A Study on Aerodynamic Analysis and Design of Wind Turbine blade

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ABSTRACT: A wind turbine blade is one of important parts in converting wind energy into electric energy. A blade has influence on the power output and efficiency of a wind turbine. In the design of a blade, the lift-to-drag ratio, material, manufacturing condition, and stable maximum lift coefficient, etc should be considered. This study is to propose the blade element method as the simplified method for the design of an aerodynamic blade and aerodynamic analysis. This process is programmed by Delphi language. Once the numerical values such as tip speed ratio, blade length, hub length, a section of shape, and maximum lift-to-drag ratio are input, the program displays chord length and twist angle, and analyzes performance of the blade.

KEYWORDS: Lift-to-drag ratio, Wind power generation, Blade element method, Flap HAWT (Horizontal Axis Wind Turbine),

1 INTRODUCTION

Recently, the interests of renewable energy are increasing because the unit price of generation of electric power is increasing and power supply is unstable. One of the most reliable renewable energy is wind power energy. This is infinite energy resources and does not need additional cost, so that many researchers are researching now. There are many problems to generate electric power using wind energy. For example, wind power needs higher unit price of generation than other conventional generation methods.

To generate the electricity using wind energy, we use the rotating force which is generated by kinetic energy of wind. Therefore, the rotor is an important part of electric power production using wind kinetic energy. Specially, an aerodynamic design of a rotor blade decides the efficiency of an equipment for power production. Researches about the rotor blade have been studying all around the world. Various types of airfoils have been presented in wind power production. Regarding power generation, the characteristics of an airfoil should not to be changeable according to the contamination and damage on the surface of an airfoil. Generally, NACA 63618 is the popular airfoil, because the lift to drag ratio of this type is excellent. The lift to drag ratio is a general index for characteristics of an airfoil. The type of NACA 6 is widely used in electric power production of wind energy. In this study, the NACA 63618 is adopted for the rotor blade and the effect of various flaps is tested as a high lift device.

The purpose of this study is to develop the program to design rotor blade using Delphi language and to design the turbine rotor blade using the blade element method.
2 AERODYNAMIC ANALYSIS AND OPTIMAL DESIGN

2.1 Blade element method

A blade element method is a theoretical method to predict the aerodynamic efficiency of a wind turbine blade. The aerodynamic efficiency can be calculated by integrating the results from CFD (Computational Fluid Dynamics) and 2-Dimensional flow experiment. Figure 1 shows the blade element and velocity triangle, where the location is \( r \), local pitch angle is \( \Theta \), and the angle of attack is \( \alpha \). Figure 2 shows the streamtube model of the flow through a HAWT rotor. Using blade element method, the torque and thrust can calculated as follows.

\[
\begin{align*}
\frac{dT}{dr} &= B \cdot C \left( \frac{1}{2} \rho W^2 \right) C_n \, dr \\
\frac{dQ}{dr} &= B \cdot C \left( \frac{1}{2} \rho W^2 \right) C_r \, dr
\end{align*}
\]

where \( W \) is relative velocity, \( C_n \) and \( C_t \) are coefficients related with the lift and drag respectively, \( B \) is the number of blade, and \( C \) is the length of airfoil.

![Fig. 1. Blade element and velocity triangle](image1)

![Fig. 2. Streamtube model of flow through the HAWT rotor](image2)

2.2 Aerodynamic analysis and design program

Figure 3 shows the flowchart of the aerodynamic analysis process for blade design. As mentioned above, the design program consists of Delphi language according to this progress. The details are included in references. In order to analyze accurately aerodynamic performance of a blade after stall, the information of stall condition is needed. In general, there are few data after stall, we have to calculate the drag and lift coefficients after stall. In this paper, the equation which is proposed by Viterna – Corrigan has been used to calculate the drag and lift coefficients after stall.

This program is coded to bring the file of the drag and lift coefficients and to input freely the number of blades, length of a blade, length of a hub, and main velocity. Therefore, the power coefficient can be calculated automatically using input data. Generally, a flap device has been used to decrease the length of takeoff and landing, but in this study, a flap is used as the high lift device that is devised to design a highly efficient blade. A flap is one of the high lift devices, which is located at the bottom of the trailing edge of a blade. If the size of a flap is larger than a chord length, the lift to drag ratio become worse, because the amount of lift increase is smaller.
than that of drag increase. So it is very important to determine the optimum height of a flap for good design.

Fig. 3 Flowchart of airfoil design

3 RESULTS AND DISCUSSION

(a) Flap length 2%    b) Flap length 10%

(c) Flap length 20%    (d) Flap length 30%

Fig. 4 Effects of tip speed ratio and flap angle at various flap lengths
In a three dimensional airfoil of an airplane, tip vortexes are generated due to the pressure difference between the upper and down sides and distribution of circulation surrounding an airfoil decreases. This is the main reason of the loss at a blade tip. A wind turbine also experiences the same phenomena known as blade tip loss. In order to consider the loss at the tip, the theory of tip loss which is suggested by Prandtl and Goldstein is applied. The power coefficients are calculated by the blade element method.

Figure 4 shows the relationship between the power coefficient and tip speed ratio according to the change of flap angle and flap length. Though the flap expresses high power coefficient when tip speed ratio is smaller than 5, power coefficient rapidly decrease when tip speed ratio is over 5. However, the flap of 2% length and 10° angle shows high power coefficient at all tip ratios considering now. It can be predicted that the flap of 2% length and 10° angle is the optimized shape. If the flap is set up at an optimized condition, the power coefficient is larger than no flap blade.

4 CONCLUSIONS

In this study, the aerodynamic theory is applied to design the blade of a wind turbine. And using the blade element method, the performance analysis also is carried out for the blade with flap as a high lift device. Following conclusions are obtained.

(1) The blade with flap expresses high power coefficient when tip speed ratio is smaller than 5, comparing with the blade with no flap.

(2) Though the power coefficient rapidly decrease when tip speed ratio is over 5, the flap of 2% length and 10° angle shows high power coefficient at all tip ratios.

(3) The Mechanism between optimum flap and flow pattern should be studied further.

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6 REFERENCES
