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Microhydro Water Turbine Design and Construction for Energy Supply in Remote Rural Areas

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ABSTRACT

Purpose: *The design and development of microhydro turbines represent an effective solution for addressing energy access challenges in remote rural areas. This study focuses on the design, simulation, and laboratory testing of a Crossflow microhydro turbine tailored for rural electrification.*

Subjects and Methods: *Hydrological data from a representative rural site were analyzed to determine flow rate and head potential. Based on these parameters, a Crossflow turbine prototype was designed using locally available materials. The design was validated through Computational Fluid Dynamics (CFD) simulations and prototype laboratory testing.*

Results: *The results indicate that the turbine operates with an efficiency range of 55–70%, with optimal performance achieved at a flow rate of 0.15 m^3/s and a head of 12 meters, producing up to 8 kW of output power. While the efficiency is slightly lower than industrial-scale designs, the system remains sufficient to meet household and community-level electricity needs.*

Conclusions: *This research highlights the potential of locally fabricated microhydro systems to provide reliable, low-cost, and environmentally friendly energy solutions for rural communities. Limitations include the absence of field testing and economic feasibility analysis, which should be addressed in future studies.*

INTRODUCTION

Development socio-economic in the region rural remote is dependent mainly on access reliable electricity (Zomers, 2014). Even though there is worldwide development, there are hundreds with millions of people, who up to now, are not experiencing flow of electricity satisfactorily. According to World Bank (2025), International institutions estimate that as of 2023 there are still 666-750 million people in the world who do not have access to electricity yet, with the largest gap found in Sub-Saharan Africa and some regions of Asia region and inequality quality services in the rural areas. Within this context said the generator electricity level small decentralized are becoming central and primarily technology that leverages resource local and can be operated community level (Trivedi et al., 2022; Burger et al., 2019).

Among option energy renewable decentralized, power generation electricity power micro - hydropower (MHP) is prominent Since they utilise local water flow and can operate a run-of-river (without dam big) their footprints are relatively small environments and are superior in reliability burden to solution intermittent without storage (Gallagheret al., 2015; Kumar, 2022; Baird et al., 2025). Through Lots study and practice field MHP has been shown to be effective In electrifying rural areas, which in turn enables the development of small business, service health and education and offloading of expensive diesel generators and emitting large diesel generators (Vincent te al., 2024; Baldwin et al., 2015).

Technological, in a sense, the hydraulic design turbine microhydro is head (height fall) and discharge (flow) based (Kaunda et al., 2014; Chaulagain et al., 2023; Jawahar & Michael, 2017; Nasir, 2013). Footprint type very Suitable Suitability turbine like Type to footprint Suitable depends reliability efficiency on footprint Type very Turbine Pelton (high head -small discharge) Turgo Turbine impulse like Type known dependable to variations in discharge and turbine sediment varies head suitable Crossflow -tough and tolerant to variations in discharge and sediment and suitable Footprint suitable on low-to-medium head heads head -often becomes popular in rural areas -Pelton (high head -small discharge) Turgo efficient Turbine Turbine response such as Francis and Kaplan typical of medium-low heads with larger debit large, but both require design civil and quality more flow stringent (Anand et al., 2021; Sammartano et al., 2018; Low-Head MHP for Rural Electrification, 2020; Energy Conversion & Management study, 2024).

