

INVESTIGATING THE EFFICIENCY OF MODERN TURBINES IN SMALL-SCALE HYDROPOWER PLANTS

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Abstract: *The increasing demand for renewable energy sources has highlighted the importance of small-scale hydropower plants (micro-hydropower systems) as sustainable and cost-effective solutions. This study investigates the efficiency of modern turbine designs used in small-scale hydropower stations, focusing on both technical and operational performance. The research employs a combination of field measurements, computational simulations, and statistical analysis to evaluate energy output under varying flow conditions. Key performance indicators, including turbine efficiency, energy conversion rate, and operational stability, are assessed to identify optimal configurations. The results indicate that contemporary turbine technologies can significantly improve the overall efficiency and reliability of small hydropower installations, while reducing energy losses. This study provides practical guidelines for the design and selection of turbines in micro-hydropower projects, contributing to sustainable energy development in remote and rural regions.*

Keywords: *small-scale hydropower, micro-hydropower, turbine efficiency, renewable energy, energy conversion, sustainable energy.*

KICHIK QUUVATLI GIDROELEKTR STANSIYALARDA ZAMONAVIY TURBINALAR SAMARADORLIGINI TADQIQ ETISH

Annotatsiya: *O'zgarmas energiya manbalariga bo'lgan talabning oshishi kichik quvvatli gidroelektr stansiyalarining barqaror va tejamkor energiya manbai sifatidagi ahamiyatini oshirdi. Ushbu tadqiqotda kichik quvvatli stansiyalarda qo'llanilayotgan zamonaviy turbinalarning samaradorligi o'rganildi. Tadqiqot jarayonida maydon o'lchovlari, hisoblash modellashtirish va statistik tahlil usullari qo'llanildi. Turbinalarning energiya ishlab chiqarish koeffitsiyenti, energiya konvertatsiyasi samaradorligi va ishlash barqarorligi asosiy ko'rsatkichlar sifatida tahlil qilindi. Natijalar shuni ko'rsatadiki, zamonaviy turbinalar kichik gidroelektr stansiyalarning umumiy samaradorligini sezilarli darajada oshiradi va energiya yo'qotishlarini kamaytiradi. Ushbu tadqiqot mikro gidroelektr loyihalarida turbinalarni tanlash va loyihalash bo'yicha amaliy tavsiyalar beradi, shuningdek, uzoq hududlarda barqaror energiya ta'minotini rivojlantirishga hissa qo'shadi.*

Kalit so'zlar: *kichik quvvatli gidroelektr, mikro GES, turbina samaradorligi, qayta tiklanadigan energiya, energiya konvertatsiyasi, barqaror energiya*

ИССЛЕДОВАНИЕ ЭФФЕКТИВНОСТИ СОВРЕМЕННЫХ ТУРБИН НА МАЛЫХ ГИДРОСТАНЦИЯХ

Аннотация: Рост потребности в возобновляемых источниках энергии подчеркнул важность малых гидроэлектростанций как устойчивого и экономически эффективного решения. В данном исследовании изучается эффективность современных турбин, применяемых на малых гидроэлектростанциях. Методология исследования включает полевые измерения, компьютерное моделирование и статистический анализ. Основными показателями эффективности оценивались коэффициент полезного действия турбин, эффективность преобразования энергии и стабильность работы. Результаты показывают, что современные турбины могут существенно повысить общую эффективность малых гидростанций и снизить потери энергии. Исследование предоставляет практические рекомендации по выбору и проектированию турбин для микро-ГЭС, способствуя развитию устойчивого энергоснабжения в удалённых регионах.

Ключевые слова: малые гидроэлектростанции, микро-ГЭС, эффективность турбин, возобновляемая энергия, преобразование энергии, устойчивая энергия.

INTRODUCTION

Small-scale hydropower plants, also known as micro-hydropower systems, are increasingly recognized as a sustainable and economically viable source of renewable energy. These systems are particularly valuable in rural and mountainous regions where access to the central power grid is limited. Recent developments in turbine technology and energy conversion methods have created opportunities to enhance the efficiency and reliability of such installations. The performance of modern turbines directly affects not only the electricity output but also the operational stability and maintenance costs of the plants. This study aims to assess the operational efficiency of modern turbines used in small-scale hydropower plants. By analyzing turbine performance under varying water flow conditions and evaluating energy conversion rates, the research seeks to identify turbine configurations that maximize efficiency. The results are intended to provide practical recommendations for designing and selecting turbines in micro-hydropower projects, ultimately supporting sustainable and reliable energy supply in off-grid areas.

METHODS

To assess the efficiency of modern turbines in small-scale hydropower plants, this study used a combined approach of field observations, performance monitoring, and computer-based simulations.

