World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Research Article)

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Integrating sustainability and economic efficiency in renewable power: A Dual-Source Pico Hydro–Steam Turbine Design

Angela Georgia P. Villa [1,*], Kristobal John E. Gonzales [1], Nicolai D. Fuentes [1], Nice S. Patricio [1], Alexis G. Dela Cruz [1] and Lorie Mae A. Castro [2]

[1] *Asuncion National High School, Division of Davao del Norte.*
[2] *Mindanao State University – Tawi-Tawi College of Technology and Oceanography.*

World Journal of Advanced Research and Reviews, 2025, 28(02), 1312–1322

Publication history: Received on 05 October 2025; revised on 13 November 2025; accepted on 15 November 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.28.2.3842

Abstract

The purpose of this research is to design and fabricate a Pico Hydro-Steam Turbine that combines steam and rain-catching technologies for power generation, addressing identified issues and implementing modifications to enhance efficiency. The research used an experimental-developmental approach, involving the concept development, testing, and prototyping phases. It was revealed that in the water phase, the turbine requires a flow rate above 0.0000574 m^3/s to produce electricity, and in the steam phase, it begins to spin when the pressure exceeds 42.8 PSI. Measured efficiencies reached 94.164% in the water phase and 81.549% in the steam phase at the highest water flow rate and pressure, indicating that the turbine could operate at even higher efficiency. It was also observed that the increased flow rate and pressure enhance turbine performance. Statistical analysis of Trial 1 showed significant differences in the independent variables water flow rate and pressure flow with values of 0.011 and 0.023, respectively, both below the 0.05 significance level. This confirms that these independent variables have an impact on the turbine's performance. The findings are informative for energy companies, utility providers, homeowners, and future researchers, offering insights into optimal operational thresholds. The study recommends the use of rainwater in the water phase, steam powered by solar energy in the steam phase, incorporating control elements, and adding battery storage. This research confirms that integrating water and steam technologies within the Pico Hydro-Steam Turbine for electricity generation is efficient and has the potential for further improvement.

Keywords: Turbine; Steam; Water; Power Generation

1. Introduction

Electricity is fundamental to modern life, powering transportation, devices, appliances, and essential machinery for daily functions. However, electricity production largely depends on fossil fuels, which make up over 60% of global energy production [1] and release pollutants that harm the environment and human health. According to the U.S. Environmental Protection Agency (2024), the energy sector accounts for about 25% of total global greenhouse gas emissions, with coal being the largest single source, responsible for approximately 44% of CO_2 emissions [2]. Such emissions intensify extreme weather events, increase average global temperatures, and disrupt ecosystems. This reality presents a significant challenge: meeting civilization's electricity needs sustainably while reducing environmental consequences [3].

High energy consumption escalates pollution and climate change, significantly contributing to rising global temperatures. Climate change itself further increases electricity use, especially in warmer regions where cooling appliances are required. As global populations and wealth rise so does energy demand, which results in higher costs

* Corresponding author: Angela Georgia P. Villa

and further dependence on fossil fuels [4]. This interdependent cycle between high demand and climate change intensifies environmental risks and highlights the need for innovative, renewable energy solutions.

In the Philippines, the energy sector faces similar issues. The Department of Energy (DOE) projects a 4.6% annual increase in electricity demand until 2040, driven by urbanization and industrial growth. Coal-fired plants, which produce over 50% of the country's electricity, contribute significantly to CO_2 emissions and pollution [5]. According to the PAGASA, the Philippines, among the most climate-vulnerable nations, faces intensified typhoons, sea-level rise, and droughts. Rising temperatures also increase energy demand for cooling, compounding the environmental impact of fossil fuel reliance and driving an urgent need for renewable energy solutions.

To meet rising demand, grid operators use a hierarchy of power plants based on costs, starting with lower-cost sources like water, wind, and solar. When additional capacity is needed, costlier coal and fossil fuel plants are used, raising wholesale electricity prices and, consequently, consumer rates [6]. As recently seen in the Philippines, Meralco raised its rates to Php11.6012 per kWh, directly affecting household budgets [7]. This additional demand also exacerbates pollution, as fossil fuel plants generate more emissions, endangering public health and the environment [8]. Communities experience blackouts when high temperatures strain power grids, as seen in a study in Masbate, where 97.7% of respondents reported regular power interruptions [9].

