AC 2008-1645: RESEARCH AND DESIGN ON WIND TURBINES

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Research and Design on Wind Turbines

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Abstract

Since the need for alternate power sources is becoming more prevalent with each new day, a decision was made to work on the research and design for a laboratory-scale wind turbine as an undergraduate research project. As such, the main goal of the project was to create advancements in wind power technologies. The objective of this research was to design and build a wind turbine for experimental tests. Two different wind turbine blades are tested on the model of the wind turbine. These results will further research that can help develop less expensive and smaller turbines that can be used in homes and farms.

Introduction

The challenge for this research project was to understand the relationship of wind to its impact on turbine performance and reliability. This was done by designing and building a laboratory-scale model of a wind turbine. The wind turbine was tested in a 24” open circuit wind tunnel. Then the data was collected and analyzed to predict aerodynamic loads on turbines under varied inflow conditions and understand the specific behavior of small wind turbines. Based on the optimum parameters studies, the design of the turbine blades can be improved to increase energy capture.

The research has also taken a comprehensive look at what has already been accomplished in wind power technologies. The mathematical models that guide the principles of wind power will be investigated. The equation \( P = 0.5 \rho Av^3 \), as an example, gives the possible wind power within a certain cross sectional area, and the velocity, a cubed variable, is especially important to the design of windmills. The research will also review the varied existing designs of windmills for their strengths and weaknesses. This comparison will find what designs are suited for what applications.

Background

There are two main classes of wind turbines: horizontal axis and vertical axis. The wind turbines seen in today’s wind farms with the rotating blades atop a tower are called horizontal axis wind turbines because their blades rotate about a horizontal axis. The other type of windmill, the vertical axis wind turbine, has blades or paddles that rotate around the axis of the tower that supports it. Often these windmills look like gigantic eggbeaters.

Vertical axis wind turbines
The vertical axis wind turbine (VAWT) can either use drag or lift to gather power. The type of VAWT that uses lift is known as a Darrieus machine and it comes in many designs.

Vertical axis wind turbines have a main shaft running vertically with several rotors or sails running along that shaft. There are several advantages of vertical axis wind turbines over horizontal turbines. With vertical axis turbines the generator and gearbox can be on the ground to make it easier for maintenance. They also generally begin to rotate at a slower wind speed. Another advantage is that they are quieter and do not have to be pointed into the wind to generate energy.

**Horizontal axis wind turbine**

Horizontal axis wind turbines (HAWT) are the most commonly used. Horizontal axis wind turbines have a main rotor shaft with a generator and gear box that is at the top of the tower. Most small wind turbines have a wind vane that points the blades into the wind whereas the larger wind turbines have wind sensors and a motor to turn the blades in to the wind.

Although a VAWT has some advantages over a HAWT, a HAWT has more advantages overall. For example, the blades are able to be pitched to catch more wind or to avoid storm damage. The tall towers, although they make the turbine harder to maintain, allow the turbines to be placed higher in the air to catch faster wind and also allow the turbines to be placed on uneven ground and even offshore. Disadvantages of the modern wind turbines include the fact that there are turbulent winds behind the blades. The tall towers and long blades are also hard to transport and assemble on site.

**Concept Generation**

The concept generation with student groups involved the types of turbine (horizontal axis or vertical axis); the types of generator, gear box or direct-drive; and the flexibility of replacement for rotor and blades. After concepts were compared by Pugh selection chart and weighted decision matrix, it was finally decided to use a small, direct drive, horizontal axis wind turbine. The decision was mainly based on ease of design, simplicity, proven effectiveness, safety, and consistency.

**Design, Manufacturing and Assembly**

**Blades design and manufacturing**

The design of the windmill and its specific components are another integral part of the research. For instance, it was discovered that windmill blades on horizontal axis machines are given a twisted taper in order to prevent vortex formation with an even pressure distribution. Structurally, a twisted blade is stronger than a non-twisted blade. Using computer aided drafting software and hand drawings, scale models to place into our turbine and hook up via a direct motor to see their power output were created.
Two different types of blades were designed. The first one is based on the NACA 4415 aerodynamic geometry profile (see the cross section area in Figure 1). It can span a greater area than other designs. The twist and slope of decrease was put in by using Computer Aided Design Solidworks, and then altered for a 3” chord. The second one was designed with a smaller size and a twist angle of 30 degrees, and it was designed for running three to six blades on the wind turbine.

