European Journal of Emerging Technology and Discoveries
ISSN (E): 2938-3617
Volume 2, Issue 10, October - 2024

MODELING OF MICRO HYDROPOWER PLANTS OPERATING UNDER LOW PRESSURE AND HIGH-WATER FLOW

Uzbekov Mirsoli Odiljonovich
PhD, Associate Professor, Fergana Polytechnic Institute, Fergana, Uzbekistan
Email: m.uzbekov@ferpi.uz

Sanjarbek Rakhmonjonovich Ormonov
PhD Candidate, Fergana Polytechnic Institute, Fergana, Uzbekistan
Email: sanjarmirzo0021@mail.ru

Abstract
Micro hydropower plants (MHPs) are a promising solution for harnessing renewable energy, particularly in regions with high water flow but low-pressure environments, such as streams and small rivers. This paper presents a comprehensive model for the operation of MHPs under low pressure and high flow rate conditions, emphasizing their efficiency, energy output, and feasibility in remote or rural areas. The model incorporates key hydrodynamic parameters and turbine performance metrics to optimize power generation. Through computational simulations and real-world data analysis, the study demonstrates that MHPs can be an effective and sustainable energy solution. The findings highlight the potential of these systems to contribute significantly to the global transition towards greener energy, with minimal environmental disruption. This research provides a framework for further development and deployment of MHPs, particularly in geographically challenging areas.

Keywords: Micro hydropower plants (mhps), low pressure hydropower, high water flow energy, renewable energy, small-scale hydropower, water turbine optimization, low-head hydropower, sustainable energy systems, rural energy solutions.

Introduction

As global demand for clean and renewable energy continues to rise, micro hydropower plants (MHPs) have emerged as a viable solution for small-scale energy production. These systems, which convert the kinetic energy of flowing water into electricity, offer significant advantages in regions where larger hydroelectric dams may not be feasible due to geographical or environmental constraints. Typically, MHPs are designed to operate in small rivers or streams, which are abundant in many rural and remote areas. However, one challenge with such locations is that they often feature low water pressure, making conventional hydropower technology less effective.

The focus of this study is on developing a model for MHPs that can operate efficiently under conditions of low pressure but high water flow rates. These specific conditions are prevalent in areas where water volume is high, but the elevation change or "head" is minimal, making energy generation more challenging. By addressing this issue, the research aims to provide a pathway for harnessing energy from water resources that are currently underutilized.

This paper explores the technical modeling of MHPs in such environments, analyzing the performance of various turbine designs and optimizing their operation for maximum energy output. The objective is not only to improve energy efficiency but also to assess the environmental and economic feasibility of implementing such systems in diverse geographical locations. The study's findings have implications for both the future of renewable energy infrastructure and the sustainable development of communities that lack access to conventional energy sources.

Hydropower remains a critical renewable energy source for many countries, especially those with abundant water resources. However, maximizing the efficiency of hydropower systems requires careful analysis of turbine and nozzle design, particularly in low-pressure, high-flow environments. This study leverages COMSOL Multiphysics 6.1 to model the behavior of nozzles in micro HPPs, assessing how water flow and pressure impact turbine performance.

Materials and Methods

The modeling process in COMSOL Multiphysics 6.1 used stationary Navier-Stokes equations to simulate the behavior of water as it enters the nozzle. The water velocity entering the nozzle was calculated as the vector sum of the linear velocity along the turbine's circular axis and the velocity of water exiting the guide vanes. The following boundary conditions were applied to the nozzle walls, and the water pressure and velocity at the nozzle's exit were determined using the equations for turbulent kinetic energy (k) and turbulent dissipation rate (ε).

Additionally, to optimize computational efficiency, the nozzle height was divided symmetrically, and symmetrical boundary conditions were applied. This reduced the time and memory required for the simulation without compromising accuracy.

The study explored two main pressure conditions: 30 meters and 2.5 meters of water pressure. Under a pressure of 30 meters, the turbine nozzle produced a consistent and strong pressure force in the direction of flow, with no negative pressure or vortex formation within the nozzle. The results were consistent at lower pressure levels (2.5 meters), demonstrating the effectiveness of the nozzle design for different pressure conditions.

For the larger flow volumes, the nozzles were designed to maintain optimal flow even under lower water pressures. A turbine with a diameter of 0.5 meters had radial guide vanes with a height of approximately 6 cm, and the nozzle’s radial height was 23 cm. The simulations also revealed that the water flow velocity at the nozzle’s exit reached up to 165 m/s, with an initial inlet velocity of 67.4 m/s after accounting for energy losses due to hydraulic resistance.