In response, renewable energy has emerged as a practical and sustainable solution for the Philippines. By using renewable sources like solar, wind, and geothermal, the country can reduce dependence on fossil fuels and lower household utility costs [10]. Hybrid renewable systems with multiple sources of energy show efficiency improvements, reduced emissions, and a reliable source of energy supply, especially for those sites characterized by several resources and variations in climate conditions [11]. Although hybrid turbines exist, no dual-source turbine uses water and steam. This is a latent system whereby, if fully realized, it would increase huge numbers of clean energy production in relation to emissions and make the power supplies reliable.

To bridge this gap, a dual-source turbine system design using both water and steam sources for energy generation is proposed. This way, the product can be used as an energy source in rainwater and solar-generated steam, making the turbine to be used for many purposes in cleaning up power generation. This hybrid approach has the potential of building climatic resilience while supporting national and international emission reduction targets. The bottom line of this study is the minimization of the renewable technology gap toward a sustainable energy future.

2. Review of related literature

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This study concludes that hybrid energy systems that couple wind, solar, and other renewable sources have a powerful advantage, maximizing the strengths of each type of energy. These systems were studied in both Newcastle, UK, and Patani, Nigeria, where they are shown to be able to reliably serve local energy needs, using abundant wind and solar resources where appropriate. However, hybrid energy systems may be challenged by varying weather conditions and higher cost of operation than traditional grid electricity, but over the long term, sustainability and reduced dependence on non-renewable resource benefits seem to outweigh the challenges. With the strategic support, these systems can contribute enormously in the way of reaching clean and reliable energy for several communities.

3. Methodology

3.1. Research Design

This study used an experimental-developmental approach, combining the testing of new ideas with the improvement of the prototype. The experimental phase focused on evaluating how well the turbine system works, which generates power using both water flow and steam pressure. By conducting controlled experiments, variables such as water flow rate, pressure, and environmental conditions are adjusted to measure the turbine's efficiency and versatility. This structured testing helps assess how effectively the turbine can process water and steam inputs for electricity production. The developmental phase focused on improving the turbine design based on the results of our experiments. After the initial tests, we make changes to boost the turbine's performance and ensure it runs reliably. This might involve fine-tuning parts like the turbine blades or adjusting the control systems so they can easily utilize water and steam energy sources. The main aim of this research would be to realize an optimized turbine that may work well and efficiently harness power with the help of both water and steam. Ultimately, such a system could be versatile and practical enough to be applied to renewable energy to fulfill real-world needs sustainably.

3.2. Research Instrument

This research applied the turbine efficiency formula as an instrument in data gathering for the evaluation of the performance of the turbine. Efficiency refers to the situation whereby the energy put into a turbine or machine is utilized and converted into useful energy output. In an ideal turbine, all input energies would be converted to energy output without loss in the system. However, it is practically impossible to achieve 100% efficiency mainly due to conditions such as friction, heat dissipation, and others that occur in the system of the turbine.

This is presented through the following equation:

$$Efficiency\ (\eta) = Output/\ Input$$

In this paper, the input energy of the fluid water is computed by the following hydraulic power formula:

$$Pin = \rho \cdot g \cdot Q \cdot H$$

Where ρ is the density of water normally 1000 kg/m^3, g is the gravitational acceleration, Q is the flow rate of the water, and H is the height difference of the water from the turbine. Whereas the input energy of the steam fluid is computed based on the formula:

$$Pin = m^{\cdot} (\Delta h)$$

Where m is the mass flow rate of steam and Δh is the change in enthalpy and the output energy is calculated using the power formula:

$$P = V \cdot I$$

Where V is the voltage and I is the current.

3.2.1. Locale

The project Pico Hydro-Steam Turbine was made in Asuncion National High School at Asuncion, Davao del Norte. This is because it has very spacious facilities, and most of the tools and equipment required for the project are available here. Asuncion National High School is provided with laboratories that carry the essential scientific instruments to facilitate proper examination and testing of the performance of the turbine. There are areas outside and ideal for the installation of a turbine prototype; there are also power tools to construct and assemble the system, all of which will be conducive for the successful development and assessment of effectiveness of Pico Hydro-Steam Turbine and thereby support the school's mission in fostering innovation and practical learning about renewable energy technologies.

3.2.2. Data Gathering Procedure

These experiments will be carried out by the researchers to collect the necessary data to measure the functionality and performance of the Pico Hydro-Steam Turbine.

