Performance ‘S’ Type Savonius Wind Turbine with Variation of Fin Addition on Blade

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Performance ‘S’ Type Savonius Wind Turbine with Variation of Fin Addition on Blade

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Abstract. Wind power has been receiving attention as the new energy resource in addressing the ecological problems of burning fossil fuels. Savonius wind rotor is a vertical axis wind turbines (VAWT) which has relatively simple structure and low operating speed. These characteristics make it suitable for areas with low average wind speed such as in Indonesia. To identify the performance of Savonius rotor in generating electrical energy, this research experimentally studied the effect of fin addition for the ‘S’ shape of Savonius VAWT. The fin is added to fill the space in the blade in directing the wind flow. This rotor has two turbine blades, a rotor diameter of 1.1 m and rotor height of 1.4 m, used pulley transmission system with 1:4.2 multiplication ratio, and used a generator type PMG 200 W. The research was conducted during dry season by measuring the wind speed in the afternoon. The average wind speed in the area is 2.3 m/s with the maximum of 4.5 m/s. It was found that additional fins significantly increase the ability of Savonius rotor VAWT to generate electrical energy shown by increasing of electrical power. The highest power generated is 13.40 Watt at a wind speed of 4.5 m/s by adding 1 (one) fin in the blade. It increased by 22.71% from the rotor blade with no additional fin. However, increasing number of fins in the blade was not linearly increase the electrical power generated. The wind rotor blade with 4 additional fins is indicated has the lowest performance, generating only 10.80 Watt electrical power, accounted lower than the one generated by no fin-rotor blade. By knowing the effect of the rotor shape, the rotor dimension, the addition of fin, transmission, and generator used, it is possible to determine alternative geometry design in increasing the electrical power generated by Savonius wind turbine.

1. Introduction
Indonesia has great abundant source of wind energy, which is estimated to generate 950 MW of electrical energy. However, it has not been fully utilized yet as current installed wind turbines can only produce in total of 3.61 MW electrical energy power [1]. Even though the wind speeds in Indonesia are generally low (around 3-7 m/s), there is a great potential of increasing the wind power capacity in Indonesia.

Savonius wind turbine which firstly developed by Sigurd J. Savonius in 1922 is a drag type turbine that is relatively suitable for low wind speed as in Indonesia. The advantages of the Savonius type wind turbine are to receive wind from all directions, easy and inexpensive in its manufacture, and can rotate at a fairly low angular velocity [2]. The Savonius wind turbine has great initial torque at low wind speeds [3]. The drawbacks of the standard Savonius type designs still have low efficiency compared to other vertical wind turbine types. Savonius wind turbine works based on the difference from the drag force that concerns the rotor surface. The amount of drag force when it is positive will be able to rotate the turbine shaft.
The results of the rotor performance improvement show that the rotor with 2 blades is more efficient than the 3 and 4 turbine blades. The turbine rotor with the addition of end plates causes the turbine efficiency to increase. The Savonius 2 wind turbine blade produces slightly higher rotation than the blade 3 turbine, with the rotor speed of 2 blades being 127 rpm at wind speed of 4.8 m/s and 120 rpm at 4.8 m/s wind speed for rotor 3 blades. The torque produced by the turbine 2 blades is also higher than the 3 blades [4,5].

The profile of the U blade as well as the blade L profile with a 10 mm offset value produces more power than the offset of 0 mm. Savonius 2 wind turbine blades capable of spinning at a lower speed compared to 3 and 4 blades. The Savonius wind turbine profile L is good at the number of 2, 3 or 4 blades capable of spinning at a lower speed than the U profile, but the L profile produces lower power than the U profile. This is because the sunken side of the U turbine is capable of absorbing more energy than the straight blade on the L turbine [6].

Since its inception, many studies have been conducted to improve the efficiency of the Savonius type wind turbines. Modifications affecting the performance of Savonius turbine are end plates, aspect ratio, buckets spacing, overlap buckets, bucket number, rotor stages, buckets and rotor shapes, shafts, Reynolds number and turbulence intensity and other modifications [2]. All these modifications are made only to increase the angular velocity and the maximum torque that the Savonius turbine can produce. This research will evaluate the effect additional fin on the turbine blade on the performance of the turbine to generate electrical power.

