Design of a Hybrid Renewable Energy System Utilizing Rainwater and Wind for Sustainable Power Generation

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Abstract -*This study explores the integration of Archimedes Screw Turbines for micro-hydropower generation in urban high-rise buildings. With an effective head of 3.96 meters and a discharge rate of 0.0547 cubic feet per second, the system demonstrates strong feasibility for rainwater energy conversion. Optimized screw design, including a 6.94-meter length at a 35° inclination, a diameter ratio of 0.5–0.6, and a blade pitch of 24.3 cm, ensures efficient water conveyance and structural stability. The turbine operates at 146.69 RPM with an efficiency of 71.2%, achieving stable power output. This research highlights the potential of rainwater-driven micro-hydro systems as a sustainable energy solution, complementing wind sources. This research work is more efficient and self-sustaining renewable energy models in urban environments andsustainable power generation.*

Key Words: Archimedes, Hydraulic Turbine, Prototype, renewable resources, Sustainability

1. INTRODUCTION

As cities strive for sustainable energy solutions, integrating wind and rainwater energy offers a promising pathway. This research introduces an innovative method for generating electricity in high-rise buildings by harnessing both wind and rainwater as complementary renewable energy sources. The proposed system combines a Liam F1 mini wind turbine—renowned for its efficiency in urban environments—with an Archimedes screw-based hydraulic turbine to effectively convert rainwater runoff into usable energy.

Urban areas often struggle with inconsistent wind patterns and space constraints, limiting the feasibility of large-scale renewable energy installations. The vertical axis wind turbine (VAWT) design is particularly well-suited for high-rise buildings, as it efficiently captures wind from multiple directions and operates effectively at lower wind speeds typical of urban settings. Simultaneously, rainwater—an often underutilized resource—is channeled through an Archimedes screw mechanism to generate supplemental power.

By integrating these two renewable energy sources, the proposed system reduces reliance on conventional power grids while promoting sustainable urban development. Enhancing energy generation in densely populated areas, this model represents a viable and scalable solution for improving building energy efficiency and advancing renewable energy adoption in smart cities.

2. PROBLEM DEFINITION

The objective is to design an Archimedes screw-based hydraulic turbine and an Archimedes screw wind turbine to generate renewable energy for a three-story building with a total area of 3,000 square feet. The hydraulic turbine will utilize rainwater runoff to produce electricity, while the wind turbine will harness wind energy, ensuring efficient power generation within an urban setting. This dual-energy system aims to enhance sustainability by optimizing energy production in limited spaces, making it a viable solution for urban renewable energy applications.

3.OBJECTIVES

1. Harness rainwater and wind energy from high-rise buildings for clean electricity.
2. Integrate Archimedes screw and Archimedes screw wind turbine for hybrid power generation.
3. Optimize placement and design to maximize energy conversion efficiency.
4. Assess feasibility, scalability, and cost-effectiveness for urban applications.

5. Select and integrate VAWT (vertical axis wind turbine) and Archimedes screw turbine for efficient energy generation..

4.STUDY OF EXISTING ENERGY GENERATION SYSTEMS

Wind Energy Systems – Traditional horizontal-axis wind turbines (HAWTs) are widely used but are inefficient in urban areas due to inconsistent wind patterns. Vertical-axis wind turbines (VAWTs) offer better adaptability in cities by capturing wind from multiple directions and operating at lower wind speeds.

Rainwater-Based Energy Systems – Existing rainwater harvesting systems primarily focus on water conservation rather than energy generation. While some large-scale micro-hydro turbines are used in water distribution networks, their application for localized urban energy production remains limited.

Hybrid Renewable Systems – Most hybrid energy solutions combine solar and wind power, with little research dedicated to integrating wind and rainwater energy for electricity generation.

5. DESIGN OF PARTS IN CONVEYOR SYSTEM

Parts designed:

1. Archimedes screw hydraulic turbine

5.1 Archimedes screw hydraulic turbine:

- 25-60 mm/day rainwater Western ghats Area of terrace (A): 3000 sq feet
- Height of terrace wall (H): 2.5 feet Consider rainfall
- Depth to feet: 10mm = 0.1312 feet
- Volume of rainfall collected = 3000 x 0.1312
  = 393.9 cubic feet/day
- Discharge Rate = 0.0547083 cubic feet/s
  = 1.52 lit/s

5.2 To Determine pipe diameter

Flow rate Q=AXV

- A= cross sectional area of circular pipe

  (Where hydraulic turbine archimedesscrews to be inserted) (sq feet)
- V= Velocity of fluid (feet/s)

  = (3-4 m/s) for small hydro turbine
  = (0.5-13 ft/s)
- A=πx (d/2)^2
- D=dia of pipe

Rearrange the d based on Q&V;

$d = 2 \times \sqrt{(Q/\pi x V)}$
$d = 2 \times \sqrt{(0.0547/3.14 \times 6.5)}$
d = 0.1035835 Feet
d = 3.154 cm

Let's consider height of each Floor is generally around 9 to 10 feet (~2.7m to 3m)

so for three story building let's consider the maximum height of the building

Average height of the one story is 10 feet

10 x 3 = 30 feet

By adding some extra height for roof parapet,the total height would be around

30+3=33 feet =10m

5.3. Archimedes screw design according to:

1. Turbine head, H = Z1 - Z2

Z1, Z2 are the heights of the free surface at turbine inlet & outlet.

