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Micro-hydropower plants: resource assessment, turbine technologies, electrical control, and sustainable rural electrification

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ABSTRACT

Micro-hydropower plants (MHPs), commonly known in Indonesia as *Pembangkit Listrik Tenaga Mikrohidro* (PLTMH), convert the energy of small streams, irrigation flows, and other low-head water resources into electricity for local use. They are particularly relevant to remote communities where grid extension is costly, yet successful deployment requires more than identifying a flowing river. This review synthesizes research on resource assessment, hydraulic layout, turbine selection, electromechanical conversion, control, economics, and environmental and social sustainability. The literature indicates that dependable flow-duration data and net-head estimation are foundational because seasonal variation and hydraulic losses directly affect available output. Cross-flow and Pelton turbines are frequently suitable for decentralized schemes, although selection must reflect the actual head-discharge range, sediment conditions, manufacturing capacity, and maintenance skills. Electronic load controllers and variable-speed strategies can improve voltage and frequency regulation, but their reliability depends on appropriate protection and locally serviceable components. Evidence from Indonesia and other developing regions further shows that community participation, financing, operator training, and long-term maintenance determine whether technical potential becomes a durable electricity service. The review concludes with an integrated planning framework for reliable, affordable, and environmentally responsible PLTMH development.

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1. INTRODUCTION

Access to reliable electricity remains a major development challenge for remote and geographically dispersed communities. Extending national electricity grids to isolated settlements can require substantial investment in transmission infrastructure, particularly in mountainous regions and small islands. Micro-hydropower plants offer an alternative by converting locally available water energy into electricity near the point of consumption. Their relatively small infrastructure requirements and potential for continuous generation make them attractive for rural electrification and productive community activities [1], [2].

Indonesia has considerable opportunities for micro-hydropower development because of its rainfall, river networks, mountainous terrain, and numerous irrigation systems. Previous studies have examined the potential of micro-hydropower in Indonesia and demonstrated that both impulse and reaction turbines can be applied depending on local hydraulic conditions [2]. However, the existence of a river does not automatically establish the technical or economic feasibility of a power plant. Seasonal discharge variation, inadequate civil works, unsuitable turbine selection, limited maintenance capacity, and weak project management can reduce performance or cause premature system failure [3]–[9]

This review examines the technical and non-technical factors that determine successful PLTMH implementation. It focuses on water-resource assessment, hydraulic infrastructure, turbine technologies,

electrical generation, control systems, and project sustainability. The discussion draws on peer-reviewed research and conference publications available up to 2018, with particular attention to applications relevant to developing countries. The central argument is that PLTMH performance must be evaluated as an integrated system rather than as an isolated turbine or generator installation.

2. WATER-RESOURCE ASSESSMENT AND HYDRAULIC DESIGN

Accurate assessment of water resources is the first requirement in PLTMH planning. Two fundamental site characteristics are available water discharge and effective hydraulic head, which together determine the energy that can be converted into mechanical power. Discharge measurements should represent seasonal and dry-period conditions rather than relying exclusively on observations collected during the rainy season. A flow-duration assessment is therefore important because it helps determine the dependable water supply and the proportion of the year during which the plant can operate [1], [3].

Hydraulic head must also be evaluated carefully because the gross elevation difference is not necessarily the head available at the turbine. Water loses energy as it passes through the intake, channels, screens, bends, valves, and penstock. These losses depend on pipe dimensions, material roughness, flow velocity, and the geometry of the water-conveyance system. A study of low-head micro-hydropower optimization in Indonesia demonstrated that modifications to the penstock and turbine dimensions could substantially improve the generation potential of an existing installation [10].

The civil infrastructure should be designed to deliver water reliably while limiting sediment entry and unnecessary hydraulic losses. Typical components include an intake structure, settling basin, headrace channel, forebay tank, penstock, turbine housing, and tailrace. The intake should maintain sufficient water supply while allowing debris and sediment to be removed before they reach the turbine. Existing irrigation channels and water-distribution infrastructure can also provide opportunities for micro-hydropower development, potentially reducing the need for extensive new construction [3], [11].

