# Blade Design of Vertical Axis Wind Turbine for Golf Car Battery Charger

Muhamad Azizul Bin Mijan
Faculty of Electrical Engineering
Universiti Teknologi MARA Malaysia
40450 Shah Alam, Selangor, Malaysia
e-mail: azizulmijan@gmail.com

*Abstract*— **In this paper, the research has been done to design the blades for the small Vertical Axis Wind Turbine (VAWT) system. There are many factors to be studied to design the best blade including aerodynamic design or airfoil type, coefficient of drag, suitable number of blade in a system, size and chord length of a blade, rotational speed, torque and the output power that can be produced by the shaft. All design was drawn using CATIA software before simulated using Star CCM+ software. All of these characteristic will be studied to produce the blades that can capture as much as wind to generate high power and suitable with the application at golf car which is for battery charging. Finally, the conclusion are, the suitable NACA series is NACA 0018 and the best chord length is 50mm because can produce higher drag coefficient, thus the maximum power produced fro the blade is 6.90704 Watt.**

**Keywords; NACA series, CATIA, STAR CCM+.**

## I. INTRODUCTION

In Malaysia, wind speed is varied from season to season about 2m/s to 12m/s and average of 3m/s only [1]. The usage of wind energy in Malaysia is not very popular yet. It is because of the low average wind speed in Malaysia. However, the application of the system can be maximized.

The concept is when wind attacks the blades, in will produce the lift force and drag force on the blades, thus the blades will rotate which held by rotor shaft. The rotational speed is depends on the wind speed. That relationship is called as tip speed ratio [3]. When the rotor is rotating, it will produce the kinetic energy to the shaft and the generating power. That kinetic energy will be converted to the electric energy using generator [4]. The wind is characterized by speed and direction, which are effected by several factors like geographical area, height above ground, speed of baggie car and the surface topology.

Objective of this project are; first is to determine the suitable NACA series for small VAWT, second is to determine the suitable chord length for the blade and third is to find the maximum power that resulting from the blade and suitable with the application at golf car. There are three commonly used NACA series for the VAWT, NACA 0015, NACA 0018 and NACA 0020 [5], [6], [7]. This part is the most important part for this system because it responsible to capture the wind and then rotating the shaft, thus produce power. In order to get high power generating from shaft, the blades should produce high lift force for power calculation [8]. STAR CCM+ software was used for simulation [9], [10].

Steven D. Miller [5] has carried out the analysis of lift coefficient and drag coefficient of NACA 0015. As the result, the drag coefficient analysis is important in order to get the best power performance in term of power coefficient and also important to determine suitable angle of attack. In VAWT drag coefficient required to perform high torque thus, produce high power and have been discussed in some researches [2], [4].

About the effect of blade number was carried out by Nurul Natasha Binti Mokhtar with her research of "Effect Of Number Of Blades On The Permormance Of Drag-based VAWTs" and M. Predescu, A Bejinariu and O. Mitiroi with their research of "Influence Of The Number Of Blades On The Mechanical Power Curve Of Wind Turbines" [6], [7]. Experiments were done by using wind tunnel. Wind turbine was placed in a wind tunnel and some experiment was conducted to study the effects of changes in number of blade towards the torque and power produce by the shaft and the result shown that by increasing the number of blade, the torque and power also increase.

Other researchers such as Muhamad Sani Bin Che Haat [9] and Nazrul Idzham Bin Nasir [10] have been conducted the simulation to determine the drag coefficient, resulting from a single blade. They have used STAR CCM + since it matches with some CAD software. From the study, the resulting drag coefficient is closely related to the selection of a suitable airfoil in terms of size, thickness and chord length.

## II. METHODOLOGY

### A. Flow Chart

Figure 1 shows a flow chart of analysis that conducted to find the blade that is suitable for small VAWT system which will be applied to the golf car. Analyses to find the suitable NACA series, the appropriate chord length and power calculations were set as shown in this flow chart.

