Aerodynamic Noise Analysis of Wind Turbine Blade

Gwo-Chung Tsai, Jau-Ching Jiang

Abstract— **The main goal of this research is to study the noise of the wind turbine blade. The green energy is developed vigorously and the environmental problems were concerned. The blades of wind turbine applied by the wind will produce the torque and noise that depends on the wind velocity. In this research, three parameters: wind velocity, torque and noise were put together to get the best efficiency of the wind turbine blade. The finite element analysis is used to perform the analysis. The finite element model is created to use ANSYS/Workbench, then CFX is used to do the fluid dynamic analysis and calculate the sound pressure with different parameters. The optimization data for the wind turbine blade at different conditions can be obtained. All these data can be used to develop the design of the turbine blade.**

Index Terms— **Finite element method, optimization , ANSYS , CFX , blade.**

I. INTRODUCTION

The energy crisis had been met since 1973, and the storage chemical energy is decreased and the pollution seriously affects the earth environment. The human beings start to think the replace energy [1]. In 1998, a barrel of crude oil is up to USA 150 dollars that seriously impact the economic development of the world. Because the carbon-oxide was released too much and cause the earth to get the higher temperature that make the ice cap in the north pole is melted quickly and raise the level of the ocean. Some islands in the Pacific Ocean will be under the sea level to make some countries disappear. All of these things are very serious and will impact the human's life. All of the countries on the earth are forced to think to develop new and non-pollution green energy to replace the chemical energy [2]. Wind power source ia a nature and reproduce energy. Mankind had used the wind turbine to produce the electricity for long time ago. Up to 2008, the electricity produced by the wind turbine is around 1% of the total electricity created in the worldwide. The problem for the development of the wind turbine are not only the efficiency, output electricity, but also the low frequency noise that will lower the living quality of the human beings[3]. Taiwan is an island. Country and there has plenty of wind power. Therefore, 162 wind turbines were installed till 2008 along the coastal line. All of these wind turbines obviously interrupted the bird transportation and damage the bird living place and the breed. The noise produced by the wind turbine is up to 100 dB [4] that will affect the living quality and the environmental protection.

In 21 century, the electricity produced by the wind turbine has the higher efficiency for all of the green energy. Wind turbine didn't produce the pollution air, pollution water or the other pollution materials as done by the chemical energy. The advance development for the wind turbine is how to raise the efficiency and decrease the noise level. After the blade began to rotate, the air will flow through the blade. At this time, the friction and impact of the wind on the blade will produce turbulence plus the eddy current. All of these will make the wind flow become unstable and cause the noise which is called fluid flow noise [5-7]. The flow field did not only affect the noise produced by the wind turbine blade, but also increase the resistance of the blade rotating which will reduce the efficiency of the kinetic energy transformation. Even if the blade is developed further, the air field in the air space and unstable strong wind environment is changed anytime, therefore, how to get the balance between the efficiency and noise of the wind turbine is a major research topic. Because the finite volume method is developed very fast, the noise problem of the wind turbine can be solved and get the accuracy results. In this research, the parameters included torque, rotating speed, wind velocity for the wind turbine are considered to find the best efficiency of the turbine blade and try to reduce the noise level..

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II. BASIC THEORY

A. Narrow Band and Broad Band Frequencies

The air flow noise produced by the rotating blade of wind turbine and it is also named to be air dynamic noise. Generally, the noise can be divided into the narrow band noise and broad band noise. From the noise frequency viewpoint, if the sound source part is within the scope of the narrow frequency band shown in Fig.1. The reason to produce the narrow frequency band noise is that the air flow over the surface of the blade to cause the turbulence when the blade is rotating. If noise frequencies were made by the high frequencies, middle high frequencies and low frequency noise, the left frequencies are called broad frequency band noise when the narrow band frequencies were not included. All noise produced by the wind turbine are related to the rotating speed of the blade. Three different kinds of noise:(1) Aerodynamic noise came from the pressure change which the hub and blade impacted on the air flow field due to the rotating of the hub, (2) air flows over the blade and hub to form the layer flow and create the turbulence and eddy current on the blade and hub,(3) when the blade is rotated, the axial velocity distribution on the blade is not even to cause the pressure change and produce the noise.

