Study of Wind Turbine Blades under Static Loading Using Acoustic Emission Method

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Abstract

Wind is the fastest growing and the most widely utilized emerging renewable energy technology. Many techniques are used for monitoring and detecting defects in wind turbines blades such as Ultrasonic, Strain gages, Thermal cameras and Acoustic Emission. Acoustic emission method is the most used method used for continuous monitoring. The present study investigates the AE propagation behavior in carbon fiber blades under static loads. This study clarifies and enhances the knowledge of the acoustic emission testing with the Carbon Fiber material. Two experiments have been applied in laboratory. The first experiment is the pencil break test is used to simulate the AE wave’s propagation in Carbon Fiber blades (i.e. model FY-58B). The Second experiment, applied a single-point bending test on the tip of the wind blade. AE impedance and velocity are estimated for the Carbon Fiber. Also, the behavior of AE under static loads has been presented.

Keywords: Acoustic Emission, Wind Turbine, Carbon fiber, Blades, Bending.

1-Introduction

The growing demand on energy due to modern civilization requires new sources of energies to overcome the decrease in the conventional energy sources such as oil. Since most of the conventional energy sources causes environmental side effect such as global warming, a clean and renewable energy sources became essential demand. The usage of renewable energy sources increases day after day such as wind, solar, waves, etc..

Wind energy is one of the most useful and efficient renewable energy sources. Therefore, wind turbine, which is used to generate electrical energy, has become one of the important sources of electrical energy that shares by a growing portion of the total energy required. Wind energy has sustained a 25% compound growth rate for well over a decade, and total capacity now exceeds 60 GW [12].

Due to the growth of wind energy and to enhance its availability, a continuous monitoring and fault diagnosis of wind turbine became mandatory [12,13]. Since, accurate and fast fault diagnosis system enhance the overall system availability and safety. Different techniques have been scattered in literatures. However, fault diagnosis methods can be divided into signal based, model based or a combination of both [12,13]. Among the components of a wind turbine is the blade, which is the most damageable component (e.g. bending caused by atmospheric wind turbulence). Hence, it is necessary to understand stresses which are occurring during the operating of wind turbine blade [7].

Different sensing techniques can be used to monitor and diagnosis turbine blade such as Ultrasonic [12], Strain gages [12], Thermal cameras [12] and Acoustic Emission [12]. The aim of this work is to study the effectiveness of using acoustic emission (AE) in diagnosis of the wind
blade specially under bending stresses. Two experiments are presented to study the AE propagation and AE signal feature due to bending load.

2- Modeling and simulating

The force that causes the bending stresses in wind turbine blades is estimated from the average speed of wind in Egypt, which is measured to be approximately 7.7 m/s [4]. The bending force can be calculated through bernoulli equation [5]. Equations (3) , (4) and (5), assuming that at high speed the area of the three blades are as a solid disk with Surface area facing the air flow ($A_\text{s}$). The surface area can be calculated from:

\[ A_\text{s} = \pi r^2 \]  

(1)

where $r$ is the turbine radius = **0.63 m**. then $A_\text{s}$ = **1.246 m²**.

\[ V_2 = \frac{V_1}{3} \]  

(2)

\[ V = \frac{V_1 + V_2}{2} \rightarrow \frac{V}{2} = \frac{1}{2} V_1 \]  

(3)

From Bernoulli equation:

\[ P_\text{atm} + \frac{1}{2} \rho V_1^2 = P_\text{b} + \frac{1}{2} \rho V_2^2 + P_\text{atm} \]  

(4)

\[ P_\text{atm} + \rho \frac{1}{2} \rho V_r^2 = V_2^2 + P_\text{atm} \]  

(5)

\[ F_\text{axial} = A_\text{x} (P_\text{b} - P_\text{a}) \]  

(6)

where $P_\text{b}$ is the pressure downstream the wind turbine; $P_\text{a}$ is the Pressure upstream the wind turbine; $V$ is the Air velocity at the wind turbine; $V_1$ is Air velocity upstream the wind turbine=7.7m/s [4]; $V_2$ is the Air velocity downstream the wind turbine; $\rho$ is the Air density =1.187kg/m³[6] and $F_\text{axial}$ is the Axial force as shown in Figure 1. By substitution into equations (3) and (4) using equations (1) and (2) and the value of the $V_1$ and of $\rho$.we get

$P_\text{a} = -11.7299 N/m^2$, $P_\text{b} = 19.71 N/m^2$. Then by substitution by $P_\text{a}$, $P_\text{b}$ and $A_\text{x}$ into equation (5), we get $F_\text{axial} = 40 N$.

