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Performance Evaluation of Spiral Water Turbine

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Abstract

Water is a fundamental component of renewable energy and may produce power through the utilization of a water turbine. These turbines utilize electromechanical energy converters to harness the kinetic energy of flowing water. The research seeks to enhance and evaluate the existing spiral water turbine design, in addition to assessing the turbine's power production via testing. The mechanism and control system were analyzed, and a comprehensive design of the water turbine was created in SolidWorks. The testing was conducted at the Sungat Bantang waterfall, with evaluations performed at heights of 0.21m, 0.51m, and 0.87m. The turbine experienced two modes of operation: half submerged and fully submerged. The analysis of the findings is based on data collected during testing, which includes water velocity, current, voltage, and power output. The findings indicated that power output increases with water velocity as a result of increased kinetic energy in the flow. In the trials, the turbine's power output reached 28.99 W, 176.77 W, and 357.11 W under partially submerged conditions, corresponding to water velocities of 2.03 m/s, 3.16 m/s, and 4.13 m/s, respectively. Simultaneously, fully submerged conditions produced power outputs of 29.74 W, 132.34 W, and 312.34 W, respectively. Consequently, higher velocity results in increased power. In conclusion, although it was tested just at the rapid's minimal height of one meter, the turbine effectively generated energy.

1. Introduction

Water is a vital energy element and can generate renewable energy sources for a sustainable future [1]. Hydro energy, also known as hydropower, is a type of renewable energy that derives its origin from falling or flowing water under the influence of gravity. Globally, it is one of the most important sources of energy, contributing nearly 24% to the overall energy mix [2]. Over 15% of Malaysia's energy production comes from hydropower, making it the country's largest renewable energy source [3]. Hydropower is a flexible method of producing electricity in addition to being effective at it. Furthermore, the planning of hydroelectric projects heavily considers cost, underscoring the importance of the project's financial success [4]. The Archimedes spiral turbine, also known as a spiral turbine, employs blades shaped like spirals. The architecture of the turbine enables it to effectively harvest energy from fluid fluxes, be they air or water.

A spiral-shaped rotor with blades intended to capture the kinetic energy of the fluid flow makes up the structure of a spiral turbine. The turbine's spiral design allows it to efficiently extract energy from the fluid under a variety of flow conditions, which makes it appropriate for a number of uses, including the conversion of tidal energy [5]. The spiral water turbine has the ability to generate faster turbine rotation when compared to a traditional water intake, indicating the spiral design's efficiency in power generation [6]. Scientists have also looked at the hydrodynamics of a marine current energy converter with profiling floats and noticed that the spiral blade has a specific torsion angle and can start itself easily. This shows that it could be used to convert energy efficiently in marine current energy conversion [7].

The parameters that affect the performance of turbines are similar for both spiral wind turbines and spiral water turbines, including the number of blades, blade profile, and water velocity. Studies have demonstrated that altering the number of blades can significantly influence a turbine's power coefficient. However, the study discovered that adding additional blades will not generate more energy and can instead raise manufacturing and maintenance expenses [8]. Furthermore, the blade profile significantly influences the performance of the Archimedes spiral water turbine. A study focused on how the blade angle affected the rotating speed of the various turbine models. The data clearly show that there is an inverse relationship between the blade angle and the maximum power coefficient [9]. Next, water's kinetic energy is an important quantity in many applications related to fluid dynamics and hydraulics. For example, research indicates that the turbine power output will increase by 3.5 times when the free stream velocity increases from 1 m/s to 1.5 m/s. The power coefficient does not change even with the increase in input velocity. At velocities of 1 to 2 m/s, the highest power coefficient is approximately 32% to 35%. As a result, it is believed that selecting a higher current velocity is appropriate for the turbine design [8].

Several researchers have conducted studies on small-scale hydro turbines in Malaysia, including one study [10], which explored the potential for small-scale hydropower in Malaysia. It concentrated on two locations: Gunung Ledang, Tangkak, Johor, and Kg. Tual, Raub, Pahang. The Gunung Ledang site can create 4.75 kW with Kaplan or crossflow turbines for RM0.159 per kWh, while the Kg. Tual site can generate 266.99 kW with Pelton or Turgo turbines at a cost of RM0.017 per kWh.