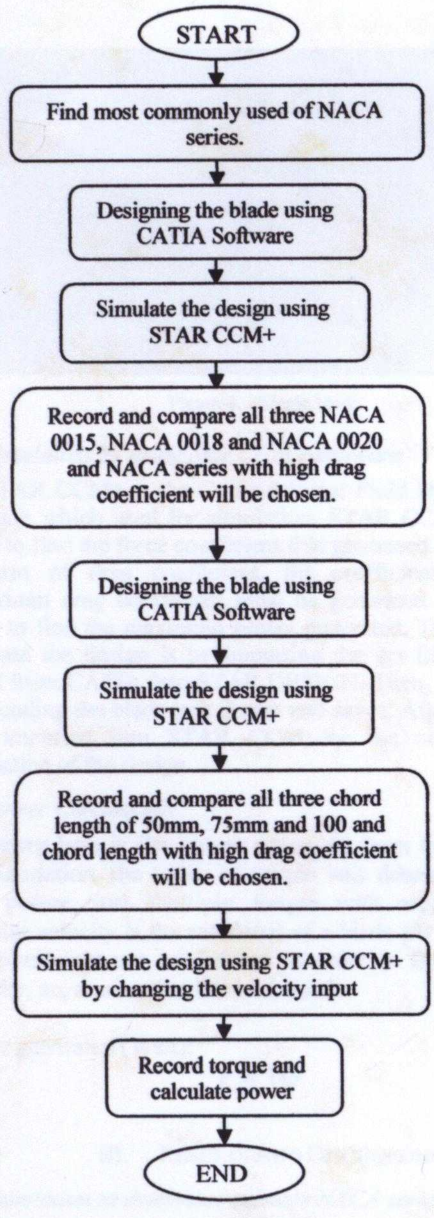


Figure 1. Flow chart

## *B. NACA 4-series aerodynamic profile*

There are many types of airfoil being used in the aerodynamic field. NACA 4-series is selected in this project because it is easy to manufacture. NACA is Stand for Numerical Advisory Committee for Aeronautic. The first two digits indicate whether it is symmetrical or not and the last two digits indicate thickness of the airfoil. There are three NACA series that most commonly used for VAWT system. Those are NACA 0015, NACA 0018 and NACA 0020. In this project, analysis was done using simulation to find best NACA series from those three, in term of drag coefficient. NACA series that perform higher drag coefficient will be chosen in the design. Figure 2 shows an airfoil.

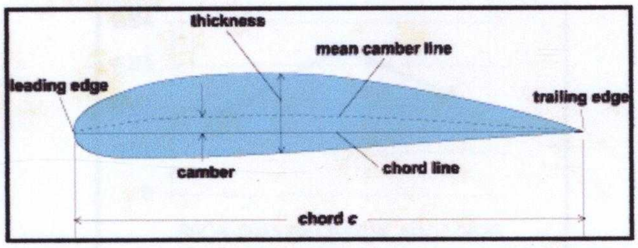


Figure 2. An airfoil

Figure 3 shows the NACA 0020 coordinate generated using Microsoft Excel [9]. There are several criteria that must be considered in order to produce a coordinate for the NACA. First, there is a formula often used to generate coordinate for the NACA 4-series.

— — ) (1)

Where $0 < x < 1$ and y is the vertical coordinate and x is the horizontal coordinate. Then the coefficients are

$A = 0.2969$
$B = -0.1260$
$C = -0.3516$
$D = 0.2843$
$E = -0.1015$

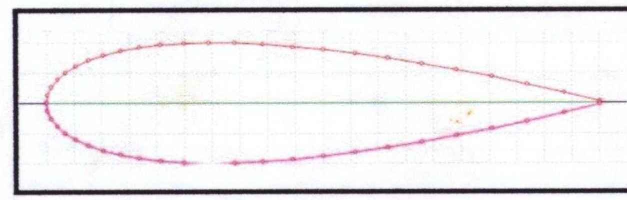

Figure 3. NACA 0020 Coordinate

## *C. Chord length analysis*

Simulation has been carried out to determine the appropriate chord length. Three chord lengths will be analyzed which are 50mm, 75mm and 100mm. the best chord length is when it can produce the highest drag coefficient.

## *D. The drawing of the design using CATIA software*

CATIA software is used to design the drawing of the blade and do the measurement on the blades. CATIA software is used in this work due to the 3D design and file format that matched with STAR CCM+, the simulation software. Besides, CATIA is friendly user compare to other software such as Solidwork and AutoCAD.

The first step of drawing is by inserting the picture of the coordinate NACA profile into the CATIA. Then, by using sketch mode, coordination of that NACA profile was sketch. Then, scaling technique was used at the drawing until the exact value is found. After finish draw the suitable blade on CATIA, the drawing was saved in *igs* format to be imported into STAR CCM+. Figure 4 shows a blade design drawn by using CATIA.

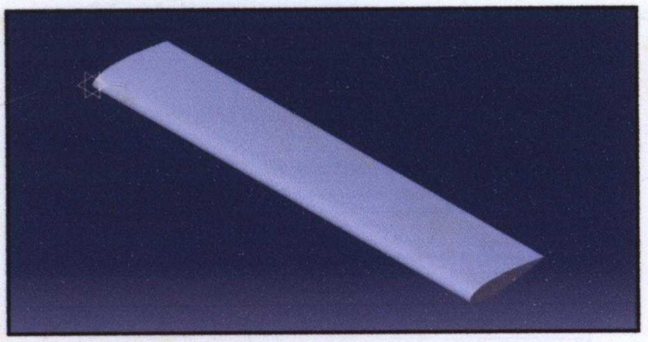

Figure 4. Single blade

*E. Simulation by using Star CCM+ software*

STAR CCM+ is the Computational Fluid Dynamic (CFD) software which used for simulation. STAR CCM+ is used in order to find the force coefficient that generated from the blade in term of drag coefficient, lift coefficient and torque. Maximum drag coefficient must be generated from blade in order to find the maximum power generated. The first step to simulate the design is by importing the *igs* file that already saved from CATIA into STAR DESIGN. Then, wall boundary surrounding the blade was drawn and saves. After that, the file was imported into STAR CCM for the next procedure, simulation of the design.

