Indonesian Journal of Advanced Research (IJAR)
Vol. 4, No. 12, 2025: 2579-2590

Effect of Vertical Shaft Propeller Turbine Blade Geometry on Generated Power

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A R T I CLEINFO

Keywords: Pico Hydro, Performance Tubin, Turbine Propeller

Received : 27, October
Revised : 29, November
Accepted: 31, December

A B S T R A C T

Electricity availability is essential for improving quality of life in rural areas, particularly in remote regions of eastern Indonesia that lack access to the national power grid due to limited energy supply, transportation constraints, and weather conditions. To address this challenge, this study develops and tests a pico-hydro power system using a vertical-shaft propeller turbine capable of operating under low water flow conditions. The research was conducted in Tetey Village, North Minahasa Regency, utilizing irrigation canal water from rice fields. Direct experimental testing was applied to evaluate turbine performance under varying parameters, including blade type (plate and standard), blade angles of 30° and 40°, a water fall height of 50 cm, and a flow velocity of 0.68 m/s. The results show that the maximum turbine power of 200 W was achieved at 1800 rpm with a torque of 1.5 Nm using a standard four-blade turbine with a 30° blade angle and a water discharge of 0.065 m^3/s. Overall, flow rate, fall height, blade type, and blade angle significantly affect turbine performance, demonstrating the potential of pico-hydro systems as an environmentally friendly electricity solution for rural areas with limited water flow.

DOI prefix: https://doi.org/10.55927/ijar.v4i12.15855
ISSN-E: 2986-0768
https://journal.formosapublisher.org/index.php/ijar

INTRODUCTION

Indonesia is a tropical region crossed by the equator, where the availability of natural resources is very abundant, and one of its natural resources is water [1]. The potential of water energy resources in Indonesia is estimated to reach 75,000 MW, but only about 9% has been utilized as hydroelectric power plants or hydropower on a small to large scale [2]. The availability of electricity supply in rural areas is one of the very important needs to support the quality of life of the community. The problem for areas in rural regions that have not received electricity services from PLN (State Electricity Company) is usually addressed by building small-scale Hydroelectric Power Plants (PLTA) or Pico-Hydro PLTA. Pico-Hydro PLTA is one of the systems to convert energy from water into renewable electrical energy [3]. The requirements that must be met in the development of this system are the availability of high-pressure water flow in the form of river flow or small-scale waterfalls with adequate current speed [4]. If these conditions are not met, it will pose a problem for rural areas that do not have sufficient water sources. To address this issue, an innovation was developed through the design and implementation of a Pico-Hydro Power Plant capable of operating under conditions of insufficient water flow speed. Pico hydro turbines are turbines with a very low head or height difference [5]. If a turbine has a low head and relatively large flow rate, then the reaction type turbine is more suitable for application compared to the impulse type turbine [6]. One type of reaction turbine that is widely used and capable of operating with high efficiency is the propeller turbine [7]. Based on its criteria compared to several other types of turbines, the propeller turbine has advantages in terms of these criteria compared to other turbine types [8].

From several of these statements, it serves as motivation for the author to try to create a propeller water turbine with vertical blades on a small scale that has the optimal ability to generate electrical energy of 150 Watts with an adjusted flow capacity, by conducting tests based on variations in water flow speed and the shape of the blade type to obtain the optimal turbine rotational speed and torque from each designed turbine blade type.