- Preparations and test setup of the turbine system
- Input data collection
- Collection of Output data

3.3. Data collection

For each trial, the researchers logged the following data: input measurements, including water flow rate or steam pressure, and output measurements, including the power generated (in watts). The data were then organized into a table to facilitate easy comparison and analysis.

3.4. Data analysis

The researchers will determine the efficiency of the turbine using the following formula:

ɳ = (Power Generated/Output)/(Hydraulic power or Thermal Power/ Input)

This calculation enables the researchers to analyze how the efficiency of the turbine change as the different water flow rate and pressure is also applied. This analysis aims to provide insights into the performance dynamics of the turbine under different operational conditions.

3.5. Statistical Treatment and Analysis of Data

The differences in the water flow rate, mass flow rate, and efficiency are the statistical treatment and analysis of data on water and steam inputs critical for evaluating the performance of the turbine under various conditions.

In gathering the data, the mean for the outcome of every trial will be computed and interpreted.

3.5.1. Mean

The mean values of water flow rate, pressure flow, input power, voltage, current, power output, and efficiency are calculated to have an understanding of the actual behavior of the turbine.

In ascertaining whether there is a significant difference between the water flow rate and efficiency and the mass flow rate and efficiency, Kruskal Wallis test was utilized. This is a non-parametric test to compare whether there is any difference between several groups of data that are not normally distributed in variations, wherein these factors determine if changes are meaningful to turbine efficiency.

3.6. Data Interpretation

A statistically significant Kruskal-Wallis test result ($p < 0.05$) would signify that the rate of flow in water and mass flow have to be optimized for the betterment of the turbine's efficiency. A non-significant result (p-value ≥ 0.05) means that there is little effect caused by flow changes, and thus performance would be stable in conditions without any requirement for adjustments. All of these results may be passed on to guide refinements that will increase effectiveness.

This statistical analysis is performed in Microsoft Excel, calculating the mean, then doing the Kruskal-Wallis test to find the p-value in order to make a decision. This approach gives further detail in the performance of the turbine so that any results derived would be well-founded on data.

4. Results and discussion

Table 1 presents the average performance metrics—including hydraulic power, voltage, current, electrical power, and turbine efficiency calculated from three trials conducted at each of five different constant water flow rates and water heads.

Table 1 Average Performance Metrics of Water

Flow Rate (m^3/s)	Head (m)	Gravitational force (m/s^2)	Hydraulic Power (W)	Voltage V (v)	Current I (A)	Electrical Power (W)	Efficiency (%)
0.0000574	1.26	9.81	0.7095	0.109	0	0	0
0.000175	1.26	9.81	2.163	3.382	0.117	0.397	18.07
0.000194	1.26	9.81	2.398	4.60	0.3	1.39	57.95
0.000233	1.26	9.81	2.88	5.52	0.462	2.561	88.552
0.000292	1.26	9.81	3.6093	6.05	0.562	3.404	94.164

The testing results reveal how the pico hydro turbine performs under different flow rates, showing how it might operate in real-life scenarios. At the lowest tested flow rate of 0.0000574 m^3/s, the turbine does not rotate, so no electricity is produced, resulting in zero efficiency. This flow rate could represent a very light rain or just occasional raindrops, which don't provide enough water energy to start the turbine. However, at a flow rate of 0.000175 m^3/s, the turbine starts rotating, producing 0.397 W of electrical power with an efficiency of 18.07%.

As the flow rate increases to 0.000194 m^3/s, the turbine generates 1.39 W of electrical power from 2.398 W of hydraulic input power, achieving an efficiency of 57.96%. Further increases in flow rate led to even better performance: at 0.000233 m^3/s, the turbine produces 2.561 W of electrical power from 2.88 W of hydraulic input, reaching an efficiency of 88.55%. At the highest tested flow rate of 0.000292 m^3/s, the turbine produces 3.404 W of electrical power from a hydraulic power input of 3.6093 W, resulting in an efficiency of 94.16%.

In all tests, the water head and gravitational force were constant, simulating real conditions. If this setup were applied to a practical rainwater harvesting system, such as using a standard downpipe from a roof gutter at a height of 2.74 meters, it would generate significantly more hydraulic power and electrical output. This suggests that a properly designed rainwater collection system with adequate height could serve as an effective, renewable energy source, particularly during periods of heavy rainfall.