2. Methods
In this study, a Savonius vertical wind turbine type "S" was developed with the specifications shown in Table 1 and Figures 1 and 2.

Table 1. Design of ‘S’ type Savonius wind turbine

<table>
<thead>
<tr>
<th>Specification</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tower height</td>
<td>2500 mm</td>
</tr>
<tr>
<td>Generator (PMG type)</td>
<td>200 Watt</td>
</tr>
<tr>
<td>Pulley transmission ratio</td>
<td>1: 4.2</td>
</tr>
<tr>
<td>Main shaft diameter</td>
<td>20 mm</td>
</tr>
<tr>
<td>Rotor diameter</td>
<td>1100 mm</td>
</tr>
<tr>
<td>Blade diameter</td>
<td>600 mm</td>
</tr>
<tr>
<td>High blade / blade</td>
<td>1400 mm</td>
</tr>
<tr>
<td>Overlap blade</td>
<td>50 mm</td>
</tr>
<tr>
<td>Number of blades</td>
<td>2 blades</td>
</tr>
<tr>
<td>Material of blades</td>
<td>Aluminium 0.3 mm</td>
</tr>
</tbody>
</table>

Figure 1. Dimensions of wind turbine Savonius
The experiments were performed in the area of UNS Campus Pabelan area to evaluate the effect of adding 1, 2, 3 and 4 fins to the power generated by wind turbine during the test period. Data of wind speed, rotation of generator, electric voltage and electric current were taken for 3 days on March 29-31, 2017 at 14.30-17.30 WIB during cloudy weather conditions. The measurement is conducted by taking 5 wind speed data in the interval of 0.1 m/s. The sampling aims to reduce the bias due to significant changes in wind speed. The magnitude of the electric power generated by the wind turbine is obtained from the multiplication of the measured electrical current in Ampere and the voltage in the Volt.

3. Results and discussion

3.1. Wind speed and rotation of generator

The wind speed distribution for the area around UNS Campus Pabelan is displayed in Figure 3. Apparently, the wind speed at the area is quite low, with an average of 2.32 m/s. This result is quite similar to the finding of previous research [7].
Based on Figure 4, it can be concluded that 1 additional fin variation generates the highest rotation of 265.9 rpm at a wind speed of 4.5 m/s, while the additional 4 fins yields the lowest rotation speed of the generator compared to the other test variations of 239.6 rpm at a wind speed of 4.5 m/s.

3.2. Electrical power generated

Electrical voltage generated at a wind speed of 4.5 m/s for blade without fin is 12.7 volt, while the additional fins of 1, 2, 3 and 4 fins generated electricity in the following voltage: 14.1; 13.2; 12.9; and 12.7 Volt, respectively. Electric current generated at a wind speed of 4.5 m/s for non-fin turbines and with variations of 1, 2, 3, and 4 fins are 0.86; 0.95; 0.90; 0.88; and 0.85 Ampere, respectively.

Figure 5. Electrical voltage generated under various number of fins

Figure 6. Electrical current generated under various number of fins

Figure 7. Electrical Power generated under various number of fins

Figure 7 shows that the highest power is generated by adding 1 fin on the blade which is 13.40 Watt. Adding 4 fins on the blade produces the lowest electrical power, which is 10.80 Watt compared to other variations. This shows that the addition of fin on the blade affects the electrical power generated by the generator. Electricity increased by 22.71% in variation of 1 fin addition, increased by 8.79% in 2 fin variations, and increased by 3.93% in 3 fin variations compared to finer variations. However, the 4 fin variation decreased 1.09% compared to the variation without fin. It is proportional to the large rotation speed generated because the greater the rotation speed of the generator, the electric power generated is also greater.
Savonius wind turbine works by utilizing a positive drag force (push) wind. It is indicated that the more fin numbers installed will minimize the positive drag force that acts on the turbine blades (turbine rotor). The addition of the fin on the blade means dividing the area of the impeller chamber that catches the wind, so that the wind is directed and fills the space in the blade more quickly. This causes the turbine blades to rotate at a lower velocity than without the addition of fin. The area of the split blade also increases the drag force that occurs along the blade area. The larger the drag force acting on the blade, the increased pressure along the blade area increases. The increased pressure caused by the turbine blade area and the increased drag force occur on both sides of the turbine blades, thereby minimizing the pressure difference between the two turbine blades. Therefore, the more number of fins added, the smaller the pressure difference on the two blades as the wind speed increases. The smaller the pressure difference on the two blades, the positive drag force acting on the blade is also smaller.