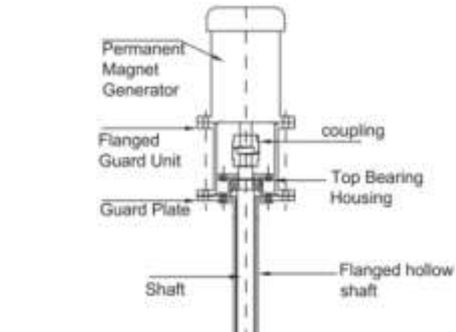

Figure 1. Propeller Water Turbine Construction with Vertical Blades [9]

In this study, examining the blade geometry of a water turbine greatly affects the turbine's performance, where in designing a water turbine, it is necessary to understand the parameters that will impact its performance, so that an optimal and well-planned design can be produced [9]. According to research [10] on the studies conducted, it states that the shape of the propeller blades affects the shaft power of the turbine. The research method using a propeller is easier to use for designing the curvature angle geometry of a propeller turbine blade. This is because the reference of the zero point as a determinant of the curvature is easier.

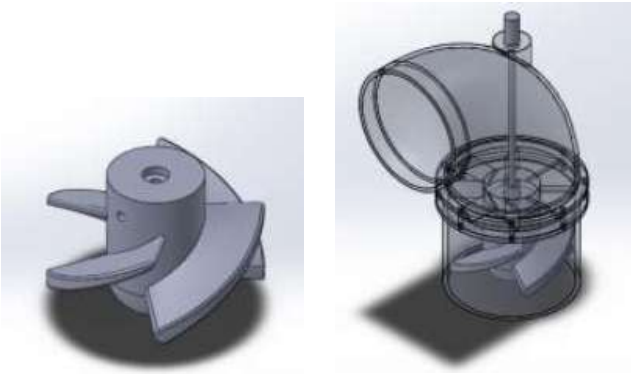

Figure 2. Propeller Design

In propeller turbines, not only the parameter of the number of blades affects turbine performance, but there are also other parameters that have an impact. Geometrically, the number of blades will affect the gap between the blades; the more blades there are, the narrower the gap between them will be [11];[12]. Thus, after reaching the optimal point, turbine performance will decrease. This is because as the gap between the blades becomes narrower, the water flow through the blades is obstructed, causing a drop in turbine performance. On the other hand, before reaching the optimal point, the more blades there are, the higher the turbine performance, as a greater number of blades increases the axial force received by the turbine [8].

Just like with the blade number parameter, the blade pitch parameter also indicates different optimal blade pitch levels in each study. This is because, in propeller turbines, not only the blade pitch parameter affects turbine performance, but there are also other parameters that influence it. The blade pitch affects the shape and geometry of the turbine; specifically, the smaller the blade pitch angle, the narrower the gap between the turbine blades [11]. The performance of the turbine will continue to decline, which is caused by the blade inclination after reaching its optimal point where the water flow does not fully strike the blade because the blade angle moves further away from the perpendicular line to the axis or water flow, resulting in a decrease in the tangential force on the turbine [14];[15]. Meanwhile, before reaching the optimal point, the turbine performance shows an upward trend. This is because at blade inclinations before reaching the optimal point, the gaps between the blades become narrower, which hinders the water flow and reduces performance [11];[14].

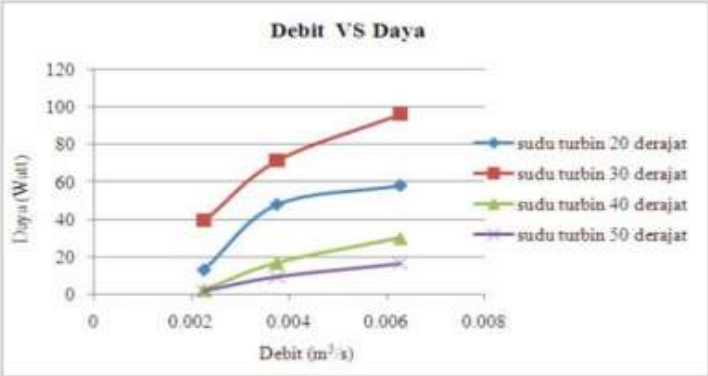

Figure 3. Relationship between blade angle and electrical power [14]

