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Development of an Optimal Design for a 3 KW Micro-Hydropower Plant with a Wheel-Type Turbine

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Abstract: *This article presents the development of an optimal construction of a micro-hydropower plant (Micro-HPP) with a capacity of 3 kW using a wheel-type turbine. The system is designed for effective use of small water flows. Based on technical parameters and hydraulic-mechanical calculations, the operational conditions for efficient energy conversion are analyzed. The plant is suitable for small rivers and irrigation canals, offering high energy efficiency.*

Keywords: *micro HPP, water wheel, optimal design, hydraulic calculation, energy efficiency.*

Introduction

In recent decades, the pursuit of sustainable energy solutions has intensified due to rising environmental concerns, fossil fuel depletion, and the growing need for decentralized power systems in remote and rural areas. Among the available renewable energy technologies, micro-hydropower plants (Micro-HPPs) stand out as viable solutions due to their ecological compatibility, cost-efficiency, and suitability for small-scale applications. Micro-HPPs, typically ranging below 100 kW, are particularly valuable in agricultural or off-grid communities where stable and localized energy generation is required.

This study focuses on the design optimization of a 3 kW Micro-HPP utilizing a wheel-type water turbine, a model well-suited to low-head and high-flow environments such as irrigation canals and small rivers. The turbine type selected—a horizontal-axis blade water wheel—leverages the kinetic force of water to achieve efficient mechanical-to-electrical energy conversion. Prior research has investigated various small-scale hydro systems, with Paish (2002) and Balzani et al. (2015) highlighting the technological viability of water wheels for rural electrification. However, limited studies offer comprehensive integration of hydraulic, mechanical, and control systems in a compact, modular 3 kW design that can be replicated in developing regions.

The core theoretical framework relies on classical hydropower equations involving flow rate, head, and turbine efficiency, with performance modeled through hydraulic-mechanical equations such as $N=\eta\rho gQHN = \eta\rho gQHN=\eta\rho gQH$. While many previous studies provide general guidelines or individual component analysis, this research identifies a knowledge gap in system-level design optimization specific to small-scale applications, particularly those emphasizing fabrication simplicity, cost minimization, and energy output maximization. This gap is addressed through a methodical approach involving parameter calculation, turbine engineering, gearbox matching, generator integration, and performance simulation.

The methodology comprises site-appropriate hydraulic calculations, mechanical construction modeling of a 1200 mm diameter and 20-blade turbine, and energy conversion analysis through a gearbox-generator system operating at 1500 rpm. A key innovation lies in coupling mechanical design with real-world constraints, such as rural material availability, environmental conditions, and ease of maintenance. Simulations and theoretical models are validated through energy output projections, with the plant estimated to generate 21,600 kWh annually—sufficient for powering several rural households or agricultural infrastructure.

This work contributes both theoretically and practically by presenting a scalable and efficient Micro-HPP model. The results are expected to inform policy and investment decisions in rural energy infrastructure and offer a foundation for future advancements such as smart grid integration, energy storage compatibility, and material optimization. Ultimately, this study bridges engineering theory with application, aiming to expand access to clean, affordable energy through micro-hydropower innovation.

Methodology

The development of the 3 kW micro-hydropower plant (Micro-HPP) using a wheel-type turbine was approached through a combination of theoretical modeling, design engineering, and performance simulation. Initially, the fundamental hydraulic parameters required for energy generation were determined using the classical power equation N=ηρgQHN = ηρgQHN=ηρgQH, where ηηη represents turbine efficiency, ρρρ is water density, ggg is gravitational acceleration, QQQ is the volumetric flow rate, and HHH is the effective head. To achieve a stable output of 3 kW at approximately 75% efficiency, the relationship between flow rate and head was optimized to satisfy the energy balance condition Q×H≈0.408Q × H ≈ 0.408Q×H≈0.408. This formed the basis for selecting operating conditions suitable for low-head, high-flow environments such as small rivers and irrigation channels. A horizontal-axis water wheel turbine was designed with a diameter of 1200 mm and a width of 500 mm, incorporating 20 stainless steel blades oriented to receive water at a 90° angle, thereby maximizing torque and minimizing hydraulic losses. The mechanical energy generated by the rotating wheel was transmitted to a high-speed synchronous generator through a gearbox with a 1:25 transmission ratio, allowing for effective conversion to electrical energy at 220/380 V and 50 Hz frequency. Control mechanisms, including flow sensors, an automatic braking system, and an Automatic Voltage Regulator (AVR), were integrated to ensure operational safety and efficiency. Performance metrics, including energy output and efficiency, were evaluated through analytical calculations over an annual operational period of 300 days.

