Experimental Study on the Effect of Variation of Blade Arc Angle to the Performance of Savonius Water Turbine Flow in Pipe

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Abstract— **Water is one of the renewable energy sources that can replace fossil energy sources for supplying electricity needs. Savonius water turbine is capable of operating at a low rotational speed and suitable for hydroelectric power plants using limited water head at wastewater pipe in the high rise building. However, this turbine has disadvantages at low power and torque coefficient. Research has been carried out to improve the performance of the turbine, such as varying the number of blades and angles of curvature in the prototype U-type turbine rotor. This study discusses the process of designing and testing a prototype of L type turbine rotor with three variations of blade arc angle; 120°, 135° dan 150°. The result shows that type L turbines with arc 135° blade angles have the highest power coefficient of 27% on a TSR of 1,32 compared to others.**

Index Terms— **Horizontal axis water turbine, Savonius, Arc blade angle, power coefficient, Pico hydro.**

I. Introduction

Around the world, it consumes energy every year. Also, the need for fuel oil is expected to increase every year until 2050 by 5%[1]. Has done a lot of research in developing new renewable energy [2] [3]. The use of fossil energy sources for electricity generation is increasing every year. Coal is the most common source for electricity generation, the domestic coal consumption reaches 70 million tons (85.37%) for the power plant, and the rest is for the metal industry, paper industry and other industries [4]. The potential of Hydroelectric Power Plants (PLTA) and Micro / Hydro Power Plants (PLTMH) is estimated to reach 75,000 MW, while utilization is still around 11% of the total potential [5].

The Rain Water Harvesting (RWH) method is a method for storing rainwater in a tank before being reused for a specific purpose. Rain Water Harvesting experiments have been carried out using a single-stage Savonius turbine type. The investigation resulted in the Savonius turbine system having an excellent performance by producing a constant voltage and strong current [6]. The Savonius turbine is a drag-type vertical axis wind turbine (VAWT), has a simple construction, and the turbine is able to operate at low speeds but has low efficiency [7]. Various studies that have been carried out on Savonius hydro turbines are dominated by the change of aspects of geometry, including the overlap ratio [8], and Multi-Stages [9].

In another study, the blade was changed on the Savonius Horizontal Axis Water Turbine (HAWT) turbine[10][11]. The Savonius semi-cylindrical type with the number of blades 3 has the highest tip speed ratio (TSR) and the best performance compared to the other [12]. Several other studies show that modification of blade parameters such as overlap ratio, aspect ratio, blade shape, and so on can affect turbine performance [13]. Other research on savonius turbines is research on the effect of depth to width ratio has been carried out by Hadi et al. Blades with 0.29 have the best performance at TSR 0.61 because blades with 0.29 depth to width ratio have a larger volume so that they can produce higher torque and rotating speed [14]. Then in 2007, Soelaiman et al. compared the form of U and L type of Savonius blades, the results showed that the L type Savonius blade produced the best torque compared to the U type [15] and Sukanta Roy et al. compared the blade arc angle variations in the L type Savonius blade from Φ = 90° - 165° at 15° intervals. The study has shown that blade with L type at the arc of blade Φ = 135 ° can increase performance by 36%. [16]. L type of blade is a very interesting topic to be applied to the Savonius water turbine.

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In this research, was testing on the L type Savonius water turbine with blade arc angle variations. Tests were conducted to observe the effect of blade arc angle variations on electrical power, power coefficient, and TSR so that the most optimal blade arc angle was obtained.

II. Method

Savonius published his rotor design in 1920, in which the rotor was capable to operate on air fluid/wind. In this study, it was also found that the rotor is both used in water and wind fluids, and the rotor can operate at low water speeds. The rotor operates at a water velocity of 0.6 m/s, which is similar to a wind speed of 5.5 m/s [17]. Rotor Savonius is an adaptation of the rotor system at the Flettner Principle. The work of the Savonius rotor is applying a different resistance coefficient between two blades in the turbine. The torque produced by the concave blade is higher than advance the blade so that a rotation occurs. At the same time, some fluid flows and arrives at a convex underwater surface through a fluid tunnel that produces torque.. Savonius rotor has a disadvantage of low efficiency. However, the Savonius rotor has several advantages, such as simple geometry and ease construction assembly. In general self-starting, performance independent of the wind direction, low starting wind speed, easy to maintain, and relatively inexpensive in terms of material, construction, and maintenance costs [18].

