Improved Savonius double blade performance using modified blade shaped with variations of the wind flow ratios on the blade inlet and outlet side

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Abstract. The Savonius turbine is a wind turbine that has a vertical shaft parallel to the turbine blade and has advantages that can save wind energy from all directions at low speeds. The purpose of this study is to examine the Savonius turbine model with variation in the ratio of the blade inlet side and the blade outlet side to improve turbine performance. The research method used is turbine research; conduct an experimental test by varying the ratio of the inlet and outlet sides of the blade (1:1 and 1:2) to the speed of the blade's wind flow. Then conduct turbine performance analysis to get the best efficiency between the ratio of the inlet and outlet sides of the blade. The test was carried out at wind speeds of 5 m/s, 7 m/s, 9 m/s, 10 m/s, and 12 m/s with lamp loads distributed between 5-40 Watts. Analysis of turbine performance test The test results show that Savonius single blade wind turbine has the best efficiency of 8.43% at 5 m/s wind speed and is able to produce electricity of 10 Watts and then the best efficiency released by a 1:2 double blade wind turbine that has efficiency by 6, 9% at a load of 20 Watt and a 1:1 double blade wind turbine which has an efficiency 4.37% at a load 10 Watt.

1. Introduction
Electricity is the most important aspect supporting the activities of human life. Lots of alternative energy in Indonesia that can be utilized to produce electricity. One example of alternative energy that can be chosen is wind [1,2]. Wind energy is energy that is environmentally friendly and is renewable, for that it has the potential to be developed. The condition of Indonesia's wind speed has low wind speeds ranging from 2 m/s - 6 m/s. So it is necessary to design a wind turbine that is suitable for low wind speed areas and can meet electricity needs. Indonesia has a huge wind energy potential of around 9.3 GW and the total installed capacity is currently around 0.5 MW [3-5]. Wind is the air that moves due to the rotation of the earth and the difference in air pressure around it.

Betz Element's momentum theory based on the two-dimensional flow model of wind on the rotor explains the principle of conversion of wind energy in wind turbines [5,6]. The kinetic energy of an air mass m moving at velocity v can be expressed as [7-9]:

\[ E = \frac{1}{2} m v^2 \]

Considering a certain area, A, where air passes with velocity v, the flow rate of the volume of air V through over a given unit of time is [7-9]:
\[ V = v \ A \]

The potential of the wind energy used in moving the wind turbine with a cross section \( A \) (\( m^2 \)) is exhaled by the wind in the area with velocity \( v \) (\( m/s^2 \)), then the rate of mass air flow passing through a place is [7-9]:

\[ \dot{m} = \rho \ A \ v \]

So that the maximum kinetic energy produced by the union of time or the maximum kinetic power of the wind that passes through the turbine rotor [7-9]:

\[ P_{\text{kin}} = \frac{1}{2} \rho \ A \ v^3 \]

\[ C_p = \frac{P_{\text{mech}}}{P_{\text{kin}}} = \frac{1}{2} \left[ 1 - \left( \frac{v_2}{v_1} \right)^2 \right] \left[ 1 + \frac{v_2}{v_1} \right] \]

So we get a value,

\[ C_p = \frac{P_{\text{mech}}}{P_{\text{kin}}} \]

Tip speed ratio \( \lambda \) is the ratio between the speed of the tip of the blade and the speed of the wind passing through it. If \( \lambda > 1 \) means more blades experience lift. If \( \lambda < 1 \) means that more parts of the blade have a thrust [10-12].

\[ \lambda = \frac{\pi D n}{60 v} \]

Where \( D \) is the diameter of the rotor, \( n \) is the rotor rotation, and \( v \) is the wind speed. Power coefficient and torque coefficient are different from tip speed ratio. The optimum tip speed ratio is determined by the rotor where the most efficient energy transfer and \( C_{p, \text{max}} \) are for the maximum power coefficient [7].