2. Methodology

The procedures started with the fabrication process, a multi-step process that involved acquiring the necessary materials and tools, followed by assembly before any testing could commence. The next step involved setting up the electrical connection, which required the power-generating motor to be connected to other components for proper operation. Following this, the entire system was assembled. Following the assembly process, the test run confirmed the water turbine's ability to generate energy successfully. The experiment commenced by situating the water turbine in a location that allows it to operate under both half-submerged and fully submerged conditions, followed by the measurement of three different heights of the rapid. The experiment then set up the multimeter to measure the voltage and current outputs from the DC motor. After all readings were taken, the calculation of the power output was calculated by using the formula related to this study.

2.1 Design and Assembly

Initial steps consist of enhancing the design of the water turbine, followed by the development of electrical circuits for the purpose of energy generation and storage. Once it is complete, the turbine is put through tests in a real-world environment. An analytical calculation is eventually performed in order to determine the maximum power output of the turbine. For the purpose of presenting the results, both the power (in Watts) generated, and the efficiency of the system will be utilized. In this experiment, the components were then assembled to form a single system. The energy storage system, gear pulley system, and engine were all acquired. The experimental apparatus comprised the subsequent equipment and materials:

Table 1 *List of apparatus and materials used to build spiral water turbine*

List of Equipment and Materials	Amounts (Units)
Fabricated rotor	1
Supporting frame	1
Ball bearing	2
115cm of shaft	1
12V DC motor	1
500ml waterproof coating spray	1
Driving gear	1
Motor gear	1
Steel chain	1
Zink sheet	1
Battery	1

Coupling	1
Connecting wire	4
Inverter	1
Solar charge controller	1
Multimeter	1

2.2 Power Output Calculation

Next, the formula related to obtaining the results to determine the power generated. The height of a waterfall directly influences the water's flow velocity. As water descends from a higher altitude, its potential energy transforms into kinetic energy as it speeds down. The formula below can be used to compute the velocity of the water at the foot of the waterfall in accordance with the principle of conservation of energy.

$$v = \sqrt{2gh} \tag{1}$$

The quantity of power produced or created by a system or apparatus is referred to as its power output. In this context, the rotating turbine blades produce mechanical or electrical power, which we refer to as power output. There are two formulas for determining power output:

- Power output from Betz equation

$$P_{out,max} = 0.5926 \times \frac{\rho A v^3}{2} \tag{2}$$

Note that invariant 0.5926 is the coefficient variation of maximum power ($\boldsymbol{C_{p,max}}$) or Betz Coefficient.

- Electrical power output

$$P = IV \tag{3}$$

2.3 Submersion Condition

The heights of the rapid at the waterfall were chosen to compare the power output depending on the water velocity. The testing is conducted on two different submersion levels, which are partially submerged and fully submerged.

(a) **(b)**

Fig. 1 *Submersion level (a) Partially submerged; (b) Fully submerged*

3. Results and Discussion

The study evaluates the performance of a spiral water turbine under varying submersion levels and flow conditions. Tables 2 and 3 display the data from theoretical calculations to determine the generated power output, as well as the experimental calculations based on Equation 3. The analytical calculations rely on the Betz equation, which includes parameters such as height, water velocity, and cross-sectional area, while the experimental calculations utilize water velocity, voltage, and current. The readings of voltage and current were being observed while the turbine was operated. The theoretical calculations indicate that the turbine can generate a maximum output of 136.33 W, 514.23 W, and 1148 W at heights of 0.21 m, 0.51 m, and 0.87 m, respectively. owever, during the experiment, the turbine's power output increased to 28.99 W, 176.77 W, and 357.11 W for partially submerged conditions, and to 29.74 W, 132.34 W, and 312.34 W for fully submerged conditions. Theoretical outputs (calculated using the Betz equation) for maximum potential power were substantially higher than experimental results. For example, at a height of 0.87 m, the theoretical maximum was 1148 W, compared to an experimental maximum of 357.11 W.