Figure 1 illustrates the relationship between water flow rate (in cubic meters per second) and turbine efficiency (in percentage). As the water flow rate increases, the turbine's efficiency also improves, following a trend of rapid initial gains that gradually level off as flow rate continues to rise. At lower flow rates, from approximately 0.0000574 m^3/s to 0.000233 m^3/s, the turbine shows a steep increase in efficiency, rising from close to 0% to around 88.54%. This pattern indicates that the turbine benefits significantly from small increases in water flow within this range, rapidly enhancing its performance. Beyond 0.000233 m^3/s, the increase in efficiency begins to slow down, reaching approximately 94.2% efficiency at a flow rate of 0.000292 m^3/s. While the graph suggests that efficiency stabilizes around this point, this value reflects the average trend based on multiple trials and may not represent the absolute maximum efficiency of the turbine. Under different conditions or in optimal setups, the turbine could potentially achieve higher efficiencies than shown here. In summary, the data indicates that as water flow rate increases, turbine efficiency improves significantly before leveling off around higher flow rates.

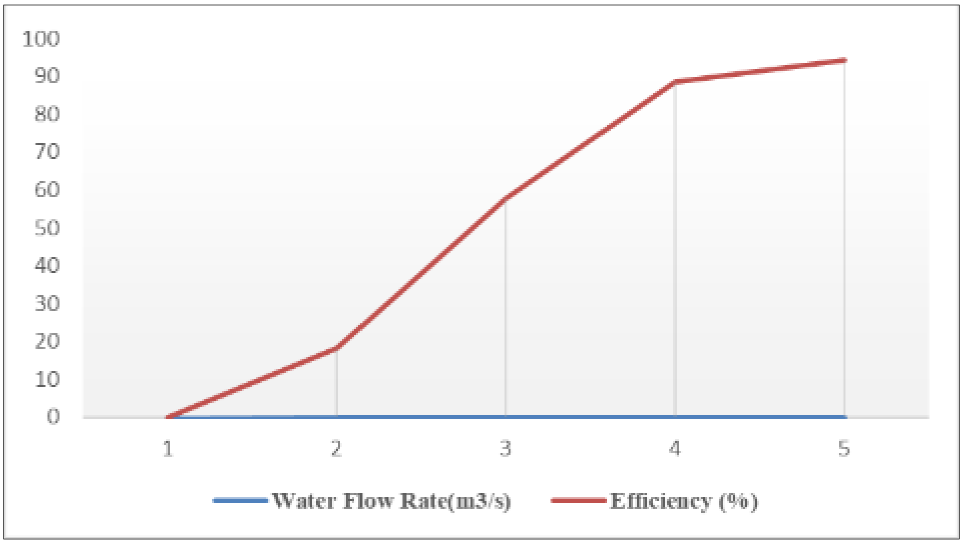

Figure 1 Water Flow Rate vs. Turbine Efficiency

Table 2 presents the result of the Kruskal-Wallis test indicates that the assumption is rejected (p = 0.011). Since the p-value (0.011) is less than the significance level (0.05), we reject the assumption. This means that there is a statistically significant difference in the distribution of Trial 1 across different categories of Water Flow Rate.

Table 2 Kruskal Wallis Test on Water Flow Rate and Efficiency

Assumption	Test	Sig. a.b	Decision
The distribution of Trial 1 is the same across categories of Water Flow Rate.	Independent- Samples Kruskal-Wallis Test	0.011	Reject the assumption.

The significance level is 0.050 Asymptotic significance is displayed.

Table 3 presents the average performance metrics including input power, voltage, current, electrical power, and turbine efficiency calculated from three trials conducted at each of five different constant water flow rates and water heads

Table 3 Average Performance Metrics of Steam

Pressure (PSI)	Mass Flow Rate (kg/s)	Change of Enthalpy (kJ/kg)	Input Power (W)	Voltage V (v)	Current I (A)	Electrical Power (W)	Efficiency (%)
42.8	0.001031	2165.08	2.232	0.09	0	0	0
80	0.001385	2096.1	2.903	3.374	0.507	1.643	56.076
100	0.01124	2067.62	23.24	9.99	1.86	18.605	81.117
130	0.01504	2030.91	30.545	12.37	2.01	24.957	81.549

