Design and Testing of a Cost-Effective Gravitational Vortex Turbine for Rural Power Supply in Bangladesh.

A thesis
by

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of

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DECLARATION

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We further undertake to indemnify the university against any loss or damage arising from breach of the foregoing obligation.

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ABSTRACT

This thesis presents the design, testing, and performance optimization of a cost-effective Gravitational Vortex Turbine (GVT) to address the persistent energy deficit in rural Bangladesh. The system is designed for decentralized, off-grid power generation by harnessing the kinetic energy of flowing water at ultra-low heads, making it suitable for remote and hilly regions where conventional grid extension is impractical. The core objective was to develop a turbine that generates renewable electricity from small amounts of water flow by systematically varying design parameters to improve energy output and efficiency. The working principle involves channeling water tangentially into a conical basin to create a stable vortex. This vortex drives a turbine runner, converting its rotational energy into electricity via a generator and pulley system, with power available for immediate use or storage. The methodology was informed by a review of existing international patents and models, alongside relevant engineering guidelines. A structured workflow guided the process from problem definition and preliminary design to fabrication and experimental investigation. Key parameters optimized included the inlet channel width, notch length, and runner position within the conical basin. Experimental results identified optimal configurations that maximized power output, demonstrating the technology's potential. The study concludes that the GVT is a promising, eco-friendly solution for small-scale rural electrification, offering advantages in simplicity, minimal environmental impact, and operation at low heads. Primary limitations include a dependency on consistent water flow and a power generation capacity suited for micro-scale applications. Future work should focus on advanced blade and basin design optimization and the integration of smart monitoring systems to enhance performance and reliability.

Keywords: Gravitational Vortex Turbine, Renewable Energy, Low-Head Hydropower, Rural Electrification, Bangladesh, Sustainable Design.

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LIST OF ACRONYMS & ABBREVIATIONS

IFC – International Finance Corporation

FERC – Federal Energy Regulatory Commission

ITDG – Intermediate Technology Development Group

JICA – Japan International Cooperation Agency

MGSP – Mini Grid Support Program

GVHP – Gravitational Vortex Hydro Power

SDG – Sustainable Development Goals

ESHA – European Small Hydro Association

AEPC – Alternative Energy Promotion Center

ISA – International Society of Automation

IUCN – International Union for Conservation of Nature

CHT – Chittagong Hill Tracts

UNDP – United Nations Development Programme

SHP – Small Hydro Power

GWHP – Gravitational Water Hydro Power

GWVPP – Gravitational Water Vortex Power Plant

VIVACE – Vortex-Induced Vibration Aquatic Clean Energy

VIV – Vortex-Induced Vibration

CHAPTER 1

INTRODUCTION

1.1 Background

Bangladesh, with its rapidly growing commerce and industries, is facing a severe power crisis. The national grid is unable to meet the rising electricity demand, particularly in rural and remote areas where transmission and distribution costs are high, and supply is unreliable. Although the country's per capita energy consumption is only 154 kWh, far below that of developed nations. The shortage in generation capacity is estimated at around 2500 MW. This energy deficit has hindered economic growth and discouraged foreign investment.

Currently, Bangladesh relies heavily on fossil fuels and natural gas, both of which are depleting at an alarming rate. Large-scale hydropower projects exist but are limited by flat terrain and environmental challenges, while grid extension to remote areas is often economically unfeasible. In this context, renewable alternatives such as solar, wind, biomass, and micro-hydropower are being explored. Among these, micro-hydropower systems—particularly those that operate in low-head water conditions are gaining attention for their ability to provide decentralized, off-grid electricity in hilly and rural regions at comparatively low cost.

One innovative approach is the Gravitational Vortex Turbine (GVT), which utilizes a conical basin to create a vortex from low-head water sources, driving a turbine to generate electricity. The simplicity of design, minimal infrastructure requirements, and eco-friendly operation make GVT an attractive option for countries like Bangladesh, especially in the Chittagong Hill Tracts (CHT). By harnessing such renewable technologies, Bangladesh can move closer to achieving energy security and sustainability while improving socio-economic development in remote areas.

1.2 Problem Statement

Bangladesh faces a persistent gap between electricity demand and supply, especially in rural and hilly regions where grid extension is costly and unreliable. Dependence on depleting fossil fuels and the limitations of large-scale hydropower, solar, and wind highlight the urgent need for sustainable, low-cost, and decentralized energy solutions. Innovative small-scale hydropower technologies, such as the Gravitational Vortex Turbine (GVT), offer a potential alternative to address this crisis and improve energy access in underserved areas

.

1.3 Objectives

1. To study the generation of renewable electricity from low-head water sources with small water flow.
2. To design and test a cost-effective gravitational vortex turbine.
3. To improve energy output and efficiency by changing various parameters.

1.4 Gravitational Vortex Hydro Power

The experiment employs an impulse turbine, where the fluid strikes the blades radially, converting its kinetic energy into mechanical energy to rotate the shaft and generate electricity. Performance evaluation was carried out in terms of mechanical, hydraulic, and overall efficiency. From this analysis, a generalized equation was formulated to determine the maximum attainable efficiency based on blade angle and, uniquely for this study, gate angle.

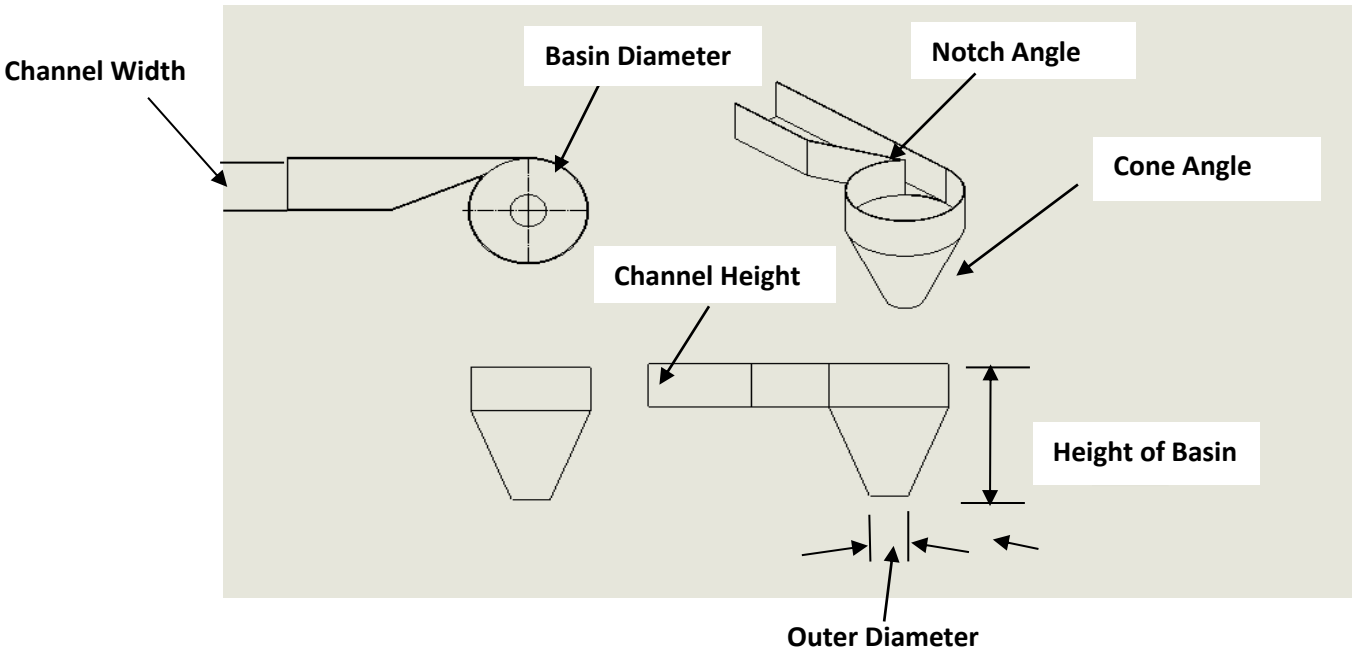


Figure 1.1: Vortex Turbine

1.5 Structure of the Thesis

In chapter 1, the background of the experiment, how it started, and some general information about it are explained.

