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Evaluation of Power Generated by using Savonius Horizontal Axis Water Turbine

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Abstract: This study focuses on the fabrication and analytical calculations of a Savonius Horizontal Axis Water Turbine (SHAWT) for power generation. The fabrication involves the construction of a turbine with twisted blades at a 90˚ angle, incorporating a shaft, ball bearing, supporting frame, and a DC motor. Analytical calculations were conducted to estimate the maximum power output of the turbine. The analyses indicated a power output range of 3.35 to 4.64 MW at water velocities ranging from 28.0 to 31.3 m/s based on the height of the waterfall in Gunung Pulai ranging from 40 to 50 meters. The calculations considered factors such as water velocity, blade design, and efficiency based on Betz Law, providing valuable insights into the turbine's power generation potential. While the analytical calculations provide estimations based on theoretical assumptions, experimental validation is necessary to confirm the accuracy and reliability of the results. Future work should include experimental testing to compare the calculated power output with actual measurements, enabling a comprehensive evaluation of the turbine's performance. Overall, this study contributes to understanding the fabrication and analytical calculations involved in designing and estimating the maximum power output of a SHAWT. Further experimental validation will enhance the reliability and practical application of the results.

Keywords: Savonius, Water Turbine, Fabrication

1. Introduction

A horizontal-axis water turbine is designed to harness the power of flowing river water and convert it into valuable mechanical or electrical energy [1]. The main problem it aims to address is the generation of power from river water. To achieve this, the turbine needs to efficiently capture the kinetic energy of the flowing water and convert it into rotational motion, which can then be used to generate electricity. The project's objectives involve designing and fabricating the turbine, considering factors like blade profile water velocity, and performing analytical calculations related to fluid dynamics and mechanical aspects to optimise its performance. The expected outcome is a well-designed turbine that

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can effectively generate power by converting a significant portion of the water's kinetic energy into rotational motion, ultimately providing a renewable and sustainable source of electricity from the river water. The maximum power generated calculated is the targeted value for the water turbine.

1.1 Savonius

The basic shape of the Savonius rotor is an 'S' type and slightly overlaps the semi-circular blades [2]. With strong beginning properties, it can receive fluid from any direction. Compared to a Darrieus-type turbine, it has a low aerodynamic efficiency [3]. Traditional Savonius turbine rotors have low efficiency and a wide range of static torque. As a result, several research was conducted to improve the Savonius rotor's performance and eliminate the problem of considerable variations in static torque. An endless variety of blade shapes may influence the performance curves of the Savonius rotor. The rotor with a 90° twist angle has the most significant average static torque coefficient (0.442), followed by rotors with a 0° twist angle (0.434) and 180° twist angle (0.385), all of which have static torque coefficients. This increase in static torque coefficient will benefit the Savonius rotor's overall performance as well as its starting capabilities [4].

1.2 Height of waterfall at Gunung Pulai

The height of a waterfall directly affects the velocity of the water flowing over it. As the water falls from a higher elevation, it gains potential energy, which is then converted into kinetic energy as it accelerates downward. According to the principle of energy conservation, the water's velocity at the waterfall's base can be calculated using the formula, where v is the water velocity, g is the acceleration due to gravity, and h is the height of the waterfall. This equation shows that water velocity increases with the square root of the waterfall height. Consequently, taller waterfalls have higher water velocities at their base, influenced by several factors such as erosion, ecological processes, and hydropower potential. The height of the main waterfall at Gunung Pulai ranges from 40 to 50 metres [5].

2. Materials and Methods

In this project, fabrication of the Savonius Horizontal Axis Water Turbine analytical calculations of the turbine is carried out.

2.1 Design of the SHAWT

In this project, both blade and twisted are selected to analyse the performance and determine the maximum of the SHAWT. SHAWT was designed based on the dimensions of the blade of the actual wind turbine located at UTHM. The model of the Savonius water turbine is designed on SOLIDWORK 2022, and the dimensions are in Table 1. The Savonius blade drawn using SOLIDWORK is shown in Figure 1.

Table 1: The dimensions of the SHAWT

Dimension	Value
Number of blades, n	2
Twist angle, θ	90˚
Blade radius, r	150 mm
Length of turbine, L	1000 mm

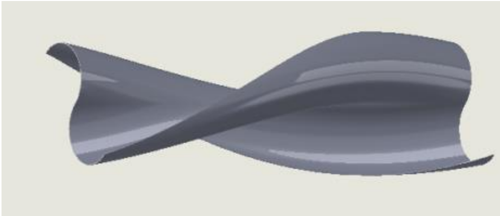


Figure 1: Drawing of Savonius blade using SOLIDWORKS 2022

2.2 Fabrications

The components needed for the fabrications are listed in Table 2.