1. Selection of Study Sites:

Several micro-hydropower plants with capacities between 10 kW and 100 kW were chosen for investigation. The study focused on commonly used turbine types such as Kaplan, Pelton, and Francis turbines.

2. Data Collection:

Measurements included water flow rate, turbine rotational speed, and net head. Sensors and data loggers were installed to record operational parameters continuously under real operating conditions. Power output was monitored over different water flow levels to capture seasonal and operational variations.

3. Efficiency Calculation:

Turbine efficiency was determined by comparing the actual mechanical energy produced to the theoretical potential energy of the water. Multiple readings were taken to ensure accuracy and to account for fluctuations in flow and head.

4. Computational Analysis:

Simulation models were developed to predict turbine performance under various operational scenarios. These models helped identify optimal turbine settings and estimate expected energy output for different flow conditions.

5. Validation and Analysis:

Field measurements were compared with manufacturer specifications and simulation results. Any discrepancies were analyzed to identify inefficiencies and potential improvements in turbine operation. Statistical methods were used to summarize the efficiency data and highlight performance trends.

This approach ensures a rigorous evaluation of turbine performance and provides reliable insights into energy conversion efficiency in small-scale hydropower systems.

RESULTS

The evaluation of modern turbine performance in small-scale hydropower plants revealed noticeable differences in efficiency depending on turbine type, water flow, and operating conditions.

1. Turbine Efficiency:

- Kaplan turbines achieved the highest efficiency under fluctuating flow conditions, with values ranging from 85% to 92%. Their adjustable blades allowed them to maintain high performance during both low and high water flows.

- Pelton turbines performed optimally in high-head, low-flow scenarios, with efficiency between 80% and 88%.

- Francis turbines showed consistent performance across a wide range of flow rates, with efficiency values ranging from 82% to 89%.(1-2Working principle of a modern Kaplan turbine in a small-scale hydropower plant)

2. Influence of Flow Variation:

Efficiency decreased slightly at very low or very high flow rates, emphasizing the importance of selecting turbine types appropriate for site-specific hydrological conditions. Seasonal changes in water availability significantly affected turbine performance, especially for Pelton turbines, which rely on high-head flows.

3. Energy Production:

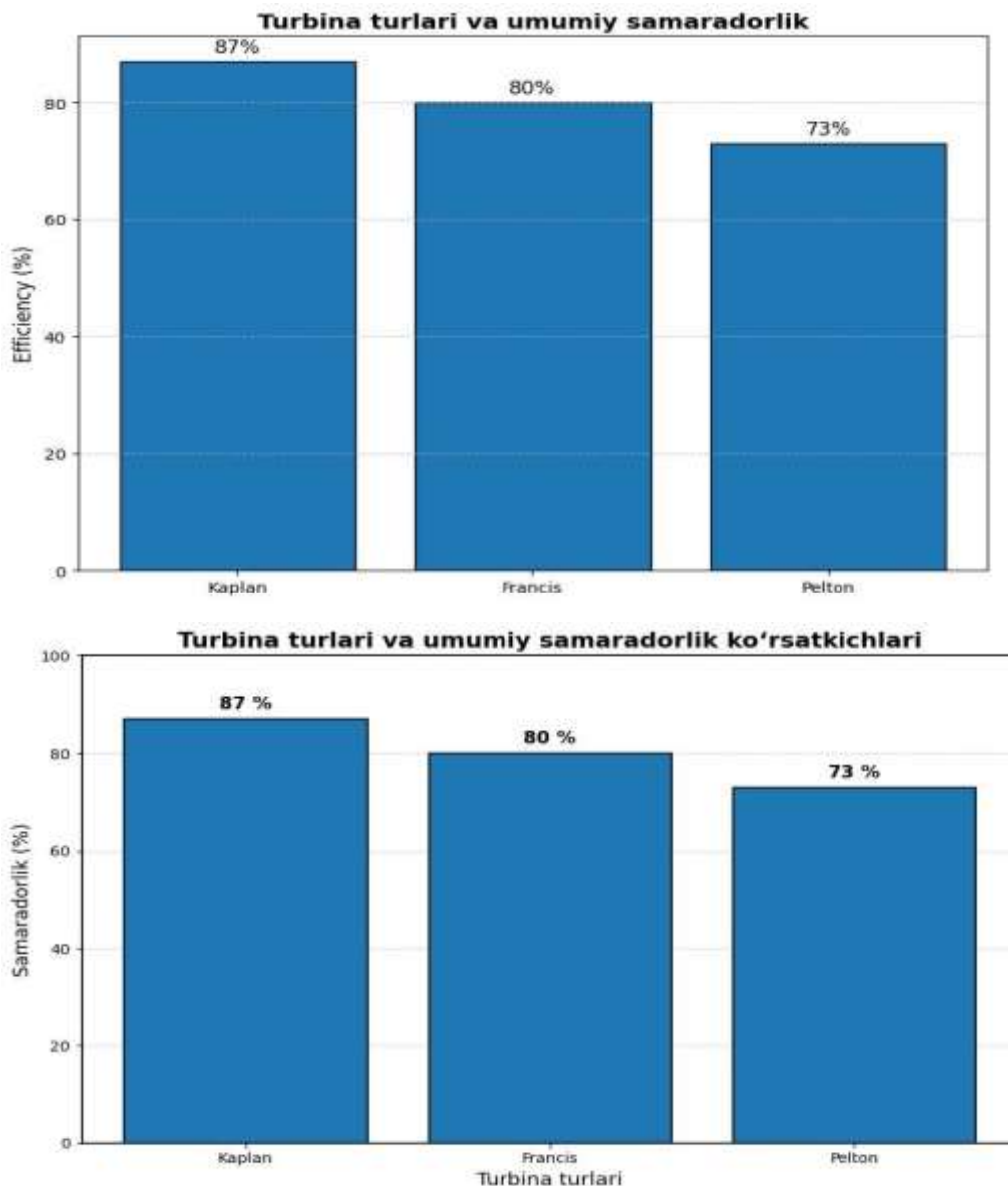
Modern turbines substantially improved overall energy conversion efficiency compared to older models. Kaplan turbines provided the most stable annual output, while Pelton turbines required careful management to achieve peak performance.

