MECHTA
International Journal Of Mechanical Engineering Technologies & Applications
ISSN 2722-3213 articles 1, pp. 1 – 9, 2023
V04 N.1

AN EXPERIMENTAL STUDY OF THE EFFECT OF VARIATION OF IMPACT LEVELS ON WORKING EFFICIENCY OF ARCHIMEDES SCREW TURBINE ON MICRO-HYDRO POWER PLANT

Andy Nugraha [1], Dani Surya Hamonangan Silalahi [1], Pathur Razi Ansyah [1], Muhammad Nizar Ramadhan[1], Apip Amrullah[1], Gunawan Rudi Cahyono [1] ✉

[1]**Mechanical Engineering Department**
Lambung Mangkurat University
Jl. Brigjen H. Hasan Basri, Banjarmasin
South Kalimantan, Indonesia
andy.nugraha@ulm.ac.id (A Nugraha)
danishs69@gmail.com (DSH Silalahi)
pathur.razi@ulm.ac.id (PR Ansyah)
nizarramadhan@ulm.ac.id (MN Ramadhan)
apip.amrullah@ulm.ac.id (A Amrullah)

Abstract

Micro-hydro power plants take advantage of the energy potential of low-head airflow. with the development of technology that can support it, namely the Archimedes screw turbine as the driving force. Various parameters must be considered to determine the performance of micro hydro power plants with Archimedes screw turbines. A design is carried out with a discharge parameter flow rate of 2 l/s, a turbine slope of 300, and an immersion level variation of 0.3, 0.5, and 0.7, where the final result shows the value of torque, hydraulic power, mechanical power, generator, and efficiency, which decreases with the level of water immersion in the last blade.

Keywords: Archimedes Screw, Micro Hydro, Immersion Level, Performance.

1. INTRODUCTION

Renewable energy is being used due to the effects arising from the limited supply of renewable energy. One way to overcome this is by utilizing renewable energy sources, namely water energy, solar energy, wind energy, and biomass. One of the power plants sourced from water energy is the Micro-Hydro Power Plant (MHPP).

Micro hydro power plants utilize the flow potential of water as a source of electrical energy with low head and discharge. Utilization of water potential at this time is usually limited to flows of water with a high head and/or large discharge. However, many areas in Indonesia have very low energy potential for river water flow, such as in South Kalimantan. So, currently, there is a need to develop a type of turbine that can take advantage of the energy potential of water with a low head. One of the technologies developed to support this MHP is the Archimedes screw turbine, which is the prime mover of the MHP [1].

In this study, an experimental test of the Archimedes Screw turbine model was carried out with variations in the level of immersion (I) on a fixed variable (debit) and a fixed turbine angle (tilt) to determine the optimal point for the level of water immersion in the turbine. In extreme conditions, when applied in the field (e.g., during a flood), the water flow that passes through the turbine will increase and cause the turbine's bottom to be submerged at a certain level. In this condition, the turbine's performance will change according to the level of water immersion. Tests of the performance of the Archimedes screw turbine also include differences in the outlet level (h_{out}) at the angle of inclination and constant water flow. Water discharge (Q) and angle of inclination (K) are constant parameters to optimize the performance of the screw turbine for the specified screw placement and construction materials.

Corresponding Author:
✉ **Gunawan Rudi Cahyono**
gunawan.rudy@ulm.ac.id
Received on: 2021-12-24
Revised on: 2022-01-15
Accepted on: 2022-01-15

DOI: 10.21776/MECHTA.2023.004.01.1

1.1. Micro-Hydro Power Plant

A possible small-scale power plant is a Micro Hydro Power Plant (PLTMH), which has several advantages compared to other power plants: it is environmentally friendly, not excessive in the use of water, more durable, requires less operating costs, and is suitable for the region. -remote areas [2]. The nature of this micro hydro energy is renewable, or in other words, inexhaustible, with several advantages, including being able to operate fully because the airflow does not depend on time, its operation not requiring many costs, and several other benefits.

1.2. The Working of Micro-Hydro Power Plant

Technically, MHP has three main components: water as an energy source, a turbine, and a generator. Water with a specific capacity is channelled to the installation house (turbine house or powerhouse) at a certain height. In the installation house, the water will hit the turbine. The turbine will process the water energy and convert it to mechanical energy by rotating the turbine pivot. Furthermore, the rotating pivot will be sent to the generator using a clutch. Electrical power is generated by a generator and fed into a distributed current control system for home and other purposes.