![NACA 4415 Airfoil Chord](image)

Figure 1: NACA 4415 stations and ordinates given in percent of airfoil chord

Since the blade material should be stiffer and stronger while lighter and adaptive in order to reduce system loads, ABS (Acrylonitrile Butadiene Styrene) material provided by the University’s three dimensional printer was used. The rapid prototyping 3-D printer has a fast manufacturing process, especially for the shapes of blades with twist angles. Figure 2 shows the blades designed and manufactured for the wind turbines.

![Blades design by Solidworks and manufactured by rapid prototype 3-D printer.](image)

Figure 2: Blades design by Solidworks and manufactured by rapid prototype 3-D printer.

**Stand design and creation**

The design criteria for the stand were:

- Needs to hold weight of motor, rear fin, blades and hub.
- Needs to withstand 40+ mph winds.
- Capable of spinning and catching into wind no matter what the direction was relative to base position.
- Needs to be economically designed.
• Need front surfaces of blades to always be orthogonal to wind direction for maximum efficiency.
• Needs to accommodate for horizontal and vertical wind turbine designs.

The stand was designed and manufactured to satisfy all the requirements and also integrated radial thrust bearing into design. The common stand can easily make exchanges of the rotor and blades. It is made with aluminum (see Figure 4). To generate the power, a permanently magnetic and electrically reversible DC motor was used. It is a 12 V motor rated at 3100 rpm. The torque is 15 oz-in.\textsuperscript{4}.

**Assembly**
The first part of the assembly was to attach the motor to the stand. This consisted of a clamp style mount that went around the outer diameter of the motor. This piece was threaded in the bottom and two screws could be put into the bottom to hold it on the base. A three inch diameter hub that had three threaded holes for the blades to be attached to was fabricated. Once the blades were attached, the hub could be screwed onto the shaft of the motor. The model was attached directly to the wind tunnel to prevent the model from blowing over or moving (see Figure 5).

![Figure 4: Common Stand to support wind turbines](image1)

![Figure 5: Wind turbine assembly the created in SolidWorks.](image2)
Testing

The experimental tests were performed in the 24”x 24” wind tunnel (see Figure 7). The wind velocity ranged from 3.0-30.5m/s, or 10.0-100.0 ft/s (0.684 – 68 mile/hr).

Test Wind Turbine (A)
The wind turbine with NACA 4415 airfoil design was tested for minimum base rotation speed, minimum blade rotation speed, and voltage at maximum allowed wind tunnel speed. The results are shown in Figure 8.

Test Wind Turbine (B)
This model was tested using various wind speeds and blade numbers. The tests began by using three blades with a 15 degree pitch. The blades did not start to rotate until the wind speed reached 36 mph. When the wind speed reached 45 mph there were 3.00 volts of
electric potential produced. For our next test the blades were turned around 180 degrees to see if that effected the results. It was found that it did have a considerable effect with the start up speed (cut-in speed). The blades began to spin at 30 mph and produced 4.15 volts of voltage with a wind speed of 45 mph. The third test was done with all six blades pitched at 15 degrees. With extra blades there was more surface area so the blades stared to spin at a much lower speed than with only three blades. The blades started at only 20 mph. At a top wind speed 45 mph there were 5.40 volts of voltage produced. This was the best combination of blade number and pitch. It produced the most current at top speed and started to spin at a lower speed. In the last test the pitch of the blades was increased to 30 degrees. The blades required a higher wind speed to start spinning. The blades started to rotate at 23 mph. When the wind speed reached 45 mph the output was 4.10 volts. The results are shown in Figure 9.

Results and Discussion

According to Figure 8 and Figure 9, wind turbine A’s starting performance with cut-in speed is better than wind turbine B. It shows that the blade design of A is a better design, since power is extracted at the lowest wind speed. This is more important for small machines. In Figure 9, it shows that the six-blade with 15 degree pitch performance is dramatically better the only three blades for initial start up and cut-in speed. Also the smaller pitch to the blades allowed the turbine to produce more voltage, even with only three blades. This is partially because the design of the blades for turbine B incorporates drag.

Figure 8: Test result from wind turbine (A)
Conclusion

A lot has been learned from the research and design process. The two turbine models work very well and will allow for further research and experimental tests. The data that has been collected will be compared to the performance of a standard model based on current technology. The focus will mainly be on the design of blades and other mechanical modifications, but other benefits such as reduced noise and reduced vibrations to increase usage in gust prone areas may also be looked at. Hopefully, a positive impact in wind power technologies will be made.

References

5. Students’ Project Final reports from ENME 371, Product Engineering and Manufacturing, 2007, Frostburg State University

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