Handy-Scan 3D Scanner, Figure 2, is used to scan 3D of the wind blade as shown in Figure 3. Solid-works software is used to simulate the stress from bending test on the blade. The stress analysis on the blade is simulated for single-point of bending test using force of 40 N, which is calculated above section. The bending test simulation on the software shows the stress distribution on the blade due to the loading of the blade as shown in Figure 4. Accordingly, Figure 5 is showing the displacement (deformation) occurs due to the force applied.
Figure 1. Pressure distribution diagram before and after the wind-turbine

Figure 2. 3D Scanner

Figure 3. The blade 3D Scanning

Figure 4. Stresses resulted from the simulation

Figure 5. Displacement resulted

3-Experimental Setup and procedures

There are two series of experiments carried out in this work AE acquisition system and experimental set-up has been used, Figure 6. All experiments have been done using a Physical Acoustics Pocket AE and consisting of an array of two sensors. A carbon fiber wind turbine blade (model FY-58B) of 0.58 m long is used in both of the two experiments is shown in Figure 6. The first experiment is carried out to investigate the propagation of AE signal in the wind
turbine blade from simulated (pencil lead break) and the second experiment is a simulation of real bending test.

First series of experiments have been applied using a mechanical pencil with in-house machined guide ring was used to generate simulated AE sources by breaking a 2H pencil lead (i.e. Hsu-Nielsen source) [1], as shown in Figure 7. As far as could be judged visually, the lead was broken under the same conditions, in the same position, using the same length and the same orientation of the pencil for all tests [1].

This experiment is made to indicate and recognize the wave propagation and the wave speed for the acoustic wave in the material of the blade. The first (trigger) sensor was fixed at 85mm from the hub end of the blade. The second sensor moving axially in regular distance of 100mm from the Trigger sensor along the blade. The data was sampled at 10 MSPS. Pencil lead breaks were performed on the surface of the blade beside the trigger sensor, as shown in Figure 8. A total of five positions were used, and the experiment being repeated four times at each position. The AE sensors and the hand-held are fixed on the blade as shown in Figure 9.
The second series of test was used a manual loading weight as shown in Figure 10. An AE sensor is mounted on the most hot spot with stress appears in the simulation. Moreover a displacement sensor in fixed on the tip end of the blade to measure the displacement and deformation in the blade. The loads are applied in a sequence as 0.5 kg force (included in the holder and the load meter). Then a load of 0.5 kg force is added then 3 loads of 1 kg force is added one by one.
5-Results and Discussion

The velocity of AE has been estimated using the following equation:

\[ x = \frac{1}{2}(D - v \Delta t) \]  

(7)

where \( D \) is the distance between sensors; \( v \) is the constant wave velocity; \( \Delta t \) is the time difference between hits; \( x \) is the source location measured from the first hit sensor [13], as shown in the Figure 11.
The average time difference is calculated for each position of the five positions through four breaks. Figure 12 is used to estimate the wave velocity of AE in Carbon Fiber which is \( v_{\text{avg}} = 2719.14 \, \text{m/s} \).

As the theoretical velocity in a carbon-fiber rod is approximately equal 11600-21200 m/s. The energy attenuation is also estimated using the formula [14].

\[ \ln E_x = \ln E_0 - E_x \]

Thereafter, the attenuation factor 0.792 is estimated from the curve shown in Figure 13.

Finally, the bending test results show that the material of carbon fiber has no response with the acoustic emission because the material layers deform or bend together without any slipping or shear taking place between the layers.

6-Conclusion

Two series of experiments has been presented to study the behaviour of AE propagation in the wind turbine blades. Carbon fiber is high attenuated material, consequently the acoustic emission
testing failed to sense the bending stress. The Carbon fiber materials layers deformation take place together, accordingly the AE senses only from the movement between the layers. More future work of dynamic test for sequence of unbalancing on wind turbine blades will be monitored using AE method.

References