1.3. Archimedes Screw Turbine

Initially, Archimedes designed this turbine with the intention of removing water from the inside of the ship and perfecting it for use in raising water from the river. The working principle of this turbine is to rotate in reverse and let the water control the turbine; then, an electric generator is installed on top of the turbine, so as long as the generator is not exposed to water or wet, electricity can be generated. Therefore, the screw turbine is the opposite of the screw pump function.

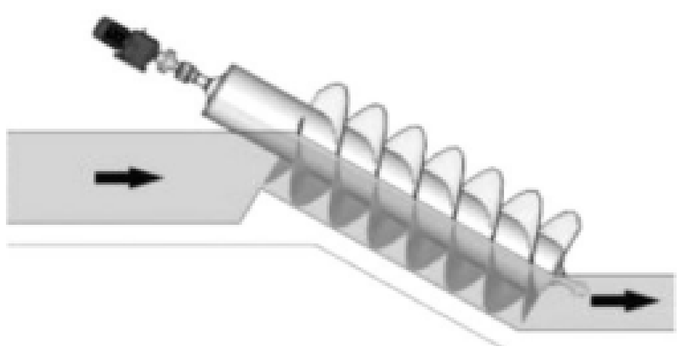

Figure 1. Archimedes Screw Turbine

Water serves as the prime mover of the blade or screw turbine, where the momentum generated depends on the amount of water and the water level (energy generation potential). Debit is the amount of water that rotates the turbine per required time (l/s) and the height of the water-fall (head) on the turbine, namely the distance between the water level and the turbine. Then the potential energy is also converted into mechanical energy from the turbine through the turbine blades or screw. And the mechanical energy generated from the turbine will be transmitted to the generator by the connecting pivot (rotation). The generator converts mechanical energy into electrical energy [1].

1.4. Turbine Selection Parameters

The factor of the height of the water-fall and the flow rate that will be used for turbine operation, where the more tilted it is, the possibility of finding sufficient head for the MHP is greater

$$\alpha = 〖\tan〗^{(-1)} (y/x) \quad (1)$$

The power factor is related to the head and water flow used.

$$\text{Debit} = \text{Volume/time} \quad (2)$$

The efficiency factor is related to the level of turbine immersion and the power generated. Where, the more increased level of turbine immersion and decreased power will reduce the efficiency value [3].

1.5. Water Immersion Level

To compare the results, we can define an appropriate immersion level according to the following ratio.

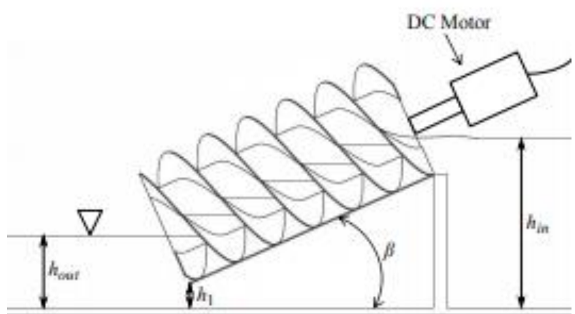

Figure 2. Testing Process

Where:
h_{out} = distance from the surface of the tub to the center of the immersion
h_i = distance from the surface of the tub to the bottom of the turbine
B = turbine tilt angle

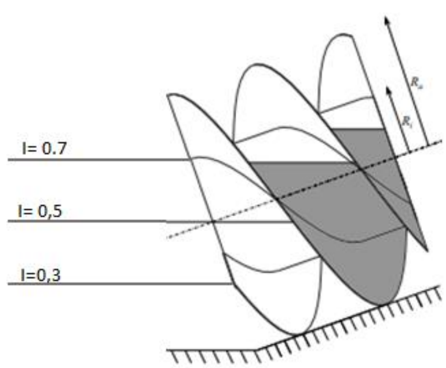

Figure 3. Variable of Turbine Immersion Level

Thus, for I = 0, the water level is at the low end of the screw. In contrast, for I = 1, the end of the screw is completely sunk. Different levels of immersion are represented [4].