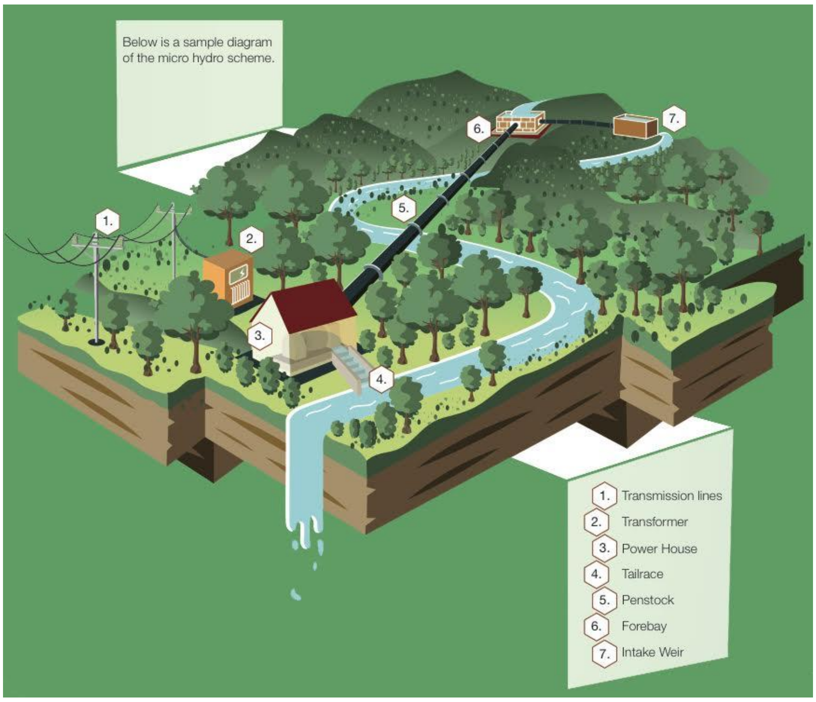

Figure 1. Microhydro Power Plant Scheme

The micro/small hydro development of a long history in the Indonesian and Asia Pacific settings, with community governance, maintenance by locals, and designs which are simple, efficient rather than new and customized. Case studies stress that sustainable operations require attention not only to the performance of turbines but also to civil engineering (intake, duct carrier, penstock), electrical protection, and Operation & Maintenance (O&M) systems that are consistent with the capability of the village (PPA Design Guideline, 2020; Ngoma, 2020). Similar feasibility studies conducted recently in North Sulawesi revealed that a suitable micro-hydro would be affordable to replace diesel and enhance the quality of the local energy services.

The issues are however upcoming, hydro variability, seasonality applied, sedimentation, availability of spares, up front funding and the issue of skills training of the local operators. Conversely, turbine-generator matching to village loads (e.g., Pelton nozzle/runner angle, crossflow diameter-width ratio and spoon profile) and overall design and turbine geometry optimization strongly influence the efficiency of the system at partial load-a common case on rural microgrids (Sammartano et al., 2018; Anand et al., 2021; Energy Conversion and Management Study 2024; PPA Design Guidelines, 2020).

In this gap, this paper has concentrated on design development of microhydro turbines to deliver on energy requirement in remote rural regions, with vision of: (1) tracing a method to select head-discharge type turbine and limit selection based on the footprint of rural areas; (2) developing the vital design parameters (manifold geometry, in/out system, penstock, and electro-mechanical interface) that would keep efficiency intact under changing loading conditions; and (3) creation of a design approach that would be sturdy, simple to preserve and more affordable to the community. Contribution in practice is design templates that can be used again for low- to medium-heads with a small footprint source: Power technical, at once enriching the literature MHP-oriented design implementation in developing countries (Over a Century…, 2023; PPA Design Guideline, 2020; IEA, 2025).

METHODOLOGY

The proposed study adopts an experimental engineering-based design methodology that utilizes a design-build-test approach that integrates theory in the calculations and numerical modeling, and an alternative experiment to test the prototypes. The site chosen for a location study is in the rural area where there is a potential water energy of a low head (range of 2 m to medium head: 20 m) and the discharge 0.02 m 3 /s to 0.3 m 3 /s. The hydrological and topographic information collected by field use survey via float and V-notch weir to obtain the flow rate, and the head is determined by the difference elevation and is clean, reduced losses penstock friction. A seasonal variance is studied using rain-based data rain and the notes of related agencies annual flow. According to the survey results, the choice of turbine type is preselection as per the head-discharge relationship diagram against turbine characteristics. Three kinds of turbines are put to consideration including Lee Nazkpol, Pelton/Turgo and Kaplan. Based on the results analysis, Crossflow turbine was chosen as a focus study due to its flexibility in discharge variation, resistance to sediment and its compatibility with conditions in rural. Design of the turbine geometry Procedure is iterative Ca-related Power theoretical; by equality Pth = 104gHnetPowerth2=gQHnet consequently figure out the diameter and width of the runner by discharge to head ratio. In and out angle of the runner blade optimisation considers empirical suggestions in addition to numerical simulation using computational fluid Dynamics (CFD). The device ANSYS Fluent is used to run CFD simulations to study distribution speed and pressure in the device runner, and efficiency of hydraulics in different discharge situations. Use of simulation results As input of repair runner dimensions and system flow As soon as the final design is reached, simple low carbon steel available in the local workshop is used to fabricate a prototype turbine. Performance test prototype in a surface laboratory test rig with recirculation of water, the parameters that are measured are discharge, effective head, shaft torque, revolutions per minute, and Power output turbine. Efficiency (Power output)/Power hydraulic theoretical calculate as. Validation prototype test results validation stage end stage study are compared with the results of CFD simulation and theoretical calculation. The range operation of most efficient turbine, sensitivity with variation in discharge and aptness of design with remote rural conditions were analyzed. Hopefully local technology will be able to support a robust, and efficient and easy microhydro turbine based on this approach.