The narrow band noise frequency can be calculated in the following:

$$Fi = \frac{iZN}{60}[Hz]$$

Where

F_i is the blade character frequency,

Z is total number of blades,

N is the rotating speed of the blade（rpm）

i is harmonic frequency character index

When I is equal to1, F_i is called the fundamental frequency. But i is equal to 2, it is called the second harmonic frequency. Noise level of harmonic frequency has the possibility to be higher than the fundamental frequency. Analyzing the frequency of the narrow band is more approximate noise frequency. If fundamental harmonic frequency is an integral of the fundamental frequency, then narrow band noise can be more obvious. The broad frequency band noise came from the turbulent sound field produced by the instable fluid flow. The major reason is to cause the noise due to the pressure change that came from the air current left the boundary layer The rotating wheel hub rubbed mutually with the atmospheric flow field will produce the turbulence and eddy current. I t is concluded that the noise for the wind turbine will depend on the power set, wheel hub, the blade, and the tail vane. The rotating blade will produce the major part of noise. In order to reduce the turbulent flow, it may design the low attack angle or add the wing trailing vortex installment that can avoid losing the speed.

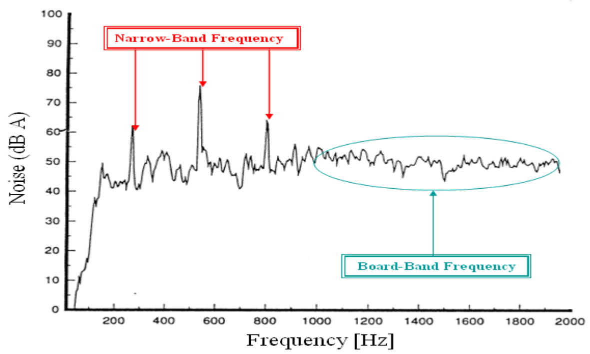

Fig.1 Frequency spectrum

B. *Sound Pressure*

The sound is refers to the pressure change came from the vibration of molecule and can be transferred through the air , water or other mediums. The intensity of sound (S) is defined by the loudness and phone (LN). The relationship between S and LN is defined by the following:

$$S = 2^{0.1(LN-40)}$$

The unit of sound is defined by [bel]. Because bel is too small and will be magnified to be 10 times, therefore the unit is defined to be [decibel]. The Sound pressure Level）L_p is expressed by the following：

$$Lp = 10\log_{10}\left[\frac{P}{P_0}\right] = 20\log_{10}\frac{P}{P_0}[dB]$$

where

P：sound pressure

P_0：sound pressure reference= $2\times10^{-5}\dfrac{N}{m^2}$

For $Lp = 0[dB]$, the sound pressure is $2\times10^{-5}\dfrac{N}{m^2}$

III. Simulation Analysis

In this section, the blade element theory is used to do the design of wind turbine blade. The attack angle, tip speed ratio, and lift coefficient can be considered in the design. At the same time, the aerodynamic characters and noise are also considered to get the best efficiency of the wind turbine. In this section, a series of NACA blade is selected to be the analytical model, because it has a better aerodynamic character. In this project, the cross section of NACA 4 blade is selected shown in Figs. 2-3.

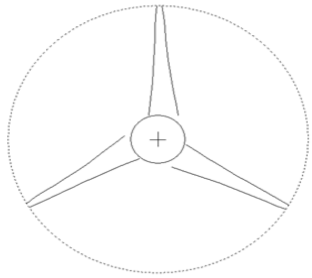

Fig.2 Top view of the wind

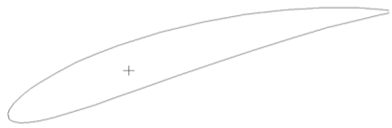

Fig.3 Cross section of wind

A. *Finite Element Analysis*

In this project, Pro/E 2Dis used to create the solid model and ANSYS Workbench is used to create finite element model as shown in Fig. 4. In this model, there are 561408 elements and 520059 nodes. After mesh was created, the fluid zone is also created as shown in Fig. 5 that the rotating domain was assigned to the blade area and the steady domain was assigned in the other area.

