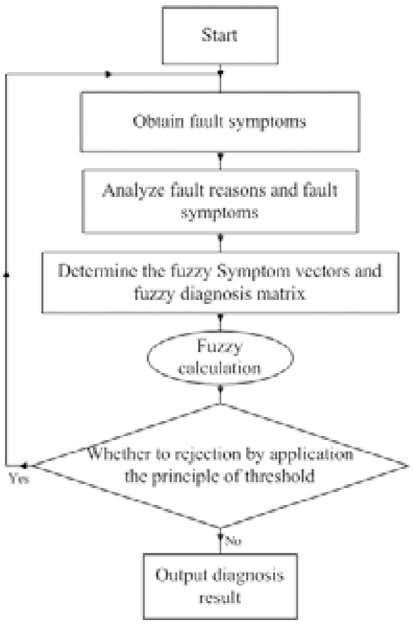

Figure.2 Diagnostic reasoning flow chart

## 4. Conclusion

In the present study, a fault diagnosis in pitch-controlled system of wind turbine using fuzzy interference with fault tree is developed. The causal relationship between various faults and fault reasons can be reflected intuitively by use of FT in graphical interpretation. Fuzzy inference is used for fault diagnosis in pitch-controlled system. The fault data obtained from wind farm indicated that this method is effective for increasing the accuracy of fault diagnosis under various operation conditions.

1) It is a try for solving pitch system of wind turbine based on the fuzzy inference, and there is no information to reference now.

2) The faults of pitch system can be diagnosed by this method quickly and accurately.

3) The relationship between this accuracy and fuzzy diagnosis matrix has a high degree of dependence; its core work is to determine the fuzzy diagnosis matrix.

4) The grade of membership and fuzzy rules, with collected operating data and fault information of wind turbine in wind farm, by trying neural network method, can be determined so that the dependence of experience and intuition can be reduced.

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