Z1 = 33 feet
Z2 =33 - 13 feet = 20 feet
H = Z1 - Z2
H = 33 - 20 H = 13 feet
H = 3.96 meter

2.Screw length, L

L depends on the angle of installation & turbine head heightaccording to given relationship,

$L = Z1 - Z2 / \sin\theta$

$= H / \sin\theta$ $L = 3.96 / \sin(35°)$

$\theta = 35° \rightarrow$ because maximum power is obtained at this angle.

3.No of blades (N)

No of blades should be chosen as to max power transmitted to shaft while keeping runner as light as possible.

N = 2 leads to marginal increase in efficiency while N = 2 causes a significant reduction in turbine performance.

Therefore N=3 is concluded as optimal no of blades

4. Diameter ratio(δ)

= Di / De

Range=0.45 to 0.55 according to our study experimental results obtained.

After optimization study it concluded that diameter ratio should be

0.54 - for no of blades targeting 1 to 4

The decrease in diameter ratio δ leads to an increase in Blade surface accompanied by an increase in the hydraulic forces that acts on blade, on the one hand the axial component of the forces increases, causing higher axial thrust that loads to bearing and the torque it produces is not increase significantly.

5. Blade Pitch (λ):

First we have to calculate the outer diameter of the Archimedes screw.

$D_e = (18.63KQ/N(1- \delta^3))^{3/7}$

$= (18.63x0.00151xtan35/13(1-0.54^3)^{3/7}$

D_e= 19.9 cm

$\Lambda=2^{ND}{}_e/k(4+N)$

=0.243 m

=24.3 cm

$\Delta = D_i/De$

0.54=Di/0.199

D_i=0.107m

6. Speed (n):

$n_{lim}=50/D_e{}^{2/3}$

n =146.690 rpm

7. Volume of bucket V_b:

$n = 60Q/NV_b$

$V_b = 60Q/Nn$

V_b= 60x0.00151/3x146.690

V_b= 0.0000205876 m3

8. Turbine efficiency:

Average efficiency is 71.2% with standard deviation of 3.4%

9. Shaft Power:

Ps = 9.81 η Q H [KW]

Ps = 9.81 x 0.71 x 0.0011 x 39.6

Ps = 0.041608712 [KW]

6. CAD MODELLING USING ANSYS SOFTWARE

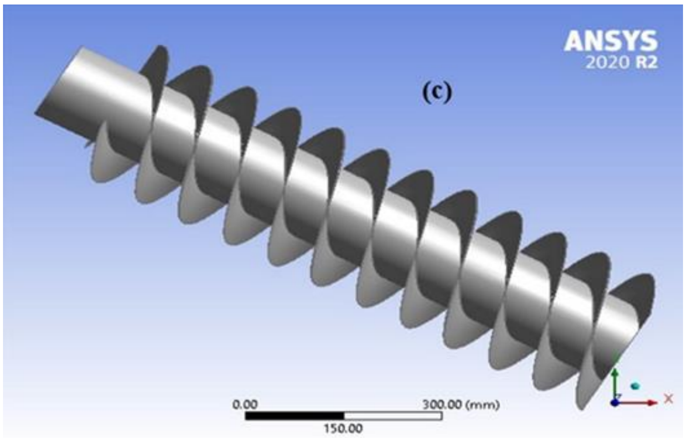

Figure1: Archimedean screw

7. RESULTS:

Turbine Head & Flow Rate – The effective head was meticulously calculated at 3.96 meters, with an estimated discharge rate of 0.0547 cubic feet per second, rendering it highly suitable for micro-hydropower applications.

Screw Design Optimization – The optimal screw length was precisely determined to be 6.94 meters, inclined at 35°, ensuring peak power generation. The diameter ratio (Di/De), ranging from 0.5 to 0.6, coupled with a blade pitch of 24.3 cm, facilitates seamless and efficient water conveyance. To strike the perfect balance between operational efficiency and structural robustness, an ideal configuration of three blades (N = 3) was selected.

Turbine Performance & Efficiency – Operating at an impressive 146.69 RPM with an efficiency of 71.2%, the turbine achieves a stable shaft power output of 0.0416kW, signifying a well-optimized and reliable energy conversion system.

Practical Implications – This study reaffirms the immense potential of integrating rainwater-driven micro-hydro systems into high-rise buildings, seamlessly complementing wind and solar energy solutions. By harnessing multiple renewable sources, this innovative approach paves the way for a more sustainable and self-sufficient urban energy ecosystem.

8. CONCLUSIONS:

- **Feasibility of Archimedes Screw Turbines** – The research confirms the viability of using Archimedes Screw Turbines for small-scale hydropower generation in urban settings.

- **Efficiency & Performance** – Design calculations and performance analysis indicate an energy conversion efficiency of over 70%, effectively utilizing rainwater flow for power generation.

Optimized Design – Key turbine parameters, including blade configuration, diameter ratio, and pitch, were optimized to enhance efficiency while minimizing structural stress.

Renewable Energy Potential – Rainwater-driven micro-hydro systems offer a viable renewable energy solution for high-rise buildings, complementing existing energy sources.

Future Enhancements – Further advancements in materials, system integration, and energy storage can improve performance and sustainability.

Scope for Future Research – Experimental validation and real-world implementation can refine performance metrics and explore hybrid renewable energy models integrating solar, wind, and hydropower for maximum efficiency.

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