Chapter 2 includes a review of existing research related to the experiment. It covers patents, earlier models, and how they affect the environment. Some examples are also given. The mathematical formulas used are listed here.

Chapter 3 provides a detailed description of the hardware components used in the system and the software tools applied for analysis.

Chapter 4 is titled "Design, Fabrication and Experimental Investigation" It describes the steps taken to complete the thesis, along with a flowchart and explanations.

In chapter 5, the results from the experiment are discussed, and charts are used to show the findings. These results are then compared with other studies from around the world.

Chapter 6 has the final conclusions. After that, the list of references and the appendix are included.

CHAPTER 2

LITERATURE REVIEW

2.1 Working Principle

The working principle of this Water Vortex Turbine Project integrates multiple components to generate and monitor electrical energy using flowing water. The system begins with a reservoir, which continuously flows water through a channel. Water is diverted from a reservoir or river and guided tangentially into a wide, conical basin. This inlet forces the water to spin, creating a stable, funnel-shaped vortex. Gravity pulls the water down through this whirlpool, concentrating its energy into a powerful rotation. At the center of this vortex, the spinning water drives the blades of a turbine. The turbine's shaft is connected to a generator, which converts the rotational energy into electrical energy. This electricity can then be used immediately to power equipment or stored in batteries. After passing over the turbine, the water exits calmly through an outlet at the bottom of the basin, returning to the river or water tank with its energy harnessed.

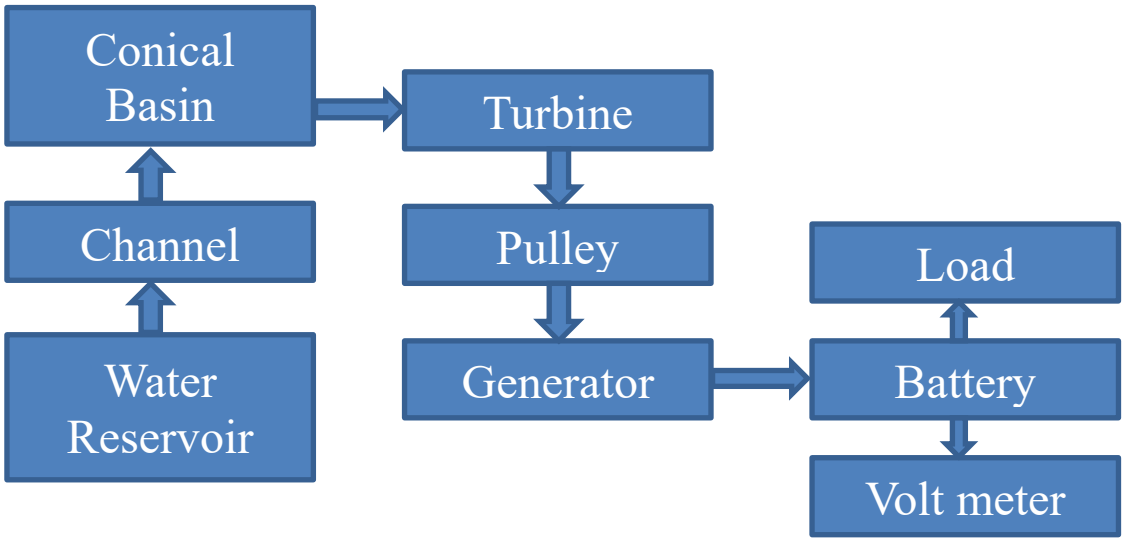


Figure 2.1: Block Diagram of Gravitational Vortex Turbine

2.2 Existing working models of GVHP

An article by Jon Hardy mentions a gravitational vortex hydropower plant that produces 15 kilowatts of electricity and has been set up in Bali, Indonesia. This project needed just 2 meters of space, making it very small and environmentally friendly. The system pulls 1.2 cubic meters of water through the turbine each second. There were some unexpected challenges, like not having any existing structures, so everything had to be made from scratch. Another example of gravitational vortex hydropower is discussed in a journal by reference in Bangladesh. There's a plan to build a micro hydropower plant along the Sangu River in Bandarban, which would generate 140 megawatts of electricity using the same method. However, this project needs a thorough environmental study and must consider the impact on the local tribe, who rely on the river for their daily lives. The project is still in the planning stages. Another article talks about the future of small hydropower in Chile. Right now, Chile produces 7,055 megawatts from hydropower, but there's a growing interest in mini hydropower. The government has approved 100 new micro hydropower projects that are expected to add about 20 megawatts of electricity by 2019. However, these projects face serious issues. Chile doesn't have enough proper electricity lines to connect to the main power grid, which is holding them back. A 2017 source from Hydropower.org supports this. An article by Amit Ranjan (2018) covers the relationship between India and Bhutan when it comes to hydropower. India has mainly funded hydropower projects in Bhutan, which has rich water sources from the Himalayas. Because of this, Bhutan has become India's cheapest source of hydropower. Even though most of the plants are large, there's a move towards more eco-friendly options. Countries like Nepal and Bhutan have a lot of potential for hydropower.

2.3 Patents

There are several types of patents available for this turbine, covering different aspects like setup, design, and various water height levels. One of these patents was filed by Geert Slachmuylders, the founder of Turbulent Hydro, in 2017. The patent number is F03B 3/18 (2006.01). This patent is considered the best and most useful version of GVHP in real-life situations. It works well when the water flow has a small height difference, which makes it harder for other types of water turbines to function properly. Another patent was created by George F. Round and Viljo K. Valavaara in 1999. It focuses on a low-head, low-speed water

turbine. This design uses a vertical housing with water entering from the top and exiting from the bottom. The main idea is to work with water sources that have little flow, which helps generate electricity. The patent number is US08/939,664. A more advanced patent was developed by Metin Ilbay Yaras and Mohammad Golriz in 2007. It works by using the pressure difference between the low-pressure areas of swirling water and the higher pressure before the turbine. This helps increase the mechanical energy of the water, which in turn boosts the electrical power generated by the generator. The patent number is US11/736,766.

2.4 Impact on Ecology

In recent years, nations that depend significantly on hydropower have encountered significant difficulties caused by long periods of drought and decreasing water levels in reservoirs. This heavy reliance on large hydropower systems makes national electricity networks susceptible to changes in weather patterns. Alternative options, such as the Gravitational Water Vortex Hydropower Plant (GVHP), can be very useful, as they do not need large dams or barriers to function.

Hydropower is often seen as having both positive and negative effects. On the positive side, small hydropower projects are effective and eco-friendly, providing a clean way to generate electricity compared to using diesel or gas. However, even small hydropower plants can cause harm to fish populations and the environment. These systems typically require dams or concrete structures, which change the natural movement of water and can result in soil erosion.

Micro-hydropower systems are commonly used in remote areas where communities rely on rivers for food and economic activities. Even though these plants offer necessary electricity, they can also harm local environments and impact the ways of life for nearby residents. In comparison, GVHP provides renewable energy with less interference to river ecosystems, making it a more sustainable choice for producing small amounts of electricity.