3. TURBINE TECHNOLOGIES AND SELECTION

Turbine selection is a major determinant of PLTMH efficiency, reliability, and manufacturing cost. Hydraulic turbines are generally classified as impulse or reaction machines according to how they extract energy from water. Pelton and Turgo turbines are examples of impulse turbines, while Francis and Kaplan turbines are commonly classified as reaction turbines. The appropriate technology depends primarily on the available head and discharge, but site accessibility, sediment concentration, operating range, and local manufacturing capability must also be considered [1], [6].

The cross-flow turbine is particularly relevant to decentralized micro-hydropower because of its relatively simple construction and suitability for a range of operating conditions. Water passes through the runner and transfers energy through two stages of interaction with the blades. Its comparatively straightforward fabrication makes it attractive for communities and workshops with limited manufacturing resources. Adhikari and Wood emphasized that nozzle design and the matching of nozzle and runner geometry are essential for achieving high cross-flow turbine efficiency [4].

Pelton turbines are generally suitable for sites with relatively high head and lower discharge. Their operation depends on high-velocity water jets striking specially shaped buckets attached to a rotating runner. The runner diameter, bucket geometry, jet diameter, and operating speed influence the conversion of hydraulic energy into mechanical output. Numerical and computational fluid dynamics investigations have demonstrated the importance of appropriate runner dimensions and flow characteristics in achieving satisfactory Pelton turbine performance [5].

Low-head sites require different design considerations because conventional high-head turbines may not be economically or technically appropriate. Water wheels, gravitational vortex turbines, and pumps operating as turbines are among the alternatives investigated for small-scale applications. Gravity water wheels can be useful where the available head is limited and construction simplicity is important, while pump-as-turbine systems may reduce equipment costs by using commercially available machinery. These alternatives broaden the range of sites that can be considered for PLTMH development, although their performance must be verified under actual operating conditions [1], [12], [13].

4. GENERATOR SYSTEMS AND ELECTRICAL CONTROL

The generator converts the turbine's mechanical output into electrical energy and therefore forms a critical part of the PLTMH system. Synchronous generators can provide controlled voltage and frequency when equipped with suitable excitation and regulation systems. Induction generators are also attractive

because of their relatively simple construction, availability, and robustness. However, standalone induction-generator systems require appropriate excitation and control arrangements to maintain acceptable electrical output as operating conditions change [7].

One of the principal challenges in standalone PLTMH operation is maintaining stable voltage and frequency when consumer loads vary. A sudden reduction in electrical demand can cause the turbine-generator set to accelerate, while an increase in demand can produce a reduction in rotational speed. An electronic load controller (ELC) addresses this problem by regulating the electrical load connected to the generator. When consumer demand decreases, the controller diverts surplus power to a ballast or dump load, helping maintain a more consistent operating condition [7].

ELC design must consider switching reliability, thermal management, power quality, and component lifetime. Conventional resistive dump loads are relatively simple, but they dissipate excess energy as heat rather than using it productively. The review by Singh and colleagues examined several ELC configurations and identified limitations associated with component stress and long-term operation. More advanced control arrangements, including variable-speed operation, provide additional opportunities to improve system response under changing hydraulic and electrical conditions [7], [8].

Electrical protection is equally important because PLTMH installations often operate in locations where technical support is limited. Protection devices should address overcurrent, short circuits, overvoltage, undervoltage, and abnormal operating conditions. Monitoring of generator speed, voltage, frequency, and temperature can help operators identify developing faults before they cause major equipment damage. A practical control architecture should therefore combine automatic regulation with clear operating procedures and components that can be maintained or replaced locally.

5. ECONOMIC, ENVIRONMENTAL, AND SOCIAL SUSTAINABILITY

The economic feasibility of PLTMH depends on more than the initial construction cost. Project evaluation should include civil works, turbine and generator procurement, electrical equipment, installation, transportation, operation, maintenance, and eventual component replacement. Existing irrigation networks and water infrastructure can improve feasibility because they may reduce the need for additional hydraulic construction. Research on micro-hydropower in irrigation systems has proposed practical methods for evaluating technical suitability, costs, and expected income before implementation [3].

