Design, fabrication and performance analysis of a horizontal axis wind turbine using hawk wing system at Baru Beach, Yogyakarta, Indonesia

Widodo¹², M Syamsiro¹², M Iskandar³, Mujiyono⁴

¹Department of Mechanical Engineering, Janabadra University, Jalan Tentara Rakyat Mataram 55-57 Yogyakarta 55231 Indonesia
²Center for Waste Management and Bioenergy, Janabadra University, Jalan Tentara Rakyat Mataram 55-57 Yogyakarta 55231 Indonesia
³Mechatronics Engineering Department Yogyakarta State University, Yogyakarta, Indonesia
⁴Diploma Mechanical Engineering Department Yogyakarta State University, Yogyakarta, Indonesia

E-mail: widodoft@janabadra.ac.id

Abstract. South Java Coast in Indonesia is a potential location for developing wind power due to the abundant wind resources. One of the prospective areas is Baru beach, Srandakan, Bantul, Yogyakarta. In this area, the wind speed could reach 0-12 m/s with the average speed was 6 m/s. The objective of this research is to design and manufacture of Hawk Wings blades. The blades were hardly stop when spinning resulting quick rotation and high torque which were suitable for the wind characteristics at Baru beach. The windmill installation consists of some main components, i.e. blade, AC generator 3 phases, tower and foundation, wind orientation control, rectifier, battery, and load. The direct method using 2000 watt generator was used to design the windmill. The blade was disassembled and then installed to the generator axis. The DC electricity was used as a power for charging 12 volt batteries. At Baru beach, the blade with a radius of 95 cm, width 24 cm base, 8 cm wide end a angle of 0-37° produced rotation of 0-2000 rpm, and voltage of 0-48 volts. The tests were carried out for 38 hours resulted in 3224.86 watt hour energy. As a result, the average of 1 hour production process generated electrical energy in the form of DC at 84.86 watt-hour.

1. Introduction

The wind resources have become one of the most potential energy resources in the world. According to Stanford University, the use of 20 percent of the economically viable inland wind resource for power generation could exceed the world’s electricity consumption in 2000 by a factor of seven (Global Wind Energy Council, 2008) [1]. It means that, the wind power has a great capacity to support the world energy.

Furthermore, it has been accepted commercially and has become an economically feasible source of energy. It is easy to install and takes a short time for its realization compared to other power plants. The encouraging international trends are clearly indicative of an increasing role of renewable energy sources in general and wind in particular in meeting the future energy demands [2]. Moreover, the direct
utilization of wind energy does not cause air pollution, or it can be said as environmentally friendly utilization. Wind energy is a clean and low-cost ocean source of renewable energy [3].

The wind can be produced into a productive energy from its natural process. Due to the movement from high into low pressured air, wind produces kinetic energy which can be converted or transferred into other forms of energy such as electric or mechanical energy by using wind turbine or wind turbine. Therefore, windmill or wind turbine is often referred to as a Wind Energy Conversion Systems (WECS).

In Indonesia, wind turbine has its place to contribute to the national power supply. With the longest coastline in the world, about ± 80791.42 km, it becomes a potential area for development of wind power plants. Moreover, Indonesia has average wind speed about ± 5 m/s. The wind speed of 4 m/s to 5 m/s is classified as low-sized with a potential capacity of 1-100 kW [4]. However, its potential of wind energy has only been used approximately 0.03% potential which is about 3.07 MW [2].

One of the prospective areas is Baru beach, Srandakan, Bantul, Yogyakarta. The wind at Baru beach with average speed of 0-17 m/s which is very feasible for the energy production. To maximize its potential, the energy generated from the wind on the Baru beach should consider the maximum blade dimension design to produce high energy, (Source: 2014 KKAi race committee Sanata Darma & Higher Education: Yogyakarta) [5].

During the past decades, the nominal power of wind turbines has grown significantly, and today, the biggest operational turbines are within the magnitude of 7.5 MW. Wind turbines with a power rating of 10 MW and beyond are under design [6]. To support the effective design of wind turbine, the research used the most common design of a modern wind turbine which is the horizontal axis wind turbine (HAWT). In this design, the rotation axis is parallel to the ground. The focus has been intensified on designing wind turbine blade for maximum aerodynamic performance using hawk blade design. The design was employed to gain good efficiency thus obtain better turbine performance. The main benefit of the hawk design was the continuous and consistent performance under the slow wind blow. Moreover, it moves fastly under any circumstance.

Through this research, the researcher developed a wind-powered electricity generation as the utilization of renewable energy that can be used as seed given the length of the coast in Indonesia. The study of the windmill should be developed so that any areas that have the potential of wind energy can be self-sufficient regions.