2.5 Codes/Standards/Guidelines

A guidebook issued by the European Small Hydropower Association (ESHA) in 2004 is considered the standard reference for establishing hydropower plants within the European Union. It reflects the EU's strict regulations aimed at improving the quality of life and reducing environmental harm. This guidebook offers detailed insights into the official processes involved in developing a hydro power plant. There are numerous procedures involved, with administrative requirements being one of the most important factors. Each EU country has its own water regulation laws that outline what is permitted and what is not for hydro power projects. The operation of a plant may be done independently or in coordination with the country's ministry of energy, depending on the plant's current capacity. Most countries also set a specific operating period for a power plant, which varies from a minimum of 15 years in England to 99 years in Belgium. The Federal Energy Regulatory Commission oversees the development of hydropower facilities, adhering to its principle of "DO NOT HARM." It enforces strict guidelines for drilling and near-embankment dams, along with laws that specify necessary measures to prevent issues such as drilling hazards, hydraulic fracturing, and erosion. A guideline by Pushpa Chitrakar (2015), published in Nepal, primarily focuses on hydrology and identifies suitable regions in Nepal for micro hydro projects. The method used is known as the Medium Irrigation Project Method. April is taken as the standard month, and based on climatological data, stream flow records, topographical maps, groundwater data, and wading, hydrological data is collected. This data is then used for further development of the micro hydro project. The mean monthly flow is calculated, which provides a clear understanding of the timeline during which the hydro plant can operate at its maximum capacity.

2.6 Small Hydro Resources in Bangladesh

Bangladesh has significant untapped potential for hydropower development. At present, the Karnafuly Hydropower Station is the only large-scale facility, generating 230 MW of electricity. In addition, a 10 KW micro-hydropower unit has been installed along the Matamuhurri River, providing power to 140 families in the remote hill regions of Bandarban.

Another project on the Sangu River is in the planning stage, with an expected capacity of 140 MW.

However, the development of hydropower in Bangladesh is hindered by several factors. The country's flat terrain restricts most opportunities to the Chittagong Hill Tracts, and the high population density makes it challenging to find suitable locations for small hydropower projects. Also, the accuracy of current data on hydropower resources is questionable. Most of the available sites are low-head, which makes technologies like the Davis turbine—designed to operate without the need for a dam—particularly useful.

Research indicates that micro-hydropower systems using these technologies can achieve up to 90% efficiency and produce electricity at costs that are nearly 70% lower than traditional energy sources. This underscores the potential of small hydropower as a cost-effective and sustainable option for expanding renewable energy in Bangladesh, especially in rural and off-grid areas.

2.7 Mathematical Formulas

Formula

- $Q = AV = b \times h \times V$

where Q is the volumetric flow rate (volume per unit time), A is the cross-sectional area of the flow, and v is the average velocity of the fluid.

$$V = \sqrt{2gh}$$

V = velocity of fluid (m/s)

g = acceleration due to gravity (9.81 m/s²)

h = height (head) of the fluid (m)

- $P_{in} = \rho gQH$, is used to calculate the **input hydraulic power** available from a water source. Let's break down its specification (each parameter):

- $\mathbf{P_{in}}$ → Input hydraulic power (Watt, **W**)
- **ρ** → Density of water (kg/m³) → typically 1000 kg/m^3 for fresh water
- **g** → Gravitational acceleration (m/s²) → standard value 9.81 m/s^2
- **Q**→ Flow rate of water (m³/s)
- **H** → Effective head (m)

- $P_{out} = V \times I$, represents the **electrical output power** specification.

- **Pout:** Output Power (measured in Watts, W)
- **V:** Voltage across the load (Volts, V)
- **I:** Current flowing through the load (Amperes, A)

➢ The specification is:

$\eta=(Pout/Pin) \times 100\%$

Where:

- η = Efficiency (%)
- Pout= Output power (W)
- Pin = Input power (W)

Given Our Data:

- Basin Height, H_b: 0.43 m
- Net Water Head, H: 0.7 m
- Flow Rate, Q: 0.0025 m^3/s
- Water Density, ρ: 1000 kg/m^3
- Gravity, g: 9.81 m/s^2

Hydraulic Input Power:

$P_{in}= \rho gQH =1000\times9.81\times0.0025\times0.7=17.1675$ W

Measure:

i) Voltage (V)

ii)Current (I)

Use:

$P_{out}=V\times I$

Calculate efficiency:

$\eta=(Pout/Pin) \times 100\%$

2.8 Learning Tools for Analysis and Reporting

2.8.1 Mendeley

Using Mendeley, the process of citing sources has become much simpler, and most of the research related to the thesis can be easily accessed through a straightforward website.

2.8.2 Microsoft Word

Microsoft Word provides several benefits for writing a thesis. It has an easy-to-use interface along with strong formatting tools that simplify the process of organizing lengthy documents. Features such as an automatically generated table of contents, tools for managing citations and bibliographies, and options for creating tables, graphs, and document styles help keep the work consistent. The software also supports teamwork by enabling features like adding comments, tracking changes, and collaborative editing. Built-in tools like spelling and grammar checks, along with pre-designed templates, help increase accuracy and reduce time spent on formatting. Furthermore, Word's ability to work with various software and file formats ensures that the thesis can be easily shared and submitted without any issues.

2.9 Literature Review

This study explores a gravitational vortex turbine (GVT), a form of hydropower that produces electricity by harnessing the vortex created by water in a conical basin. Water enters the basin through a linear entrance, generating a vortex that discharges out a central outlet at the base. A turbine situated in the vortex utilizes its rotating force to produce energy, rendering this technique appropriate for low-head applications (0.7–3 m). The study used CFD analysis in ANSYS Fluent 14.5 to investigate flow velocities at various outlet dimensions. Findings indicate that an output diameter of 30% of the basin diameter (0.3D) produces the maximum tangential velocity and greatest turbine efficiency [1].

Gravitational Water Vortex Power Plants (GWVPP) can generate electricity from low water heads, making them ideal for rural and remote areas. With potential to expand renewable

energy, GWVPP offers socio-economic, financial, and environmental benefits. Design comparisons of different basin shapes, outlet diameters, and flow parameters help optimize power output. Future improvements—like cascade systems, advanced blade design, and energy storage—can enhance performance and support commercial viability [2].1

The gravitational vortex turbine generates electricity using a water vortex formed as water drains from a tank. It's efficient at low head and flow rates but has complex flow due to its free surface. This study used experiments and simulations to analyze its performance, showing consistent results for torque, output, and efficiency. It also found that higher runner speed expands forward flow, while reduced air core enlarges backward flow [3].

This study explores the design and performance optimization of a gravitational vortex water turbine for small-scale hydropower in the Chittagong Hill Tracts, Bangladesh. Aiming to support clean energy development, the turbine utilizes gravity-driven vortex flows to generate electricity efficiently. CFD simulations using ANSYS Fluent analyze the complex flow patterns and velocity distribution, helping refine the turbine design. The research examines how the number of blades affects performance and emphasizes the benefits of decentralized energy solutions. Results show the turbine can meet or exceed the energy demands of identified small hydro sites, supporting its potential as a reliable renewable energy source. However, further feasibility and site-specific studies are recommended for practical implementation. The work highlights the role of advanced computational methods in developing sustainable hydropower technologies [4].

A gravitational water vortex turbine was optimized using Minitab software to maximize torque. Experiments revealed that the ideal setup—55 LPM flow rate, 40° cone angle, curved incline blade B1, and blade position P1—produced a predicted torque of 5.788 Nm, which was confirmed by tests. The study highlights a systematic method for improving turbine efficiency and offers valuable guidance for future sustainable energy applications [5].

This study investigates the performance of vortex turbines with different blade counts (5, 7, and 9) under varying water velocities. Turbines with seven blades perform best at low velocities but lose efficiency more rapidly as velocity increases. Nine-bladed turbines maintain high efficiency over a wider range but also drop at high speeds. Five-bladed turbines show steady performance, staying between the two. Despite lower initial efficiency, the 7-blade turbine offers the most stable efficiency across water speeds. Overall, turbines with more blades (7 and 9) demonstrate better energy conversion and higher power output. The research uses

experimental methods and custom test equipment to explore how turbine design and vessel geometry affect Gravity Water Vortex Power (GWVP) performance. Results highlight that optimizing blade number significantly enhances efficiency, supporting GWVP as a promising renewable energy technology [6] .