The formulas used in this test are as follows:

a. Water flow rate,

To determine the amount of water flowing. The volume of flowing water is called the water flow rate. The flowing water flow rate can be calculated using the equation:

$$\mathbf{Q = V/t} \quad \text{........... 1)}$$

b. Water velocity,

Water velocity is a measure of the amount of water volume that can pass through a place or that can be contained in a place per unit of time. A flow of water is said to have ideal properties if the water cannot be utilized and moves without experiencing friction. This means that in the movement of the water, it has a constant velocity at each point in the pipe and its movement is orderly due to the influence of Earth's gravity. Water velocity can be calculated using the formula:

$$\mathbf{v} = Q/A \quad \text{........ (2)}$$

c. Density,

Density is the measurement of mass per unit volume of an object. The higher the density of an object, the greater the mass for each of its volumes, which can be expressed with the following equation:

$$\rho = m/V \quad \text{or} \quad m = \rho \times V \quad \text{.........(3)}$$

d. Water power,

Calculating water power is carried out to determine the water power that will be used, so that the efficiency of the use of a certain power can be obtained, which can be formulated as follows:

$$P_{water} = \rho \times g \times Q \times H \quad \text{......... (4)}$$

e. Turbine power,

Calculation of the turbine power that can be produced by a water turbine with the following equation:

$$Pt = \tau \times \omega \quad \text{or} \quad Pt = Pair \times \mu \quad \text{......... (5)}$$

f. Turbine efficiency,

The efficiency generated by a water turbine can be calculated using the following equation:

$$\eta = (Pt/Pair) \times 100\%, \quad \text{or}$$
$$= (PG/Pair) \times 100\%$$

……..(6)

METHODOLOGY

The method used in this study is the Experimental Method by designing and manufacturing a working tool/apparatus and then testing a small-scale vertical turbine. The focus of the experiment is to determine how the geometry of the blades, particularly the number and type of blades, affects the efficiency and electrical output of the turbine under controlled water flow conditions, as recommended by previous studies in pico-hydropower turbine design [17];[18];[10]. The entire manufacturing process was carried out at the Mechanical Engineering Workshop, Department of Mechanical Engineering, Manado State Polytechnic, while the testing was conducted in Tetey Village, Dimembe District, North Minahasa Regency. This location was chosen due to its access to the necessary manufacturing equipment and measuring instruments, allowing for precise production and evaluation of turbine components. The materials and equipment for the propeller turbine consist of several main components. The blades have a diameter of 9 inches (22.86 cm) and are made with a blade angle of 30° or 40°. The experiment compared turbines equipped with four blades, each tested in two types of blades: flat and standard. The flat/straight blades are propellers made from 2 mm plates, while the standard blades are the commonly used propellers for marine motors made of aluminum. The turbine frame is specially made from 1.2 mm steel plates with 4x4 cm angle iron, while the shaft is made of stainless steel and sealed ball bearings are used to ensure smooth rotation and minimize friction loss. The water channel is made of boards using river water, built with a channel head of 33 cm (producing a flow rate of 0.065 m^3/s), with a channel width of 29 cm. The water flow velocity in the channel was carefully measured for each head, resulting in 0.68 m/s for a 33 cm head and 0.51 m/s for a 25 cm head. The main measurement instruments included a tachometer for rotational speed (RPM), a torque meter for shaft torque, digital voltmeters and ammeters for electrical output, as well as traditional measuring tools such as a stopwatch and a measuring tape for accurate readings of flow rate and dimensions. The independent variables in this study were the number of blades, four in total; (flat/straight versus standard) with blade angles (30° versus 40°), and water flow conditions (high and low head/flow). The measured dependent variables include the turbine rotational speed (RPM), torque (Nm), electrical power output (Watts), and efficiency (%). The research procedure begins with a comprehensive literature review and planning phase, based on an analysis of previously studied micro-hydro and pico-hydro designs. The testing apparatus/equipment can be seen in Figure 4;