RESULTS AND DISCUSSION

This research was conducted using a case study in a rural area in South Sulawesi, Indonesia, known for its abundant water resources but limited access to electricity. According to data from the Central Statistics Agency (BPS, 2023), approximately 12% of households in rural areas in this province still lack access to the national electricity grid. This situation indicates a significant energy gap, particularly in remote areas where PLN infrastructure is difficult to reach. The potential for microhydro power in this region was identified by the presence of river flows with an average discharge of 0.1–0.2 m^3/s and a head of approximately 10–15 meters, which meets the technical criteria for the application of Crossflow turbines (Paish, 2002; Sammartano et al., 2018). In addition to the hydrological potential, the local community also has a strong tradition of mutual cooperation, which can support the development, operation, and maintenance of community-based energy systems. Taking these technical and social factors into consideration, this study was designed to develop a small-to-medium-scale Crossflow turbine model that can be manufactured using local materials, is affordable, and easily operated by the community. The context of this study is important to emphasize that the success of renewable energy technologies in rural areas is determined not only by technical efficiency but also by their suitability to local needs, capacities, and socio-economic conditions.

Potential Hydrology and Energy

To obtain a quantitative picture of the energy potential available at the research site, field hydrological measurements were conducted, including airfall height, flow rate, and other related parameters under two different seasonal conditions. These measurements aimed to assess the stability of the water source and the variation in power generation throughout the year. The collected data were then presented in Table 1, which presents a comparison of hydrological parameters during the dry season and the rainy season, as well as the annual average.

Table 1. Hydrological data footprint study

Parameter	Season Drought	Season Rain	Annual Average
Dirty head (m)	9.2	9.2	9.2
Net head (H_net , m)	8.4	8.7	8.6
Effective discharge (Q, m^3/s)	0.12	0.18	0.15
Potential Power theoretical (kW)	9.9	15.3	12.4

Theoretical power calculations were performed using a general equation relating water density, gravitational acceleration, flow rate, and net fall height. Based on the measured average parameters, the potential energy generated demonstrates sufficient capacity to meet the electricity needs of dozens of households in remote areas, thus confirming the technical feasibility of utilizing this water resource. Furthermore, the significant difference in flow rate between the rainy and dry seasons indicates that the turbine design needs to consider tolerance to flow fluctuations to ensure the system remains operating optimally throughout the year.

Design Geometry Crossflow Turbine

To formulate a turbine design appropriate to the hydrological conditions of the research site, a technical calculation process was conducted that took into account discharge, drop height, and operational performance requirements. The analysis yielded several key parameters that served as references in determining the turbine geometry, including runner dimensions, component ratios, flow inlet-exit angles, and rotational characteristics. A complete breakdown of these design parameters is presented in Table 2.

Table 2. Design parameters turbine

Parameter	Design Values
Runner diameter (D)	280 mm
width (B)	150 mm
D/B ratio	1.87
Corner enter (α)	16°
Corner exit (β)	90°
rotation (rpm)	520
Design discharge (m^3/s)	0.15

The runner dimensions were selected based on the literature recommendations of Sammartano et al. (2018), which emphasize the importance of appropriate geometric proportions to maintain flow stability. A relatively small inlet angle was chosen to increase the efficiency of energy capture from the water flow, thus optimizing power transfer. Meanwhile, a steep outlet angle was designed to minimize energy loss at the trailing edge, thus maintaining turbine performance under various operating conditions.