As the demand for clean energy grows, small hydropower systems like the gravitational vortex water turbine offer an effective solution for remote regions. Small hydropower offers a sustainable solution, especially in mountainous regions, by providing low-cost, eco-friendly, and reliable power. This study used an impulse turbine powered by gravity-driven water flow to generate electricity with minimal environmental impact. By optimizing blade design—specifically using five curved blades at a 44° angle and adding baffle plates—the system achieved 82% efficiency and produced 6.91 kW of power. This setup shows strong potential for sustainable energy in areas like the Chittagong Hill Tracts [7].

The Gravitational Water Vortex Power Plant (GWVPP) is a suitable technology for harnessing kinetic energy from water at low-head sites. This study focuses on designing a turbine runner for a conical basin-based Gravitational Water Vortex Turbine (GWVT). Seven geometric parameters influencing runner performance were examined through both numerical and experimental analysis. Among these, runner height was identified as the most critical factor, with optimal performance observed at a runner-to-basin height ratio of 0.31–0.32. Experimental results showed that the turbine's efficiency reached up to 47.85% [8].

Gravitational Water Vortex Power Plants are promising for low-head, eco-friendly energy generation. This study tested a single-stage turbine with curved blades in a conical basin under different heads and flow rates. The best performance—172 rpm and 0.59 m vortex height—was observed at 0.7 m head and 0.004 m^3/s flow rate. Poorer results occurred at extreme values due to unstable vortex formation. Vortex shape and height were found to greatly affect rotational speed. An Analysis of Variance (ANOVA) confirmed the significance of input parameters on performance[9].

The Gravitational Water Vortex Turbine (GWVT) is a micro hydropower system designed for low-head sites (0.7–3 m), using water from rivers, streams, or canals to generate electricity. It stands out for being low-cost, eco-friendly, and easy to install. This study experimentally evaluated a single-stage GWVT with a conical basin and curved blades. A total of 25

experiments were conducted, varying head and flow rates to assess performance metrics such as torque, RPM, vortex height, shaft power, and efficiency. Results showed the best performance at 0.70 m head and 0.004 m^3/s flow rate, with a peak efficiency of 54.44%. Higher flow and head reduced overall performance[10].

Water-based energy generation is one of the most economical power sources, with micro-hydropower plants preferred for their low head and flow rate requirements. Among these, Gravitational Water Vortex Power Plants (GWVPPs) are emerging due to their simple installation, minimal setup time, and low technical requirements. This study investigates vortex formation and energy generation efficiency using a strong air-core vortex. Simulations in ANSYS CFX and experimental validation were used to analyze the effect of basin design and blade shapes under a 0.5 m head. Reducing flow rate improved efficiency, and cross flow blades delivered the highest performance, reaching 68.84% efficiency, with experimental errors ranging from 5–12%. The method can guide blade design and predict power output based on site conditions [11] .

As energy demand rises, especially in developing countries, renewable sources like hydropower are gaining importance. In remote areas where grid access is limited due to challenging terrain, low-head hydropower systems offer a practical solution. The Gravitational Water Vortex Power Plant (GWVPP) is one such system that generates energy by creating a vortex through tangential water flow into a basin. This study evaluates different basin shapes and runner positions to enhance power output. Using SolidWorks for modeling and ANSYS Fluent for simulation, followed by experimental validation, results showed that conical basins provide higher efficiency than cylindrical ones. Maximum power was achieved when the runner was placed at 65–75% of the basin's total height from the top [12] .

This study optimized and tested a runner prototype for a gravitational vortex turbine (GVT). Using a DoE approach, parameter effects on efficiency were analyzed, and the best configuration was found: a 55° rotation angle, six blades, a 250 mm top diameter, and a 120 mm bottom diameter. The runner was produced via molten material deposition using PLA, highlighting the cost-effectiveness of 3D printing for experimental models. For CFD analysis, the SMM method proved efficient in capturing vortex effects and providing reliable power and efficiency data, while the 6-DoF model required more computation and setup. Experimental validation showed a 5.1% difference from SMM simulations, with cubic fits confirming close agreement. The method successfully improved runner efficiency [13].

Hydropower is a sustainable renewable energy source, and gravitational water vortex hydro turbine (GWVHT) systems are well-suited for rural areas in developing countries due to their small scale and low cost. A GWVHT system mainly consists of inlet and outlet channels, a basin, and a turbine with blades. This paper reviews the development of GWVHT systems, including basin designs, channel configurations, blade variations, vortex dynamics, and numerical models. A case study in PNG is presented, and key challenges with future research directions are discussed [14].

The gravitational water vortex turbine serves as a renewable energy alternative, converting the hydrokinetic energy of rivers into electrical energy while eliminating the need for a reservoir. Research indicates that the hydraulic efficiency may rise or fall depending on the turbine's geometric design. This document offers an analytical and numerical (CFD) comparison of conical and cylindrical outlet designs. The findings indicate that conical geometry outperforms the cylindrical tank. In CFD and analytical studies, the fluid dynamics show a rise in tangential velocity close to the air core and the outlet hole (exhibiting similar behavior). The highest theoretical power produced was 167 W for the conical design and 150 W for the cylindrical design. The variations in the geometries of the outlet openings using CFD and analytical models were 11% and 7%, respectively. Nevertheless, the results nearest to the CFD model exhibited varying values of 31% and 29% for the conical and cylindrical designs, respectively. The most distant outcome from the CFD analysis was 55%. The main difference arises from tank shape, changes in the discharge area, and the ratio of tank diameter to outlet hole, which can enhance or diminish tangential velocity and lead to a more powerful and stable vortex formation. The theoretical power produced is an effective criterion for choosing the rotor's placement height [15].

The gravitational water vortex power plant is an ultra-low head hydropower system that generates electricity by rotating a prime mover through a free-surface vortex. Studies have shown that a conical basin design offers higher power output than the conventional cylindrical basin. This work investigates the effect of adding a secondary “booster runner” positioned below the main runner on the same shaft to enhance power generation. Three booster runners

were designed by varying parameters such as blade angles, number of blades, runner height, taper angle, and outlet diameter. Numerical modeling was carried out in CATIA and ANSYS using 3D steady-state simulations, followed by experimental verification. Performance of both single and coupled runners was analyzed and compared. Results indicate that the booster runner can improve efficiency by about 6% under optimal conditions[16].

The growing demand for clean energy has driven researchers to explore hydropower as a sustainable solution, particularly through gravitational vortex turbines for low-head water sources. These micro-hydro turbines generate power by utilizing the rotational energy of a water vortex. This study focuses on improving turbine efficiency through design optimization, CAD modeling, governing equations, and ANSYS simulations of vortex formation in the main tank. The project also aims to ensure watertight sealing for generator safety, reduce vibration losses with a smaller shaft, and promote cost-effective manufacturing using 3D printing, given Pakistan's limited access to advanced fabrication technologies. The overall objective is to provide an efficient, low-cost, and reliable energy solution for off-grid communities [17].

This study compared four turbulence models k-ϵ standard, k-ϵ RNG, k-ω SST, and k-ω standard—for simulating a gravitational water vortex turbine in ANSYS Fluent. The models showed clear differences: k-ϵ RNG and k-ω standard gave stable circulation values, k-ϵ standard overpredicted, and k-ω SST fluctuated. For mass flow rate, the first three models stabilized around 2.1 kg/s, while k-ϵ standard varied between 1.9–2.1 kg/s. ANOVA results confirmed that turbulence model choice strongly affects predictions. Experimental validation showed the k-ω SST model best matched the real vortex, followed by k-ϵ RNG. The main thing this research adds is a full review of these turbulence models, which helps people decide which one to use for simulating gravitational water vortex hydraulic turbines [18].

This study examines which conical basin shape best supports gravitational vortex hydropower (GVHP) by tracking the movement of the water vortex center. Three basin types were tested: a straight-sided basin (type A, 20 mm height), a conical basin (type B, 20 mm height, 60° cone angle), and another conical basin (type C, 50 mm diameter, 20 mm height, 45° cone angle). Two approaches were applied: an analytical study of vortex formation geometry and CFD simulations under multiphase, transient-SST, and steady-state conditions. Results showed that type B produced the highest water velocity and strongest vortex, due to pressure reduction from increased velocity near the outlet. Thus, type B was identified as the most effective basin design for forming a strong water vortex [19].

