The Effect of Airfoil Thickness in the Performance of the Two-Bladed Airfoil Fixed Pitch Straight Vertical Axis Wind Turbine with Central Panel

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Abstract

Straight vertical axis wind turbine was used in this study. Vertical axis wind turbines are advocated as being capable of catching the wind from all directions but incapacitated to self-start even with substantial wind velocity. Central panel was provisioned and using asymmetric airfoil at different thickness to search its effect for self-starting feature by attempting different parameters finding the highest efficiency. The airfoil blades that were used were somehow considered to be a combination of Darrius and Savonius wind turbines. Various types of testing were conducted to know the most efficient type of airfoil blade thickness, attachment location and pitch angle configuration. Five thickness types of airfoil blades were used and classified as follows: (a) 15%, (b) 18%, (c) 21% and (d) 24%. The pitch angle was varied ranging from –15º to 15º with 5º interval in reference from its neutral axis at five (5) different attachment locations and three spoke attachment distances were tested using a model searching out the wind turbine optimized power output versus the configuration of pitch angle and blade attachment location and aids self-start with the highest efficiency.

With the series of test conducted using the testing model, result shows satisfactory performance and self-starts the wind turbine using 24% thick air foil blade attached at 50mm from the toe at spoke attachment B, 10º pitch angle, using asymmetric airfoil blade to straight vertical axis wind turbine. This might be a highly classified wind turbine from its family of vertical axis that does not need self-starting mechanism from a minimum wind velocity of 4 m/s with a power coefficient of 24.64% at the tip speed ratio of 51.51%. The Prototype with same configuration of the model with optimum performance shows power coefficient of 18.92% at TSR of 50.58% using industrial fan and power coefficient of 17.31% at TSR of 92.47% using the natural wind.

Keywords: *Solidity, Pitch angle, Tip speed ratio, Aspect ratio, Asymmetric, Airfoil thickness, Airfoil, Power Coefficient*

1. Introduction

This study focuses in using wind energy as an alternative source of energy. Wind can drive a wind turbine to transform wind energy into mechanical energy. The turbine turns the shaft directly of an electrical generator. In the electric generator, an electrical potential is created when magnetic flux is rotated within the generator, the action transform, mechanical energy into electrical energy. Wind energy using wind turbines can be a primary mover to drive generator in the production of electrical power. Wind energy has several key advantages as follows:

- Wind energy as a renewable energy source, makes the environment healthier as they do not pollute the atmosphere with carbon dioxide and other toxic gases. Being a renewable source of energy, there are no emissions.
- Wind energy as a renewable energy technology is cheaper as they require less maintenance and have much lower overall cost of construction and operation in the long run.
- Wind energy is available in abundant quantity and free to use. It does not require some form of fuel for the operation.

1.1. Background of the study

The physicist Albert Betz showed that for a hypothetical ideal wind-energy extraction machine, the fundamental laws of conservation of mass and energy allowed no more than 16/27 (59.3%) of the kinetic energy of the wind to be captured. This Betz' law limit can be approached by modern turbine designs which may reach 70 to 80% of this theoretical limit.

1.2. Statement of the problem

The airfoil blade is responsible in converting wind energy into mechanical energy which may lead to be the prime mover of the generator in the production of electrical power. To further investigate this phenomenon, question arise as follows:

- Is the airfoil thickness of the blades influences the performance of the straight vertical axis wind turbine?
- What is the thickness of the airfoil blades that results to best performance of the straight vertical axis wind turbine?
- Is the pitch angle also affects the rotational speed and power output of the straight blade vertical axis wind turbine?

1.3. Conceptual framework

The main concept of this study is to know the effects of the airfoil blade thickness on the performance of the straight vertical axis wind turbine (see Figure 1.1.).