2. Experimental

2.1. Materials

There are some components required to design the wind turbine. Those are blade, generator, tower and foundation, control system, and system control. A generator is one of the most important components in the manufacture of wind turbine systems. A wind turbine generator includes a rotor that rotates by wind power. A is the major components of a HAWT containing the hub and typically three or two blades. It also includes nacelle (including the generator, main frame, drive train that contains rotating parts such as the main shaft and possibly a gearbox and control and electrical systems) and a tower and foundation [7]. This generator can transform mechanical energy into electrical energy.

In designing wind turbine, there are things that should be considered, i.e. the power needed, the speed of the wind, and the number of blades that should be used. Aerodynamic efficiency of wind turbines extremely depends on the performance of the rotor blade, the airfoil section, and the design form. The theoretical maximum for the power coefficient, $C_p$, marked by the Betz limit $C_p, max = 16/27 = 0.593$. Modern horizontal axis wind turbines (HAWTs) work with $C_p$ up to 0.5, nearby the Betz limit. The Blade Element Momentum (BEM) model which is used here is the most common model used in aerodynamic and aero elastic codes for wind turbine performance [8]. "The wind-powered electricity generates apparatus in which strain can be monitored with high accuracy on windmill blades or a tower [9]. The first thing to consider in the design of the windmill is TSR (Tip Speed Ratio) or comparative speed in each windmill (tip) and wind speed obtained by the wheel. To calculate TSR ($\lambda$), we can use the equation below:
\[ \omega \times \frac{\text{rotor}}{v} = \lambda \quad (1) \]

Torque of a windmill can be calculated using the equation below:

\[ \text{TORQUE} = \frac{v^2 x R^3}{\lambda} \quad (2) \]

2.2 Design and Try Out Methods

The experiment follows some steps as shown in Figure 1.

The design steps are [10]:

1. Selection of Materials
   The material used was aluminum with a thickness of 3 mm for the blade. The aluminum material was used because of the corrosion resistance, the lightweight materials, and the ability to withstand wind pressure while rotating.

2. Used Tools
   a. Cutting Machines
      Cutting machines were used to cut sheet of aluminums to form size according to the working drawings.
   b. Bending machine
      A bending machine was used to make an angle in accordance with working drawings dimension. It will determine the speed of rotation when the wind was blowing from the sea.
   c. Lathe
      Lathes were used to create shock and external connection thread to blade with the shaft generator.
   d. Frais machine
      A milling machine was used to divide the three spots by 120° x 3 to maintain the balance while the propeller wheel spins

3. Working Process
   The first is the process of cutting, bending the aluminum plate and making the hole for blade manufacturing process. Welding process was done for the pole. Finally, the finishing process was done.

2.3 Electronics Program
   The first step is to rotate wind turbine vane of 200-1000 rpm by connecting the generator shaft. Type of AC generator was used, then it took the regulator rectifier into a DC output using LM317 and diode.
(controller unit). DC output was channeled to the batteries (battery) with a capacity of 12 volts, completed with the data loader of energy. Recording device energy out put on a string of DC output after the load on the battery.

![Image](image-url)

Figure 2. The control circuit system operators.

3. Result and Discussion

3.1. Controller Program Electronics

The experiment was done in 1st to 2th December 2013 until December 2014. The result of the experiment shows that the windmill produced rotation of 0-2000 rpm, voltage of 0-37 volt. The experiment was done for 48 hours resulting 3224.86 watt hour energy. As a result, the average of 1 hour production process generated electrical energy in the form of DC at 84.86 watt-hour.

![Image](image-url)

Figure 3. The Controller.

Basically the control circuit had a generator that used the same principle to the common control circuit. In this experiment, the researcher used the circuit which set the voltage to control the output voltage which would be entered into the load beside the current remains constant. So, the greater the voltage, the power to lifting weights would also increase in accordance with the formula of 3 phase power, namely:

\[ P = V \times I \times V_3 \times \cos Q \] \( \text{the root of three x Cos Q} \ldots (3) \)

where \( P \) = power; \( V_3 \) = root three; \( V \) = Voltage; \( \cos Q \) = Power Factor; \( I \) = Flow

Maximum output of the circuit shown above no-load amounting to 23 Volt adjusted to the level of security of control systems to be connected to the logger data, while maximum current output of 1 Ampere and \( \cos Q \) of this circuit is assumed to be 0.8. The power of this circuit in accordance with the power formula is stated below.

\[ P = V \times I \times V_3 \times \cos Q \] \( \ldots (4) \)
\[ P = 23 \times 1 \times 1.73 \times 0.8 \]
\[ P = 31.832 / 32 \text{ Watt} \]

The produced power then be used to supply the load, i.e. the battery and the lamp. There were two alternative loads, i.e. DC load from a load of energy stored in the battery and AC load with the help of an inverter.

Generators used in this system was 2000 Watt generator. In order to optimize the output voltage so that it remains constant adapted to the design of the turbines so that the power from the system generates power in accordance with the calculation in the formulation of the control circuit.