Table 2: List of components for fabrication

Components	Quantity
Blade	1
Ball bearing	2
Shaft	1
Supporting Frame	1
DC Motor	1

The assembly process includes fabricating supporting frames, installing the ball bearings, and attaching the shaft and blade assembly.

Figure 2: Full Assembly of SHAWT

2.3 Equations for Analytical Calculations

To determine the maximum power the SHAWT generates, all related formulas must be performed to get the results.

Power input refers to the mechanical power or energy needed to rotate the turbine blades and generate power. The power input is an essential factor that affects the performance of a Savonius water turbine.

$$P_{in} = T\omega \qquad \text{Eq. 1}$$

Where P_{in}: Power input , C_t: Torque Coefficient, ρ: Density of water, V: Velocity and A: Area

Power output refers to the amount of power generated or produced by a system or device. In the context of a turbine, power output refers to the electrical or mechanical energy generated by the turbine blades' rotation.

$$P_{out} = \%_{efficiency}\ P_{in} \qquad \text{Eq. 2}$$

3. Results and Discussion

This section presents the results and discussion obtained from a comprehensive study conducted on the Savonius Horizontal Axis Water Turbine (SHAWT), focusing on the calculation analysis of the maximum power that the turbine can generate. The study considered a range of water velocities based on a thorough literature review. The calculations and analysis yielded significant results regarding the performance of the SHAWT at different water velocities. The obtained results demonstrated the relationship between water velocity and the maximum power output of the turbine.

3.1 Results

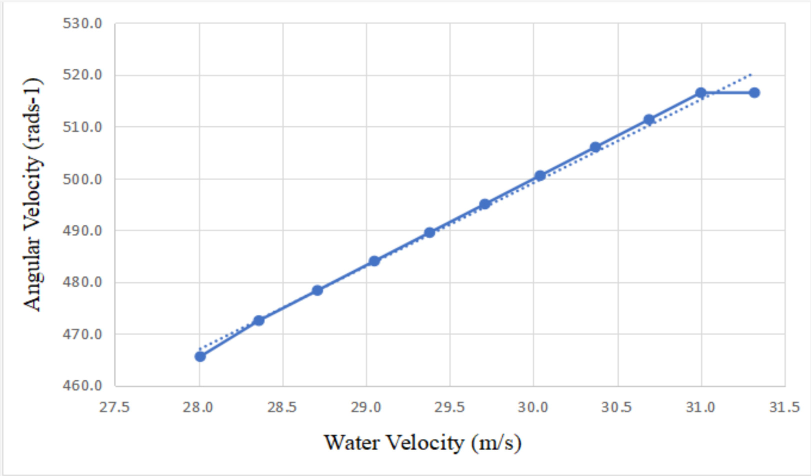
The analytical calculations are based on Betz's law to estimate the maximum power output of the twisted SHAWT. The parameters considered are the swept area of the turbine blades, the water velocity taken from the literature review, the density of the water and the twist angle. Table 3 shows the theoretical calculations based on Betz Law with water velocities ranging from 0.217 to 0.582 m/s. The parameters include the water velocity (V), rotational speed, angular velocity (ω), torque (T), power input and power output.

Table 3: Data of Analytical Calculations based on Betz's Law

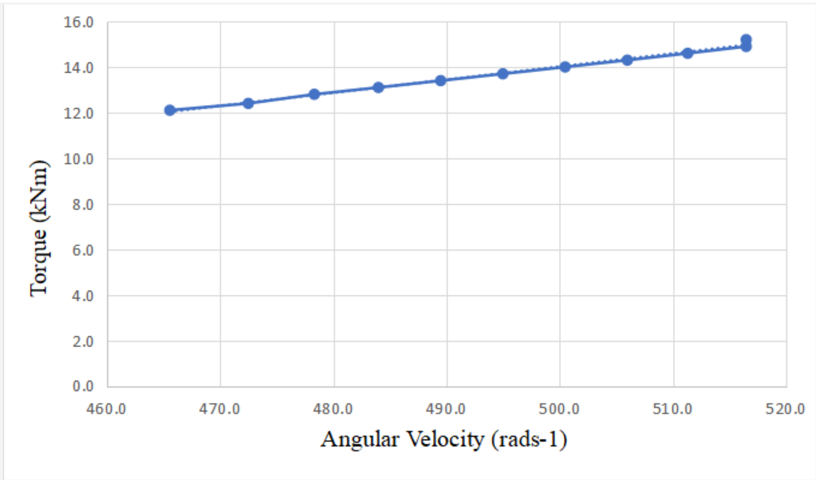
H(m)	V(m/s)	RPM	ω ($rads^{-1}$)	T (Nm)	P_{in} (W)	P_{out} (W)
40	28.0	4446.6	465.6	12.1	5.65	3.35
41	28.4	4512.8	472.5	12.4	5.88	3.49
42	28.7	4568.5	478.3	12.8	6.10	3.62
43	29.1	4622.6	484.0	13.1	6.31	3.74
44	29.4	4675.1	489.5	13.4	6.53	3.87
45	29.7	4727.6	495.0	13.7	6.76	4.01
46	30.0	4780.1	500.5	14.0	6.99	4.15
47	30.4	4832.6	506.0	14.3	7.21	4.28
48	30.7	4883.5	511.3	14.6	7.45	4.42
49	31.0	4932.9	516.5	14.9	7.68	4.55
50	31.3	4932.9	516.5	15.2	7.83	4.64