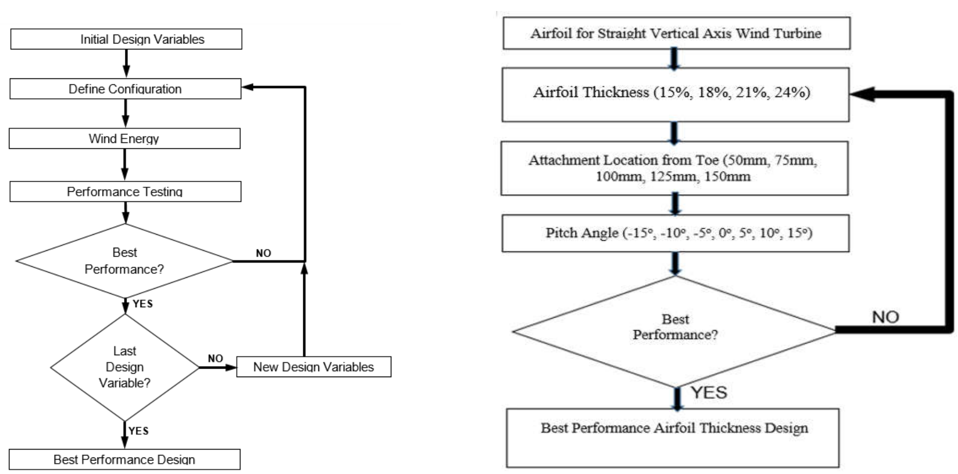

Figure 1.1 Airfoil thickness selection algorithm

Figure 1.1. Show's the algorithm of the study from having a different thickness of airfoil blade up to knowing the most efficient parameters of the selected airfoil thickness with best performance. The output of this algorithm will be used in the fabrication of the scaled prototype.

1.4. Objective of the study

The main objective of the study is to find highly efficient wind turbine generator by enhancing the design of a straight blade vertical axis wind turbine with a combination of Darrius and Savonius type wind turbine base on airfoil thickness.
The specific objectives of this study are to:

- Know if the straight vertical axis wind turbine efficiency can be improved by varying the thickness of the airfoil blade.
- Design a wind turbine airfoil blade with highly aft (asymmetric) geometry that has a best performance.
- Know if the solidity affects the efficiency of the straight blade vertical axis wind turbine using airfoil blade.
- Know the parameters of the straight vertical axis wind turbine using selected airfoil thickness with highest efficiency.

1.5. Scope and delimitations of the study

The study is limited to be tested using the fan and duct system facility of the ME laboratory of the University of Perpetual Help Calamba campus in Calamba, Laguna. The prototype may be tested using the natural wind breeze in the lake shore in Mamatid, Cabuyao, Laguna with minimum wind velocity of 4 m/s. Also the study is limited to using only one type of material for the airfoil blade which is the galvanized iron gage # 24.

2. Methodology

2.1. Research Design

The study uses modelling and prototyping technique following the algorithm as mentioned previously in finding the wind turbine parameters that will produce optimum efficiency to this new breed of vertical axis wind turbine and still can self-start in any direction of the wind. To see the efficiency of this new breed of vertical axis wind turbine, the proponents had tested every airfoil blade with thickness varying from 15%, 18%, 21%, and 24%, based on its chord length. Based on the gathered data from the test, the proponents can conclude which among the thickness of the new breed of vertical axis wind turbine produces the highest efficiency.

2.1.1. Design of four airfoil blades in different thickness for testing:

The NACA airfoil designation was used in this study. The following airfoil blades was designated as NACA 4415 for 15% thick airfoil, NACA 4418 for 18% thick airfoil, NACA 4421 for 21% thick airfoil, and NACA 4424 for 24% thick airfoil. This means that the airfoils are asymmetric airfoil with 4% maximum camber located at 40% of the chord length. The four airfoil blades with different thickness for testing has the same length and the same height. The length of blade is 0.24 m from the toe to tail of the blade and the height is 0.30 m. After the thickness and form was determined in testing airfoil blade, the proponents draw to scale the pattern in Auto-CAD computer application. The drawn pattern was the basis in producing the airfoil model.

After forming the top and bottom side of the airfoil, it was wrapped with steel sheet to form a hollow airfoil blade in their respective thickness. The airfoil blades were produced in pairs, one pair of testing airfoil blade for every different thickness. Five (5) holes with 3 mm in diameter were provided parallel to the line connecting the toe and the tail. The distance between the toe and the first hole is 0.05 m and the distance between the hole is 0.025 m in succession to the 5th hole. These holes are identical in the top and bottom of the airfoil blade. (see Figure 2.1)