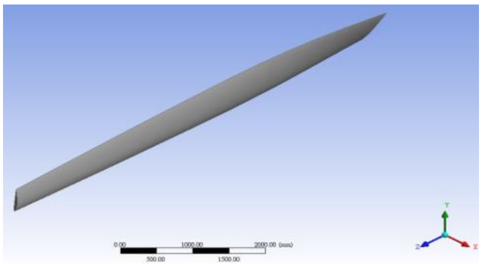

Fig. 4 Finite element model of blade

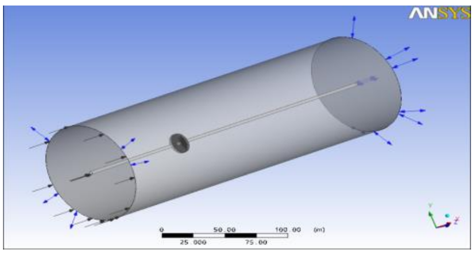

Fig. 5 Fluid zone in Fluid dynamic analysis

B. *Pitch Angle Adjustment*

The pitch angle adjustment is always installed in a middle and big wind turbine to control the pitch angle as shown in Fig. 6. Because the wind velocity is not a constant and the blade wants to have a good lift force, therefore pitch angle adjustment must be used to adjust blades to a good windward position. In real case the wind turbine can be controlled to be not stalled through the fluid dynamic analysis to find a best pitch angle. In this project, we can simulate different pitch angle to get the best values of the torque and noise. In this research, a constant wind velocity is considered because for a lower velocity the turbulence and eddy current will not affect the wind behavior and the pitch angle didn't adjust too much. For a wind velocity of V=5m/s, the pitch angle is set to be 3 degrees. For a higher wind velocity of 15 m/s and 20 m/s, the pitch angle must be set at 6 degrees to avoid the stall. Under this operation, the blade can get a better lift force and it is easily to maintain the noise at a lower level.

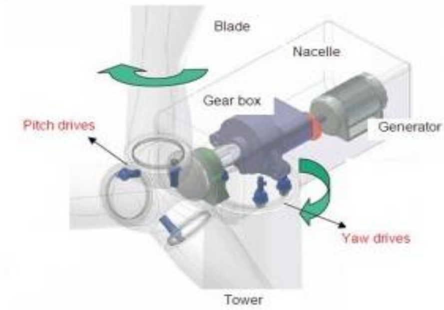

Fig. 6 Mechanism of pitch control

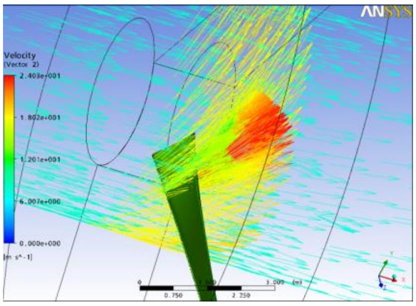

Fig. 7 Velocity distribution with V=2.5m/s

IV. Analytical Results

The flow velocity distribution through the blade is shown in Fig. 7. Six different wind velocities of V=2.5m/s、V=5m/s 、V=8.67m/s 、V=10m/s 、V=15m/s 、V=20m/s are considered to perform the analyses. The noise and torque values related with the different rotating velocities at a constant wind velocities of 2.5 m/s are plotted in Figs.8-9. It indicated the turbine can get a maximum torque as a rotation speed of 10 rpm. But the torque is going down as the rotation speed is increased and the noise is also increased. The results showed the turbulence is increased when the rotation speed is over 10 rpm and why the noise is increased. The turbulence will increase resistance of blade and why the output torque is going down listed in Table 1.