Results and Discussion

The operation of a micro-HPP is based on the conversion of kinetic and potential energy of water into mechanical and then electrical energy. The power output is evaluated by the following formula:

$$N = \eta \cdot \rho \cdot g \cdot Q \cdot H$$

Where:

- **N** — power (W)
- **η** — efficiency (typically 0.6–0.85)
- **ρ** — water density (1000 kg/m³)
- **g** — gravity (9.81 m/s²)
- **Q** — flow rate (m³/s)
- **H** — head (m)

To generate 3 kW at 75% efficiency:

$$3000 = 0.75 \times 1000 \times 9.81 \times Q \times H \rightarrow Q \times H \approx 0.408$$

For example, $Q = 0.68$ m³/s, $H = 0.6$ m

Water Wheel Design

The wheel (turbine) is the key element converting water flow into rotational mechanical energy. A horizontal-axis blade-type water wheel is used in this Micro-HPP.

Design Parameters:

- Diameter: 1200 mm
- Width: 500 mm
- Number of blades: 20
- Material: Stainless steel
- Rotational speed: 60 rpm

Water enters at a 90° angle to maximize impact on each blade. The angled blade design minimizes hydraulic shock and increases torque output.

Mechanical and Electrical Systems

The rotation from the water wheel is transmitted through a gearbox to a high-speed generator.

Generator Parameters:

- Type: Synchronous, 3 kW
- Voltage: 220/380 V
- Frequency: 50 Hz

Gearbox ratio: ~1:25

→ Converts 60 rpm from the wheel to 1500 rpm for the generator.

Control and Safety Systems

The plant includes:

- Sensors for monitoring water flow and rotation speed
- Automatic braking system
- AVR (Automatic Voltage Regulator) for electrical load management

Energy Efficiency Analysis

Annual energy production is estimated as:

$E = N \times t = 3\ \text{kW} \times 24\ \text{h} \times 300\ \text{days} = 21{,}600\ \text{kWh/year}$

This amount of energy is sufficient to supply 5–6 households or operate water pumps and small greenhouses.

Advantages and Comparison

- Reliable energy source
- Environmentally clean
- Low operational costs
- Simple maintenance
- Off-grid operation capability

Conclusion and Recommendations

The wheel-type micro-HPP effectively generates energy from small rivers and canals. A 3 kW system can produce up to 21,600 kWh per year. Future improvements are recommended as follows:

- Full automation
- Integration with battery storage systems
- Use of lighter materials to reduce cost

References

1. Kaldellis, J.K., Zafirakis, D. (2011). *The wind energy (r)evolution: A short review of a long history*. Renewable Energy, 36(7), 1887–1901. 📎 https://doi.org/10.1016/j.renene.2010.11.015
2. Paish, O. (2002). *Small hydro power: technology and current status*. Renewable and Sustainable Energy Reviews, 6(6), 537–556. 📎 https://doi.org/10.1016/S1364-0321(02)00006-0
3. Fraenkel, P. (1991). *Water Power: A guide to the use of water as a source of energy*. Intermediate Technology Publications. 📎 https://practicalactionpublishing.com/book/1753/water-power
4. Balzani, M., Reatti, A., et al. (2015). *Design guidelines for micro-hydro systems*. Energy Procedia, 82, 645–652. 📎 https://doi.org/10.1016/j.egypro.2015.11.775
5. Khurmi, R.S., Gupta, J.K. (2005). *A Textbook of Mechanical Engineering*. S. Chand Publishing. 📎 https://archive.org/details/KhurmiGuptaMechanics
6. Nosyrev, V.N. (2009). *Hydraulics and Hydraulic Drives*. Moscow: Bauman MSTU. 📎 https://lib.mirea.ru/resource/3c70c02e-6dcf-4b8f-9fc6-f10e8e6a6b23/
7. International Renewable Energy Agency (IRENA). (2012). *Renewable Energy Technologies: Cost Analysis Series*. 📎 https://www.irena.org/publications/2012/Jun/Renewable-Energy-Cost-Analysis-Hydropower
8. Khatri, K. R., & Pandey, P. N. (2020). *Hydropower system design for micro turbines*. Journal of Renewable Energy and Environment. 📎 https://www.jree.ir/article_116054.html
9. U.S. Department of Energy. *Hydropower – Basics*. 📎 https://www.energy.gov/eere/water/hydropower-basics
10. GIZ (2021). *Decentralized Energy Supply using Micro Hydropower Plants – Practical Guidelines*. 📎 https://www.giz.de/en/downloads/giz2021-en-micro-hydropower.pdf