A pilot-scale Gravitational Water Vortex Hydropower Plant (GWVHP) of 1 kW capacity was developed to verify laboratory findings and assess practical applicability. The four-month project showed that the pilot results closely matched lab-scale tests, with the system achieving 49% overall efficiency. The study confirmed that a conical basin design can operate effectively in real-world conditions, requiring only minor modifications. These findings highlight the potential of GWVHP as a reliable renewable energy option for disaster-affected and remote areas, and they provide a foundation for scaling up to larger micro-hydro projects[20].

The study revealed that both the number of blades and the addition of baffle plates significantly affected turbine efficiency. 5 blade turbines provided the best performance, generating the highest torque due to effective blade spacing for water capture. Adding baffle plates further enhanced efficiency by retaining an optimal water volume, with a 50% curve area proportion found to be most effective. At a flow rate of 0.06 m^3/s and a 25 W load, the turbine with top and bottom baffle plates reached 43.83% efficiency, an improvement of 6.59% compared to the turbine without baffles. The results also indicated that higher flow rates consistently improved overall system efficiency[21].

The purpose of this research was to examine how the materials used in turbines affect the efficiency of power generation in a water free vortex hydroelectric plant constructed from steel and aluminum. These turbines had five blades, which were angled along their height to optimize water flow. By replacing heavier materials with lighter ones while keeping the turbine size and shape the same, it was possible to enhance the efficiency of electricity production. During the experiments, at the highest flow rate of 3.63 cubic meters per minute, the maximum efficiencies achieved by the steel and aluminum turbines were 33.56% and 34.79%, respectively. The results indicated that the aluminum turbine produced higher torque and electricity generation efficiency compared to the steel turbine, with an average difference of 8.4% and 8.14% respectively. Additionally, the aluminum turbine reached its maximum speed faster than the steel turbine because it was lighter, which reduced the time needed to achieve the same rotational speed. This study demonstrated that reducing the weight of water turbines can lead to improved torque and increased power generation efficiency[22].

2.10 Summary

The ideas and results talked about earlier have been widely covered in many past studies and written literature. These works show how important and relevant the topic is, and they also give useful information about how it can be used in real situations and where it might go next. By looking closely at these studies, we learned more about the subject and found some areas that still need attention or improvement. This thorough review has really inspired and encouraged us to do our own research, with the goal of adding new ideas and useful results to what is already known.

CHAPTER 3

SYSTEM DESIGN CONSIDERATION AND COMPONENT ANALYSIS

3.1 Introduction

This section discusses the Water Vortex Turbine along with the description and features of its components. The system consists of fabricated hardware such as the basin, runner, power transmission, and storage units, each contributing to efficient energy conversion.

3.2 Hardware & Software

Hardware

- Generator Motor
- Battery
- Volt Meter
- Ball Bearing
- MS Sheet
- Belt Pulley
- Water Turbine
- Pump Motor
- Flow Meter

Software

- SolidWorks

3.3 Generator Motor

A motor–generator (M–G set) converts electrical power into another form, such as different frequency, voltage, or phase, and can also isolate loads from the supply line. Large sets served industrial power conversion, while smaller ones boosted DC battery voltage. An M–G set can use separate machines or a single dynamotor, where motor and generator coils share one rotor with commutators at opposite ends, making it more compact, lightweight, and cost-effective.



Figure 3.1: Generator Motor

Specification

Type: DC Motor (TP motor – often tubular permanent magnet type)

Rated Voltage: 220–240 V DC

Power Output: 180–400 W (depending on load & model)

3.4 Battery

Lithium batteries, or lithium-metal batteries, are primary batteries that use metallic lithium as the anode. They have high energy density and cost more than typical batteries, producing voltages from 1.5 V up to about 3.7 V depending on design and chemistry. Unlike rechargeable lithium-ion or lithium-polymer batteries, disposable lithium batteries use metallic lithium directly. Lithium-ion batteries use lithium compounds instead, making them safer since pure lithium reacts violently with water or moisture. These batteries are widely used in portable electronics. They require 0.15–0.3 kg of lithium per kWh, and their cathodes gradually fill with lithium ions during discharge.



Figure 3.2: 3.7V Battery

3.5 Voltmeter

A voltmeter is used to determine the electric potential difference between two points in an electrical circuit. It is connected in parallel with the circuit components. To ensure it does not significantly affect the circuit, a voltmeter has a very high resistance so that it draws very little current. Analog voltmeters use a moving pointer



Figure 3.3: Voltmeter

to indicate the voltage, and they can be constructed from a galvanometer by adding a resistor in series. Digital voltmeters, on the other hand, show the voltage as numbers on a display, which is achieved through an analog-to-digital converter. Some voltmeters are portable and are often included in multimeters, while others are permanently installed in control panels to monitor equipment. These devices can measure various physical quantities that have been converted

into voltage, such as pressure or temperature. The accuracy of voltmeters varies: general analog meters typically have an error of a few percent, digital meters often provide accuracy better than 1%, and specialized laboratory instruments can achieve precision down to parts per million. To maintain accuracy, voltmeters are calibrated, sometimes using a Weston cell or other electronic reference standards.

Specification

- Measuring range: DC 2.5V-30V
- Working current: <30Ma
- Input range: Dc 5-30V
- Display: Three: 0.36inch
- Refresh rate: ≥200mS/times
- Measurement accuracy: 1%
- Operation Temp: -10℃-+65℃

3.6 Ball Bearing

A bearing is a mechanical component that allows specific types of movement between parts while reducing friction. It can permit free spinning, straight-line movement, or limit motion by managing the forces applied. Bearings help support forces acting sideways (radial) and along the axis (axial) while keeping friction low. The most basic kind of bearing is a plain bearing, which involves a shaft moving inside a hole, typically with some kind of lubrication. Another common type is the rolling-element bearing, such as ball bearings or roller bearings, which use balls or cylinders to lessen friction caused by sliding. There are also other types, such as jewel bearings that use tough materials like sapphire, fluid bearings that rely on gas or liquid for support, magnetic bearings that use magnetic fields for support, and flexure bearings that depend



Figure 3.4: Ball Bearing

on bending components. Bearings are selected based on their ability to improve efficiency, strength, and overall effectiveness.

3.7 MS Sheet

Mild steel sheet, also referred to as MS sheet, is a type of flat metal product created from low-carbon steel. It is popular across many industries because of its strong, long-lasting, and adaptable characteristics. MS sheets are generally made by rolling the steel and come in various thicknesses, widths, and lengths to suit different needs.



Figure 3.5: MS Sheet

These sheets are soft and easy to work with, allowing them to be cut, welded, and shaped conveniently for multiple uses. They have average tensile strength and good flexibility, which helps them bend without breaking. To improve their ability to resist corrosion, especially in harsh outdoor or industrial settings, MS sheets are often coated or painted.

Applications of MS Sheet

- Manufacturing of automotive parts and machinery components
- Construction purposes like roofing, cladding, and panels
- Fabrication of furniture, cabinets, and storage containers
- General engineering and industrial applications

3.8 Belt Pulley

A pulley is a basic machine made up of a wheel that has a groove around its edge, which holds a rope, belt, or cable. It helps change the direction of a force applied to it and allows heavy objects to be lifted or moved with less effort. The wheel turns around an axle, and the rope moves smoothly within the groove, which lowers friction. Pulleys can be used on their own, like a single fixed pulley, or together with other pulleys in a block and tackle setup to gain mechanical advantage. They are widely used in cranes, elevators, gym equipment, and many other industrial and household tools for lifting purposes.



Figure 3.6: Belt Pulley

3.9 Water Turbine

A water turbine is a device that converts the energy of flowing or falling water into mechanical energy, commonly used to generate electricity in hydroelectric plants. It captures the kinetic and potential energy of water with specially designed blades or runners, causing the rotor to spin. This rotational energy is then transferred through a shaft to a generator to produce electricity.

