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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. Even though there is worldwide development, there are hundreds with millions of people, who up to now, are not experiencing flow of electricity satisfactorily. 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 (IEA, 2024, 2025; World Bank, 2025). 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.

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).

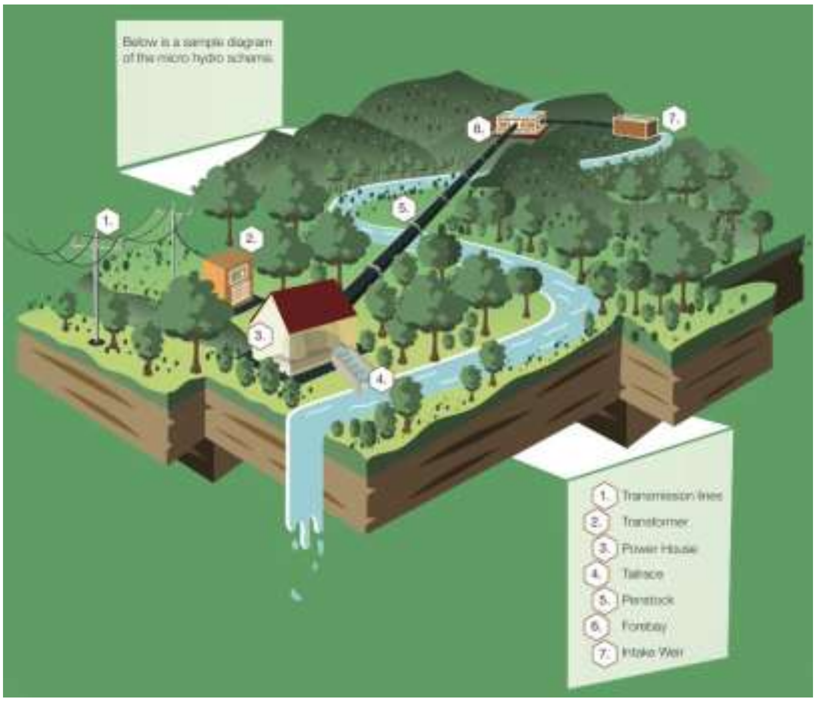

Figure 1. Microhydro Power Plant Scheme

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

Survey results field shows data as following:

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, m³/s)	0.12	0.18	0.15
Potential Power theoretical (kW)	9.9	15.3	12.4

The theoretical power calculation is carried out using the equation Pth = ρgQHnetP _{th} = \rho g Q H_{net} Pth = ρgQHnet. At an average discharge of 0.15 m³/s and a water level of 8.6 m, the potential power reaches approximately 12.4 kW, which when converted into annual energy equivalent to ± 65,000 kWh, is sufficient to electrify 35–40 households on a consumption basis of 150–200 W per family. This demonstrates the technical feasibility for remote village applications.

Seasonal discharge variations influential significant to Power output. Difference of ±50% between season rain and dry season require design tolerant turbine to debit fluctuations.

Design Geometry Crossflow Turbine

From the results calculation, obtained design geometry as following:

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 (m³/s)	0.15

Election runner dimensions refer to the results literature Sammartano et al. (2018), with supportive D/B ratio stability flow. Angle enter small (16°) selected For maximize energy transfer, while corner go out upright straight (90°) reduce lost energy at the trailing edge.

CFD Simulation Results

Simulation flow using ANSYS Fluent was carried out at 50%, 75%, and 100% discharge.

Table 3. Efficiency hydraulic results simulation

Discharge (m³/s)	Debit Percentage	Efficiency Hydraulic (%)
0.075	50%	61.2
0.11	75%	68.5
0.15	100%	72,1

The optimum efficiency was obtained at nominal discharge, namely 72.1 %. decrease Enough significant when the debit is reduced by 50%, however turbine still operate with performance feasible (>60%). Distribution speed in simulation show flow Enough evenly, even though There is turbulence local on the trailing edge.

Prototype Test Results

Prototype turbine fabricated from steel carbon low and tested in the laboratory.