Table 2 *Data of theoretical calculation*

Height, h (m)	Cross sectional area, A (m^2)	Water velocity, v (m/s)	Maximum power output, P_{out} (W)
0.21	0.055	2.03	136.33
0.51	0.055	3.16	514.23
0.87	0.055	4.13	1148.00

Table 3 *Data of experimental calculation*

Height (h), m	v, m/s	Voltage (V), V				Current (I), A				P_elec (P), W
		1	2	3	Avg	1	2	3	Avg	
Half-submerged										
0.21	2.03	2.049	1.949	2.074	2.024	14.69	14.98	13.39	14.35	28.99
0.51	3.16	4.145	4.244	4.310	4.233	43.61	38.78	42.98	41.79	176.77
0.87	4.13	5.244	5.983	6.821	6.016	58.43	43.28	76.25	59.32	357.11
Fully submerged										
0.21	2.03	1.581	1.643	1.581	1.602	19.21	19.21	17.35	18.59	29.74
0.51	3.16	3.542	3.648	4.465	3.885	35.02	32.85	34.18	34.02	132.34
0.87	4.13	7.112	5.957	6.824	6.631	48.56	45.66	47.11	47.11	312.34

Fig. 2 shows the result of power output against water velocity, which indicates a positive relationship between these two variables. The power output is proportional to the water velocity. As the water velocity rises, the turbine's blade interacts more forcefully with moving water, which causes the turbine to spin faster and generate more electricity. Fig. 3 shows the graph efficiency against water velocity under two submersion conditions, which are partially submerged and fully submerged. The efficiency of the partially submerged turbine rose from 0.21 at a water velocity of 2.03 m/s to 0.34 at 3.16 m/s. However, efficiency slightly dropped to 0.31 at a higher velocity of 4.13 m/s. Meanwhile, the fully submerged turbine showed a consistent rise in efficiency as the water velocity increased.