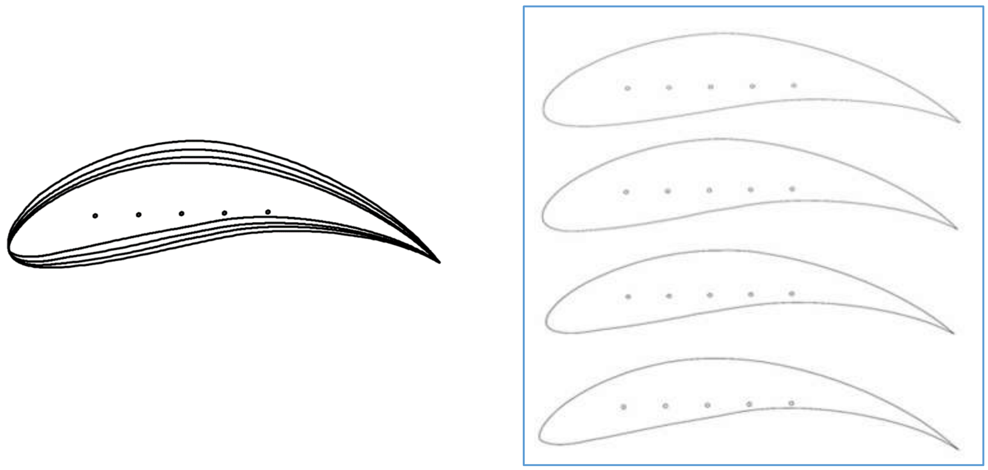

Figure 2.1 Airfoil blades with different thickness

2.1.2. The Acrylic spoke mounting plate:

The acrylic mounting base (see Figure 2.2a) was used to fix the airfoil blade testing model and the central panel. For the variation of the pitch angle and the radius. The acrylic mounting base have a three holes with different radius (0.12 m, 0.16 m, and 0.20 m) from the center of the acrylic mounting base and the holes represent a Hole A, Hole B, and Hole C. Both side of each hole has a circular slotted hole that has an arc angle of 30^{o} to represent as a variation of pitch angles setting (15°, 10°, 5°, 0°, -5°, -10°, and -15°).

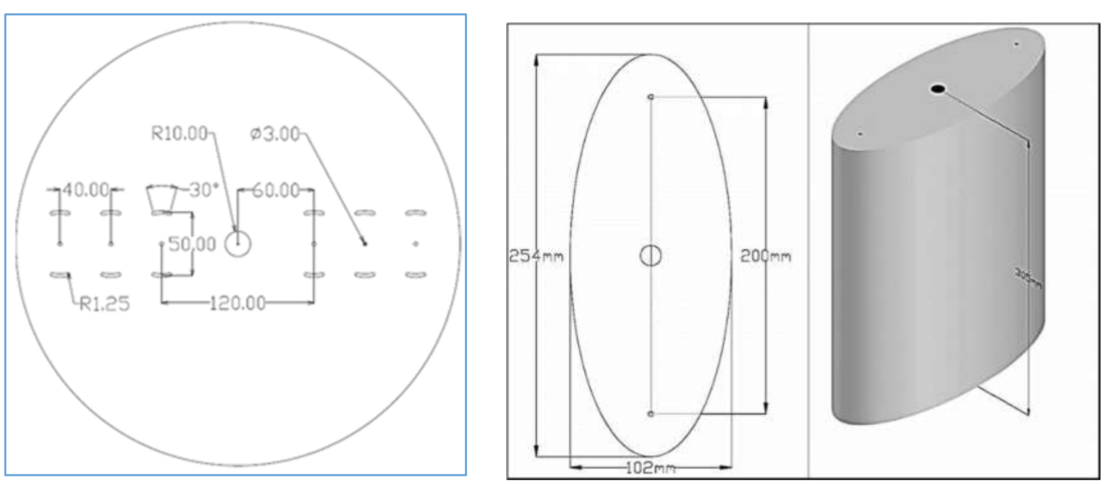

Figure 2.2 The acrylic spoke mounting plate and the central panel of the testing model

2.1.3. The Central Panel of the testing model:

The central panel was used and was connected to the central shaft that holds the acrylic spoke which on the other end is connected to the generator as the load. The central panel was theorized to function trapping the wind and pushing it into a circular motion of the wind turbine. The length of the central panel is 0.254 m and the maximum thickness is 0.102 m. The height of the central panel is 0.3048 m and the distance between the two holes wherein the acrylic spoke is connected and fixed by the metal screws (see Figure 2.2a).