*F. Power Calculation*

Power here is the power generated from the shaft. From the simulation, the value of torque was determined. And to find power, just multiply torque with angular velocity. Angular velocity is the rotational of a blade per minute. Since the experiment not carried out in order to find the angular velocity, so, assumption has been made.

Power generated (Watt):

$$P = T\omega \quad (2)$$

## III. Results And Discussions

*A. Simulation to determine suitable NACA series*

Simulation has been done to determine the best NACA series. TABLE I shows the drag coefficient recorded from simulation between NACA 0015, NACA 0018 and NACA 0020. Those three NACA series use same parameter, 50mm chord length, 250mm blade length and 10m/s velocity input.

TABLE I. Drag Coefficient Between Between Three NACA Series

| Drag Coefficient | NACA Series | | |
|---|---|---|---|
| | *NACA 0015* | *NACA 0018* | *NACA 0020* |
| $C_d$ | 0.019088 | 0.033984 | 0.02349 |

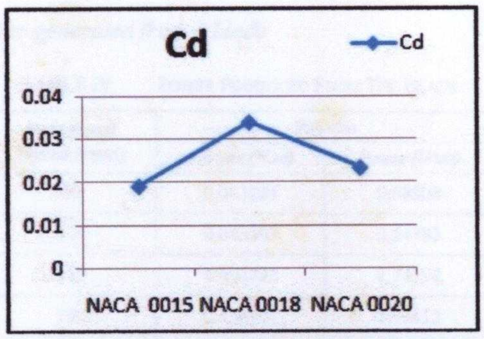


Figure 5. Drag coefficient produce between three NACA series

TABLE I and Figure 5 shows the comparison between the NACA 0015, NACA 0018 and NACA 0020. NACA 0018 has the highest drag coefficient compared to other NACA series. This means that the NACA 0018 is most suitable to be used in this system. This is because, NACA 0018 is stable in terms of chord length, blade length and also has suitability to receive 10m/s velocity of the wind thus producing high drag coefficient.

*B. Simulation to determine suitable chord length*

TABLE II. Drag Coefficient Between Three Chord Length

| NACA 0018 | Chord Length | | |
|---|---|---|---|
| | *50mm* | *75mm* | *100mm* |
| $C_d$ | 0.034594 | 0.028563 | 0.025719 |

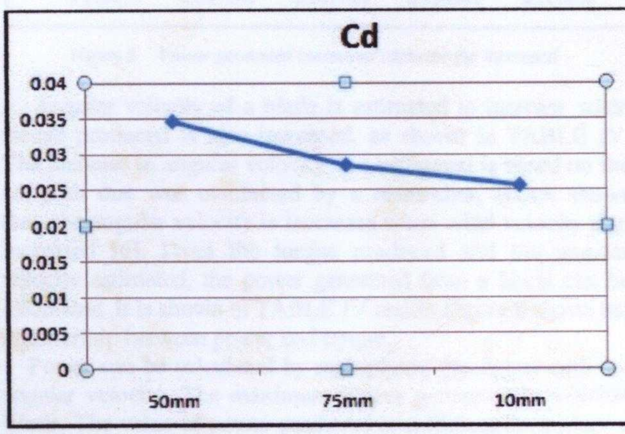


Figure 6. Drag coefficient produce by three different chord length.

TABLE II and Figure 6 shows the comparison between three values of the chord length which are 50mm, 75mm and 100mm. Simulation was conducted using a NACA 0018 was selected earlier and the blade length is fix to 250mm for each chord length. Therefore, the simulation result in TABLE II shows the chord length of 50mm was produce the highest drag coefficient compares to other chord length. This means that the chord length of 50mm is suitable for this system.

There are several factors that can be concluded from the result shown, by reducing chord length, mean surface area will decrease thus the higher drag coefficient will be produced. In addition, the thickness will be reduced because the thickness is depending on the value of chord length. So, in practical, the mass of the blade can also be reduced thus increase the torque of the blade.