In this study, the turbine design and apparatus test refer to previous studies [6], [13], [15], [16]. This study uses the head height of 1.8 m and 2 m and uses the apparatus test, as shown in Figure 1. Considered in this work, it consists of; 1. Top Tank, 2. Multitester, 3. Alternator, 4. Centrifugal Pump, 5. Bottom tank, 6. Tachometer, 7. Turbine, 8. Deflector

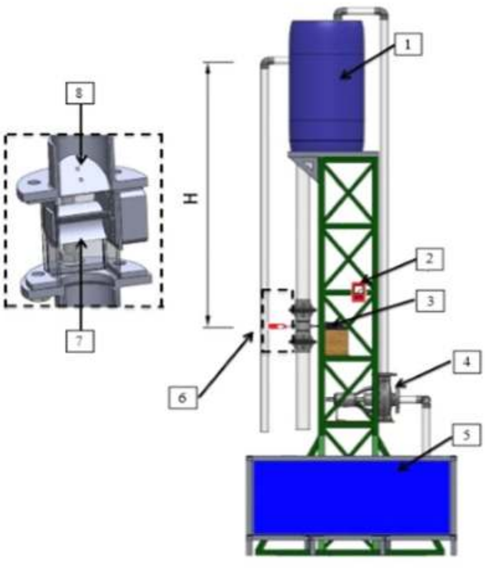

Figure 1. Apparatus test

The configuration of the turbine geometry is as follows; blade diameter is 82 mm; aspect ratio (H/D) is 1, and endplate parameter (Do/D) is 1. Savonius rotors were fabricated from Acrylonitrile Butadiene Styrene, whose thickness is 2 mm. Turbines have an arc radius improvised from Roy's research, et al. [16], with S2 = 16.8 mm and S1 = 20 mm, blade gap (a) 0% and have blade arc angle variations (Φ) 120^0, 135^0 and 150^0. The savonius L turbine design can be seen in Fig. 2 and Fig. 3.

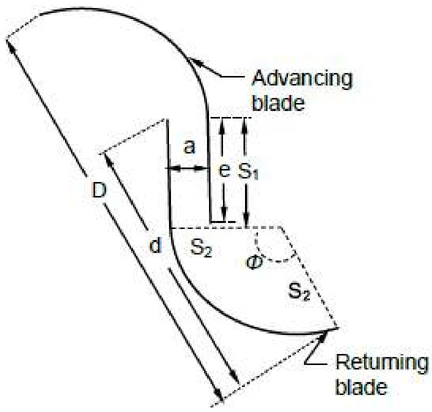

Figure 2. Design of type L. Savonius Turbine

Four water flow discharges variation in each turbine was conducted in this research [10]; 5.66x10-3 m^3/s, 7.97x10-3 m^3/, 9.73x10-3 m^3/s, and 11.61x10-3 m^3/s. Detail of various blade arc angles of turbine variations is shown in Fig. 4 and Fig. 5.

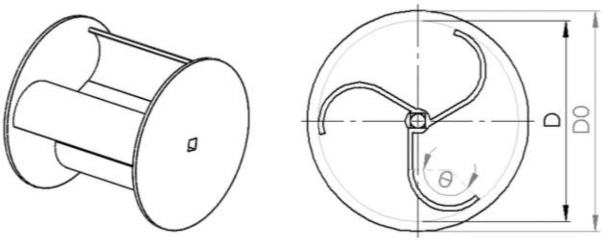

Figure 3. Basic Design Savonius Turbine

The research data observed in this study include discharge, rpm, voltage, and current strength. Voltage and current value were observed using a multimeter, then rotation of the turbine rotation was observed using a tachometer, then processed using equations to calculate the performance parameters. These equations are:

TSR (Tip Speed Ratio) :

$$TSR=\frac{\omega D}{2U} \quad (1)$$

Coefficient Power (C_p):

$$Cp = \frac{P.out}{P.in} \quad (2)$$

Where U is the free flow velocity, ρ for water density, D is the Diameter of the Rotor, ω represents the angular velocity and Cp for the Power coefficient.