2.1.4. The base plate of the wind turbine testing model:

The airfoil blade and the central panel with the acrylic spoke mounting base of the testing model is connected by a central shaft to the base plate assembly of the wind turbine which contains the generator as the load (see Figure 2.4a). The complete set-up of the wind turbine testing is shown in Figure 2.4b.

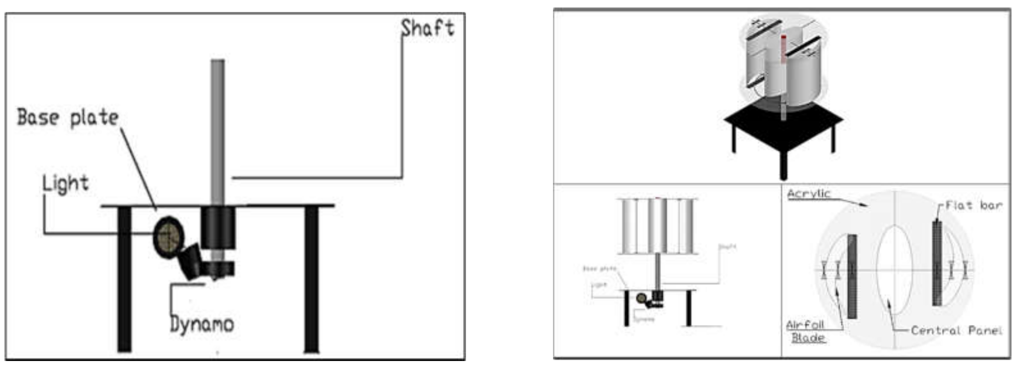

Figure 2.4 The base plate and the complete set-up of the wind turbine testing model

3. Results and Discussion

3.1. Data and Analysis:

Computing the data for analysis, the researchers start from getting the torque of the wind turbine with respect to the mounting hole of the testing airfoil blade. Torque is a force that produces rotation in this case the wind turbine. Spring balance was used to get the force exerted to start the rotation of the airfoil blade testing model. The torque is then computed by multiplying the radius from any hole to its corresponding force recorded from the spring balance. Using the digital tachometer, the angular velocity was taken and used in finding the power output (EP) of the wind turbine using the formula:

$$EP = BP = 2\pi Tn \tag{1}$$

Where: BP – Brake Power
T – Magnetic torque of the wind turbine generator
n – Angular velocity of the wind turbine

The wind power (AP) is calculated with the formula:

$$AP = \frac{1}{2}\rho A v^3 \tag{2}$$

Where: AP – Air Power from the wind

ρ – Air Density = 1.20 $\frac{kg}{m^3}$
ν – wind velocity

Finally the efficiency is calculated as the formula below:

$$C_p = \frac{Power\ Output}{Power\ Input} = \frac{Electrical\ Power}{Air\ Power} = \frac{EP}{AP}\ x\ 100\ (\%) \quad (3)$$

3.2. Summary of Findings, Conclusions and Recommendations

Based from the data gathered as analysed, the point mount location that has the highest angular velocity at point location #1. The proponents gathered all the data from that point at location point #1 and by varying its pitch angle in every spoke attachment hole (e.g. hole A, hole B, and hole C) and plotting it in a chart using MS EXCEL through their efficiency vs. Tip speed ratio. Forty five test set-up were conducted to complete the whole testing procedures and to determine the best airfoil thickness and its corresponding parameters.

Comparing the four airfoil thickness performance, the airfoil blade with 24% thickness shows superiority among the other. All air foils have the parameters set at airfoil mount location 50 mm from the toe with pitch angle set at +10º (e.g. toe) out attached at acrylic spoke hole B.