### C. Simulation to find force and torque

TABLE III. RESULT FOR FORCE AND TORQUE

| Wind Velocity (m/s) | Results | |
|---|---|---|
| | *Force* | *Torque* |
| 5 | 0.016684 | 0.013224 |
| 10 | 0.055091 | 0.043595 |
| 15 | 0.057231 | 0.092733 |
| 20 | 0.063971 | 0.158921 |
| 25 | 0.064214 | 0.219858 |

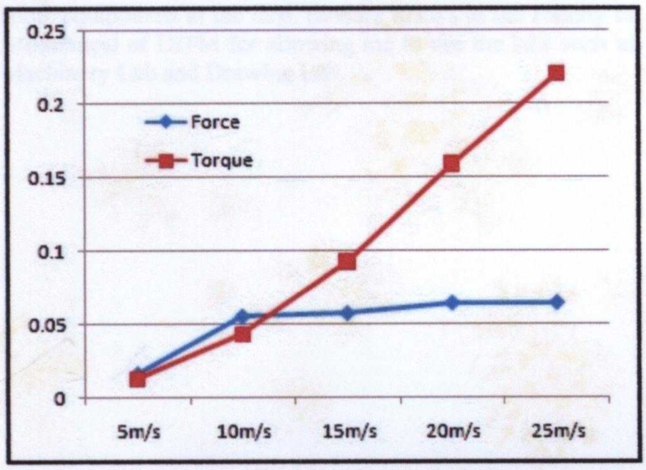


Figure 7. Force and Torque increased when wind velocity also incerased.

Force and torque resulting from the simulation have been recorded in TABLE III and were plotted as shown in Figure 7. The value of the wind velocity is estimated to increase from 5 m/s to 25m/s. This estimation is made after taking consideration with the maximum velocity in Malaysia added with the maximum velocity of golf car. Analysis showed that the higher the wind velocity, the force and torque will also increase. Force and torque are closely linked because when the blade was subjected to a high force from the wind it will produces high torque. It can be concluded that high velocity of wind is very important to produce high torque.

### D. Power generated from a blade

TABLE IV. POWER PRODUCED FROM THE BLADE

| Rotational Speed (rpm) | Results | |
|---|---|---|
| | *Torque (N.m)* | *Power (Watt)* |
| 60 | 0.013224 | 0.08308 |
| 120 | 0.043595 | 0.54783 |
| 180 | 0.092733 | 1.74798 |
| 240 | 0.158921 | 3.99412 |
| 300 | 0.219858 | 6.90704 |

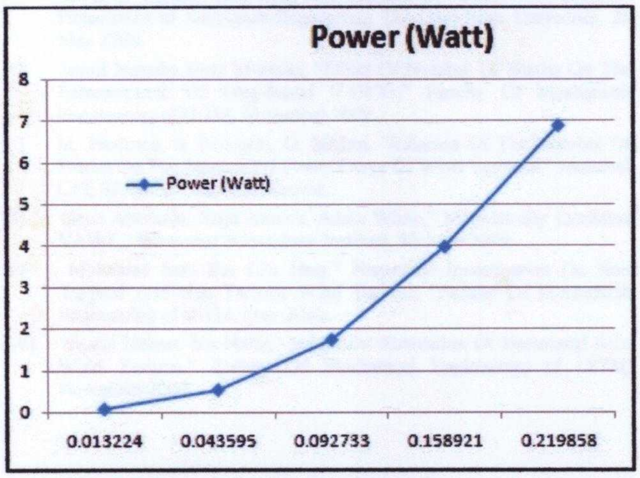


Figure 8. Power generated increased when torque increased.

Angular velocity of a blade is estimated to increase when torque produced is also increased, as shown in TABLE IV. The increase in angular velocity that estimated is based on the research that was conducted by a researcher, which shows that, the angular velocity is increases when wind velocity also increased [6]. From the torque produced and the angular velocity estimated, the power generated from a blade can be calculated. It is shown in TABLE IV and in Figure 8 shows the relationship between power and torque.

Power can be calculated by multiplying the torque with the angular velocity. The maximum power generated is 6.90704 Watts. The value of power produced is sufficient to produce a high voltage. The rest depends on the efficiency of generator and controller.

## IV. CONCLUSION

Comparison was done by comparing the drag coefficient for those three most commonly used of NACA series which are NACA 0015, NACA 0018 and NACA 0020 and also by comparing the effect by changing the chord line of NACA series. So, the conclusion are, the suitable NACA series is NACA 0018 and the best chord length is 50mm because can produce higher drag coefficient. When the drag coefficient high, the resulting high torque produced is also high, thus, the power generated is also high.

Recommended that, for further studies, analysis about unsymmetrical NACA series can be done. And also, recommended to study about the effect of angle of attack for a blade in Vertical Axis Wind Turbine system. There is another suitable Computational Fluid Dynamic (CFD) software that can be used which has just introduced by in the industry which is only for aerodynamic simulation; that is NUMECA. And then, for fabrication in the future, a suitable material which is lightweight and durable must be used. And then, a high efficiency generator must be designed to produce high value of power even the rotational of the turbine is low.

## ACKNOWLEDGMENT

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