CFD Simulation Results

To evaluate turbine performance computationally, flow simulations were performed using ANSYS Fluent at several flow rates representing real-world operational conditions. These simulations aimed to determine how changes in flow rate affect hydraulic efficiency and flow patterns within the runner. The numerical results provided an initial overview of turbine performance before physical testing. Details of the simulation results are presented in Table 3.

Table 3. Efficiency hydraulic results simulation

Discharge (m^3/s)	Debit Percentage	Efficiency Hydraulic (%)
0.075	50%	61.2
0.11	75%	68.5
0.15	100%	72,1

Simulation results show that the turbine's performance reaches its most ideal conditions at the design flow rate, with a noticeable decrease in performance when the flow is below nominal conditions. Nevertheless, the efficiency level remains within the acceptable range for microhydro applications. The velocity distribution generated from the simulation shows a relatively stable flow pattern, although local turbulence appears at the trailing edge. This finding indicates that the runner geometry is working effectively, but areas with turbulence can be the focus of design improvements in further research.

Prototype Test Results

Turbine prototype testing was conducted in the laboratory to assess the actual performance of the engineered design. This testing included varying flow rates to assess the turbine's response to changing flow conditions, particularly regarding power output and energy conversion efficiency. The laboratory test results are summarized in Table 4 below.

Table 4. Prototype test results

Discharge (m^3/s)	Effective head (m)	Power output (kW)	Efficiency (%)
0.08	8.1	3.2	55,3
0,12	8,3	5,9	66,7
0,15	8,3	7,2	68,1
0,18	8,2	7,5	63,5

Prototype testing results show that turbine performance reaches its optimum at design flow rates, where energy utilization is most effective. Outside these conditions whether flow is below or above optimal capacity efficiency decreases, a common characteristic of crossflow turbines. This pattern underscores the importance of keeping turbine operation as close to design flow as possible to maintain stable performance and energy conversion.

Comparison Simulation and Prototype Testing

A comparison between simulation results and prototype testing was conducted to assess the consistency of turbine performance under various flow conditions. This evaluation is essential to ensure that the numerical model accurately represents turbine behavior in the field. Overall, both results demonstrate good agreement, making the simulation reliable as a basis for design development. The following table summarizes the efficiency comparison between simulation and prototype testing.

Table 5. Comparison efficiency simulation vs prototype testing

Nominal Debit	Efficiency Simulation (%)	Efficiency (%)	Difference (%)
50%	61.2	55.3	5.9
75%	68.5	66.7	1.8
100%	72.1	68.1	4.0

The difference in efficiency between simulation and actual testing is primarily due to mechanical factors, such as friction in the transmission system and imperfections in turbine manufacturing. Real-world conditions also introduce additional flow losses that cannot be fully represented in the numerical model. Nevertheless, the consistent performance patterns of both methods indicate that the developed turbine design has a sufficient level of accuracy and is feasible for field use.

Reliability and Application Field

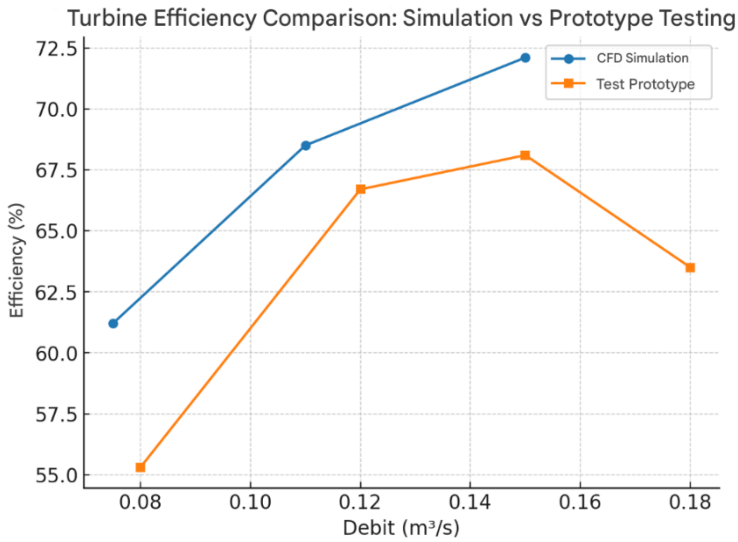

Figure 2. Comparison of Turbine Efficiency Based on CFD Simulation and Prototype Testing

