Damage identification of wind turbine blade based on dynamic characteristics

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Abstract. The wind turbine blade is an elongated structure composed of composite materials. Due to the harsh working environment and the vibration and deformation during operation, the blade is easily damaged, which seriously affects the smooth operation of the wind turbine, and has great potential safety hazards. The finite element software ANSYS is used to study the vibration characteristics under the condition of blade rotation, and different damage modal analysis can be carried out for different positions. The BP neural network is established by MATLAB to quantify the damage degree of the blade. The analysis results show that the damage and damage degree can be recognized by the change of natural frequency before and after the damage of the blade. The damage location can be identified by change rate of strain mode before and after the damage of the blade. The damage degree of the blade can be quantified and judged. The relative error rate is between -4.36\% to 2.73\%, and the recognition effect is more accurate.

1. Introduction

Long-term operation of wind turbines in harsh environments, the damage identification of wind turbine blades and the identification of rules can provide a theoretical basis for the detection of damage dynamic characteristics of the blades. It plays a particularly important role in saving energy, protecting the environment, improving efficiency, ensuring safety and saving manpower. Many scholars have analyzed the dynamic characteristics of wind turbine generator blades before and after damage. Zhang Xin, Wang Wei [1, 2] analyzed the characteristics of the wind turbine blade before and after the damage and achieved good results, but the disadvantage is that the characteristics of the blade before and after the blade damage are not considered. Consider the quantitative judgment of the damage degree of the blade with the speed. Based on the research of Hu Guoyu and Sun Wenlei [3], the natural frequency and strain mode change of the blade before and after the damage are considered. The BP neural network is used to identify the damage degree of the blade [4].

2. Damage identification of wind turbine blade

The model uses a 15KW horizontal-axis wind turbine with a total blade length of 2.0m. Following the cantilever beam structure, the front and rear widths are 0.4m and 0.2m, respectively, and the front and rear thicknesses are 50mm and 12mm respectively. Its rated speed is 400r/min. The model uses shell 181 shell element, and its boundary condition is set to the full constraint of the blade root, as shown in Figure 1.
In order to simulate the damage of the wind turbine blade, it is realized by reducing the local elastic modulus of the wind turbine blade. In the distance of 0.3m, 0.8m, 1.2m, 1.5m from the root of the blade, the damage unit is 0.1m, and the elastic modulus is reduced by 5%, 10%, 15%, 20% to simulate the four different degrees of damage of the blade. The situation and the damage units are named A, B, C, D, as shown in Figure 1.

Assuming that the elastic modulus of the wind turbine blade before and after damage is $E$ and $E'$, the damage degree is:

$$\lambda = \frac{E - E'}{E}$$

Set the angular velocity to 15 rad/s and solve the frequency order to 5 steps. The four elements of the blades A, B, C, and D are reduced by 5%, 10%, 15%, and 20% of the elastic modulus. Table 1 shows.

**Table 1.** The First five-order modes of each damage condition of the blade when the rotation speed is 15 rad/s.

| Damage unit | Damage degree | First order | Second order | Third order | Fourth order | Fifth order |
|-------------|---------------|-------------|--------------|-------------|--------------|-------------|
| Not damaged | 0%            | 10.038      | 33.386       | 52.541      | 114.20       | 138.54      |
| A           | 5%            | 10.001      | 33.230       | 52.477      | 113.93       | 138.15      |
|             | 10%           | 9.9671      | 33.125       | 52.461      | 113.58       | 138.06      |
|             | 15%           | 9.9344      | 33.009       | 52.444      | 113.20       | 137.97      |
|             | 20%           | 9.8960      | 32.880       | 52.425      | 112.79       | 137.86      |
| B           | 5%            | 10.017      | 33.272       | 52.404      | 114.03       | 138.04      |
|             | 10%           | 10.004      | 33.213       | 52.309      | 113.79       | 137.83      |
|             | 15%           | 9.9891      | 33.147       | 52.205      | 113.54       | 137.60      |
|             | 20%           | 9.9726      | 33.073       | 52.089      | 113.25       | 137.35      |
| C           | 5%            | 10.026      | 33.306       | 52.360      | 114.16       | 138.02      |
|             | 10%           | 10.023      | 33.285       | 52.215      | 114.06       | 137.79      |
|             | 15%           | 10.019      | 33.262       | 52.056      | 113.96       | 137.53      |
|             | 20%           | 10.015      | 33.236       | 51.879      | 113.84       | 137.26      |
| D           | 5%            | 10.029      | 33.323       | 52.468      | 114.18       | 137.99      |
|             | 10%           | 10.023      | 33.321       | 52.442      | 114.16       | 137.73      |
|             | 15%           | 10.016      | 33.318       | 52.414      | 114.14       | 137.44      |
|             | 20%           | 10.008      | 33.315       | 52.382      | 114.12       | 137.12      |
It can be seen from the table that no matter where the damage position of the blade occurs, the first five-order frequency has a downward trend compared with the case of no damage, and the results are the same at other rotational speeds. According to this, we can judge whether the blade is damaged by the change of the frequency before and after the damage of the wind turbine blade.

3. Determination of damage location of wind turbine blades

Taking the rotational speed of 25 rad/s and the damage degree of 10% as examples, the strain modes are extracted before and after the blade damage. Because the vibration of the blade has a large influence on the low-order frequency, the low-order frequency is also sensitive to the damage position [5, 6], the first three modes are calculated and the modal change rate before and after the damage is calculated as shown in Figure 2.

