

## Pico-hydro power generation using a small water turbine for the tertiary canal application

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### ABSTRACT

*This study aimed to develop a pico-hydro water turbine capable of generating electricity from a tertiary irrigation canal, harnessing water flow as a sustainable power source for rural communities. Various blade types and water barrier heights were tested, with data analysed using a factorial arrangement in a Completely Randomised Design. Results showed that the water barrier height significantly influenced power output, with a maximum theoretical power of 613 W at a barrier height of 0.4 m. The turbine achieved a rotational speed of 43 rpm and generated 63 W of actual power, corresponding to an efficiency of 13% at a barrier height of 0.3 m. Financial analysis indicated that the system could reduce a household's annual electricity bill by 11%, confirming its technical feasibility and economic viability as a small-scale renewable energy solution.*

*Keywords: Tertiary canal, water barrier, efficiency, water power, water turbine*

### INTRODUCTION

Renewable energy is considered a vital resource in many countries worldwide (Alnatheer, 2005). Hydropower, in particular, represents the most prevalent form of renewable energy, responsible for 71 per cent of all renewable electricity generation and 16.4 per cent of the total electricity used globally (Water Science School, 2018).

Despite hydropower's dominant role in global energy production, less than 15% of the world's primary energy consumption is derived from renewable sources, with hydropower and wood fuels primarily meeting the energy needs of developing nations

(Duic & Carvalho, 2004). The demand for renewable energy has increased significantly, accounting for approximately 19% of global energy consumption by 2013 (REN21, 2013).

Abdul et al. (2022), as cited by Quipo et al. (2024), suggest that a sustainable energy supply can be achieved by utilising renewable energy sources. Increased energy production from renewable energy sources is one approach that can help reduce greenhouse gas emissions from burning fuels and lay the groundwork for a cleaner and greener world. Quipo et al. (2024) suggest that an alternative renewable energy

source is needed to reduce the costs associated with water pumping.

Storage hydropower is the most common type (World Energy Council, 2016). However, micro-hydropower is gaining popularity due to its clean and renewable nature, particularly in rural areas where grid connectivity is absent (Gurung, Ghimeray & Hassan, 2012). A micro-hydropower plant can operate without the need for a dam, utilising a run-of-river system to generate electricity (Bhattacharyya & Srivastava, 2009), and has the potential to improve the quality of life for rural communities significantly (Fulford, Mosley, & Gill, 2000; Michael & Jawahar, 2017).

In countries like the Philippines, where many people lack access to electricity, micro-hydropower can provide a sustainable solution for rural electrification. As of 2021, approximately 1.62 million people, or 4% of the population, still lack access to electricity, underscoring the need for affordable and accessible energy solutions (DOE, 2021). The use of micro-hydro plants has the potential to supply affordable energy, reducing electricity costs while supporting local communities (Pasalli & Rehiara, 2014).

Hydropower works on the principle of converting the kinetic energy of flowing or falling water into sound mechanical energy via turbines or water wheels, which can then be converted into electricity (Yah, Oumer & Idris, 2017). The size and scale of hydropower systems vary, with smaller micro-hydro systems being particularly effective for rural electrification. A key component in these systems is the turbine, which

has replaced the traditional water wheel used in earlier technologies (Paish, 2002). Despite the benefits, micro-hydro systems do face challenges such as high initial costs and site-specific installations (Smits & Bush, 2010).

Tertiary irrigation canals, which are smaller branches from secondary canals used by farmers to withdraw water for irrigation, are an untapped resource for small-scale hydropower generation. According to Adlan, Saptomo, and Prastowo (2021), while the discharge in tertiary canals is low, they still hold potential for power generation.

To date, limited studies have been conducted on the interaction between blade configuration (fixed and flip) and water head in tertiary canal infrastructures. Addressing this research gap is essential.

Designing and implementing pico-hydro turbine solutions in such settings would also support Sustainable Development Goal 7, which aims to ensure access to affordable, reliable, sustainable, and modern energy for all (United Nations, 2015).

This study aims to harness this potential by employing small cross-flow turbines with either flip or fixed paddles to generate electricity, thereby providing a local source of power for lighting and charging appliances in rural areas.