There were loads on the system using two 12-volt batteries 45 Ampere, 8 Watt lamp and LED lamp DC adapted to the calculation of the control circuit.

Here is the blade area calculation.

Top width \(= 0.08 \text{ m}\)
Bottom width \(= 0.24 \text{ m}\)
Length \(= 0.95 \text{ m}\)

Then, the blade wide wind turbine is

\[
A = \frac{l_1 + l_2}{2} \times R
\]

\[
A = \frac{0.08 + 0.24}{2} \times 0.95 = 0.152 \text{ m}^2
\]

Wind kinetic energy of wind turbine:

\[
W = \frac{1}{2} \rho v^2 = \frac{1}{2} \times 1 \times 4^2 = 32 \text{ Joule}
\]

Wind power to move the blade is as follows, assuming a wind speed of 4 m/s.

\[
P = \frac{\rho A v^3}{2} = \frac{1 \times 0.152 \times 4^3}{2} = 4.864 \text{ watt} \ldots (5)
\]

The wind power to move the blade, note by \(P\), is calculate as follow by assumming wind speed 4 m/s:

Windmill power generated, assuming the wind speed 4.864 m/s.

\[
P = \frac{1}{12} \rho v^3 D^2
\]

\[
P = \frac{1}{12} \times 4^3 \times 1.5^2
\]

\[
P = \frac{1}{12} \times 64 \times 2.25 = 12 \text{ watt}
\]

TSR calculation, e.g. rotor rotation 200 rpm = 31.8 rad/s.

\[
\frac{\omega R}{v} = \frac{31.8 \times 0.75}{4} = 6
\]
Torque calculation Wind turbine [11]:

\[
Torque = \frac{v^2 R^3}{\lambda^2} = \frac{4^3 \times 0.75^3}{6^2} = \frac{64 \times 0.42}{36} = 0.75 \text{Nm}
\]

3.2. Turbine Blade

Based on the above data, the researcher designed the following blade. Baru beach in Bantul, Yogyakarta, Indonesia has the potential of green energy in the form of wind with a speed of 0 m/s to 12 m/sec (KKAI, 2014). This paper reports the design and manufacture of windmill- hawk wing shaped for wind power application at Baru beach. Blade designs were customized to the characteristics of the wind. The blades were 3-blade using hawk wing shaped with a radius of 95 cm and a little wider at the end. It was intended that the momentum was greater, because momentum was a multiplication of objects with the speed. The greater mass of the object had the greater momentum for objects that were the same speed. Greater momentum was profitable because of its durable rotation. The material of the blade used was 4 mm aluminum plate because of the resistant to corrosion. The manufacturing process was done by grinding pieces and then bending them.

Figure 4. 3D Blade Design.

Figure 5. The Blade Dimension Size.
The 8 meter high tower was installed in the soil using a foundation made of iron and then stook with the pole. To strengthen the tower, the researcher string 3 wires on the side of the tower.

3.3. Electrical Energy
At Baru beach, the blade with a radius of 95 cm, width 24 cm base, 8 cm wide end and a angle of 0-37° produced rotation of 0-2000 rpm; and voltage of 0-48 volts. The tests were carried out for 38 hours resulting in 3224.86 watt hour energy. As a result, the average of 1 hour production process generated electrical energy in the form of DC at 84.86 watt-hour.

Following are the Specific Energy Data of the Ferris Wheel Product from the Eagle Wing Model.

The graph above shows the continuity of energy increase for two days that the rpm rotational speed in the blade has stability above 1000 rpm. So that the energy supply continues to go in the direction of the wind speed. The above graph experienced a significant increase at certain hours, namely at 18.00-22.00 WIB. At this hour the wind speed is above 15 m / hour.
Figure 8. Voltage chart from the data logger.

Figure 9. Graph of Electric Current from the data logger.

Figure 10. Electric power chart from the data logger.

The voltages, currents, and power of the figure 11, 12 and 13 are linear that there is a cycle of increases and decreases in the first and second day trials. Stability and increase cycle is stable at 18.00-22.00 WIB where constant wind speed is around 12-17 m/hour. If seen from the results of testing the wind speed on the second day has increased compared to the first day, so the resulting cycle shows the same suitability.

4. Conclusion
Based on the research that has been done, it can be concluded that
1. The planning process generated length dimensions of 950 mm, width of 240 mm for the base, and 50 mm at the tip angle of 37°.
2. The manufacture of the windmill was started by preparing the necessary components, i.e. generator control systems, the number of blade, and blade design. Then, we test to determine the feasibility of the tool, rotation and torque.
3. The tests were carried out for 38 hours resulted in 3224.86 watt hour energy. As a result, the average of 1 hour production process generated electrical energy in the form of DC at 84.86 watt-hour.

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