Development of savonius type windmill prototype as a learning medium about wind power plants

S Markumningsih¹, B Purwantana¹ and J C Gulo¹

¹Department of Agricultural and Biosystems Engineering, Faculty of Agricultural Technology, Universitas Gadjah Mada, Jl. Flora No.1 Bulaksumur, Yogyakarta 55281, Indonesia

E-mail: sri_markumningsih@ugm.ac.id

Abstract. One of the renewable energy sources that can be used as a driving resource is the wind. Wind energy can be converted into energy in other forms, for example mechanical energy or electrical energy through wind turbines. One of the most developed wind turbines is the savonius type which includes the vertical shaft type. The investment cost for making a real wind turbine in the field is very expensive so it cannot use trial and error methods to get efficient turbines. Research to develop wind turbines is done by making a prototype of a laboratory scale wind turbine. The part of wind turbines are made in a small size so that the mini wind power plant can operate and on the other hand does not cost a lot. From the prototype parameters can be observed that affect the performance of the wind turbine. The windmill prototype was made 200 cm high and 50 cm in diameter and equipped with 4 blades. For testing in the laboratory using a wind source from the fan which is driven by an electric motor that can be adjusted by the rpm. The determination of power efficiency is applied by the turbine ability to absorb the energy of wind as represented by torque and rotational speed of turbine attacked air flow in testing. The result shows that efficiency of the savonius turbine were 5.02% - 9.12%.

1. Introduction
Population growth and the development of technology make energy needs continue to increase while on the other hand the energy source that is widely used today is fossil fuels that cannot be renewed. This causes an energy crisis in the future, so a lot of research is done to develop new and renewable energy sources, one of which is wind energy. Wind energy is converted through wind turbines. The principle of working a wind turbine is to capture mechanical energy from the wind through the blades and turn it into a shaft rotation that can move the generator to produce electrical energy [1].

The agricultural sector requires driving resources in various activities including irrigation pumps, tillage, transportation, post-harvest processing and handling and storage of agricultural products. To realize sustainable agriculture, we must begin to utilize renewable energy sources that do not damage the environment. The availability of abundant wind on agricultural lands is a potential that can be developed as an alternative driving resource. To use the wind, effective and efficient wind turbines must be built [2]. However, there are many factors that affect the performance of wind turbines, so research is needed to design efficient wind turbines. In order not to be constrained by costs, the research was conducted by making a prototype of a laboratory scale wind turbine [3]. The research aims to develop a prototype of savonius type wind turbine as a learning medium about wind power plants in agriculture.
2. Methodology
This research is conducted at Energy and Agricultural Machinery Laboratory of Agricultural and Biosystems Engineering Department, Faculty of Agricultural Technology Universitas Gadjah Mada, Yogyakarta.

Materials used in this study include: Elbow, Stainless steel plate, Cable, Generator, Aluminum plate, Electric motor, Welding electrodes, etc. And the tools used include: Blower / fan, Welding machine, Tachometer, Anemometer / Flowmeter. The research start with design making based on existing references so as to realize the design of savonius type wind turbine that can viewed at Figure 1.

![Figure 1. The design of prototype savonius type wind turbine](image)

The designs that have been drawn are then made in the workshop and each component is arranged. After that it is tested until it can operate and can be tested. The wind is blown from the fan / blower with a certain speed variation then the wind turbine speed are measured. There are three variation of wind speed made by comparing pulley. The wind speed are 8.65 m/s, 10.88 m/s and 13.94 m/s. The data that has been obtained is then analyzed to determine the performance of the wind turbine prototype includes efficiency and tip speed ratio.

3. Results and Discussion

3.1. Wind Energy
The main principle of the energy produced by wind is to convert the electrical energy that the wind has into the kinetic energy of the shaft. The amount of energy that can be transferred to the rotor depends on the air density, area and wind speed [4]. The kinetic energy for a m wind mass moving at velocity v which will later be converted into shaft energy can be formulated as follows:

\[ E = \frac{1}{2} mv^2 \quad (1) \]

m: moving air mass (kg)

v: wind speed (m / s)

This kinetic energy contained in wind is captured by wind turbines to rotate the rotor. Assuming a cross-section A, where air with velocity v undergoes a displacement of volume for each unit of time, called the volume V flow, so the energy from wind become:
The rotor is one axis with a shaft where shaft power is calculated by the equation:

\[ P_t = T \cdot \omega \]  

\( T = \text{shaft torque (Nm)} \)
\( \omega = \text{angular velocity (rad / s)} \)

The efficiency of wind turbines can be calculated using formula:

\[ \eta = \frac{P_t}{P_w} \times 100 \% \]  

\( P_t = \text{shaft power (watt)} \)
\( P_w = \text{wind power (watt)} \)

3.2. Wind Turbine

Wind turbines are devices used in wind energy conversion systems. Wind turbines are systems that function to convert the kinetic energy of wind into mechanical energy in the form of a shaft rotation. Shaft rotation is used according to requirements such as turning a dynamo or generator to generate electricity and driving a pump for irrigation [5].