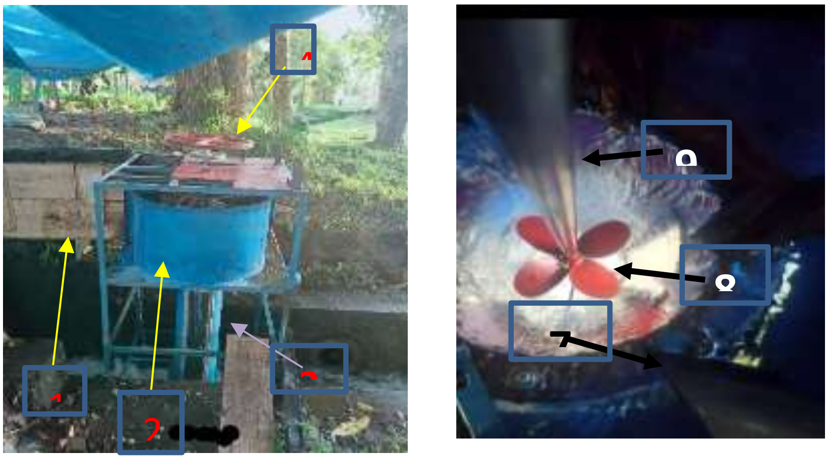

Figure 4. Testing Apparatus

- Specific Apparatus Data:

-Propeller Dimensions:

Diameter = 9 Inches = 22.86 cm
Angle Blade = 30° and 40°
Number of Blades = 3 and 4
Blade Type = Flat/Straight and Standard

-Water Channel:

Water level (h) = 33 cm
Channel Width = 29 cm
Water Flow Velocity = 0.68 m/s
Flow Capacity (Q) = 0.065 m^3/s

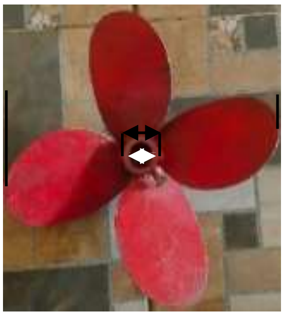

Figure 4. Straight Propeller

Figure 5. Standard Blade Model

Water flow is determined by measuring the volume of water passing through the system over a certain period of time. Water velocity is obtained by dividing the flow rate by the cross-sectional area of the blades. The density of water is assumed to be 980 kg/m^3, calculated as the ratio between mass and volume. The available water power is calculated by taking into account the water density, gravitational acceleration (9.81 m/s^2), flow rate, and water height (head). The turbine power output is determined from the measured torque and the angular speed of the turbine shaft. Finally, the turbine efficiency is calculated by comparing the turbine output power with the available water power, and the result is expressed as a percentage. All measuring instruments are carefully calibrated before use to ensure the accuracy of the recorded values, and measurement uncertainties are evaluated according to standard engineering protocols. The data obtained is organized and presented in the form of tables and graphs.

RESULTS AND DISCUSSION

This study examines the performance of small-scale vertical axis turbines under laboratory conditions designed to simulate river flow environments in rural Indonesia. Experiments were conducted at a constant water flow rate of 0.065 m^3/s and a head of 50 cm. All turbines tested used four blades, but the blade angles varied between 30° and 40°, and two types of blades were used: standard (curved) and plate/flat (straight). Each turbine configuration was evaluated based on maximum rotational speed (RPM), torque (Nm), and electrical power output (Watts), with the aim of determining which geometric design offers the best efficiency and performance under the established flow conditions.