The study explored two main pressure conditions: 30 meters and 2.5 meters of water pressure. Under a pressure of 30 meters, the turbine nozzle produced a consistent and strong pressure force in the direction of flow, with no negative pressure or vortex formation within the nozzle. This indicates that the nozzle design effectively mitigates potential flow disturbances, which is crucial for maintaining operational efficiency and longevity in hydropower applications. The results were consistent at lower pressure levels (2.5 meters), demonstrating the effectiveness of the nozzle design for different pressure conditions, which is vital for applications where water supply may vary.

For larger flow volumes, the nozzles were specifically designed to maintain optimal flow even under lower water pressures. The ability of the nozzle to perform efficiently at varied pressures

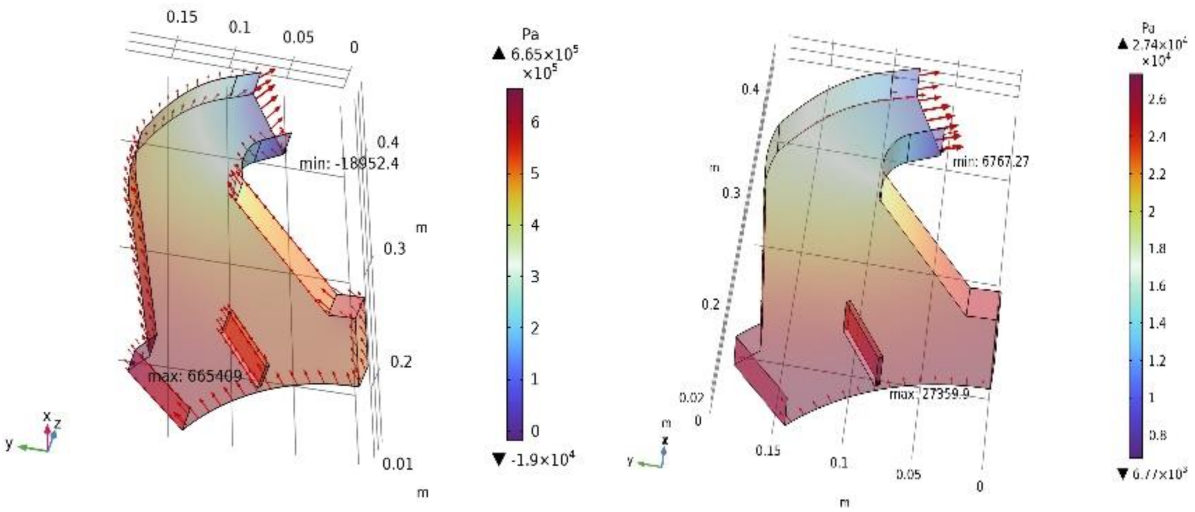
European Journal of Emerging Technology and Discoveries
ISSN (E): 2938-3617
Volume 2, Issue 10, October - 2024

enhances its adaptability in real-world applications, particularly in regions where water availability can fluctuate. A turbine with a diameter of 0.5 meters had radial guide vanes with a height of approximately 6 cm, and the nozzle's radial height was 23 cm. These dimensions play a significant role in guiding the water flow and optimizing energy conversion efficiency. The simulations also revealed that the water flow velocity at the nozzle's exit reached up to 165 m/s, with an initial inlet velocity of 67.4 m/s after accounting for energy losses due to hydraulic resistance. This substantial increase in velocity at the nozzle exit indicates a successful conversion of potential energy to kinetic energy, a critical factor in turbine performance. The high exit velocity contributes to greater energy output from the turbine, which is essential for maximizing the overall efficiency of micro hydropower systems.

Results and Discussion

Further analysis of the flow characteristics indicated that the nozzle design allowed for effective energy recovery and minimized energy losses, even in scenarios of varying flow rates and pressures. The study highlights the importance of optimizing nozzle geometries to achieve desired flow characteristics, ultimately improving the energy efficiency of hydropower installations. These findings can serve as a basis for future designs of micro HPPs, ensuring they can operate effectively across a range of conditions while minimizing environmental impacts.