![Figure 2](image-url)

**Figure 2.** Rate of change of the first three-order strain modes of each unit after (a) (b) (c) (d) unit damage (%).

It can be seen from the above figures that the rate of change of the first three-order strain modes of the blade at its damage position is more obvious than other positions. Accordingly, the damage position of the wind turbine blade can be located by using the change of the strain mode before and after the damage.
4. BP neural network identification of damage degree of wind turbine blade

There is a nonlinear mapping relationship between structural damage and its dynamic characteristic parameters. BP neural network can be used to establish a neural network to approximate the nonlinear mapping relationship between structural damage and dynamic characteristic parameters. Thus, the damage of the structure is judged [7].

Taking the wind turbine blade with the speed of 5 rad/s as an example, the first five-order natural frequency change rate is taken as the training input sample, and the damage degree of the unit is taken as the training output sample. The training samples of the BP neural network are shown in Table 2.

| Table 2. BP neural network training samples (5 rad/s) (Hz). |
|-------------------------------------------------------------|
| First order | Second order | Third order | Fourth order | Fifth order | degree of damage |
|--------------|--------------|-------------|--------------|-------------|------------------|
| 9.6577       | 33.031       | 52.189      | 113.52       | 137.80      | 10%              |
| 9.6219       | 32.914       | 52.172      | 113.14       | 137.70      | 15% A            |
| 9.5822       | 32.785       | 52.153      | 112.73       | 137.59      | 20%              |
| 9.7072       | 33.178       | 52.132      | 113.98       | 137.77      | 5% B             |
| 9.6776       | 33.052       | 51.931      | 113.48       | 137.33      | 15%              |
| 9.6603       | 32.979       | 51.815      | 113.20       | 137.08      | 20% C            |
| 9.7168       | 33.213       | 52.087      | 114.11       | 137.75      | 5% D             |
| 9.7132       | 33.192       | 51.942      | 114.02       | 137.52      | 10%              |
| 9.7049       | 33.142       | 51.604      | 113.79       | 136.99      | 20%              |
| 9.7197       | 33.230       | 52.196      | 114.13       | 137.73      | 5%               |
| 9.7195       | 33.227       | 52.171      | 114.10       | 137.47      | 10%              |
| 9.7192       | 33.224       | 52.142      | 114.08       | 137.18      | 15%              |

The BP neural network was established by using MATLAB [8]. The number of hidden layers was 12, the maximum number of training steps was 1000, the learning rate was 0.05, the minimum error allowed by the training target was 0.001, and the interval between training results was 100 steps. The learning process of the training samples is simulated. After 992 trainings, the error basically meets the target requirements, and the network learning ends. The test sample results are shown in Table 3.

| Table 3. BP neural network training test samples and results (5 rad/s) (Hz). |
|-------------------------------------------------------------|
| First order | Second order | Third order | Fourth order | Fifth order | Ideal output | Actual output(%) |
|--------------|--------------|-------------|--------------|-------------|---------------|------------------|
| 9.6903       | 33.136       | 52.205      | 113.87       | 137.88      | 5             | 5.1298           |
| 9.6931       | 33.118       | 52.037      | 113.74       | 137.56      | 10            | 9.5640           |
| 9.7093       | 33.168       | 51.782      | 113.90       | 137.27      | 15            | 14.6922          |
| 9.7189       | 33.221       | 52.110      | 114.07       | 136.85      | 20            | 21.1468          |
The BP neural network can control the damage degree of wind turbine blade damage from 4.36% to 2.73%, and the results are satisfactory. So, the damage degree of the blade can be identified by BP neural network.

5. Conclusions
(1) When the wind turbine blade is damaged, its first 5 orders of natural vibration frequency are lower than before the damage. When the damage occurs at the same position, the degree of damage increases, the natural vibration frequency decreases. When the same degree of damage occurs, there is no obvious change in the natural frequency at different locations.

(2) When the blade is damaged, the rate of change of the first three-order strain modes at the damage position is more obvious than other positions. According to this, the identification and damage location can be performed by the change of the strain mode before and after the damage of the wind turbine blade.

(3) The BP neural network is established by using the dynamic characteristics of the blade to quantify the damage degree of the wind turbine blade. The general error is controlled at 4.36% to 2.73%, and the test results are more accurate.

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References
[1] Li D Y, Fang J, Lv W G and Luo S M 2011 Unsteady aerodynamic characteristic analysis of horizontal axis wind turbine blade Journal of Shenyang University of Technology 33(1) 36-40
[2] Su T, Xue G 2017 Finite element analysis of damage identification So f wind turbine blades based on dynamic characteristics Journal of Inner Mongolia University of Science and Technology 36(1) 45-50+97
[3] Hu G Y, Sun W L and Jin A F 2015 The structural dynamic behavior analysis of large wind turbine rotational blade Renewable Energy Resources 33(11) 1652-1657
[4] Gu G M, Zhang X 2016 Structural damage identification of wind turbine blade based on deep belief networks Journal of Ginsu Agricultural University 51(4) 134-138
[5] Ghoshal A, Sundaresan M J, Schulz M J, et al. 2000 Structural health monitoring techniques for wind turbine blades Journal of Wind Engineering & Industrial Aerodynamics 85(3) 309-324
[6] Li L P, Li M M and Jin F H 2013 Applications of the Vibration Detection Technologies in Monitoring the Blade Crack Fault of Wind Turbines Journal of Engineering for Thermal Energy and Power 28(2) 207-212
[7] Niu X M, Wang F and Xiong X Y 2011 Damage Identification Method Based on Analysis of Strain Modal Journal of North University of China 32(6) 682-687
[8] Shi Y 2010 Realization of BP Neural Network Based on Matlab Journal of Xiang nan University 21(5) 86-88+111