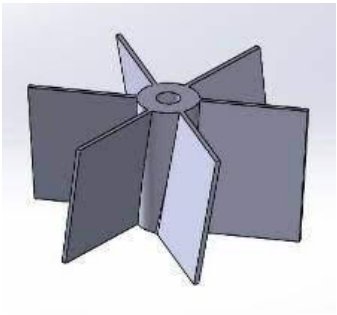


Figure 3.7: Water Turbine

Water turbines are efficient, reliable, and environmentally friendly, producing no greenhouse gases and requiring no fuel. They can be used in large dams or small rivers, making them versatile for both national grids and micro-hydro projects in remote areas.

3.10 Pump Motor

A 0.5 HP pump motor is a small and efficient device used for lifting and moving water in small to medium-sized applications. It transforms electrical power into mechanical energy, which powers the impeller to transport water from one location to another.



Figure 3.8: Pump Motor

This motor has a power output of 0.5 Horsepower, which is about 373 Watts, and is appropriate for home, farming, and light industrial purposes such as providing water to residences,

irrigating small plots, watering gardens, filling overhead tanks, and moving other fluids. It is designed to be energy-efficient, simple to set up, and needs very little upkeep, making it a good option for everyday use in areas where water demand is not very high.

Specifications

- **Model**: Gazi QB60
- **Power**: 0.5 HP (0.37 kW)
- **Voltage**: Single-phase 220V (±10%)
- **Frequency**: 50 Hz
- **Speed**: Approximately 2900 RPM

3.11 Water Flow Meter / Sensor

The YF-S201 1/2 Inch water flow sensor is a device used to measure how much water is moving through a pipe. It includes a turbine-like rotor that is positioned in the water stream. As water flows around the rotor, it causes the rotor to rotate. The sensor detects how fast the rotor spins and uses this information to determine the flow rate.



Figure 3.9: Water Flow Meter / Sensor

This sensor provides a digital output, which means it sends a digital signal that can be read by a microcontroller or other electronic device. The YF-S201 is widely used in various applications like irrigation systems, water treatment facilities, and industrial processes. It is often chosen over other flow sensors because it is simple to install and affordable. These sensors are typically placed near the water source or within pipes to monitor the flow and calculate the total volume of water that has passed through. Water flow is usually measured in liters per hour or cubic meters.

Specifications

- Model: YF-S201
- Sensor Type: Hall effect
- Working Flow rate: 30 Liters/ Minute
- Maximum Eater Pressure: 2.0MPa
- Weight: 25g
- Dimensions: 2.5 x 1.4 x 1.4 Inches

3.12 Digital Tachometer

This Victor DM6236P is a digital tachometer that uses light to measure how fast something is spinning and can detect reflections from moving objects. It has a small yellow-green LCD screen with backlighting that shows numbers up to five digits and displays the current measurement range. It can measure speeds over 60 RPM and takes about 0.8 seconds to get a reading. It can also detect objects up to 50 to 500 mm away. The unit comes with four AA batteries that last a long time.



Figure 3.10: Digital Tachometer

3.13 Solid works

SolidWorks is a computer-aided design software used to create three-dimensional models and two-dimensional drawings. In the initial stages of design, users begin by drawing two-dimensional shapes such as lines, circles, and rectangles, and then convert these into three-dimensional objects using tools like extrusion or revolution. The software enables designers to enhance their models by adding elements such as fillets, chamfers, holes, and patterns.

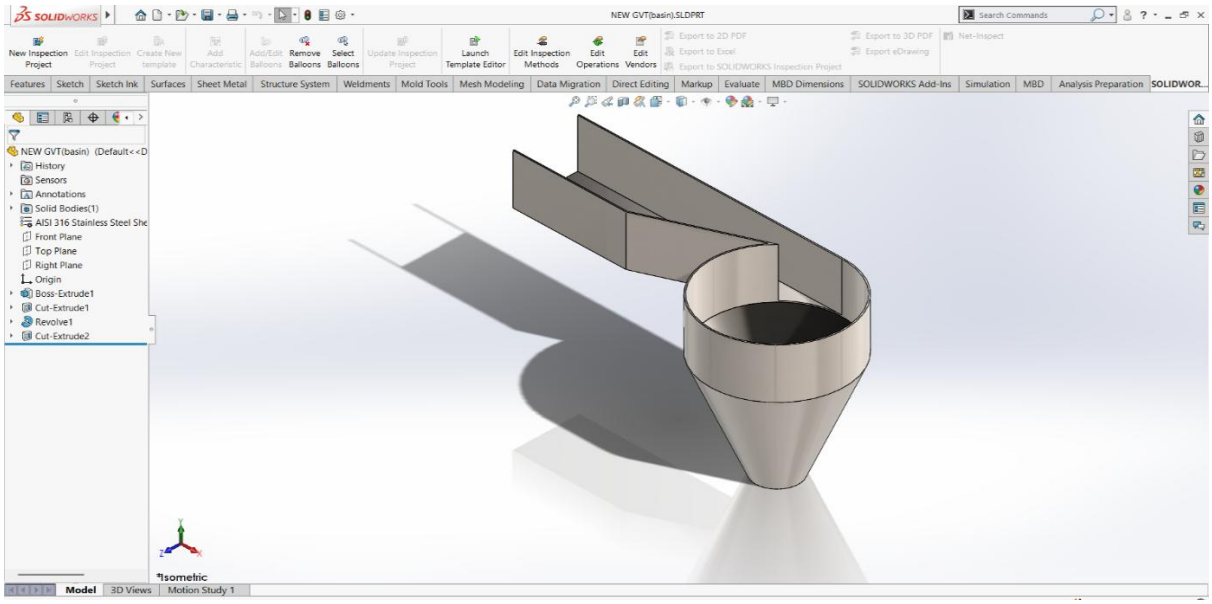


Figure 3.11: Solidworks Software

It also allows the combination of individual parts into larger assemblies and the production of detailed two-dimensional technical drawings for manufacturing purposes. SolidWorks provides an easy way to visualize, adjust, and efficiently design parts and assemblies.

CHAPTER 4

DESIGN, FABRICATION AND EXPERIMENTAL INVESTIGATION

4.1 Work Flow Diagram

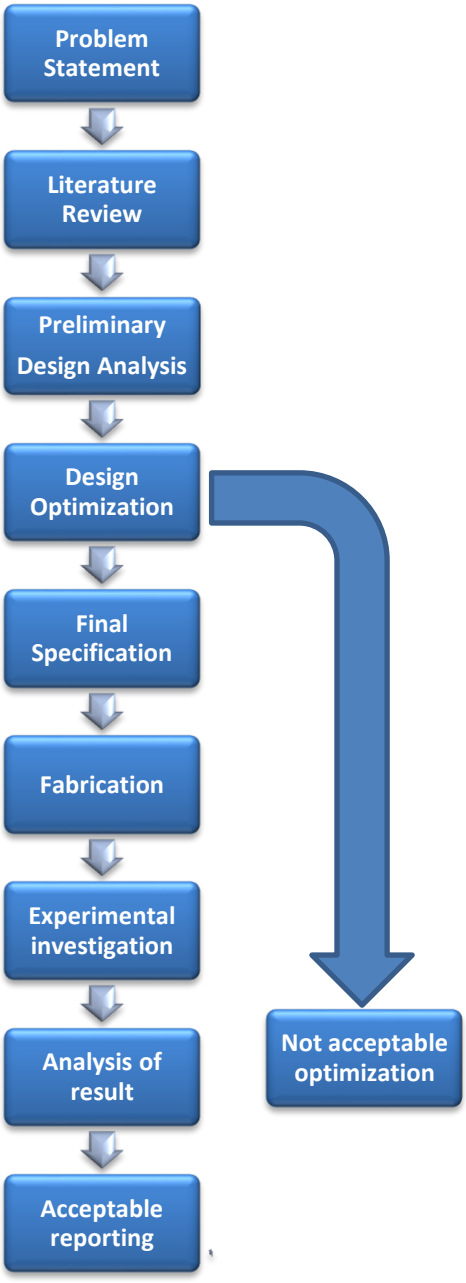


Figure 4.1: Work Flow Diagram

4.1 Problem Statement

The setup is designed to function effectively with low head, and it has been adapted for use throughout all seasons in the hilly regions of Bangladesh. This aims to improve the local living conditions and support the youth in these areas by boosting their self-esteem.