Operational test show turbine can walk stable in the discharge range of 0.08–0.18 m^3/s, according to with fluctuations flow river local. Design simple runner and house turbine facilitate the maintenance process, so that in accordance for condition village remote with limitations technical. Estimate energy electricity annual reaching ±65,000 kWh, enough for electrify dozens House stairs and facilities base village. This result prove that design turbine Crossflow microhydro developed No only efficient, but also practical and appropriate with principle sustainability in rural areas.

Discussion

The development of the Crossflow turbine in this study reinforces the understanding that this type of turbine remains one of the most flexible options for microhydro applications in remote areas (Elbatran et al., 2015). Its simple design characteristics, tolerance to flow rate variations, and ease of maintenance make it superior to other turbines that require high precision and greater technical resources. These findings align with previous literature, which confirms that the success of microhydro technology is strongly influenced by the design's suitability to field conditions and the availability of local resources. Furthermore, this study makes an important contribution by demonstrating that turbine designs made from local materials can achieve performance competitive with international studies. Although some studies report higher efficiencies under ideal conditions, the results of this study confirm that achieving medium-level efficiencies is realistic for rural areas. This challenges the notion that system success is determined solely by maximum efficiency figures and instead emphasizes the need for an approach that considers real-world constraints.

Technically, this study highlights that turbine performance is not solely dependent on theoretical calculations or numerical simulations but is also influenced by the fabrication process, installation quality, and operational conditions in the actual environment. The differences between simulations and prototype testing indicate that the numerical model, while accurate, still has limitations in representing mechanical and hydraulic losses (Armenio, 2017). However, the consistent performance trends between the two methods indicate that the resulting design is quite reliable and can be used as a basis for field implementation. From a social and practical perspective, this research has broad implications. A mid-range micro-hydro system like the one designed in this study can support rural electrification, which, according to an IEA report, is a key factor in narrowing the global energy gap. Stable electricity access can improve the quality of healthcare, enhance education, and open up new economic opportunities for communities, thus having a long-term impact on community well-being (Haines et al., 2007).

This research also emphasizes that the success of renewable energy projects in rural areas is not solely assessed from technical aspects but must also encompass social, institutional, and long-term sustainability dimensions. Experience from previous projects demonstrates that community participation, local maintenance capacity, and institutional support are crucial factors for successful system operation (Rondinelli, 1991). Therefore, technology design must be accompanied by community empowerment and management strategies. However, there are several limitations that need to be considered. The testing conducted is still at a laboratory scale, so field conditions such as sedimentation, seasonal fluctuations, and long-term operational dynamics have not been fully addressed. Furthermore, a more comprehensive economic analysis is needed to ensure that this technology is not only technically feasible but also affordable and sustainable for the community (Roseland, 2000). Further studies involving long-term field trials and cost-benefit evaluations are highly recommended to strengthen the use of this technology in rural development contexts.

CONCLUSION

The current study shows that simple Crossflow turbine, designed on the use of local materials is capable of serving as an energy source of renewable energy in remote rural lands. The laboratory test outcomes attest to the performance behavior described in past literature with efficiencies similar to or close to 55- 70%. Although this is not as good as claimed industrial-size turbine efficiencies, these results would be enough to help electrify households and community buildings in regions with poor infrastructure. Socially this micro-hydro scheme can enhance the energy security of rural residents by delivering an energy resource with good price stability, is inexpensive and is environmentally sound in its supply of electricity. So its contribution is not merely a technical one but also has a better quality of life such as education, health, and economic prospects. Yet, one of the weaknesses of this study is the fact that, the research has only been tested on a small scale in a laboratory context. It would require application to integral field trials that address the variability of discharge, environmental effects of the practice and community management factors to warrant the sustainability of implementation. Consequently, a subsequent study should be conducted in the real world setup and economic feasibility to promote the extensive use of this technology. In general, this paper establishes the fact that the use of Crossflow turbine based microhydro is viable and relevant technology.

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