The use of simple windmills has been started since the beginning of the 7th century and spread in various countries such as Persia, Egypt and China with various designs. In Europe, windmills began to be known around the 11th century and developed rapidly during the industrial revolution in the early 19th century [6].

Based on the orientation of the rotor rotation, wind turbine is divided into two types, namely horizontal and vertical axes. The horizontal axis rotors are parallel to the direction of the wind, while the vertical axis is the opposite of the direction of the wind. Horizontal axis rotors are based on lift, sleek blade and high rotating speed. Vertical axis rotor based on drag, wide blade and low rotational speed [7].

The design of a miniature wind turbine generator tool generator component is made open so that it looks magnetized and coils in order for students to know the basic components of the generator. Then the coil can be replaced by the number of turns. So props of wind power plants can be utilized maximally so that learning can be demonstrated to students directly. The results of testing the prototype to determine efficiency of wind turbine with various wind speed, and also the relationship between efficiency and tip speed ratio [8].

This research attempts to make a windmill prototype as a medium of learning about energy conversion. This prototype converts wind energy into shaft energy. The prototype consist of fan (blower), wind tunnel, and rotor (blade) that shows at Figure 2.
Blower or fan is a part as a source of wind that will drive a turbine. The components of the blower are fans connected to an electric motor using a belt pulley transmission system. Pulleys that are installed in wind tunnel are 3, 4 and 5 inches to produce varying wind speeds. The overall dimensions of the blowers are in the order of length, width and height, which is 0.66 meters, 0.88 meters and 1.3 meters. Blower or fan is shown in figure 3.

Wind tunnel is formed from SS430 steel plate with a thickness of 1.5 mm and welded to form a cylinder with a diameter of 80 cm. At the front of the tunnel the steel plate must be changed with a smaller diameter. This is intended to overcome the instability of forwarding the wind flow generated from the fan. The principle is to focus on the direction of the shot or the output of the wind towards the turbine. Wind output hole diameter from wind tunnel to turbine is 60 cm. While the total length of wind tunnel is 155.18 cm. Wind tunnel is shown in figure 4 below:

Savonius wind turbine design begins with determining blades. The basis of planning in determining blades is the area of the sweep of the wind. Because the area of the outlet is limited to that is the area of a circle with a diameter of 60 cm which is an area of 2828.57 cm$^2$, then the area of sweeping A wind on the turbine should not exceed that number. The total dimensions of the Savonius turbine, which are length, width and height are 1.07 meters, 0.88 meters and 1.95 meters, respectively.
After all parts are assembled, the prototype of the windmill will be tested using 3 variations of wind speed. The data taken is then analyzed and the results are as in table 4.1. From the table, graphs can be made between wind speed and wind turbine efficiency as shown in figure 6.

| Wind speed (m/s) | Wind power (watt) | Shaft torque (Nm) | Angular velocity (rad/s) | Shaft power (watt) | Efficiency (%) |
|-----------------|------------------|-------------------|--------------------------|-------------------|---------------|
| 8.65            | 93.00            | 0.77              | 4.81                     | 3.57              | 3.84          |
| 10.88           | 185.06           | 1.06              | 9.38                     | 9.56              | 5.17          |
| 13.94           | 389.24           | 1.40              | 17.50                    | 23.67             | 6.08          |

From the graph it can be seen that the wind speed affects the efficiency of turbine. The data shows that the higher the speed given is the higher the efficiency of turbine. However, the power efficiency value of the prototype of the wind turbine is still far from the maximum limit of the Savonius turbine in general, which is 15% with a tip speed ratio of 0.75. Tip Speed ratio ($\lambda$) is a comparison of the linear velocity of the $V_b$ with the speed of the wind $V_w$ hit the turbine. The value of $\lambda$ from the prototype for each variation of wind speed is respectively 0.18; 0.38; and 0.62. Therefore it is necessary to increase the diameter of the turbine to increase the linear speed of the rotation or in other words the tip speed.
ratio that is sought must reach the value of 0.75. This is very much done because the linear speed of the blade is proportional to the diameter of the rotation of the blade.

4. Conclusions
From the results of the design, manufacture and testing of prototype wind turbines as learning media it can be concluded: that learning media have been produced that can help students understand the concept of wind turbine. This tool can be used in student practice to see the part of prototype wind turbine and the effect of wind speed to the efficiency of turbine.

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