1.6. Hydraulic Power, Generator Power and Mechanical Power

The components in analysing hydropower plants are head and discharge. The head is the height difference between the reservoirs. The head in hydropower is defined as the height at which the water-falls. When the amount of water Q moves according to the difference in height H in the direction of gravity, then the water will work per second, P_h in power (work per second), or watts [5].

$$P_h = \rho \times Q \times g \times H \quad (3)$$

Where:
P_h = Hydraulic power/ input power (Watt)
ρ = density of water (998.3 kg/m3 at 20℃)
Q = the amount of water that passes per second or Flowrate (m^3/s)
g = the acceleration of gravity (9,81 m/s^2)
H = net height difference (Net-head) in (m)

The power generated by the generator can be calculated using the following equation: [6]

$$P_{out} = V \times I \quad (4)$$

Where:
P_{out} = generator power (Watt)
V = voltage (Volt)
I = amperage (Ampere)

Mechanical power is the power caused by the deviation by the water turbine by changing the kinetic energy of the water into mechanical energy in the rotation of the turbine pivot. Turbine power is denoted as Pt. To calculate the size of turbine power produced by kinetic energy, here's the following formulation:

$$Pt = T \times \omega \quad (5)$$

Where:
Pt = turbine power (Watts)
T = torque (Nm)
ω = angular velocity (rad/s)

To calculate the angular velocity, use the equation:

$$\omega = \frac{2 \times \pi \times n}{60} \quad (6)$$

Where:
n = rotations (rpm)
ω = angular velocity (rad/s)

1.7. Torque

The turbine speed will be transmitted to the generator. For calculating torque, the following calculations:

$$T = I \times \alpha \tag{7}$$

Where:
T = Torque (Nm)
I = Moments of Inertia (kgm^2)
α = Angular Acceleration (m/s^2)

To determine the moment of inertia, the following formula:

$$I = m \times r^2 \tag{8}$$

Where:
M = mass (kg)
r = distance to axis (m)

1.8. Efficiency

Efficiency is the ratio between the power out and the power in and can be written in the following equation:[5]

Turbine Efficiency

$$\eta_T = \text{(Turbine Power)/(Hydraulic Power)} \times 100\% \tag{9}$$

Generator Efficiency

$$\eta_G = \text{(Generator Power)/(Hydraulic Power)} \times 100\% \tag{10}$$

Total Efficiency

$$\eta_{Total} = \eta_G \times \eta_T \tag{11}$$

2. MATERIALS AND METHODS

This research goal is to see the performance of MHP using Archimedes screw turbine. This study shows the relationship between the water immersion level at the Archimedes screw turbine outlet on torque, generator power, hydrolysis power, and turbine performance efficiency.

Figure 4. MHP Prototype with Archimedes Screw Turbine

Experimental testing of MHP with Archimedes Screw Turbine includes a variable flow rate of 2 L/s, a turbine inclines of 300, and a turbine immersion level variation of 0.3 I; 0.5 I; 0.7 I. The testing process begins with adjusting the flow rate and turbine inclines on the MHP framework. Then the water will be drawn from the bottom reservoir through the pump to tub 1. From tub 1, it will be lowered to tub 2 as the water inlet to the turbine, with a flow rate of 2 l/s. Then the water will turn the turbine, and the generator will also spin. The water that passes through the turbine will go down into reservoir 3 as a place for variations in the level of water immersion. In variations of the water immersion level, tub 3 has an exhaust channel to the initial reservoir in the form of a ball valve, which is used to keep the water immersion level stable. The testing process is performed repeatedly according to the many variations in the level of water immersion and the number of experiments in one variation. The testing data retrieval in the form of turbine rotation speed (rpm), voltage (V), and amperage (A) was done 5 times. Data collection of turbine rotation speed is measured using a tachometer. Data retrieval for voltage and electric current were measured using a digital avometer.

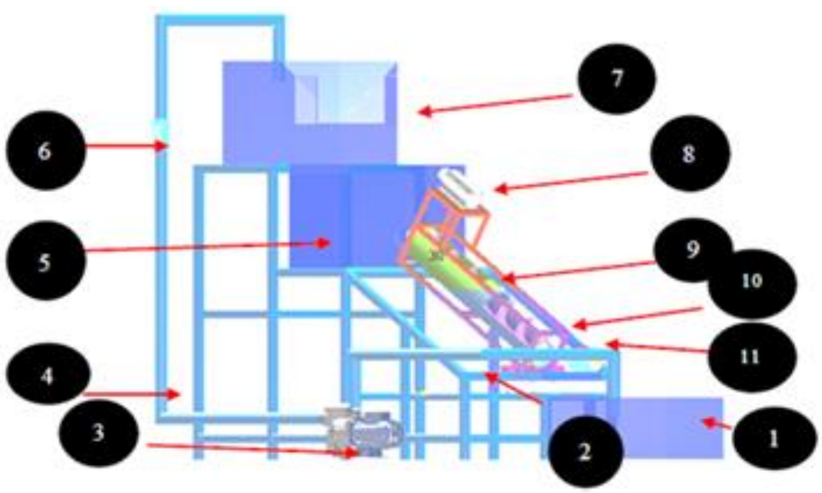

Figure 5. MHP Prototype With Archimedes Screw Turbine

Description:
1 = Water reservoir 1
2 = Suction pipe
3 = Pump
4 = Water supply pipe
5 = Water reservoir 3
6 = Ball valve
7 = Water reservoir 2
8 = DC Generator
9 = Archimedes screw turbine housing
10 = Archimedes screw turbine
11 = Water reservoir 4

3. RESULTS AND DISCUSSION

Figure 6 shows a graph of the level of water immersion against torque.