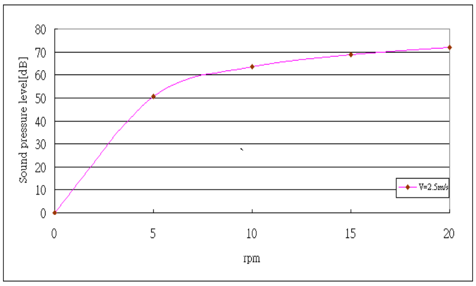

Fig.8 noise values with V=2.5m/s

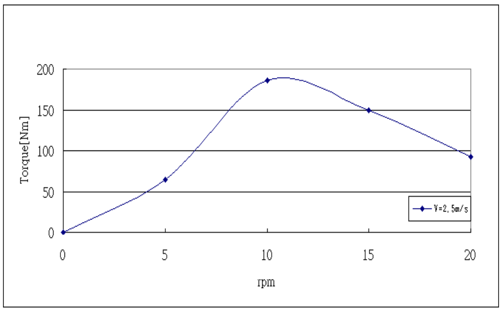

Fig.9 torque values with V=2.5m/s

Table1 V=2.5m/s reference values

V=2.5m/s		
rpm	Torque[Nm]	sound pressure level[dB]
5	61.243	50.682
10	185.596	63.555
15	149.478	68.8948
20	92.6993	71.888

V. Efficiency and Noise Optimization

The rotation speed of most large-scale wind-driven generator is around 20 rpm.To avoid the wind speed oversized will cause the blade over-speed and get damage or reach a maximum lift force to cause the blade to lose speed. Through the detailed analysis with different velocities, the time to start the pitch angle control of wind-driven generator can be found. In Fig. 10 and Table 2, two curves with V=8.67m/s and 10m/s are crossed at rotation speed of 18 rpm. It means that the pitch angle control has to initiate to maintain the wind turbine can get the best torques for those velocities.

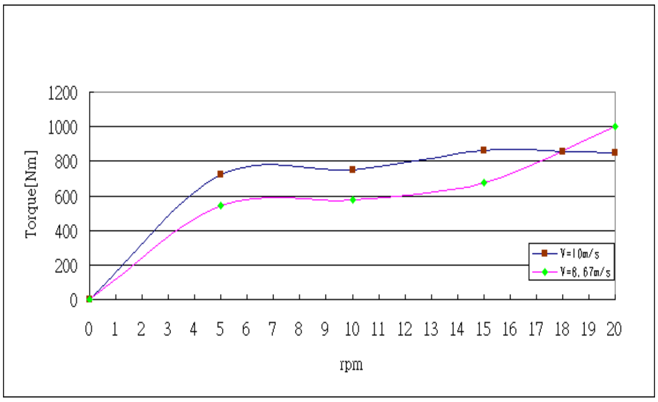

Fig.10 two torque curves for V=8.67m/s and V=10m/s

Table 2 V=8.67m/s、10m/s reference data

rpm	Torque[Nm]		sound pressure level[dB]	
	8.67m/s	10m/s	8.67m/s	10m/s
15	676.32	862.65	81.07	81.25
18	838.89	853.31	85.31	83.89
20	1001.84	847.69	85.67	83.01

VI. Conclusions

In this research, wing element theory is used to design the blade of wind turbine. The finite element method is also used to get a good result that related with the quantity of elements. The integration time step is also very important for getting a good convergence and a accurate results with less time. This research establishes the relationship between the optimum efficiency and the noise. The noise curves have not much difference but the torque values are actually rises obviously when the blade is under a high wind speed. This phenomenon expressed fully the wind turbine under a high wind speed, the force observed on the blade is more important than the noise caused from it. The wind turbine under the high wind speed to generate electricity continually, therefore, it needs to choose safe and the effective pitch angle against the wind. This analytical data is advantageous for the designer to decide that the blade angle against the wind reduces the air current and the turbulent flow that causes the blade efficiency to drop. The active control of the blade under the high wind speed will reduce the noise effectively.

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