## **MATERIAL AND METHODS**

### **Conceptual Framework of the Study**

This study was initiated in response to the growing challenges in meeting the country's electricity demand,

particularly for residential lighting applications. It aims to provide consumers with an alternative power source and a reliable backup supply during grid outages, while also addressing the rising cost of electricity.

A pico-hydro water turbine was designed and fabricated to harness the kinetic energy of water flowing through a tertiary irrigation canal and convert it into electrical energy. The generated power can be utilised to supply electricity to nearby households. Additionally, the project supports the promotion and integration of renewable energy technologies within the community. Figure 1 illustrates the study's flowchart.

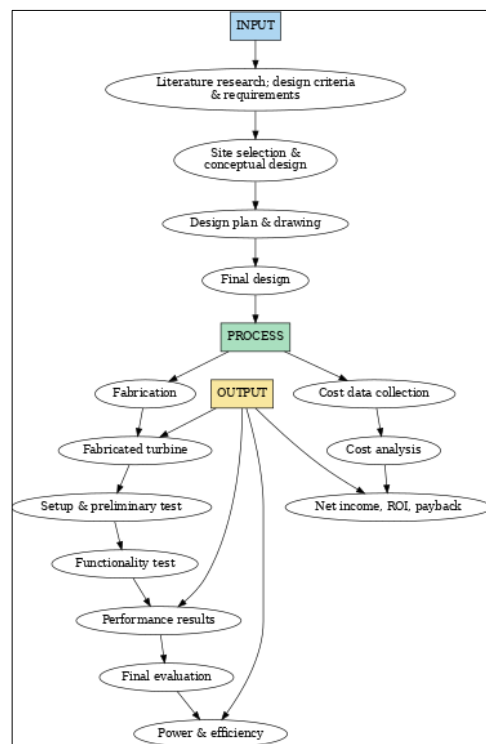


Figure 1. Flow chart of the study

### Preliminary Design of a Water Turbine

A preliminary survey was conducted to select a suitable site for the turbine

installation in Brgy. Pieza, Villaverde, Nueva Vizcaya, near houses and rice fields. The canal had a height and width of 0.71m, with an average water depth of 0.15m under normal conditions. Using the float method, the travel distance was 3m, and the average travel time was 1.99s (from five trials). The cross-sectional water area was 0.12m<sup>2</sup>, and the average water velocity and flow rate were 1.21m/s and 0.097m<sup>3</sup>/s, respectively. A CAD drawing (Figure 2) of the small water turbine was created, including the runner blades, disc, shaft, housing, power transmission assembly, DC generator, reducer, and electric load board.

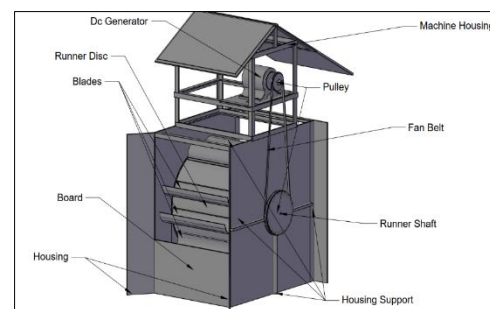


Figure 2. CAD design of a small water turbine

### Fabrication and Description of the Small Water Turbine

Before fabricating the water turbine, the availability of materials in the local market was ensured to align with the approved design. Construction involved measuring, cutting, drilling, welding, assembling, and finishing. The turbine (Figure 3) was designed as an environmentally friendly, easy-to-operate, and transportable generator for small-scale water sources, such as tertiary irrigation canals. Its dimensions are 810 x 690 x 1320 mm, and it weighs 50 kg. The turbine's runner is 450 x

500 x 550 mm, with 12 PVC blades fixed to a 450 mm G.I. disc. The runner shaft is made from hollow steel. The housing is made of angle bars and G.I. sheets, and certain parts are detachable.

The power transmission system includes a driver pulley (70 mm), a driven pulley (280 mm), and two belts (1067 mm and 1880 mm). A 3 hp DC motor with a 4000-rpm max speed, paired with a 9:1 speed reducer, powers the generator. The system includes a 12V, 12 ampere-hour battery, a 10A charge controller, and a 500W inverter for converting DC to 220V AC, making it suitable for small-scale electricity generation, particularly in rural areas. The turbine operates by capturing falling water with its blades, spinning the reducer and generator to produce electricity.