Turbine power or mechanical power [13-15], expressed by the formula as follows:

\[ P_{\text{mek}} = \frac{2 \pi n T}{60} \]

Where \( T \) is the torque; \( n \) is the turbine shaft rotation.

Subsequently, to calculate the turbine efficiency, which is the ratio between the power generated by the shaft with kinetic power, namely [15,16]:

\[ \eta_t = \frac{P_m}{P_k} \times 100\% \]

Where \( \eta_t \) is the coefficient of power or efficiency of the turbine, \( P_m \) is the mechanical power of the turbine, \( P_k \) is the kinetic power of the wind.

1.1. Generator power

Generator power is the electrical power produced by the generator [15,16].

\[ P_g = V_p \times I_p \]

Where \( V_p \) is the generator output voltage, and \( I_p \) is the generator output current. So that the efficiency of the system can be found by the following equation:

\[ \eta_s = \frac{P_g}{P_k} \times 100\% \]

2. Methods

The methods of this research include material selection, workmanship and assembly of Savonius rotor components including turbine shafts, blade flanges, turbine blades, pulleys, generators, timing belts, pillow blocks, gears, wheels, frames and loads. The next step is testing the performance of single blade,
double blade (1:1) and double blade (1:2). The final method is analysis and discussion. The results of the processing are then displayed in the form of graphs of the efficiency characteristics of the system against tip speed ratio, voltage-current-electric power, and the relationship between generator power and rotation. The performance of each component is reviewed and analyzed. So it will produce a Savonius double blade rotor model with variations in the ratio of wind flow on the inlet and outlet sides of the blade that has the best performance. The test stages are presented in the figure below, where there are 3 tests of the Savonius rotor model namely single blade, 1:1 double blade, and 1:2 double blade with various wind speed test parameters namely 5 m/s, 7 m/s, 9 m/s, 10 m/s and 12 m/s.

Figure 1. Savonius single blade wind turbines.

Figure 2. Savonius double blade wind turbine with a ratio of wind flow at the inlet side of the blade and the outlet side of the blade is 1: 1.

Figure 3. Savonius double blade wind turbine with a ratio of wind flow at the inlet side of the blade and the outlet side of the blade is 1: 2.
The Savonius turbine test circuit below is used when testing to obtain test data in the form of currents and voltages on 3 Savonius rotor models at various wind speeds. Furthermore, Savonius turbine performance was analyzed to get the turbine blade model that has the best characteristics.

![Wind turbine system testing circuit](image)

**Figure 4.** Wind turbine system testing circuit.

3. Results and discussion

The results of Savonius single blade, 1:1 double blade and 1:2 double blade wind turbines with wind speeds of 5 m/s, 7 m/s, 9 m/s, 10 m/s, and 12 m/s. Furthermore, it is processed into a graph of the characteristics of the relationship between system efficiency and speed ratio ($\eta_s-u/v$), graphs of generator power and turbine rotation characteristics ($P_g-n$), and graphs of current voltage characteristics ($V-I$) and electric current ($P-I$). The results of the study are Savonius sturbin models shown in the figure below. This step is done by designing a Savonius Wind Turbine model single blades and double blades with variations the ratio in the inlet blade and outlet side blade (1:1, 1:2, 1:3, 1:4) to the wind flow to improve performance.

![Savonius wind turbine performance: efficiency to tip speed ratio ($\eta_s-u/v$)](image)

**Figure 5.** Savonius wind turbine performance: efficiency to tip speed ratio ($\eta_s-u/v$).

Figure 5 shows that efficiency tends to increase with increasing tip speed ratio values. In certain conditions the efficiency will decrease after reaching the saturation point. It happens because of changes in the load given to wind turbines, so that it will reduce the efficiency of the turbine. The test results in Figure 5 show that the highest system efficiency is owned by a single blade wind turbine at a wind speed of 5 m/s at 8.43% with a tip speed ratio ($u/v$) ratio of 0.619 at a 10 W load. Whereas the double blade ratio 1:2 wind turbine has the highest efficiency of 6.90% with a speed ratio ($u/v$) of 0.587 at a load of 10 W. This is followed by a decrease in system efficiency that occurs in a Savonius double blade 1:1 rotor of 4.37% with a speed ratio ($u/v$) of 0.479 at a load of 20 W.
Figure 6. Performance characteristics of voltage-current-power of the Savonius wind turbines.