4.2 Preliminary Design Analyses

After looking closely at existing research and previous studies, a conical basin shape was chosen as the main design for holding the turbine blades. The fluid flows into the basin at an angle and moves outward in a radial direction, which creates a controlled spinning motion inside the basin. This is different from traditional impulse turbines, which usually work with high water pressure and use jets or nozzles to speed up the water. Instead, this design is meant for situations where the water pressure is lower. To deal with the lower pressure, a unique gate angle was developed. This gate controls how the fluid enters the basin, limiting the flow and making the water pressure stronger near the end. This helps improve the effect of the water behind the turbine, which in turn increases how much energy is transferred to the blades. This change allows the turbine to work well even with less water pressure while still using the basic idea of impulse turbines, which rely on changing the water's speed to get energy.



Figure 4.2: Straight Blade

4.3 Design Optimization

To improve the turbine's performance, several important factors were closely examined, such as the blade shape, the angle of the adjustable inlet Channel, the blade angle. In this study, only one turbine was used for testing. The blades were placed at a 90-degree angle and had a straight shape to suit the flow conditions of the conical basin. Because the basin was shaped like a cone, the turbine blades were made to fit this design. The top part of the blades had a larger diameter, while the bottom part was smaller. This design helped align the blades more effectively with the flow inside the conical basin, which in turn improved how efficiently energy was transferred. The blades were made from steel to ensure strength and long-lasting performance, while the shaft was constructed from mild stainless steel. This choice was made because mild stainless steel is lighter, which helps reduce inertia and makes the turbine spin more efficiently.

4.4 Final Specifications

After completing the theoretical analysis and refining the design, the parameters for each part of the turbine were defined. All the chosen parameters fell within the established limits, as outlined in the literature reviews.

Atmospheric Condition		
Parameter	**Value**	**Unit**
Density	1000	kg/m^3
Inlet Pressure	101,325	pa
Constant Parameter		
Parameter	**Value**	**Unit**
Design Head	0.7	m
Channel Height	0.2	m
Channel Width	0.2	m
Basin Diameter	0.44	m
Basin Height	0.43	m
Gravitational Acceleration	9.81	m/s^2
Geometric Parameter		
Parameter	**Value**	**Unit**
Blade Angle	90	degree
Notch Inlet Channel	0.05, 0.06, 0.07, 0.08	m
Notch Length	0.39, 0.37	m
Cone Angle	23	degree
Inlet Width	0.2	m
Rotor Diameter	0.4	m

Table 4.1: Specification

4.5 Fabrication Works

The fabrication process began once the specifications were prepared. Sheet metal served as the main construction material. The setup parameters were clearly defined, and a welding workshop near Sonargaon University was assigned the task. Welding was carried out using the oxy-fuel welding technique.

4.5.1 Cost Analysis

The turbine was designed with the goal of minimizing costs while ensuring high overall quality. Pulley belts are constructed from a variety of materials, such as different types of rubber, plastics, and even synthetic and natural fabrics. An infrared tachometer was employed to measure the revolutions per minute. A significant portion of the total cost was allocated to the production of the runner and the basin. Rubber was utilized to prevent leaks. Water flow is manually measured to ensure an accurate flow rate.

Sl. no	Particulars	Specification	Qty.	Unit Price (Taka)	Total Price (Taka)
1	Pump Motor	0.5 HP QB60 Model	1	3550	3550
2	Water Flow meter/ Sensor	YF-S201	1	550	550
3	Pully		1	1500	1500
4	Power Generator Motor	DC220-240V 400W	1	700	700
5	Volt Meter		1	300	300
6	Tachometer	DM6236P Model	1	1200	1200
6	Battery	3.7 V 2200mAh	2	100	200
7	Vortex Turbine with Frame			12000	10,000
				Total	18000

Table 4.2: Cost Analysis

4.6 Hardware Implementation



Figure 4.3: Generator Motor



Figure 4.4: Pulley



Figure 4.5: Bearing



Figure 4.6: Turbine



Figure 4.7: Water Storage Chamber



Figure 4.8: Water Flow Channel



Figure 4.9: Project Progress Image (Side)



Figure 4.10: Project Progress Image (Front View)



Figure 4.11: Complete Setup

4.7 Analysis of Result

After finishing this project, we checked how well it worked and saw that it ran smoothly and exactly as we planned. The system worked carefully and efficiently, giving the right results with all parts working properly. The tachometer correctly picked up the rotations of the wheels and rollers, counting pulses accurately, while the water flow from the reservoir kept a steady supply to make sure the turbine ran smoothly. The flow meter also measured the water flow correctly, showing how well the system was working and helping us keep track of its performance. The turbine, with its pulley setup, turned the water's movement into mechanical spinning power, which the generator motor then used to make a steady voltage. The battery charged steadily, proving the system could store renewable energy, and the voltmeter showed consistent charging levels, confirming the project's overall energy efficiency.

4.8 Reporting

Reporting has been happening all week during the last part of the semester. The literature reviews and the main analysis were already shared with the supervisor and approved. Once the data was collected and the graphs were made, the report was finished.

CHAPTER 5

RESULT ANLYSIS AND DISCUSSION

5.1 Experimental investigation

The main goal of the project is to find the most effective structure for GWVPP. To do this, different types of experiments and observations are carried out by modifying various parts of the GWVPP. These include:

A. Varying the Inlet Channel

We observed how the output power varies by changing the inlet channel.

Inlet Channel	Voltage	Current	Power
5 cm	5 V	0.00034 A	0.0017 W
6 cm	7 V	0.00029 A	0.0020 W
7 cm	6.45 V	0.00031 A	0.0019W
8 cm	5.83 V	0.00018 A	0. 0010 W

TABLE 5.1: EFFECTS OF INLET CHANNEL ON CONICAL BASIN

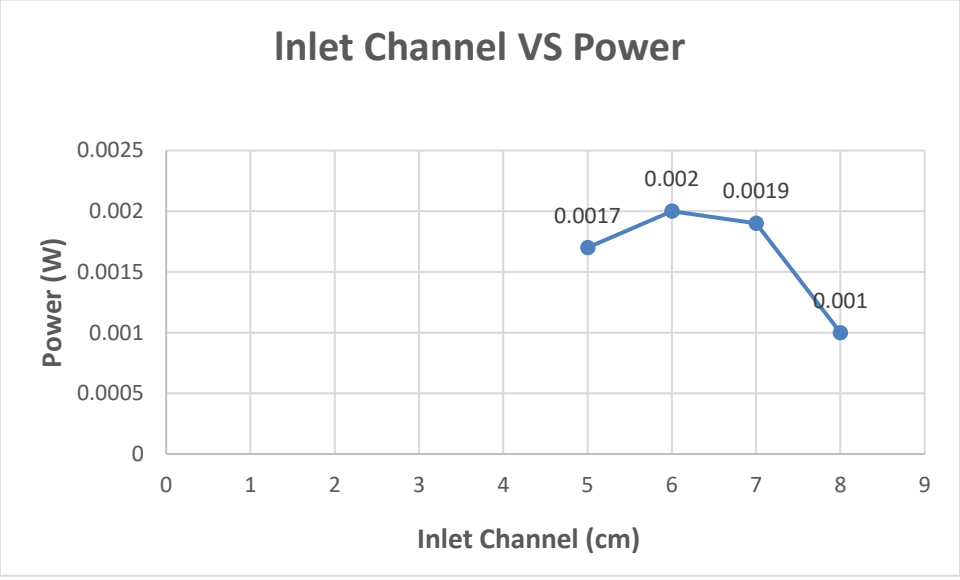


Fig. 5.1: Inlet Channel VS Power graph for Conical Basin

We observe an increase in inlet channel leading to a decrease in power generation in basins. We found the highest power output in the 6 cm inlet channel.