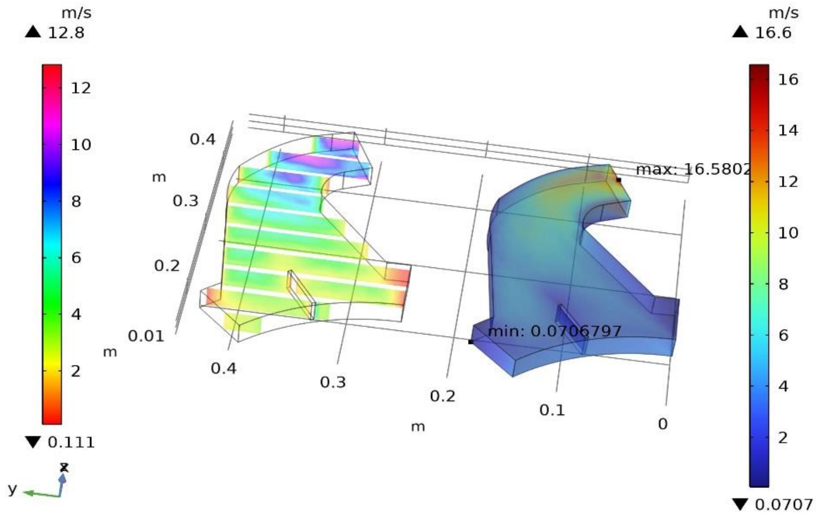
Additionally, the research suggests that future developments could explore the integration of advanced materials and technologies, such as smart sensors and adaptive control systems, to further enhance nozzle performance and efficiency. Implementing such innovations could lead to even greater energy recovery and more sustainable operation of hydropower systems.



a) b)

1-figure. The nozzle of the impeller designed for high water flow: a) under 30 meters of water pressure; b) under 2.5 meters of water pressure.

1- In **Figure a**, according to the mathematical modeling of the turbine nozzle operating under 30 meters of water pressure, the pressure force acting in the direction of rotation is significantly greater than in the opposite direction for this type of nozzle. No negative pressure or vortex flows were observed inside the nozzle. Similarly, the flow characteristics of the same nozzle under a low pressure of 2.5 meters are shown in **Figure b**. The results were the same at low pressures as well. These types of nozzles can be used with any water source under various pressure conditions with high water flow.



2-figure. The nozzle of the impeller designed to operate with high water flow at low water pressure.

In **Figure 2**, the velocity field of water flowing at 2.5 meters of water pressure inside the nozzle of the eight-nozzle impeller is shown. According to the colors displayed on the left-hand side isosurface, we can analyze that, in the region leading up to the curve of the nozzle, the velocity increased uniformly at all points from 3.5 m/s to 5–5.5 m/s. Starting from the curve, the velocity increased toward the center of the nozzle, reaching an average of 12.5 m/s at the exit. The image on the right shows the velocity field, where the maximum velocity at the nozzle exit is 16.5 m/s. Due to local and hydraulic resistance, the water's velocity entering the nozzle, after losing 6.5% of its energy, was 6.74 m/s.
The analysis highlighted the critical role of nozzle design in maximizing the efficiency of micro HPPs. The use of "right-angle curved" nozzles proved advantageous in high-flow, low-pressure environments, minimizing the amount of unused water and ensuring that water flows close to the nozzle walls, thereby increasing the reactive force generated by interaction with the nozzle's inner walls.
Moreover, the study showed that the number of nozzles affects flow dynamics, with more nozzles leading to reduced energy dissipation and a more consistent flow velocity across the nozzle's exit.

Conclusion

The results of this study demonstrate that efficient nozzle design can significantly enhance the performance of micro HPPs, particularly in conditions of low pressure and high water flow. The use of COMSOL Multiphysics 6.1 allowed for precise modeling of water flow dynamics, providing valuable insights into optimizing turbine and nozzle configurations. Future research could explore the integration of these nozzles with advanced turbine technologies to further improve the energy efficiency of micro HPPs.

References

1. Bradshaw, P. (1987). "Turbulent Secondary Flows," *Annual Review of Fluid Mechanics*, 19(1), 53–74. doi:10.1146/annurev.fl.19.010187.000413.
2. Larsson, I. A. S., Lindmark, E. M., Lundström, T. S., Nathan, G. J. (2011). "Secondary Flow in Semi Circular Ducts," *Journal of Fluids Engineering*, 133(10), 101206–101214. doi:10.1115/1.4004991.
3. Versteeg, H. K., Malalasekera, W. (2007). *An Introduction to Computational Fluid Dynamics: The Finite Volume Method,* Pearson Education Limited. ISBN 9780131274983.