The descriptive analysis presented in Table 8 reveals that the turbine requires a minimum pressure threshold to operate effectively. At 42.8 PSI, the turbine doesn't rotate, resulting in zero electrical output and efficiency, indicating that this pressure is insufficient to overcome mechanical resistance and initiate rotation. At 80 PSI, the turbine starts to produce power, achieving an electrical output of 1.643 W from an input power of 2.903 W and an efficiency of 56.076%. This efficiency suggests that 80 PSI may not be the true starting pressure that can rotate the turbine, but rather the lowest tested pressure at which it produced measurable power. At 100 PSI, the turbine's performance improves dramatically, reaching an efficiency of 81.117% with an input power of 23.24 W and an electrical output of 18.605 W. This sharp increase in efficiency suggests that 100 PSI likely represents a more effective operating pressure, where the system can convert pressure into electrical energy more optimally. At 130 PSI, the efficiency slightly increases to 81.549%, with a higher input power of 30.545 W and an electrical output of 24.957 W. The minor efficiency gain between 100 PSI and 130 PSI implies a performance plateau, where additional pressure contributes primarily to increased power output rather than further efficiency improvements. Overall, the turbine operates most effectively at or above 100 PSI, with diminishing efficiency gains as pressure rises beyond this point.

The pico hydro turbine performs best with a sufficient flow rate and an optimal pressure around 100 PSI. Higher flow rates significantly boost efficiency and power output, while increasing pressure improves performance up to a plateau at 100 PSI. For practical applications, like a rainwater harvesting system, maintaining these conditions would enable efficient and sustainable power generation, making the turbine a viable small-scale renewable energy source.

Figure 2 shows the relationship between pressure (in PSI) and turbine efficiency (in percentage). As the pressure increases, the turbine's efficiency also improves, with rapid gains at lower pressures that gradually slow as pressure continues to rise. At lower pressure levels, from 1 to 2 PSI, the efficiency increases steeply, rising from nearly 0% to around 60%. This suggests that even small increases in pressure within this range significantly enhance the turbine's performance. Beyond 2 PSI, the rate of efficiency improvement begins to slow. By around 3 PSI, the efficiency approaches 80%, and further increases in pressure show only modest gains. At 4 PSI, the efficiency appears to stabilize close to 80%. In summary, this data indicates that increasing pressure generally improves turbine efficiency, particularly at lower pressures, before efficiency begins to level off at higher pressures. This trend provides useful insight into the turbine's typical performance, but it does not represent the absolute efficiency limit, as the maximum efficiency varies with different operating conditions.

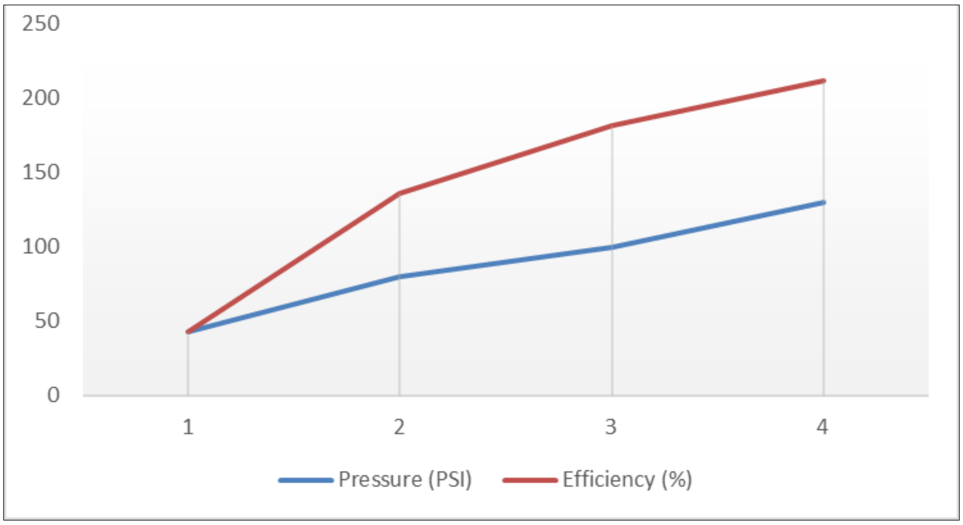

Figure 2 Pressure vs. Turbine Efficiency

Table 4 Kruskal Wallis Test on Pressure Flow and Efficiency

Assumption	Test	Sig. a.b	Decision
The distribution of Trials is the same across categories of Pressure Flow	Independent- Samples Kruskal-Wallis Test	0.023	Reject the assumption.