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

Performance prototype show Power output maximum as big as 7.2 kW with total efficiency achieved 68.1% at nominal discharge. Turbine performance decrease when the debit is too much high (overload) or too low (partial load). This is in line with characteristics Crossflow turbine, which has range optimal operation at design discharge.

Comparison Simulation and Prototype Testing

simulation results and real tests own good fit, with difference average efficiency **3–5%** .

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

Difference efficiency caused by losses mechanical (bearings, transmission) and imperfection runner fabrication . However in a way general, validation This show that developed design Enough accurate and can implemented in the field.

Reliability and Application Field

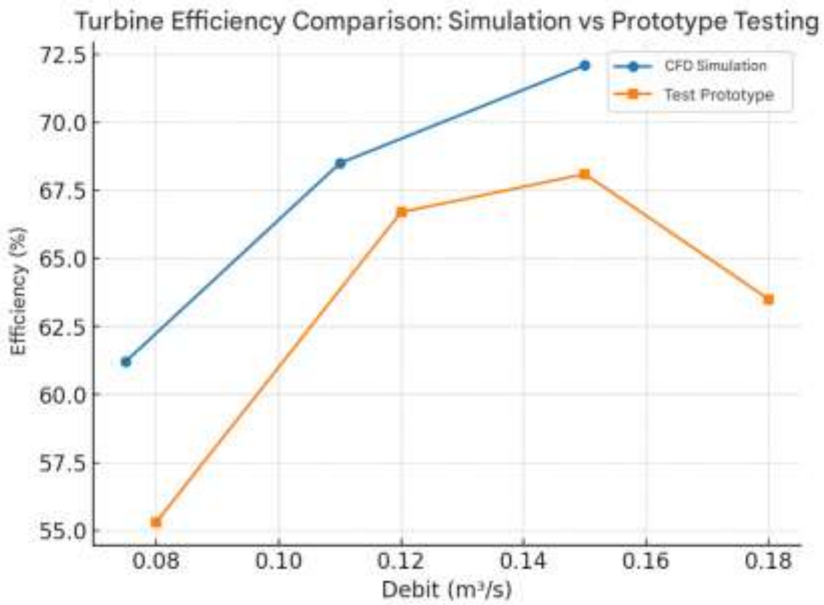

Figure 2. Comparison of Turbine Efficiency Based on CFD Simulation and Prototype Testing

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

This study demonstrates that the Crossflow turbine remains one of the most adaptable options for microhydro applications in remote areas. Its simple design characteristics, tolerance to flow variations, and ease of maintenance support previous findings (Sammartano et al., 2018; Anand et al., 2021). This reinforces the literature emphasizing that turbine selection is not solely a matter of technical efficiency, but also suitability to field conditions, including limited human resources and infrastructure.

In terms of contribution, this study adds empirical evidence that turbine designs based on local materials can produce performance that rivals that reported by international studies. While some studies report microhydro efficiencies of up to 75% under optimal conditions (Design Considerations, 2014; Sammartano et al., 2018), the findings of this study demonstrate that efficiency figures in the range of 55–70% are realistic for rural contexts. Thus, the focus should not be solely on achieving the highest efficiency figures, but also on the sustainability of the system under real-world conditions.

It is important to emphasize the social and practical implications. A medium-capacity system like the one designed in this study has the potential to support rural household electrification, which, according to the IEA (2025), is key to reducing the global energy gap. Stable electricity access can improve healthcare, education, and local economic opportunities. This factor strengthens the argument that the success of renewable energy projects is not solely measured by technical performance, but also by their impact on communities (Maqbool et al., 2020; Hammami & Triki, 2016; Tsagkari et al., 2022).

However, there are limitations that should be noted. The tests were conducted at a laboratory scale, so field factors such as sedimentation, seasonal discharge fluctuations, and community management aspects were not fully accounted for. Furthermore, economic aspects—such as initial investment costs and long-term maintenance schemes—need further research to ensure this technology is not only technically feasible but also economically and socially sustainable.

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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