Design and Fabrication of Vertical Axis Wind Turbine

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Abstract - *This project focuses on the design, development, and testing of a Savonius rotor-based Vertical Axis Wind Turbine (VAWT) as a sustainable energy solution. The study aims to enhance efficiency, durability, and cost-effectiveness by optimizing blade shape and selecting suitable materials. The turbine is tested under controlled conditions to assess power output and efficiency, with the results highlighting the potential of Savonius-based VAWTs as a reliable, low-maintenance, and environmentally friendly energy source.*

Key Words: **Vertical Axis Wind Turbine (VAWT), Savonius rotor, Renewable energy, Blade optimization, Aerodynamic efficiency, Power output, Durability testing, Sustainable energy.**

1. INTRODUCTION

Vertical Axis Wind Turbines (VAWTs) offer a promising alternative to Horizontal Axis Wind Turbines (HAWTs), particularly in urban areas and locations with turbulent wind conditions. Unlike HAWTs, VAWTs capture wind from any direction, making them adaptable to fluctuating wind patterns. The Savonius turbine, known for its simplicity and low manufacturing costs, is ideal for small-scale, low-speed applications. Advancements in aerodynamics, materials, and control systems have improved its efficiency, making it more competitive in the wind energy sector. VAWTs, including the Savonius type, are particularly suited for space-constrained areas and urban environments. Despite challenges like lower efficiency at higher wind speeds and mechanical stresses, ongoing research aims to improve their performance and durability. This paper reviews the design, development, and performance of Savonius-based VAWTs, highlighting their potential for sustainable energy generation.

1.1 METHODOLOGY

The methodology for this study on Savonius Vertical Axis Wind Turbines (VAWTs) is structured in a series of phases, each contributing to the overall design, development, and optimization of the turbine system. The following steps outline the process:

Start
↓
Design and Modelling
↓
Component Selection
↓
Fabrication and Assembly
↓
Electrical Integration
↓
Performance Testing and Optimization
↓
Implementation and Maintenance
↓
End

Chart 1- Methodology

Design:

The turbine is designed using CAD software, modeling the aerodynamic properties and optimizing geometry for various wind conditions.

Component Selection:

Components are selected based on material properties, durability, and cost-effectiveness to balance performance and longevity.

Fabrication and Assembly:

Components are fabricated and assembled with precision to ensure proper alignment and structural integrity.

Electrical Integration:

The electrical system is integrated, connecting the generator to the rotor shaft and configuring power electronics for optimal energy output.

Performance Testing and Optimization:

The turbine undergoes testing to assess efficiency and power output. Adjustments are made based on data to enhance performance.

Implementation and Maintenance:

After optimization, the turbine is installed, and a maintenance schedule is set for long-term performance monitoring.

2. DESIGN PRINCIPLES OF VAWT

Aerodynamic Efficiency

The three-blade design improves stability and smooth power generation. Optimized blade profiles enhance torque and self-starting ability. The rotor is designed for efficient operation in low-speed, turbulent wind environments.

Blade Design Considerations

The VAWT uses a three-blade configuration with 120° spacing for balance. Each blade is 660 mm in height, 460 mm before bending, and 360 mm after bending, with a 0.8 mm thickness.

Structural Stability

The frame is built from 1-inch and 3/4-inch mild steel square pipes for strength. The 20 mm diameter, 1040 mm long mild steel shaft ensures stability under load. A 6204 deep groove ball bearing supports smooth rotation, reducing mechanical stress.

Generator and Power Transmission

A 12V DC dynamo generator converts wind energy into electricity, stored in a 12V system with two 6V lead-acid batteries. A bridge rectifier converts AC to DC. Copper wiring minimizes power loss for efficient transmission.

Self-Starting Capability

A low-inertia blade design and balanced rotor enhance self-starting. High-performance bearings reduce friction, allowing the turbine to start rotating even at low wind speeds without external assistance.

Wind Flow Optimization

The turbine operates efficiently at 4-10 m/s wind speeds. The 360 mm rotor diameter results in a 0.1018 m^2 swept area, with 13.2 W available wind power at 2.78 m/s wind speed. Its omnidirectional design is ideal for urban areas.

Battery Level Indication

Battery level indication shows remaining charge, often using LEDs or displays, by measuring voltage and comparing it to set thresholds.