3.2 Graphs

Graphs in Figure 3 show the increasing trend for (a) angular velocity vs water velocity, (b) torque vs angular velocity and (c) power output vs torque.



(a)



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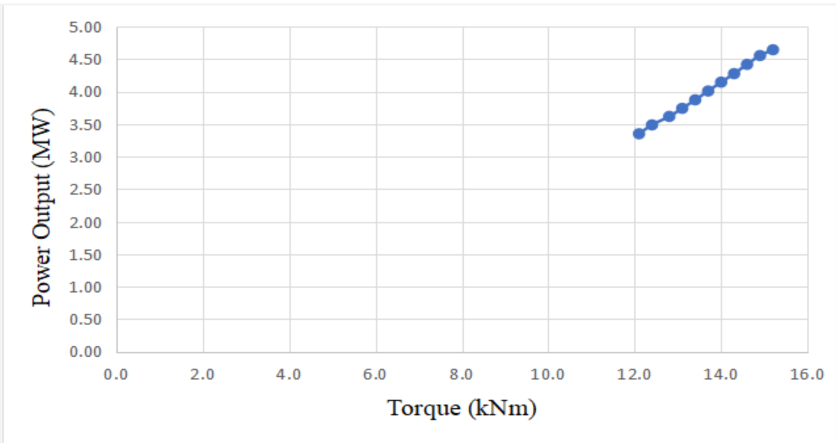

(c)

Figure 3: (a) Angular velocity vs water velocity, (b) torque vs angular velocity and (c) power output vs torque

3.2 Discussions

The analytical calculations are carried out to determine the theoretical maximum power based on the Betz limit, which sets the upper limit for the turbine efficiency at 59.3%. It signifies that no turbine, including SHAWT, can achieve an efficiency of 59.3% when converting the kinetic energy of the water flow into mechanical power. The maximum power output calculated is 4.64 W, with the water velocity at 31.3 m/s at the full height of Gunung Pulai’s waterfall, which is 50 m. The value of the maximum power output is within the expected range according to the analytical calculations and following Betz’s Law. The power output is influenced by various factors, including water velocity, blade design and other site-specific conditions.

The water velocity is a crucial parameter that significantly affects the turbine's power output. Based on the analysis, all the graphs show an increasing trend where even small increases in water velocity can substantially improve power output. In contrast, decreases in water velocity can result in reduced power generation. As the water velocities are within the range from 28.0 to 31.3 m/s, it is possible to get the power output as high as 4.64MW because the impact of the water flow that hits the rotor blades are high for the rotor to rotate continuously and in the fast rotation.

The twist in the blade design helps to optimise the blades' angle of attack as they interact with the water flow. The prototype of the SHAWT is preliminary tested with a flow of water from the pipe to ensure it can be functionally rotating. The result shows the water turbines have some self-starting capability, even the minimum water velocity required to initiate rotation and generate power. The twisted blade design can enhance the turbine's self-starting ability by facilitating better flow capture at lower water velocities. However, for analytical calculations, the values of power generated are lower because they may not be as accurate as in the actual SHAWT experiment. The analysis is done with theoretical formulas and follows the SHAWT design’s dimension.

4. Conclusion

The Savonius Horizontal Axis Water Turbine (SHAWT) is fabricated by assembling twisted blades set at a 90˚ angle, along with a shaft, ball bearings, supporting frame, and a DC motor. This design enhances the turbine's efficiency by optimising the angle of attack and reducing drag. The 90˚ angle ensures effective capturing of the water flow, maximising the conversion of kinetic energy into mechanical power. The turbine functions by converting the kinetic energy of the water flow into mechanical power through the interaction of the rotor blades with the water. This rotation drives the DC motor, generating electrical power. The fabricated SHAWT is a practical and efficient means of harnessing water flow for power generation. Analytical calculations indicate a maximum power output ranging from 3.35 to 4.64 MW, depending on the water velocity. However, experimental validation is necessary to verify and refine these calculations.

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