Variations of 1 fin additions to the blade are able to produce the largest positive drag force in comparison with other variations. It shows that variation of 1 fin addition is more effective to increase the electric power generated by wind turbine. This result supports research that says turbine rotor with 1 fin addition can increase $C_p$ turbine, with a maximum power of 5.71 Watt [8].

3.3. Coefficient of power and tip speed ratio

The power coefficient shows the amount of wind energy that can be converted from wind kinetic energy through the turbine rotor cross section, whereas the speed ratio tip shows the ability of turbine rotor to convert kinetic wind energy into mechanical energy of rotor rotation.

![Figure 8. Coefficient of Power under various number of fins](image)

![Figure 9. Tip Speed Ratio under various number of fins](image)

The value of $C_p$ and TSR from the Savonius wind turbines varied with the wind speed. TSR values at wind speeds 4.5 m/s for variations of 1 fin, 2 fin, and 3 fin additions are respectively of 0.81; 0.76 and 0.74. Variations of 4 fin and fin without fin have the same TSR value of 0.73. The value of $C_p$ at a wind speed of 4.5 m/s for the variations of 1 fin, 2 fin, and 3 fin is 0.166, respectively; 0.147 and 0.141. Variation 4 fin is slightly lower than the variation without fin, ie 0.134 and 0.135 respectively at a wind speed of 4.5 m/s.

Based on these data indicate that the coefficient of power generated by wind turbine for variation of addition of 1 fin increased 22.96%; Variations in the addition of 2 fin increased by 8.88%; Variations in the addition of 3 fin increased by 4.44%; While for the variation of 4 fin additions decreased 0.74%. The power coefficient data in Figure 8 also shows that at the speed range of 1.5-4.1 m/s the power coefficient value for all treatments tends to increase, but in the range 4.2-4.5 m/s tends to decrease.
Based on the description indicates that there is a relationship between the value of TSR and Cp Savonius wind turbine. The relationship of tip speed ratio ($\lambda$) and power coefficient (Cp) is shown in Figure 10.

![Figure 10. Coefficient of Power – Tip Speed Ratio curve](image)

Based on Figure 10 indicate that the TSR value for all variations of fin and without fin are less than 1. It means that the Savonius type vertical axis wind turbine is a drag type wind turbine, because more of parts the turbine blade impelled by a drag force [9]. The coefficient of power (Cp) values for all variations are less than 0.3 or 30%. That means according to the theory that the maximum Cp value for the Savonius wind turbine is 0.3 or 30% [10]. Figure 10 also shows that there is an increase in power coefficient (Cp) along with the increase of tip speed ratio ($\lambda$) to the peak, then decreasing the value of Cp to tip speed ratio ($\lambda$). The decrease in the value of Cp is due to the cessation of actual power generated by the wind turbine along with the increasing ideal power. In addition, when the TSR values are highest on each variation, the Cp value of the turbine becomes decreased. This is because at the time of the highest TSR value, the turbine drag is greater than the drag so that the turbine spins tend to slow down [11].

4. Conclusion
The addition of fin to the turbine blades can increase the electrical power generated by the Savonius wind turbine. The electric power in the variation of the addition of 1 fin increased 22.71%, the variation of 2 fin increased by 8.79%, the 3-fin variation increased by 3.93%, except in the 4-fin variation decreased 1.09% compared to the electric power in the variation without fin 10.80 Watt) at a wind speed of 4.5 m/s. The greater the wind speed the greater the electrical power generated by the generator. At 4.5 m/s wind speed produces 13.40-Watt power. The most optimal configuration of the Savonius wind turbine is the variation of the addition of 1 fin. The coefficient of power resulting from the variation of 1 fin addition is 0.181. The coefficient of power is highest when compared to the variations of the addition of the other fin.

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