Figure 6 shows the characteristics of the relationship between voltage and current and electric power to the current in a 1:2. double blades wind turbine. The electrical power tends to increase with increasing current values. In certain conditions the efficiency will decrease after reaching the saturation point. It happens because of changes in the load given to wind turbines, so that it will reduce the efficiency of the turbine. The largest electrical power produced by wind turbines compilation of wind speeds reaches 12 m/s, which is 3.36 W at a measured load of 15 W. However, after achieving optimal electrical power values, there is a trend of decreasing the effectiveness of electric current loading. At this time, the maximum capacity of the Savonius turbine has reached its maximum limit.

Figure 7. Performance of wind turbine between electrical power versus rotational speed at the ratio double blade 1:1.

The characteristic relationship between electrical power and rotation at the ratio double blade 1:1 is shown in Figure 7. At wind speed 5 m/s it can be seen that the minimum power of the generator is 0.48 W when the load reaches 5 W at 169.2 rpm. While the maximum power obtained is 0.7 Watt when the
load reaches 20 W at 152.64 rpm rotation. At a wind speed of 12 m/s it can be seen that the minimum power of the generator is 1.7 W when the load reaches 40 W at 235.44 rpm. The generator power will increase as the rotation speed increases. The maximum power obtained is 3.125 W when the load reaches 15 Watt at 277.92 rpm rotation. But after reaching its maximum power, the generator power will decrease. This is because the generator has reached the maximum limit and the generated power tends to fall so that the curve is parabolic. The characteristics of the generator power to the rotation of the 1:2 double blade are shown in Figure 8. At wind speeds of 5 m/s it can be seen that the minimum power of the generator is 0.405 W when the load reaches 40 W at 148.8 rpm. The generator power will increase as the rotation speed increases. The maximum power obtained is 1.1 Watt when the load reaches 5 W at 192.8 rpm. But after reaching its maximum power, the generator power will decrease. This is because the generator has reached the maximum limit and the generated power tends to fall so that the curve is parabolic. At wind speeds of 12 m/s it can be seen that the minimum power of the generator is 1.8 W when the load reaches 40 W at 238.56 rpm. While the maximum power obtained is 3.36 W when the load reaches 15 W at 288.48 rpm rotation.

![Figure 8. Performance of wind turbine between electrical power versus rotational speed at the ratio double blade 1:2.](image)

3.1. Technological excellence

3.1.1. Innovative excellence. An approach to vertical axis wind turbine technology using concentric type double blade blades to the direction of wind flow at the inlet and outlet side of the blade.

3.1.2. Comparative advantage. To increase the turbine power is done by varying the ratio of wind flow on the inlet and outlet of the blade, so that it will increase the efficiency and power of the turbine produced.

3.2. Application prospect

The design and application of the Savonius double blade turbine will increase the efficiency and power of the turbine as needed and this product can be downstreamed to people in remote areas that have not yet installed the PLN electricity grid.
4. Conclusion
The results of this competitive applied research produce turbine and generator specifications are 3 phase AC generators with additional rectifiers so that the output is DC with 200 W specifications, 12-24 Volts with rotation that can reach 150-300 rpm. Savonius wind turbines are made with galvanized plate with variations of single blade, double blade 1:1, and double blade 1:2. The ratio of the wind flow on the blade influences the speed of the blade output wind. When it reaches the best efficiency, the wind energy used to rotate the blade is more optimal, so that the resulting blade rotation is faster to be able to turn the generator and produce more power. The best system efficiency in Savonius single blade wind turbines is 8.43%, the highest efficiency in Savonius 1: 2 double blade wind turbines is 6.9%. While the best efficiency in Savonius 1: 1 double blade wind turbines is 4.37%.

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