Environmental considerations should be incorporated during site selection and engineering design. Although run-of-river micro-hydropower generally requires less reservoir infrastructure than large hydropower projects, it can still affect river flow, aquatic habitats, sediment transport, and local water use. Water abstraction should preserve an appropriate residual flow in the natural channel, particularly during dry periods. Environmental assessment before construction can help identify potential impacts and determine mitigation measures, including fish passage provisions and responsible management of sediment [14], [15].

Sediment management is especially important for installations located in rivers carrying abrasive particles. Sand and other suspended materials can gradually erode turbine surfaces, reduce hydraulic efficiency, and increase maintenance requirements. Settling basins, intake screens, suitable turbine materials, and regular inspection can reduce these problems. Research on hydro-abrasive erosion has emphasized that prevention and monitoring are generally preferable to relying exclusively on repairs after turbine damage has occurred [10], [15]–[17].

Long-term sustainability also depends on community participation and local institutional capacity. A technically successful plant may become unreliable if operators lack training, maintenance funds are insufficient, or responsibility for repairs is unclear. A sustainability assessment of a community-based micro-hydropower plant in Nepal considered technical, economic, social, and environmental indicators, demonstrating the value of evaluating these dimensions together. Local ownership, transparent management, operator training, and realistic tariff arrangements can strengthen the ability of communities to maintain their electricity services [9].

6. RESEARCH GAPS AND FUTURE DEVELOPMENT

The reviewed literature identifies several areas that require further attention in PLTMH research and implementation. First, resource assessment should increasingly use long-term hydrological observations to account for seasonal variation and uncertainty in water availability. Second, turbine development should prioritize performance across realistic operating ranges rather than focusing only on peak efficiency under laboratory conditions. Third, electrical control systems should be designed for durability, power quality, and ease of repair in remote environments. These priorities are particularly important where local technical resources and spare-part supply chains are limited [4], [6], [7].

Future PLTMH projects should also improve the integration of technical design with economic and environmental planning. Hybrid systems combining micro-hydropower with solar photovoltaic generation or battery storage may provide additional flexibility where streamflow varies significantly. However, hybridization should be justified through site-specific analysis rather than treated as a universal requirement. Further research should also examine productive electricity use, community-based maintenance models, and monitoring systems that help operators detect performance deterioration at an early stage [2], [8], [9].

7. CONCLUSION

Micro-hydropower plants provide a practical renewable-energy option for communities with suitable water resources and limited access to centralized electricity networks. Their successful implementation depends on accurate discharge and head assessment, efficient hydraulic infrastructure, appropriate turbine selection, and reliable generator-control systems. Cross-flow and Pelton turbines are important options, while water wheels, gravitational vortex systems, and pumps as turbines can extend the range of feasible applications. Electrical regulation, particularly through suitable electronic load controllers, is essential for maintaining stable operation in standalone systems.

Nevertheless, technical performance alone cannot guarantee long-term success. Environmental-flow protection, sediment management, realistic economic planning, community participation, and operator training must be incorporated throughout the project lifecycle. PLTMH development should therefore follow an integrated approach that connects hydrological assessment, engineering design, electrical control, environmental safeguards, and local institutional capacity. Such an approach can improve the reliability and sustainability of decentralized electricity services while supporting rural development.

REFERENCES

[1] A. H. Elbatran, O. B. Yaakob, Y. M. Ahmed, and H. M. Shabara, "Operation, performance and economic analysis of low head micro-hydropower turbines for rural and remote areas: A review," *Renew. Sustain. Energy Rev.*, vol. 43, pp. 40–50, Mar. 2015, doi: 10.1016/j.rser.2014.11.045.

[2] Erinofiardi *et al.*, "A Review on Micro Hydropower in Indonesia," *Energy Procedia*, vol. 110, pp. 316–321, Mar. 2017, doi: 10.1016/j.egypro.2017.03.146.

[3] D. A. Zema, A. Nicotra, V. Tamburino, and S. M. Zimbone, "A simple method to evaluate the technical and economic feasibility of micro hydro power plants in existing irrigation systems," *Renew. Energy*, vol. 85, pp. 498–506, Jan. 2016, doi: 10.1016/j.renene.2015.06.066.