The significance level is 0.050 Asymptotic significance is displayed.

The result of the Kruskal-Wallis test indicates that the assumption is rejected (p = 0.023). Since the p-value (0.023) is less than the significance level (0.05), we reject the null hypothesis. This means that there is a statistically significant difference in the distribution of Trials across different categories of Pressure Flow.

Findings of the Study

Water-Based Performance: The turbine needs a water flow rate higher than 0.0000574 m^3/s to start spinning and produce electricity. At the lowest tested flow of 0.0000574 m^3/s, the turbine does not spin, so no power is produced, resulting in 0% efficiency. At 0.000175 m^3/s, the turbine starts moving, generating 0.397 watts of power at 18.07% efficiency. As the flow increases, performance improves: at 0.000194 m^3/s, the power output jumps to 1.39 watts with 57.96% efficiency. The highest tested flow rate, 0.000292 m^3/s, delivers the best results, producing 3.404 watts and achieving 94.16% efficiency. This shows that higher water flow rates significantly increase energy production. Steam-Based Performance: The turbine's efficiency with steam depends on pressure. At 42.8 PSI, the turbine doesn't generate power, as the pressure isn't strong enough to make it spin. At 80 PSI, the turbine starts working, producing 1.643 watts at 56.08% efficiency. At 100 PSI, efficiency jumps to 81.12%, with the turbine outputting 18.605 watts from 23.24 watts of input. When pressure increases to 130 PSI, efficiency reaches 81.55%, producing 24.957 watts. Although higher pressure increases power output, the efficiency gains become smaller after 100 PSI. Overall, the turbine's effectiveness relies on achieving sufficient flow rates and pressures. For water, a higher flow rate leads to greater energy output and efficiency. For steam, optimal pressure around 100 PSI is crucial, and further increases offer diminishing efficiency benefits but more power. These insights are valuable for designing systems that use either rainwater or steam energy for small-scale renewable power generation.

4.1. Structure of the project

4.1.1. Parts, Functions, and Interrelationships

As presented in Figure 3, the Pico hydro steam turbine system is designed to convert fluid energy into electricity in an efficient and compact way. Its four major parts that work well together are: the turbine wheel, the turbine casing, the shaft with its bearings, and the generator. The turbine wheel is very light and heat-resistant as well as corrosion-resistant; because both the water and the steam exert forces upon it and it must remain undamaged. A fluid passing over the turbine blades causes the wheel to spin, converting the fluid's energy into rotational motion.