Figure 3. Fabricated a small water turbine

### Experimental set-up and procedures

A performance test (Figure 4) was conducted to assess the overall machine performance under normal working conditions on a sunny day. Treatments were randomly assigned, and test materials were prepared and labelled according to the experimental layout. Instruments were calibrated before measurements, and initial data on water head and velocity were recorded. The test followed a set sequence, measuring

the head at the water inlet and outlet, as well as the rotating components. The turbine's actual power output was evaluated by charging a battery with a 5-minute timer, using electrical bulbs of varying power ratings (3W to 50W). The load was increased gradually to determine maximum power output.

Data were analysed using a two-factor factorial in a Completely Randomised Design (CRD) with three replications, involving two blade types (folding and fixed) and three water barrier heights (0.3 m, 0.4 m, 0.5 m), totalling six treatments and 18 experimental units. The Least Significant Difference (LSD) test was used to identify significant differences.

Previous studies have demonstrated that water height plays a crucial role in turbine performance, with higher heads typically yielding greater power output (Syahnakri et al., 2024). Furthermore, folding (flip) blade designs have been reported to deliver higher efficiency than fixed-blade waterwheels under the same operating conditions, although with slightly reduced stability (Yang et al., 2023).



Figure 4. Experimental Set-up

### RESULTS AND DISCUSSION

The overall performance of the device, using two different types of blades and three levels of water barrier, is presented and discussed below. The parameters include turbine RPM, theoretical power, the

voltage developed by the turbine, actual power, and the efficiency developed by the turbine.

### Mean theoretical power

Comparing the height of the water barrier of 0.3m, 0.4m, and 0.5m, and the theoretical power produced by the water in the irrigation canal with 472, 578, and 613 watts, respectively. It shows by increasing the height of the water barrier also increases the theoretical power of the turbine. The findings suggest that the height of the water barrier is directly proportional to theoretical power output. This is due to the impact force of water on the turbine blade. This finding was supported by Quaranta's (2017) study, which stated that when a weir is installed, the power output increases with the height of the weir due to the elevation of the water entry point, thereby increasing the potential energy. Moreover, the head of the water corresponds to the power output of a turbine.

### Turbine rotation

Figure 5 revealed that a fixed type of blade with a 0.3m water barrier height produced the highest rpm at 46, while the lowest rpm, 29, was recorded with a fixed blade type at a 0.5m water barrier height. The analysis of variance revealed that neither the blade type nor the water barrier height alone was statistically significant, with p-values of 0.2838 and 0.4526, respectively, both of which exceeded the 5% level of significance. However, the combined effect of the blade type and water barrier height had a significant impact on turbine rotation, with a p-value of 0.0292,

which is less than the 5% significance level.

This suggests that both the blade type and the water barrier height have a significant influence on the turbine rpm. Specifically, the interaction effect indicates that the relationship between the two factors is not independent; instead, their combined influence leads to a noticeable difference in the observed results. Safdar et al. (2020) state that an increase in water flow rate results in an increase in the rpm of the turbine shaft. However, this relationship is not universal and can vary depending on the machine's design and characteristics.

According to Chughtai (2023), changing the load affects the engine's RPM. As the load on an engine increases, its torque decreases, resulting in a lower RPM. This occurs because the load imposes resistance on the turbine's rotation, requiring more torque to maintain the same rotational speed.