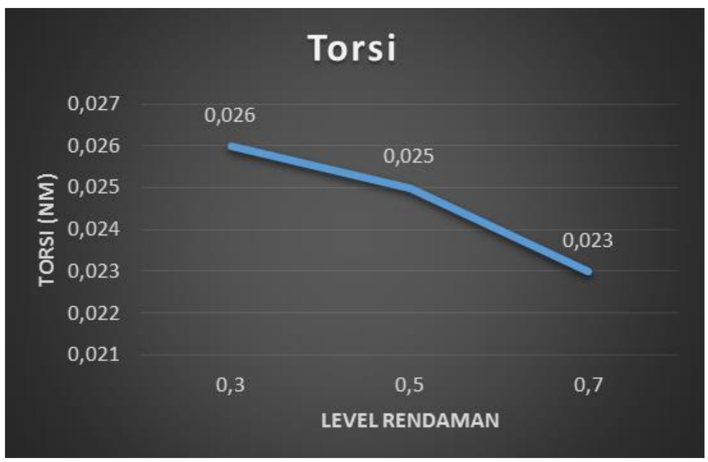

Figure 6. Graph of the Effect of Water Immersion Level on Torque

From Figure 6, it can be seen the effect of the water immersion level on the torque. The 0.3 immersion level has the highest torque value of 0.026 Nm, the 0.5 immersion has a torque value of 0.025 Nm, and 0.7 the smaller torque value of 0.023 Nm. The magnitude of the torque value depends on the hydraulic power and turbine rotation. Where the greater the hydraulic power, the greater the torque value. On the other hand, the larger the turbine rotation, the smaller the torque value.

In the Archimedes screw turbine, when the water immersion level I value increases, the torque value will decrease [4]. This condition is due to the back pressure on the last blade given by the water immersion level. If the immersion level is below the optimal point, namely I = 0.596, then there is a decrease in hydrostatic pressure on the last blade, which increases the torque value on the turbine. There is a reverse pressure in the exhaust channel when the water immersion level is at 60%, thus affecting the shaft power produced, and the torque value will also decrease due to the drag force [7].

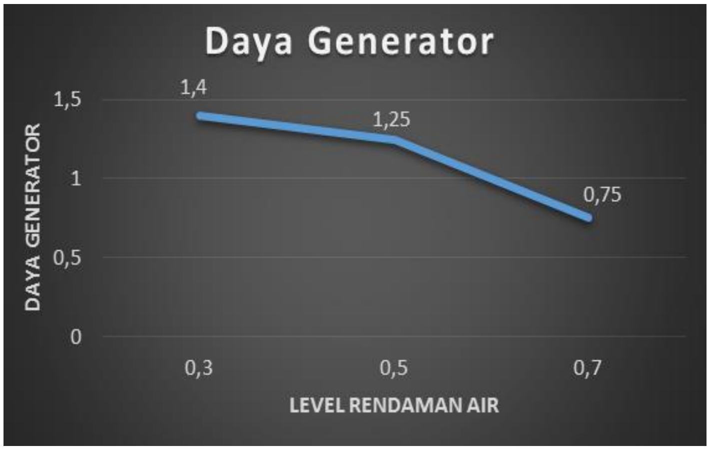

Figure 7. Graph of Effect of Water Immersion Level on Generator Power (Pout)

Figure 7 depicts the effect of the water immersion level on generator power (P_{out}).When a 0.3 water immersion produces 1.4 watts of power, in a 0.5 immersion, the resulting power is 1.25 watts, and in a 0.7 immersion, the resulting power is 0.75 watts.

Changes in the power of this generator will impact changes in the work efficiency of the Archimedes screw turbine [7]. The output power value changes slightly when the water immersion level is between 0% and 30% with various discharges. At the 0% water immersion level, it has a value greater than 30%. When the water immersion level reaches 60%, there is a decrease in the power value.

Figure 8 shows a graph of the effect of water immersion level on efficiency.