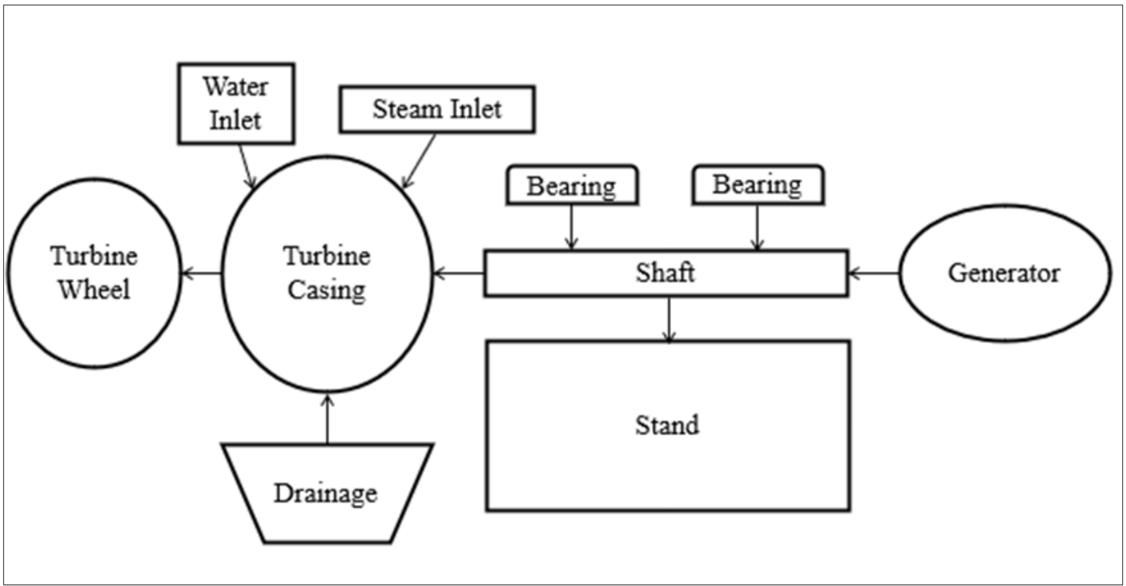

Figure 3 Interrelationship of the Parts

Inside the turbine casing is the turbine wheel and the casing has two inlets for water and steam, connected to a drain outlet by which the fluid leaves the unit. The casing supports the turbine wheel but also manages flow, making sure the turbine wheel gets just enough force to operate effectively. The casing is connected to the turbine wheel with a shaft, transferring the rotational energy from the turbine to the generator where electricity is produced. The shaft has two bearings on it supporting the shaft in such a way that wobbling is prevented and friction is reduced so that the wheels turn smoothly and reliably. The entire unit is mounted on a stand, which gives stability and positions the turbine casing, shaft, and generator in line when in operation.

One of the most interesting and best features of the system is its modular design, which makes it easier to assemble, disassemble, and transport. The turbine wheel can be withdrawn from the shaft; the turbine casing can be separated from the stand; in fact, even the generator can be removed. The components of the system are quite accessible and conveniently amenable to maintenance, repairs, or relocation according to need.

Capabilities and Limitations

The Pico Hydro-Steam Turbine operates in a manner that allows it to generate electricity from water as well as steam and allows it to source these two commodities depending on availability. Their dual nature means that users can interchangeably run the turbine on hydro and/or steam depending on the weather, thus optimizing the generation of electricity. It is designed for a variable water flow rate and steam pressure and, therefore, suited to operating in rural or urban areas. Nonetheless, the turbine efficiency may be compromised in other situations involving low water flow or irregular steam pressure. For example, in order to function in the steam phase, the pressure should be at least 80 psi; otherwise, it wouldn't rotate or make electricity. In water phase mode, a flow rate of water greater than 0.0001765 m^3/s is required for rotation and generation of electricity. To achieve this, proper operation and maintenance are crucial, and more so in conditions that experience variable resource accessibility.

4.2. Design Error Analysis and Enhancements

- The first design of the rotor lacked stability, so the researchers modified it to make it more rigid and stable. This enhancement will contribute to the stabilization of the turbine blades. Additionally, the rotor was designed to be detachable, allowing for necessary adjustments to be made, thereby reducing potential errors in the system's overall assembly.
- At first, the researchers did not expect the need for a stand. However, during the development of the system, it was realized that it would be necessary to design a stand where all the assembly could sit firmly. To ensure more stability, two bearings were added to the shaft that connects the turbine to the generator. These bearings help reduce wobbling and improve the stability of the turbine.
- The casing was made to be detachable to make it easier and more convenient in transporting the system.
- The steam inlet was also designed to be detachable and features a long single tube, which simplifies the connection between the steam inlet and the pressure cooker. The detachable steam inlet not only makes transportation easier but also helps protect the component from potential damage during handling.

4.2.1. Operating Procedures

The following procedures outline the steps to operate the Pico Hydro-Steam Turbine safely and effectively

- Make sure to get a close look at the PICO Hydro-Steam Turbine to see if there are signs of wear and tear or dent on the turbine casing, blades, or other parts of the turbine.
- Check that all parts of the turbine are in good condition, particularly the water and steam inlets of the turbine.
- Ensure that the power generator is well functioning and, in a state, to generate power as desired.
- Install the turbine in the desired position near the water source or steam inlet, making sure that the installation is stable.
- Observe the turbine rotation, confirming smooth motion without obstruction, excessive noise, or unusual vibrations.
- Occasionally observe the turbine in order to find out that no harm will be inflicted on it during the process.