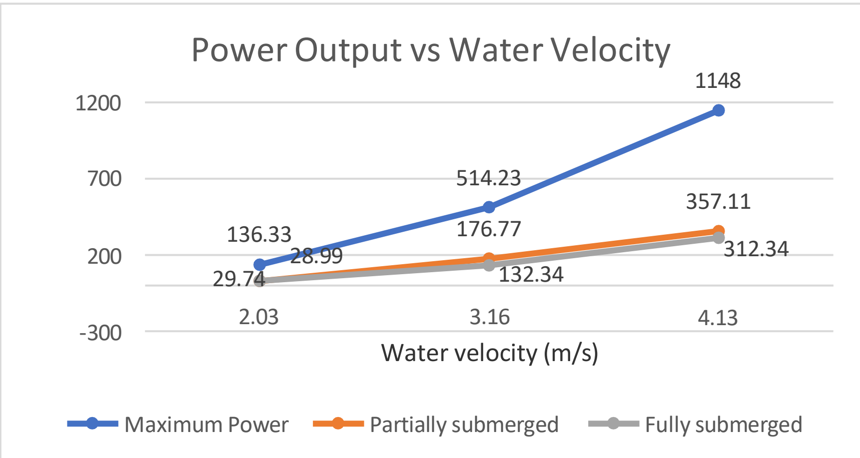

Fig. 2 *Graph power output (W) against water velocity (m/s)*

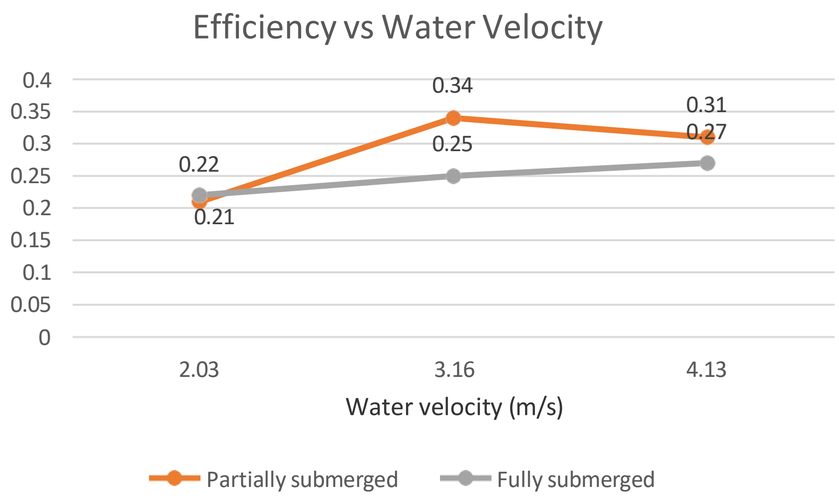

Fig. 3 *Graph efficiency of turbine against water velocity (m/s)*

4. Conclusion

This study effectively accomplished its goals of improving the design and assessing the performance of a spiral water turbine at different submersion levels and water velocities. The initial aim was successfully achieved, which involved improving the current design of the spiral water turbine prototype. The spiral water turbine can effectively generate energy, even at varying heights of rapids, as demonstrated in test runs. The solar charge controller is effective in storing power in the battery, as evidenced by conducted tests. The study also aims to evaluate the power generation of the spiral water turbine through testing. The power output increases with the water velocity of the waterfall, accomplishing the objective. The elevation of the waterfall correlates positively with the power output, due to the increased kinetic energy available for water flow. The power outputs recorded at heights of 0.21 m, 0.51 m, and 0.87 m for the partially submerged turbine were 28.99 W, 176.77 W, and 357.11 W, respectively. At heights of 0.21 m, 0.51 m, and 0.87 m, the power outputs for totally submerged turbines were 29.74 W, 132.34 W, and 312.34 W, respectively. The study highlights the feasibility of spiral turbines and identifies substantial areas for improvement to increase their practical application. To make spiral water turbines work better and make it easier for them to be used in renewable energy systems, new research should look into ways to improve the design of the blades by changing their angles, materials, and profiles. This will help them convert energy more efficiently and lose less when the water is moving quickly. To make the results more general and understand how site-specific factors affect the results, it is also important to expand the testing parameters by doing experiments with a range of waterfall heights, flow rates, and environmental conditions.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Siti Nurhajar Bahtiar, Sofian Mohd;* ***data collection:*** *Siti Nurhajar Bahtiar, Sofian Mohd;* ***analysis and interpretation of results:*** *Siti Nurhajar Bahtiar, Sofian Mohd;* ***draft manuscript preparation:*** *Siti Nurhajar Bahtiar, Sofian Mohd. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] S.J. Williamson, B.H. Stark, J.D. Booker. (2014). Low head pico hydro turbine selection using a multi-criteria analysis, *Renewable Energy*, 61, 43-50. https://doi.org/10.1016/j.renene.2012.06.020
[2] Khandekar, A., Antucheviciene, J., & Chakraborty, S. (2015). Small hydro-power plant project selection using fuzzy axiomatic design principles. *Technological and Economic Development of Economy*, 21(5), 756-772. https://doi.org/10.3846/20294913.2015.1056282
[3] Afrouzi, H., Wimalaratna, Y., Ahmed, J., Mehranzamir, K., Liew, S., Wooi, C., & Siddiquea, B. (2021). "A comprehensive review on available/existing renewable energy systems in Malaysia and comparison of their capability of electricity generation in Malaysia" [Review of the book "Entropy and Exergy in Renewable Energy" by Wang, L.S., Cao, W., & Hu, S.B.]. *IntechOpen eBooks.* https://doi.org/10.5772/intechopen.96586
[4] Yap, C. and Yap, C. (2021). Hydropower generation in Malaysia: a review and some notes. *Engineering Science & Technology*, 24-31. https://doi.org/10.37256/est.3120221074
[5] Sakaguchi, M., Kinoue, Y., Hirayama, K., Murakami, T., Shiomi, N., Imai, Y., ... & Takao, M. (2021). Bidirectional impulse turbine with spiral flow collector for tidal energy conversion. *Journal of Fluids Engineering*, 143(12). https://doi.org/10.1115/1.4052176
[6] Hidayat, M., Ronilaya, F., Eryk, I., & Joelianto, G. (2020). Design and analysis of a portable spiral vortex hydro turbine for a Pico hydro power plant. *IOP Conference Series Materials Science and Engineering*, 732(1), 012051. https://doi.org/10.1088/1757-899x/732/1/012051
[7] Wu, S., Liu, Y., & An, Q. (2018). Hydrodynamic analysis of a marine current energy converter for profiling floats. *Energies*, 11(9), 2218. https://doi.org/10.3390/en11092218
[8] Wu, H. N., Chen, L. J., Yu, M. H., Li, W. Y., & Chen, B. F. (2012). On design and performance prediction of the horizontal-axis water turbine. *Ocean Engineering*, 50, 23-30.
[9] Labib, A., Gawad, A., & Nasseif, M. (2020). Effect of blade angle on aerodynamic performance of Archimedes spiral wind turbine. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, 78(1), 122-136. https://doi.org/10.37934/arfmts.78.1.122136
[10] M. Musa, J. A. Razak, M. M. Tahir, I. S. Mohamad and M. N. Othman (2018). Small Scale Hydro Turbines for Sustainable Rural Electrification Program. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, 49(2).