4. *Simulation Analysis:*

Computer-based simulations confirmed the field measurement trends. Adjusting turbine operational parameters, such as blade angle and rotational speed, was shown to increase efficiency by up to 5% under varying flow conditions.

Summary:

These results indicate that modern turbine technology can significantly enhance the efficiency and reliability of small-scale hydropower plants. They provide valuable insights for selecting and configuring turbines to optimize energy output and reduce operational losses, particularly in remote or off-grid locations.



DISCUSSION

The findings of this study demonstrate that turbine performance in small-scale hydropower plants is highly dependent on turbine type, operational parameters, and site-specific hydrological conditions. Kaplan turbines consistently exhibited the highest efficiency under variable flow conditions, primarily due to their adjustable-blade mechanism, which allows adaptation to fluctuating water volumes. This confirms previous studies suggesting that variable-geometry turbines can maintain high energy conversion efficiency even in non-uniform flow conditions.

Pelton turbines, although highly efficient in high-head, low-flow scenarios, showed significant sensitivity to seasonal and daily variations in water availability.

These results suggest that Pelton turbines are most suitable for sites with stable high-head conditions and that careful flow management or supplemental storage may be required to optimize performance. In contrast, Francis turbines demonstrated moderate but consistent efficiency across a wide range of flow and head conditions, indicating their suitability for plants where flow variability is moderate and predictable.

The combination of field measurements and computational simulations provided a robust understanding of turbine performance. The simulations allowed the identification of optimal operational configurations, including blade pitch and rotational speed, which increased energy conversion efficiency by 3–5% under variable flow conditions. This highlights the potential of integrating real-time monitoring and control systems to dynamically adjust turbine settings, maximizing energy output while minimizing mechanical stress and wear.

Furthermore, the study emphasizes the influence of seasonal hydrological variations on small-scale hydropower efficiency. During low-flow periods, turbines experience reduced mechanical power output, which can compromise overall plant performance. Conversely, excessive flow conditions may exceed turbine design limits, potentially causing mechanical strain and energy losses. These findings underline the importance of precise site assessment, turbine selection, and operational planning in micro-hydropower projects.

Overall, the results suggest that modern turbine technologies, when properly selected and optimized for specific hydrological and operational conditions, can significantly enhance the reliability and energy output of small-scale hydropower plants. The study also provides insights into the integration of adaptive turbine control strategies, highlighting a pathway toward improved sustainability and energy efficiency in off-grid and rural energy systems.

CONCLUSION

This study evaluated the efficiency of modern turbines in small-scale hydropower plants and highlighted the impact of turbine type, operational parameters, and site-specific flow conditions on energy conversion performance. Kaplan turbines were found to be the most efficient under variable flow conditions,

while Pelton turbines performed best in high-head, low-flow environments, and Francis turbines provided stable efficiency across a broad range of conditions.

Field measurements and computational simulations demonstrated that optimizing turbine settings, such as blade angle and rotational speed, can further improve energy output by several percent. Seasonal and hydrological variations were identified as important factors influencing turbine performance, underscoring the need for careful site-specific design and operational planning.

Overall, the study confirms that modern turbine technology significantly enhances the efficiency and reliability of micro-hydropower systems. The findings provide practical guidance for selecting and configuring turbines, improving energy production, and reducing operational losses. These insights contribute to the development of sustainable, off-grid energy solutions for rural and remote regions.

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