4.2.2. Maintenance

To ensure optimal functionality and longevity of the Pico Hydro-Steam Turbine, adhere to the following maintenance steps

- The turbine parts should be frequently inspected and visually observed, especially the water inlet, steam valve, and parts in motion. Check for signs of wear and corrosion and also loose fittings, which could hinder functionality.
- The turbine also needs to be kept clean to prevent debris or even sedimentation from building up in the water inlet and steam flow. It would help keep running freely without blockages.
- Test the rotation of the turbine blades at regular intervals to check for smooth rotation using both inputs with water and steam. Check for wearing of blades and replace where necessary for continued efficiency.
- Observe the structural mounting stability and alignment of the turbine to ensure that it is correctly mounted and operates without unnecessary vibration.
- Tighten all bolted sections, screws, and other parts together, especially the intake section of steam and water, to give extra protection from any leakage or weakening that may occur with time.

- Protection covers should be used to protect the turbine from dust exposure and extreme weather conditions.

4.3. Safety and Control Measures

- In the process of transporting and placing the Pico Hydro-Steam Turbine for gutter installation, handle the device with care so that no structure or nearby person is run into, and thus all parts are left undamaged.
- Keep the turbine and any electrical components away from open flames or heat sources. Though designed to be tough, exposure to extreme temperatures can still break down the material and degrade performance.
- When operating or testing the turbine, extreme care must be taken, especially around moving parts. Hands, tools, and feet must not stray close to the working part of the turbine to prevent entrapment or a potential injury.
- Choose a section of the gutter that will allow steady water flow for optimum turbine performance. The installation should be stable and safe from debris, overhanging branches, or any obstructions that could interfere with or damage the turbine.
- For locations exposed to frequent storms or cyclones, the setup should be anchored strongly to prevent it from being toppled and displaced. Avoid setting up the turbine in clogged or seriously degraded gutters, as that may compromise both the performance of the device itself and safety.

Summary of Findings

The study found that for water-based performance, although the turbine requires a flow rate of 0.0000574 m^3/s for water flow to impact the system, this rate is insufficient to initiate rotation. A higher flow rate is needed to overcome resistance and start movement. As the flow rate continues to increase, both power output and efficiency improve, reaching a peak of 3.404 watts and 94.16% efficiency at a flow rate of 0.000292 m^3/s. For steam-based performance, increasing pressure results in higher power output, with a peak of 24.957 watts at 130 PSI and 81.55% efficiency. However, efficiency improvements become smaller beyond 100 PSI. Overall, higher water flow rates are key to better energy production, while optimal steam pressure (around 100 PSI) is necessary for maximum efficiency. These findings are important for optimizing small-scale renewable energy systems.

5. Conclusion

Based on the study's findings, the following conclusions are drawn:

- The Pico Hydro-Steam Turbine has shown strong potential as a small-scale renewable energy solution. The results demonstrated that the turbine efficiently captures power from hydro and steam sources, making it practical for various settings, from rural to urban areas. Its performance and design surpassed researchers' expectations, highlighting its promise for real-world renewable energy applications.
- Power Output from Hydraulic and Steam Testing: During hydraulic testing, the turbine reached a peak power output of 3.404 watts with an efficiency of 94.16% at a water flow rate of 0.000292 m2/s which can potentially suitable for powering smaller devices such as light bulb, LED lights, small fans, and sensors. In steam testing, the turbine achieved a maximum power of 24.957 watts at 130 PSI, with an efficiency of 81.55% which can possibly power larger devices including household devices and electronic chargers.
- To boost the turbine's performance and durability, several design enhancements were made. These included a more rigid and detachable rotor, a stand with bearings for better stability, a removable casing for easier transportation, and a detachable steam inlet. These updates improved how the turbine operates, made it more portable, and increased its lifespan. However, the researchers did face some challenges with steam testing due to limited instruments and energy system for a small sustainable residential community.

Recommendations

Based on the findings of the study, the following recommendations are presented to enhance the functionality and efficiency of the developed system:

- Use rainwater for the turbine's water source and solar steam for its steam source to generate electricity.
- The residential setup where the water-steam turbine will be installed should have a rain spout and solar steam that are both connected to the turbine.
- Design a closed-loop system where water is collected and can be recycled in powering the turbine, lessening waste and resources.

- Employ controls for variable pressure and flow rates so that the turbine can easily adapt to water and steam levels to achieve maximum efficiency and flexibility.
- Include a battery storage mechanism that will store the excess energy generated by the turbine for use in case power is needed the following day, hence providing continuous supply at home.
- It shall be tested in the residential setup over one day to estimate performance and the maximum energy output that the Pico Hydro-Steam Turbine can generate.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

Statement of ethical approval

The present research work does not contain any studies performed on animals/humans subjects by any of the authors.

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