The results from several tests conducted were compiled into a data table, and then a graph was created as follows;

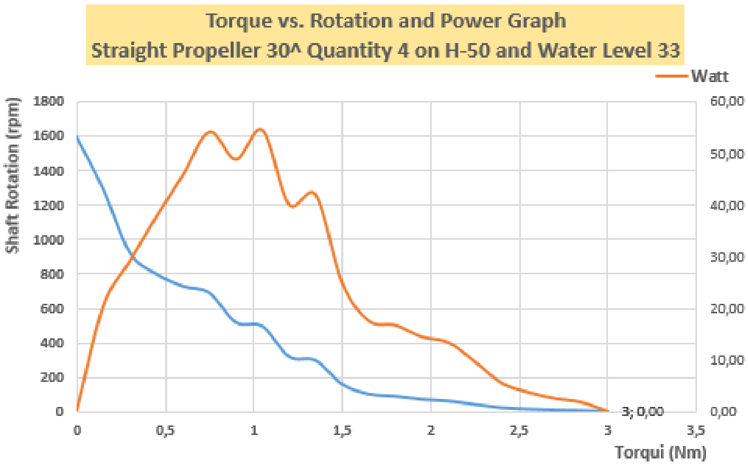

Chart 1: Condition, Head 50 cm, Number of blades-4 pieces, Angle 30^0, Standard Propeller Type.

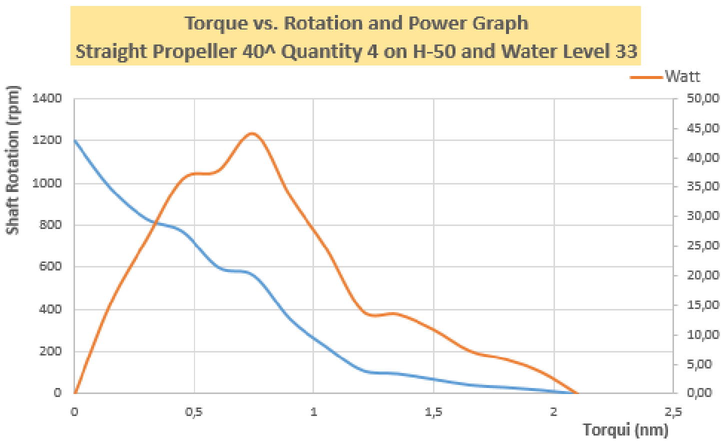

Chart 2: Condition, Head 50 cm, Number of blades-4 pieces, Angle 40^0, Standard Propeller Type.

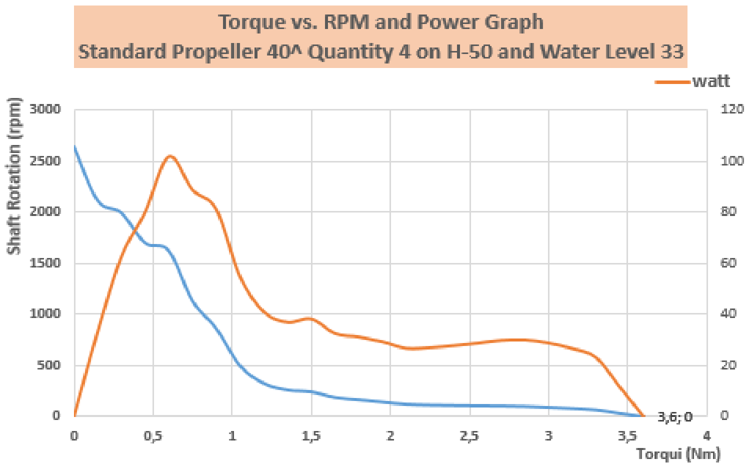

Chart 3: Condition, Head 50 cm, Number of blades - 4 pieces, Angle 30°, Type of Propeller Plate/Straight.