B. Varying the notch length

The second observation involves varying the notch length. We observed how the output power varies by changing the notch length.

Notch length	**Voltage**	**Current**	**Power**
39 cm	7 V	0.00029 A	0.0020 W
37 cm	5.13	0.00021 A	0.0010 W

TABLE -5.2: EFFECTS OF NOTCH LENGTH ON CONICAL BASIN

We observe an increase in notch length leading to an increase in power generation in basins. We found the highest power output in the 39 cm inlet channel.

D. Varying the runner Position

The Third observation involves varying the runner position. We calculated the runner position from the bottom diameter to the top diameter. The runner position was adjusted using different parameters. 49% (21 cm), 51% (22 cm), and 53% (23 cm) runner positions were used to conduct this experiment.

Runner Position	**Voltage**	**Current**	**Power**
49%	5 V	0.00034 A	0.0017 W
51%	4.98 V	0.00031 A	0.0015 W
53%	4.01 V	0.00029 A	0.0011 W

TABLE 5.3: EFFECTS OF RUNNER POSITION ON CONICAL BASIN

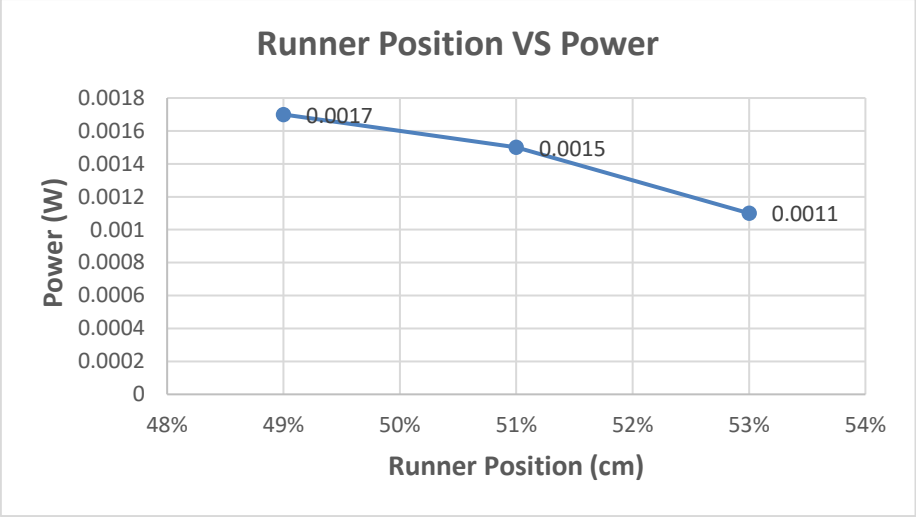


Fig. 5.2: Runner Position VS Power graph for Conical Basin

We observe an increase in runner position leading to a decrease in power generation in basins. We found the highest power output in the 49% inlet channel.

5.2 Discussion

While working on our project, we ran into some challenges because the system is quite complex. But in the end, the results we achieved were pretty good. We tested the whole system with several tasks to make sure our work was solid, and we also kept detailed notes for future improvements. Some of the things we suggest for the future include better system design and wiring, as well as adding features that can make the system more efficient. This project shows how promising gravitational vortex turbines can be as a sustainable small hydropower solution. It shows how we can use the natural flow of water through a turbine, pulley, and generator setup to create clean electricity. The inlet channel with a width of 6 cm yielded the highest power output. Increasing the notch length to 39 cm further enhanced power generation. The optimal runner position was identified at 49% of the basin height (21 cm from the bottom), which produced the maximum power. These results confirm the successful conversion of hydraulic energy into electrical energy, thereby validating the working principle of the system.

5.3 Advantage

There are several significant benefits to our project, and some of the key advantages are listed below:

- It generates renewable and eco-friendly energy.
- It operates effectively at low headwater levels, unlike large hydropower plants.
- It is a cost-effective solution for small-scale rural electrification.
- It has a simple design that requires minimal maintenance.
- It provides a stable voltage output thanks to the use of a storage battery.
- It can be constructed using locally available materials, which supports sustainability.
- It functions efficiently even at very low water head levels, ranging from 0.7 to 3 meters, where traditional turbines are unable to operate.
- Enables energy self-reliance in remote off-grid locations.
- Functions quietly, ensuring a noise-free and community-friendly operation.

5.4 Disadvantages

This project has certain drawbacks. These include:

- Limited power generation capacity, making it unsuitable for large industrial applications.
- The efficiency of the system is heavily reliant on the water flow and the head conditions.
- Variations in water availability throughout the seasons can lead to reduced power output.
- The initial installation may require specialized technical knowledge.

5.5 Application

Here are the main applications of GWVT:

- Power supply in remote rural areas.
- Irrigation and agricultural applications.
- Environmentally friendly fish-passing power generation.
- Educational and research uses.
- Application in hilly regions and near rivers or lakes.
- Support for community services and small businesses.
- Utilization of rivers and canals.

CHAPTER 6

CONCLUDING REMARKS

6.1 Conclusion

The Water Vortex Turbine project demonstrates a sustainable and innovative solution to the growing global energy demand while minimizing environmental impact. By utilizing the natural flow of slow-moving water from rivers, canals, and hilly regions, this system eliminates the need for large dams and high-pressure infrastructure. Its design, incorporating a reservoir, flow sensor, turbine, pulley mechanism, generator, and battery, ensures efficient energy conversion with simple operation and low maintenance requirements. The technology is particularly well-suited for rural and remote areas, providing a reliable, clean, and quiet source of electricity to support households and small businesses. Beyond its technical advantages, the project also contributes to the protection of aquatic ecosystems and raises awareness about renewable energy within local communities. Overall, the Water Vortex Turbine offers a practical pathway toward affordable, eco-friendly, and decentralized power generation that aligns with sustainable development goals.

6.2 Limitations

Despite its advantages, the Water Vortex Turbine system has certain limitations that must be acknowledged. Its overall efficiency is lower compared to conventional hydro turbines, particularly under conditions of high-water flow. The technology relies on a consistent supply of water with adequate flow and pressure, which restricts its applicability to specific geographical locations. Moreover, it is not designed for large-scale electricity generation and is better suited for small- or micro-hydro applications. The performance of the system is highly dependent on the precise design and construction of the basin and vortex chamber, while the presence of sediment and debris in the water can further reduce efficiency and increase maintenance requirements. Seasonal fluctuations in water availability also affect power output, leading to variability in performance. Additionally, the initial construction costs for building the basin and water channels may be relatively high, especially in rural settings. Limited standardization and low levels of commercial adoption further pose challenges to the scalability and widespread implementation of this technology.

6.3 Future Recommendations

To enhance the performance and applicability of the Water Vortex Turbine system, several improvements and advanced features can be incorporated in future development. Some of the potential directions are outlined below:

- Integration of a **microcontroller unit (MCU)** for automated control, monitoring, and data acquisition.
- **Optimization of curved blades and the conical basin notch** using advanced design and simulation techniques to maximize energy output.
- Implementation of **IoT-based remote control and monitoring**, enabling real-time performance tracking and predictive maintenance.
- Application of **Artificial Intelligence (AI) and Machine Learning (ML)** algorithms to analyze operational data, predict faults, optimize efficiency, and adapt to varying flow conditions.
- Utilization of **advanced Computational Fluid Dynamics (CFD)** modeling to study complex flow behaviors, reduce energy losses, and further refine turbine and basin designs.

These developments can significantly improve system efficiency, reliability, and adaptability, making the technology more suitable for diverse environments and long-term sustainable energy generation.

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