[4] R. Adhikari and D. Wood, "The Design of High Efficiency Crossflow Hydro Turbines: A Review and Extension," *Energies*, vol. 11, no. 2, p. 267, Jan. 2018, doi: 10.3390/en11020267.

[5] T. Nigussie, A. Engeda, and E. Dribssa, "Design, Modeling, and CFD Analysis of a Micro Hydro Pelton Turbine Runner: For the Case of Selected Site in Ethiopia," *Int. J. Rotating Mach.*, vol. 2017, pp. 1–17, 2017, doi: 10.1155/2017/3030217.

[6] C. P. Jawahar and P. A. Michael, "A review on turbines for micro hydro power plant," *Renew. Sustain. Energy Rev.*, vol. 72, pp. 882–887, May 2017, doi: 10.1016/j.rser.2017.01.133.

[7] R. R. Singh, B. A. Kumar, D. Shruthi, R. Panda, and C. T. Raj, "Review and experimental illustrations of electronic load controller used in standalone Micro-Hydro generating plants," *Eng. Sci. Technol. an Int. J.*, vol. 21, no. 5, pp. 886–900, Oct. 2018, doi: 10.1016/j.jestch.2018.07.006.

[8] Y. Fan, D. Zhang, and J. Li, "A Control Scheme for Variable-Speed Micro-Hydropower Plants," *Sustainability*, vol. 10, no. 11, p. 4333, Nov. 2018, doi: 10.3390/su10114333.

[9] R. Bhandari, L. G. Saptalena, and W. Kusch, "Sustainability assessment of a micro hydropower plant in Nepal," *Energy. Sustain. Soc.*, vol. 8, no. 1, p. 3, Dec. 2018, doi: 10.1186/s13705-018-0147-2.

[10] R. Marliansyah, D. N. Putri, A. Khootama, and H. Hermansyah, "Optimization potential analysis of micro-hydro power plant (MHPP) from river with low head," *Energy Procedia*, vol. 153, pp. 74–79, Oct. 2018, doi: 10.1016/j.egypro.2018.10.021.

[11] A. Sugiri, "Study on the Potential for a Micro-Hydropower Plant (PLTMH) at the Way Sekampung Regional Water Utility (PDAM) in Pringsewu Regency," *Mech. ; J. Ilm. Tek. Mesin*, vol. 5, no. 1, 2014, doi: 10.23960/mech.v5i1.223.

[12] E. Quaranta and R. Revelli, "Gravity water wheels as a micro hydropower energy source: A review based on historic data, design methods, efficiencies and modern optimizations," *Renew. Sustain. Energy Rev.*, vol. 97, pp. 414–427, Dec. 2018, doi: 10.1016/j.rser.2018.08.033.

[13] D. Novara and A. McNabola, "The Development of a Decision Support Software for the Design of Micro-Hydropower Schemes Utilizing a Pump as Turbine," in *EWaS3 2018*, Aug. 2018, p. 678. doi: 10.3390/proceedings2110678.

[14] M. Zeleňáková, R. Fijko, D. Diaconu, and I. Remeňáková, "Environmental Impact of Small Hydro Power Plant—A Case Study," *Environments*, vol. 5, no. 1, p. 12, Jan. 2018, doi: 10.3390/environments5010012.

[15] S. Sangal, M. K. Singhal, and R. P. Saini, "Hydro-abrasive erosion in hydro turbines: a review," *Int. J. Green Energy*, vol. 15, no. 4, pp. 232–253, Mar. 2018, doi: 10.1080/15435075.2018.1431546.

[16] M. A. Khan and S. Badsha, "Design and Analysis of Cross Flow Turbine for Micro Hydro Power Application using Sewerage Water," *Res. J. Appl. Sci. Eng. Technol.*, vol. 8, no. 7, pp. 821–828, Aug. 2014, doi: 10.19026/rjaset.8.1040.

[17] O. B. Yaakob, Y. M. Ahmed, A. H. Elbatran, and H. M. Shabara, "A Review on Micro Hydro Gravitational Vortex Power and Turbine Systems," *J. Teknol.*, vol. 69, no. 7, Jul. 2014, doi: 10.11113/jt.v69.3259.