Effect of Blade Curvature Angle of Savonius Horizontal Axis Water Turbine to the Power Generation

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Abstract. The water energy is one of potential alternative in creating power generation specifically for the picohydro energy. Savonius is a kind of wind turbine which now proposed to be operated utilizing the energy from low fluid flow. Researches about the utilization of Savonius turbine have been developed in the horizontal water pipelines and wave. The testing experimental on the Savonius Horizontal Axis Water Turbine (HAWT) by observing the effect of the blade curvature angle ($\psi$) of 110º, 120º, 130º, and 140º at the debit of 176.4 lpm, 345 lpm, 489.6 lpm, and 714 lpm in order to know the power output was already conducted. The optimal result in every debit variation was obtained in the blade curvature angle of 120º. In the maximum debit of 714 lpm with blade curvature angle of 120º the power output is 39.15 Watt with the coefficient power (Cp) of 0.23 and tip speed ratio (TSR) of 1.075.

1. Introduction

Indonesia needs enormous energy to meet its energy requirements for supporting high economic growth. Until now, fossil power plants still supply most of the electricity needs in Indonesia. Petroleum still ranks highest as energy source supplier at 51.66%, natural gas ranks second at 28.57%, and the rest is provided from oil energy of 15.34%, and renewable energy 4.43%. However, Indonesia has the greatest renewable energy potential (EBT), namely water energy (hydro) of 75,670 MW. Nevertheless, the utilization only reached 4,200 MW or about 5% of the existing potential [1]. Rainwater is one of a potency to create a pico-hydropower plant. Pico-hydro is a hydroelectric power plant with electric power generated no more than 5kW. Experiments for rainwater harvesting (RWH) using Savonius single stage turbine type have done. The result is that it can turn on LED lights of 0.3 Watt. The power plant with this RWH system depends heavily on the efficiency of blade rotation capability [2]. Research for the utilization of water energy also had been done on Vertical Axis Water Turbine (VAWT) with drag type applied to the flow in the pipe to generate electrical power as a monitor supply in controlling water quality in the tube. Maximum power achieved is 88.2 W with a water speed of 1.5 m / s and pressure drop less than 5 m [3].

Efforts to improve turbine efficiency continued with some research. Tunisian scientists conducted a study of the angle of blade curvature with numerical modeling using software SolidWorks to obtain the angle of optimal blade curvature. The study was carried out by observing the increasing effect of the blade curvature angle ($\psi$) against the depression zone and the acceleration zone [4]. Another study observed the curvature of the Savonius turbine blade with the angular variation of the blade angle ($\psi$) 60º, 65º, 70º, 75º, 80º, 85º, and 90º tested in the wave channel. The results show that the Savonius turbine with the angle of curvature of the 70º blade is the most optimal [5]. Experiments by modifying
the Savonius turbine without the shaft and with the end plate have also been performed, to increase the power coefficient and to obtain static torsional uniformity [6].

2. Research Method

The savonius turbine was designed by 5 number of blades [5] aspect ratio (\(H/D\)) of 1, and the end plate parameter (\(Do/D\)) of 1.1 [7]. The diameter of the turbine (\(D\)) is 82 mm while the thickness of the blade is 2 mm. The curvature angle is designed using the principle of arc angle in the circle as shown in Figure 1.

![Figure 1](image1.png)

**Figure 1.** Schematic design of turbine blade curvature angle.

Savonius turbine made by a 3D printing method as the fastest prototyping techniques and most precision manufacturing process for complicated shape.

![Figures 2](image2.png)

**Figures 2.** Savonius turbine (a) Blade arc angle 110 (b) Blade arc angle 120 (c) Blade arc angle 130 (d) Blade arc angle 140

3. Result and Discussion

This section will discuss the performance of turbine savonius. Turbine performance is evaluated from \(Cp\), TSR, and output power based on the same input. The input power is the power generated by water due to altitude and discharge. Maximum head height is 2 m, and maximum flow rate (\(Q\)) is 714 lpm obtained from experimental data. Power input calculated by density air, gravity, head, flow rate. The power of the input power (\(Pi\)) of each of the incoming fluid flow rate is shown in Figure 3 as follows.
Figure 3. Graph of the ratio of the input power to the flow rate of water.

Figure 3 above illustrates the amount of input power of each flow rate. At the flow rate of 176.4 lpm, 345 lpm, 489.6 lpm, and 714 lpm, the input power was 40.23 Watt, 81.51 Watt, 135.6 Watt and 233.36 Watt, respectively. The smallest input power is obtained at a flow rate of 176.4 lpm, while the highest input power is achieved at a flow rate of 714 lpm. From the results obtained, it appears that the greater the amount of water entering the greater the input power by water.

Tip speed ratio is the tangential velocity at the tip of the blade against the actual speed of the fluid, while the power coefficient is defined as the ratio of the comparison between actual power generated by the rotor blade with the power acting on the fluid. The graph of tip speed ratio (TSR) effect on power coefficient (Cp) can be seen in Figure 4 below.

Figure 4. The relationship between TSR to Cp at the curvature angle of 110° to 140°.

Figure 4 describes that in all angle variations of the blade curvature decreases the value of Cp followed by the increase in TSR value. The decline in Cp value is due to the smaller flow rate change. Debit variation is very influential on the value of Cp because if the flow rate is low, then the value of Cp will be low while if the flow rate is high, then the value of Cp will be high. Figure 4 shows that maximum $C_p$ obtained at a 120° angle of blade curvature is 0.23 with indigo TSR 1.07 whereas minimum $C_p$ value is obtained at 110° of blade curvature angle that is 0.081 with a value of TSR 1.55. Optimal rotor performance can be seen from the amount of electric power output generated by the
alternator. Figure 5 below will explain the magnitude graph of the output power produced by each angle of the blade curvature variation.

![Graph of the relationship between the blade curvatures with power electrical.](image)

Based on Figure 5 it can be seen that the angle of the blade curvature affects the electrical energy output produced by the Savonius turbine. The result of the trend between the angle of the blade curvature with the electric power output at each variation of the flow rate is the same as the magnitude of the electrical energy output at each angle of the blade curvature has increased according to the addition of the amount.

On Figure 5, the trend result shows that along with the increased angle of the blade curvature is not directly proportional to the increase in output power generated, where the angle of the blade curvature has an optimum point at the angle of the particular blade curvature. At a flow rate of 714 lpm, the electric power output value of the blade curvature angle of 110° is 29.9 Watt, increased at 120° blade curvature angle with an output power of 39.15 Watt, then decreased until blade curvature angle of 140° with an electrical energy output of 31.52 Watt. This result is in accordance to research conducted [6] with the angle curvature 110°, 124°, 135°, and 150° obtained that at the angle 124° gives the effect of the most power coefficient. Other studies corresponding to the data obtained were carried out by [8], where the angle variations of blade curvature that studied were 150°, 160°, 170°, 180°, 190°, and 200°. That, the highest positive torque on the blade can be increased by reducing the ellipticity blade, whereas the lowest negative torque is to increase the elliptic blade, where turbines with a blade curvature angle of 160° generate a maximum coefficient of power (Cp).

4. Conclusion
Effect of the blade curvature angle in the Savonius Horizontal Axis Water Turbine (HAWT) were already investigated and discussed. The highest electric power output of 39.15 Watt was obtained at blade curvature angle of 120° at maximum discharge of 714 lpm with the power coefficient (Cp) and tip speed ratio (TSR) of 0.23 and 1.075 respectively.

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