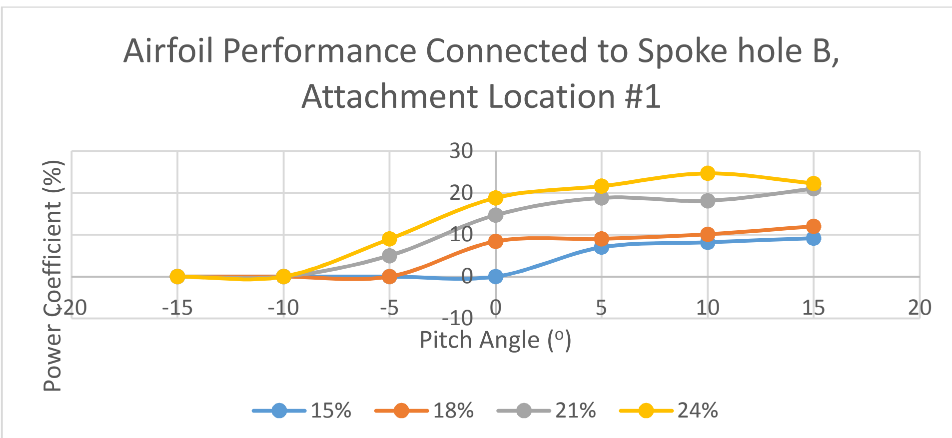

Figure 3.1 Airfoil performance graph

3.3. Findings

Since the testing model has the highest power coefficient found to be at spoke hole B, airfoil attached to location #1, the performance was graph for the airfoil with different thickness at this parameter varying its pitch angle as can be found in the figure 3.1.

The best performing airfoil is the 24% thick with parameters to be connected to spoke hole B, airfoil attachment location #1 with pitch angle attached at 10º. With this result, the prototype was fabricated using the parameter found in the testing model. The prototype was designed to be using the 24% thick airfoil based on the chord length attached to spoke hole B, airfoil attachment at location with pitch angle fixed at 10º. The size of the prototype was designed to produce an output of 200 Watts at a nominal wind velocity of 8 m/s. The wind turbine is expected to self-start at wind velocity of 4 m/s.

3.4. Scaled design of the prototype

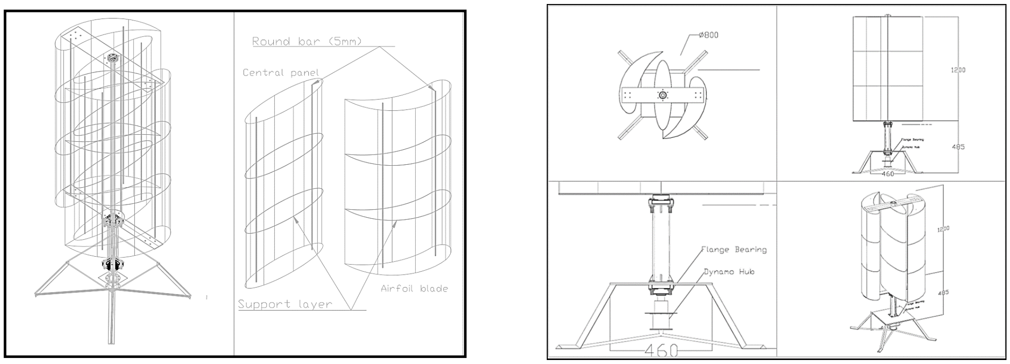

Figure 3.2 Skeletal and detailed ACAD drawing of the prototype

The efficiency of the actual prototype that was tested using industrial fan is 18.92 % and the Tip speed ratio is 50.58%. However, the efficiency of the actual prototype that was tested in natural wind is 17.31 % and the tip speed ratio is 92.47%.

4. Conclusion

The effect of pitch angle to the rotation speed and power output of the wind turbine is when the more the blade is opened (pitch angle) and far from the central panel the more it will rotate, because the central panel captures the air to push the airfoil blade to drag during the leeward and lift during the windward of the wind turbine rotation. In this study, the 24% thickness of airfoil blade with asymmetric in form design has the highest efficiency. This asymmetric design of airfoil blade attached in acrylic spoke hole B, with 10^{o} pitch angle at airfoil attachment point 1 has the efficiency is 24.64 % at the Tip speed ratio is 51.50%.

The prototype with 24% airfoil blade thickness based on chord length, the efficiency during the test using the industrial fan is lower than the natural wind. The efficiency is 18.92 % and the revolution per minute (RPM) is 64 RPM at 5.3 meter per second average wind speed and the tip speed ratio is 50.58%.

5. Recommendation

The 24.64% efficiency for this kind of wind turbine is far way behind using airfoil horizontal axis wind turbine. It is recommended to further study the airfoil design to become competent to those horizontal axis wind turbine as the straight vertical axis wind turbine does not need mechanisms to point to the direction of the wind and that the generator is accessible for repair and maintenance.

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