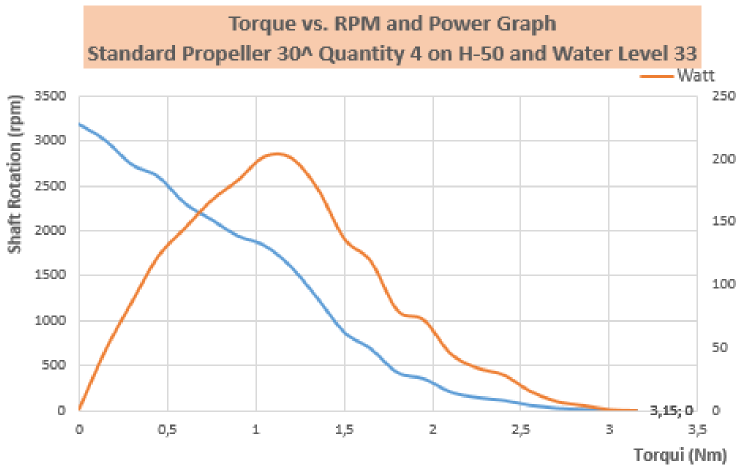

Chart 4: Condition, Head 50 cm, Number of blades - 4 pieces, Angle 40°, Type of Propeller Plate/Straight.

In this study, the researcher took samples from the maximum achievement of standard propeller-type water turbines and flat/straight blade propeller types. The results obtained are as follows:

1. Graph-1 shows the highest achievement, where the Turbine Power reaches 201 Watts under turbine rotation conditions of 1883 rpm with a Torque of 1.05 Nm, produced by a Standard Propeller turbine with 4 blades and a flow capacity of 0.065 m^3/s, with a water fall height on the turbine of 50 cm and a blade angle of 30°.
2. Graph-2 is a comparison using the same type of propeller as in Graph-1, but with a blade pitch of 40 degrees. The turbine produces 102 Watts of power at a torque of 0.6 Nm.
3. Graph-3 is a comparison of a different type with the turbine in Graph-1, where the turbine type is Flat/Straight Blades with a blade angle of 40 degrees, producing 54.6 Watts of power at a turbine speed of 497 rpm and a torque of 1.05 Nm.
4. Graph-4 is a comparison of different types of turbines with the turbine in Graph-2, where the type of turbine is a Flat/Plain Blade (Straight) with a

blade angle of 40°. The turbine produces 43.9 Watts of power at a rotational speed of 560 rpm and a torque of 0.75 Nm.

Several research findings explain that the most effective angle in performance is between 25° and 35°, providing the best balance between lift force and drag force on the turbine blades. According to reports [10];[19], excessive blade angles tend to reduce efficiency due to increased resistance, which disrupts optimal water flow and decreases shaft rotation speed. The findings of this study are consistent with these observations, as a 30° blade angle delivers significantly better performance than the 40° variant. [20] also emphasizes that angles exceeding the optimal range reduce energy transfer, ultimately decreasing the speed and output power of the pico-hydro turbine. According to [17];[18] emphasizes that an airfoil/blade shape with curved blades can maximize lift and minimize drag factors, allowing for greater shaft power and higher rotational speeds, especially under turbulent conditions with low head. Theoretically, this study reinforces the argument for integrating advanced hydrodynamic principles into the design of pico-hydro turbines.

CONCLUSION AND RECOMMENDATION

The main goal of the research was to design, build, and experimentally evaluate a small-scale vertical blade/bucket propeller turbine (pico hydro) for efficient energy generation under low flow and low head conditions in river channels commonly found in rural areas of Indonesia. The key findings indicate that water discharge and head height significantly affect the turbine's achievable output power, while optimizing blade geometry, particularly using standard (curved) blades with a 30° inclination, substantially enhances the turbine's speed, torque, and overall performance. The highest output power achieved was 200 Watts using a standard four-blade propeller with a 30° blade pitch, surpassing other test configurations and demonstrating the significant impact of blade shape and pitch. This study contributes to empirically validating that careful selection of blade type and geometry can significantly improve the efficiency of pico-hydro systems, thereby supporting sustainable rural electrification initiatives. These findings bridge a significant research gap by providing comprehensive experimental data on the combined effects of blade shape and tilt angle, offering practical design recommendations for manufacturers and rural energy planners, and ultimately advancing both academic understanding and real-world applications of micro-hydro power technology.

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