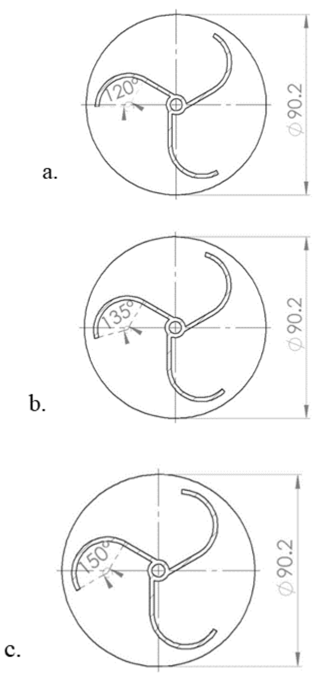

Figure 4. Rotors Variation (a) Blade arc angle120° (b) Blade arc angle135° (c) Blade arc angle150°

Figure 5. Rotors Variation (a) Blade arc angle120° (b) Blade arc angle135° (c) Blade arc angle150°

III. Result and Discussion

Power is a function of density, gravitation, discharge, and the head of water, so fluid discharge affects the resulting power. The input power flow at the turbine increase along with the flowing fluid discharge as can be seen in Figure 6. The power of 99.6 Watt is obtained at the discharge of 5.66x10-3 m^3/s. Then it increases to 140,1 Watt when the discharge increased up to 7.97x10-3 m^3/s. Finally, the highest power of 227,048 Watt is produced at the discharge of 11,61x10-3 m^3/s.

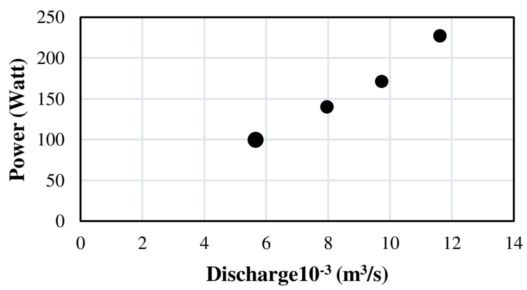

Figure 6. Graph of the Effect of Effect of Water Discharge on Power

The power produced by each turbine variation can be seen in Fig. 7. The power generated by the turbine with a blade arc angle of 135^0 is higher than the turbine with a blade arc angle120^0 and a turbine with a blade arc angle150^0. Increased discharge can increase generator power, as seen in Fig. 6, where there is an increase in generator power at a discharge of 7.97x10-3 m^3/s compared with a discharge of 5.66x10-3 m^3/s and so on.

With a smaller amount of water, the force used to turn a turbine will also be less, which can result in a decrease in the number of turbine turns. Besides, the flow of water that is blocked by the convex side of the blade arc will turn so that it hits the other convex blade side which can cause an increase in negative torque on the turbine so that the resulting rotation is also less

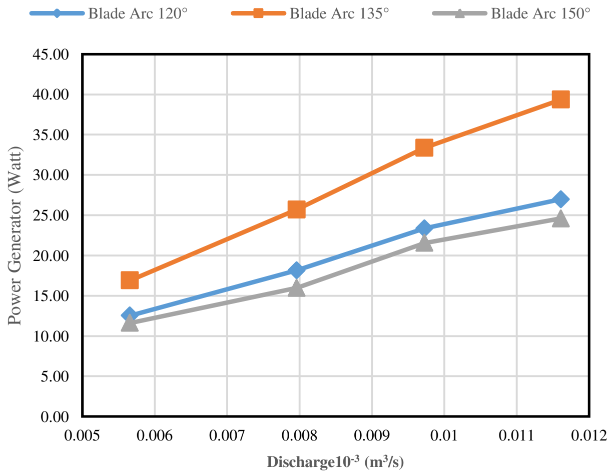

Figure 7. Graph of the Effect of Water Discharge on the Power Generator.

Turbines with a 135° arc blade angle are capable of producing the best turbine power than other turbines because turbines with 135° arc blade angles have the most optimal geometric shape compared to other turbines. So that a turbine with a 135° arc angle can produce more force than a turbine with a 120° arc angle because a larger arc angle will make a longer arc so that it can hold more water and produce a greater force to turn the turbine. However, turbines with larger blade arc angles may not be able to produce greater force. Because the turbine with a blade arc angle of 135^0 has the most optimal geometric shape compared to other turbines, it can have a larger swivel force to counter the negative torque that occurs.