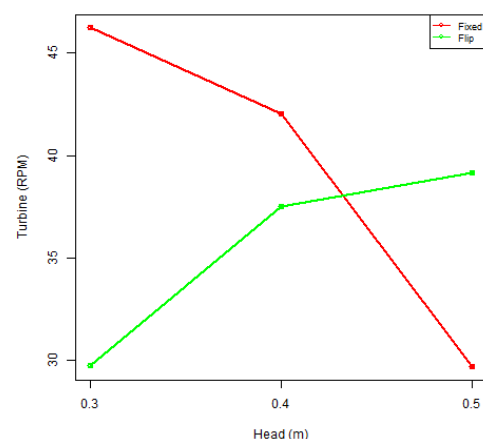


Figure 5. Interaction effect of blade type and water head on turbine rotational speed

### Actual power

The average output, as influenced by the blade type and water barrier height, is shown in Figure 6. The highest actual power produced was 63W, achieved with a flip-type blade and a 0.3m water barrier height. In contrast, the lowest actual power output, 49W, was recorded at a 0.5m water barrier height using the same blade type. In comparison, the flip-type blades produced a higher power output than the fixed-type blades. However, the variance analysis indicates that neither the blade type, water barrier height, nor their interaction significantly affects the actual power produced by the turbine, with p-values of 0.147, 0.0808, and 0.0802, respectively, all of which are higher than the 5% level of significance. This lack of significant effect can be attributed to inefficiencies encountered during the experiment, including mechanical losses, electrical losses, fluid dynamic losses, mismatched components, and various experimental issues.

According to Zainuddin et al. (2009), improper sizing or selection of turbine components can result in suboptimal system performance. One of the key factors lacking in the study was proper gearing and management of turbulent flow, which contributes to increased energy dissipation and higher fluid dynamic losses.

It is further suggested that the most significant power loss in a pico-hydro system typically occurs when power is converted into rotational mechanical energy by the turbine blades, resulting in a loss of up to 30%. Another 20-30% of the energy is lost in the generator when mechanical power is converted into

electricity. Thus, the general rule of thumb for estimating potential power output efficiency is typically around 50%.

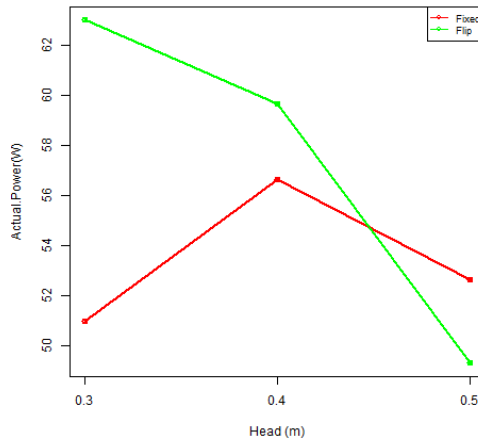


Figure 6. Interaction effect of blade type and water head on turbine actual power

### Efficiency of a water turbine

Figure 7 shows that the highest efficiency (13%) was achieved with a flip-type blade at a water barrier height of 0.3 m, while the lowest (9%) occurred with a fixed-type blade at a height of 0.5 m. Although the blade–barrier interaction was not significant ( $p = 0.0635$ ), both factors independently affected efficiency ( $p < 0.05$ ). Overall, the flip-type blade outperformed the fixed type, and lower barrier heights improved efficiency by reducing turbulence and mechanical losses.

However, the relatively low efficiency (8–13%) of both turbine blade types can be attributed to mechanical losses occurring in the power transmission system from the turbine pulley to the speed reducer, and subsequently to the electric generator. As illustrated in Figure 3, the setup incorporates multiple pulley stages, which contribute to frictional

and transmission losses between the turbine, speed reducer, and generator. These results align with the findings of Dendy, Budiarmo, and Warjito (2019), who reported that lower angles produced higher efficiency. Interestingly, while efficiency is generally expected to drop with lower rotational speeds, the experiment showed higher efficiency at lower speeds. This supports Kueh et al. (2017), who noted that reduced speed leads to higher efficiency due to lower load-related losses.

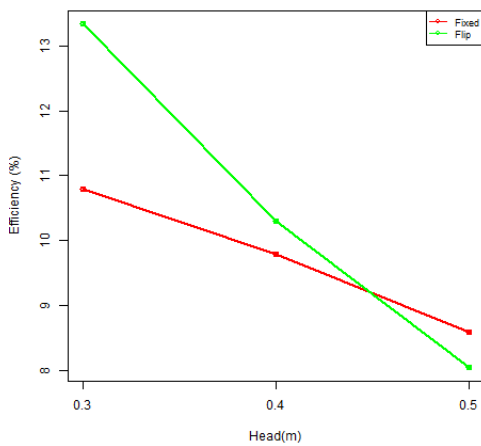


Figure 7. Interaction effect of blade type and water head on turbine efficiency

**Cost Analysis**

A cost analysis was conducted to assess the economic viability of the water turbine for electricity generation. As shown in Table 2, the total fabrication cost, including labour, was ₱29,095. The turbine operates for 270 days annually at 24 hours a day, producing 408 kWh. The annual fixed cost is ₱8,110, and the variable cost is ₱2,909. The breakeven point is 623 kWh, at which the electricity produced equals the total project cost.