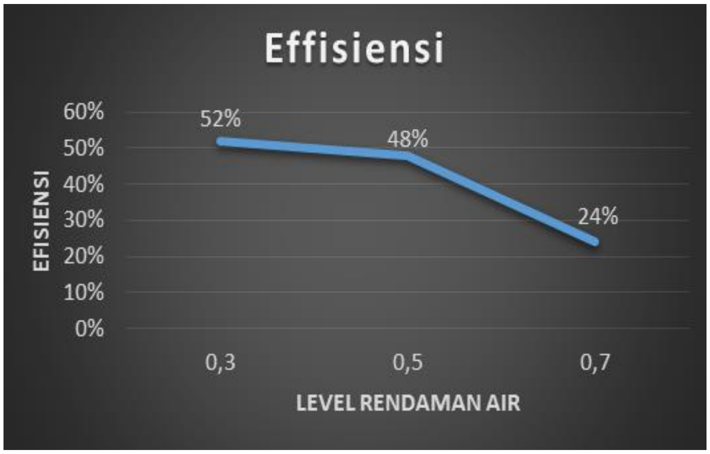

Figure 8. Graph of Effect of Water Immersion Level on Efficiency

From Figure 8, the effect of water immersion level on efficiency can be seen. When a 0.3 water immersion has a working efficiency of 52%, in a 0.5 immersion, the working efficiency is 48%, and in a 0.7 immersion, the operational efficiency is 24%.

Immersion is very influential on the work efficiency of the Archimedes screw turbine. The efficiency decreases as the immersion increases. However, the most dramatic reduction occurred between 0.5 and 1 immersion. When the water immersion level corresponds to the water level in the last (bottom) bucket, efficiency will be at its optimal point. The phenomenon is that water will try to enter the bucket when the water immersion level is at the optimal point. This phenomenon causes a decrease in turbine performance due to a slowdown in turbine rotation [7].

4. CONCLUSIONS

From the research that has been done, it can be concluded that the immersion level below the maximum point (I = 0.5) makes the turbine torque increase and vice versa. The immersion level has an inverse relationship with the generator power. The generator power drops by 0.15 watts at 0.3 to 0.5 immersion. Meanwhile, with a 0.5 to 0.7 immersion, the generator power decreases by 0.5 watts. The level of immersion has an inverse relationship with the working efficiency of the turbine, namely, in a 0.3 immersion, the working efficiency is 52%; at a 0.5 immersion, the working efficiency is 48%; and in a 0.7 immersion, the working efficiency is 24%.

5. REFERENCES

[1] SALEH, Z., SYAFITRA, M.F. “Analisis Perbandingan Daya Pada Saluran Pembawa Untuk Suplai Turbin Ulir Archimedes,” In : Simposium Nasional Teknologi Terapan 4, pp. 132–138, Yogyakarta, Nov. 2016.

[2] DODA, N., MOHAMMAD, H. “Analisis Potensi Pengembangan Pembangkit Listrik, ”Gorontalo Journal of Infrastructure Science Engineering, vl. 1, n. 1, pp. 1–10, Apr. 2018.

[3] SAPUTRA, M. A. T., WEKING, A. I., ARTAWIJAYA, I. W. “Eksperimental Pengaruh Variasi Sudut Ulir Pada Turbin Ulir (Archimedean Screw) Pusat Pembangkit Listrik Tenaga Mikro Hidro Dengan Head Rendah,” Majalah Ilmiah Teknologi Elektro, v. 18, n. 1, pp. 83–90, Jan. 2019.

[4] DELLINGER, G., TERFOUS, A., GARAMBOIS, P.A., GHENAIM, A., “Experimental Investigation and Performance Analysis of Archimedes Screw Generator,” Journal Hydraulic Research, v. 54, n. 2, pp. 197–209, Mar. 2016.

[5] JAMALUDIN, “Debit Air Optimum Model Screw Turbine Pada Pitch A=1,2 Ro Dan A=2 Ro Sebagai Penggerak Generator Listrik,” Jurnal Dinamika, v.3, n.1, 2018.

[6] SAROINSONG, T., THOMAS, A., MEKEL, a.n. “Desain Dan Pembuatan Turbin Ulir Archimedes Untuk Pembangkit Listrik Tenaga Mikrohidro,” In: Seminar Nasional Terapan Riset Inovatif, pp. TM 159-TM 169, Malang, Nov. 2017

[7] SONGIN, K., Experimental Analysis of Archimedes Screw Turbines, Master’s Theses, University of Guelph, Ontario, 2017.