Tip speed ratio (TSR) is a ratio between the tip speed of the turbine (angular) to the speed of the fluid passing through the turbine. While the power coefficient (Cp) is a comparison between fluid energy that can be extracted or captured by a turbine with the overall energy in the fluid [11]. Cp is usually used to assess the performance of a turbine. The TSR and Cp values for each turbine for each discharge variation can be seen in Fig. 8.

At 5.66x10-3 m^3/s, the turbine with the blade arc angle of 120^0 has a TSR and Cp value of 1.462 and 0.174.

Turbines with a blade arc angle of 135^0 have increased TSR and Cp to 1.563 and 0.235. Then the turbine with a blade arc angle of 150^0 has decreased TSR and Cp to 1.405 and 0.161.

The TSR value decreased when the discharge variation was 7,965x10-3 m^3/s when compared to the discharge at 5.66x10-3 m^3/s, but the Cp value increased. At this discharge, TSR and Cp turbine values with a blade arc angle of 120^0 are 1,267 and 0,179. When the turbine with a blade arc angle of 135^0 increases TSR and Cp increase to 1,320 and 0,254. Then the turbine with a blade arc angle of 150^0 decreases TSR and Cp to 1.156 and 0.158.

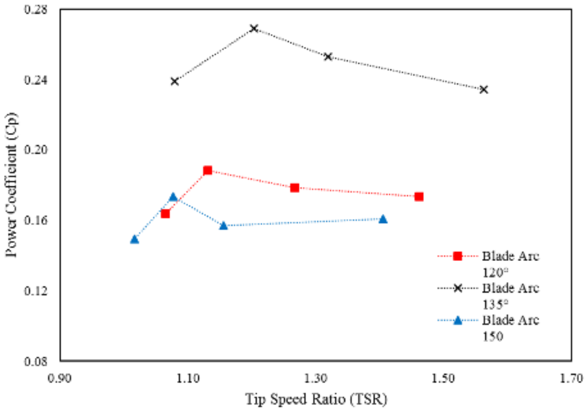

Figure 8. Graph of the Effect of Tip Speed Ratio (TSR) on Power Coefficient (Cp).

Then TSR and Cp decrease when the discharge is 11.61x10-3 m^3/s. Turbines with blade arc angle120^0 are only able to produce TSR and Cp values of 1.065 and 0.164, respectively.

Turbines with a blade arc angle of 135^0 produce TSR and Cp of 1.079 and 0.240. Moreover, the turbine with a blade arc angle of 150^0 only produces TSR and Cp of 1.016 and 0.150. Turbines with a blade arc angle of 120^0 have maximum Cp when TSR is 1.131 with Cp value of 0.189.

Then for turbines with a blade arc angle of 135^0 has a maximum Cp of 0.270 which occurs when the TSR is 1.204. While the maximum turbine Cp with blade arc angles 150^0 occurs when the TSR value is 1.077 with a Cp value of 0.174.

From the experimental data above, it can be concluded that the turbine with a 135° arc blade has the best performance compared to other turbines. This is because turbines with 135° arc angles have the highest Cp compared to other turbines, which is 0.270 with TSR of 1.204, while turbines with 150° arc blade angles have the worst performance with the lowest Cp value of 0.150 with a TSR of 1.016.

IV. CONCLUSIONS

An experimental study has been carried out by variation of blade arc angle. The findings that may be drawn from this study are as follows that the turbine with the blade arc angle of 135^0 has the highest power of 39.35 Watt compared to others. Overall, on the same TSR, the blade arc angle of 135^0 has a higher coefficient of power (C_p) each of them is 0.235, 0.254, 0.270 and 0.240 with Tip Speed Ratio (TSR) respectively 1.563, 1.320, 1.204 and 1.079. when compared to others.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Muhammad Ilham Nadhief conducted the research and analyzed the data. Dandun Mahesa Prabowoputra analyzed the data, writing the draft manuscript, approving the final version of the manuscript. Syamsul Hadi was providing research funding, checking analysis results, supervising manuscript writing, approving the final version of the manuscript. Dominicus Danardono Dwi Prija Tjahjana is supervising manuscript writing, reviewing result data, approving the final version of the manuscript.

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