With an annual cost of ₱11,020 and an Annual Energy Production (AEP) of 408 kWh at the NUVELCO grid rate of ₱15/kWh, the system yields a net income of ₱6,120 per year, calculated using Equation 1. Based on Equations 2 and 3, the investment cost can be recovered in approximately 4.75 years, with a Return on Investment (ROI) of 21%. The low recovery of the turbine is due to its high initial and operating costs.

With this, the net income represents the savings from using the turbine, which reduces reliance on the electricity grid supplied by the electric cooperative. In Nueva Vizcaya, a typical household consumes approximately 3,600 kWh of electricity annually, which translates to an annual electricity cost of ₱53,964 at a rate of ₱15/kWh. The water turbine’s output of 408 kWh per year can offset approximately 11% of this cost. While the generated power is insufficient for operating high-consumption appliances such as refrigerators or televisions, it is well-suited for supplying electricity for lighting and charging small devices like mobile phones.

$$Net\ Income = AEP \times rate/kWh \text{ (Eq. 1)}$$

$$PbP = \left( \frac{Investment\ Cost}{Net\ Income} \right) \times 100 \text{ (Eq. 2)}$$

$$ROI = \left( \frac{Net\ Income}{Annual\ Cost} \right) \times 100 \text{ (Eq. 3)}$$

Table 2. Economics of using the water turbine

PARAMETER	VALUE
Investment Cost, Php	29,095
Total Annual Cost, Php	11,020
Total Fixed Cost, Php/yr	8,110
Total Variable Cost, Php/yr	2,909

Useful Life, yrs	5
Taxes, Insurances and Shelter, 3% of IC, Php	873
Repair & Maintenance, (10%of IC), Php/yr	2909
Depreciation, 10% of IC, Php	5237
Cost of Electricity from off-grid source, Php/kWh	15

Operating Period, days/yr	270
Annual Energy Production, kWh	408
Net Income, Php/yr	6,120
Payback Period, years	4.75
ROI %	21

### CONCLUSION

The fabricated water turbine proved effective for small-scale power generation in rural areas, with the flip-type blade at 0.3 m barrier height yielding the highest efficiency (13.33%) and actual power (63 W). It can offset up to 11% of household electricity costs, making it best suited for lighting and charging small devices. Further studies should optimise blade design, explore hybrid or variable-pitch blades, reduce pulley stages, test long-term durability in canals, and assess integration with energy storage for continuous supply.

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### REFERENCES

- Abdul Baser Qasimi, Vahid Isazade, & Ara Toomanian (2022). A review of sustainable and renewable sources of energy for Afghanistan. *Journal Renewable Energy & Mechanics (REM)*. Vol. 05 No.02. DOI: 10.25299/rem.2022.vol5(02).10226.
- Adlan, S K. Saptomo, & Prastowo S. (2021). Pico hydro Turbine Building Design Utilizing Irrigation Waterpower: CFD Simulation. *IOP Conference Series: Earth and Environmental Science*.  
<https://iopscience.iop.org/article/10.1088/1755-1315/871/1/012038/pdf>
- Alnatheer, O. (2005). The potential contribution of renewable energy to electricity supply in Saudi Arabia. *Energy Policy* 2005;33(18):2298-2312.
- Bhattacharyya, S. & Srivastava, L. (2009). Emerging regulatory challenges facing the Indian rural electrification programme. *Energy Policy* 37, 68–79.
- Chughtai, M. A. (2023). RPM and Torque in Engines: Understanding the Relationship. <https://www.linkedin.com>.
- Chunxia Yang, Qian Li, Xueyuan Hu, Yuan Zheng, Jiawei Wu, Shengzhi Su, An Yu (2023). Fish injury analysis and flip-blade type optimization design of an undershot waterwheel. *Renewable Energy*, Volume 219, Part 1. <https://doi.org/10.1016/j.renene.2023.119407>
- Dendy Adanta, Budiarto, Warjito (2020). The effect of channel slope angle on breastshot waterwheel turbine performance by numerical method. *Energy Reports* 6: 606–610

- Department of Energy (2021). 37th Status Report on EPIRA Implementation. Philippine Power Situation. Retrieved from: <https://www.doe.go.ph/>
- Duic, N. & Carvalho, G. (2004). Increasing renewable energy sources in island energy supply: case study Porto Santo. *Renewable and Sustainable Energy Reviews*, 2004; 8(4): 383–399.
- Fulford, D., Mosley, P. and Gill, A. (2000). Recommendations on the use of micro hydropower in Rural Development. *J. Int. Dev.* 12, 975–983.
- Gurung, A., Ghimeray, A. & Hassan, S. (2012). The prospects of renewable energy technologies for rural electrification: A review from Nepal. *Energy Policy* 40, 374–380.
- Kueh, T C. S L Beh, Y S Ooi, & D G Rilling (2017). Experimental study to the influences of rotational speed and blade shape on water vortex turbine performance. *IOP Conf. Series: Journal of Physics: Conf. Series* 822 (2017) 012066 doi:10.1088/1742-6596/822/1/012066
- Michael, P., Jawahar, C., (2017). Design of 15 kW Micro hydro power plant for rural electrification at Valara. *Energy Procedia* 117, 163-171.
- Paish, O. (2002). "Small hydro power: technology and current status." *Renewable and Sustainable Energy Reviews*, 6, no. 6: 537–556.
- Pasalli, Y.R., Rehiara, A. (2014). Design planning of micro hydropower plant in Hink River. *Procedia Environ. Sci.* 20, 55–63.
- Quaranta, E. (2017). Optimization of breastshot water wheels performance using different inflow configurations. ResearchGate. <https://www.researchgate.net>
- Quipo, J. Quipo, R.A., Marcos, R., Bassi, R., De Guzman, P.M., Rosario, L.J. (2024). Design, Fabrication, and Testing of Small Wind Pump. *Journal Renewable Energy & Mechanics (REM)*. Vol. 07 No.02. pp. 133–143.
- Ren21, Renewables (2013): global status report, ([www.ren21.net](http://www.ren21.net)), [accessed on 25/6/2023].
- Safdar, I., Sultan, S., Raza, H. A., Umer, M., & Ali, M. (2020). Empirical analysis of turbine and generator efficiency of a pico hydro system. *Sustainable Energy Technologies and Assessments*. <https://www.sciencedirect.com/science/article/abs/pii/S2213138819305284>
- Smits, M., & Bush, S. (2010). A light left in the dark: The practice and of pico hydropower in the lao PDR. *Energy Policy*, 38(1), 116–127.
- Syahnakri, F. R., Warjito, W., Budiarmo, B., & Mizan, M. (2024). Effect of water height variations on the blades to the turbine performance of undershot pico-hydro turbine. *AIP Conference Proceedings*, 3215(1), Article 110005. <https://doi.org/10.1063/5.0237045>.
- United Nations. (2015). Sustainable Development Goal 7: Ensure access to affordable, reliable,

- sustainable and modern energy for all. United Nations. <https://sdgs.un.org/goals/goal7>
- World Energy Council (2016). World energy council resources 2016 summary. Retrieved from: <https://www.worldenergy.org/>
- Yah, N., Oumer, A., Idris, M. (2017). Small scale hydropower as a source of renewable energy in Malaysia: A review. *Renew. Sustain. Energy Rev.* 72, 228–39.
- Zainuddin, H., Yahaya, M. S., Lazi, J. M., Basar, M. F. M. and Z. Ibrahim (2009). Design and development of pico-hydro generation system for energy storage using consuming water. *World Academy of Science, Engineering and Technology* 35. <https://www.doc-developpementdurable.org/file/Energie/hydraulique/Design%20and%20Development%20of%20Pico-hydro.pdf>