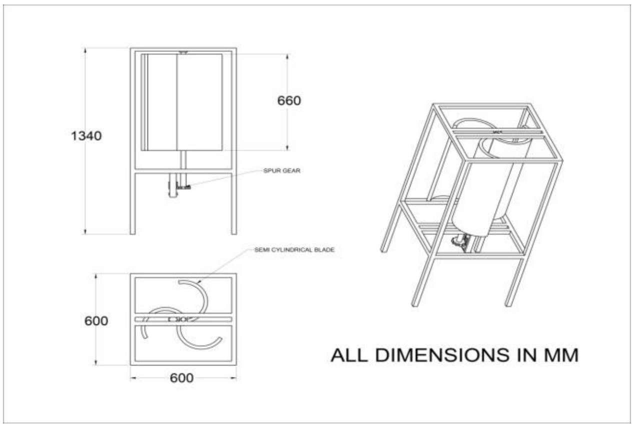

Fig 1- Design of VAWTs Assembly

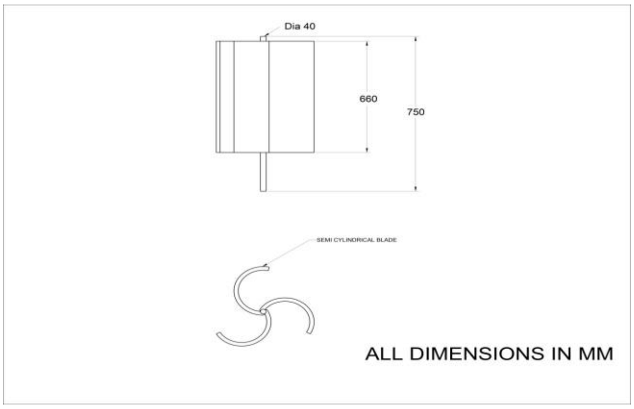

Fig 2- Design of VAWTs Rotor

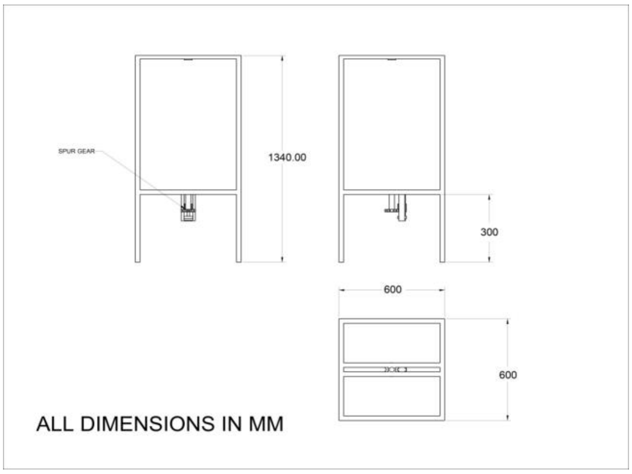

Fig 3- Design of VAWTs Frame

3. MATERIALS FOR VAWT CONSTRUCTION

Shaft and Blade: You're using a 20 mm diameter, 1040 mm long mild steel shaft and a rectangular hardened mild steel blade (0.8 mm thickness, 600 mm length, 460 mm breadth). The shaft is designed to transmit rotational motion and torque, while the blade is intended for tasks requiring strength, flexibility, and wear resistance, such as cutting or bending.

Dynamo Generator and Battery System: The 12V DC dynamo generator converts mechanical energy into electrical energy. You're also considering a battery setup with two 6V acid batteries connected in series to create a 12V system.

Bearing and Gear: A 6204 ball bearing (20 mm ID, 40 mm OD) is used to reduce friction and support loads. The spur gear will help in reducing speed and increasing torque.

Square Pipe and Body: Mild steel square pipes (1-inch and 3/4-inch) will be used for base and frame construction. The 1-inch pipe will provide primary support, while the 3/4-inch pipe will reinforce the structure.

Rectifier and Toggle Switch: A bridge rectifier will convert AC to DC, and a toggle switch will control the circuit by turning it on and off.

Arduino and LCD Display: You're using an UNO R3 SMD Arduino board and a 16x2 LCD Display with an I2C module for easy communication. This setup is ideal for embedded applications and IoT projects.

Voltage Sensor and Jumper Wire Cable: The REES52 Voltage Sensor will measure voltages up to 25V, and you'll use jumper wires for easy circuit connections.

4. FABRICATION AND ASSEMBLY PROCESS

4.1. FABRICATION

Machining and Cutting:

CNC machining automates material removal using computer-controlled tools for precision. Lathes rotate work pieces for turning, facing, and threading, mainly for cylindrical parts. Cutting uses single or multi-point tools, influenced by speed, feed, and tool material. Grinding is a finishing process using abrasive wheels for fine surfaces and accuracy in various applications.

Welding:

Welding joins metals by applying heat to melt and fuse them, using either consumable or non-consumable electrodes with filler material. It ensures strong, durable joints for various applications.

Bolting:

Bolting fastens materials using threaded bolts and nuts, creating a secure connection that can be easily disassembled for maintenance or modifications.

Coatings and Treatments:

Coatings and treatments are vital for improving the durability of materials like mild steel in Vertical Axis Wind Turbine (VAWT) components. Paint coatings protect against corrosion, UV radiation, and weathering. Anti-corrosive paints are applied to parts such as the frame, blades, and shafts to prevent rust and degradation, enhancing the turbine's lifespan and reducing maintenance needs while also improving its appearance.

4.2. ASSEMBLY

The assembly process for the Vertical Axis Wind Turbine (VAWT) involves several critical steps to ensure optimal functionality. The base assembly begins with cutting mild steel square pipes (1 inch and 3/4 inch) to specific dimensions (300mm height, 300mm breadth, and 600mm width), which are then welded or bolted together to form a rigid rectangular frame that provides support for the rotor and other components, ensuring proper alignment and stability. For the rotor, a 20mm diameter shaft is marked for the attachment of three blades, each measuring 660mm in height, 360mm in breadth (after bending), and 0.8mm in thickness. These blades are symmetrically attached to the shaft and secured using fasteners or welding for durability. Ball bearings with an inner diameter of 20mm and an outer diameter of 40mm are installed at both ends of the shaft to facilitate smooth rotation and are securely mounted to align with the rotor shaft. The 12V DC dynamo generator is fixed to the base and connected to the rotor shaft using a coupling or pulley system to efficiently transfer power. For the electrical system, a 12V battery is connected in series to store the generated power, and a bridge rectifier is installed to convert AC to DC. The system's battery voltage is monitored through a REES52 Voltage Sensor connected to an UNO R3 SMD board, with the results displayed on a 16x2 LCD screen. The connections are made securely to ensure proper data transmission and prevent voltage drops, with jumper wires linking all components. Finally, the system is powered up, and the battery voltage is verified on the LCD display, with any necessary adjustments to calibrate the readings.

Fig 4- Fabricated and Assembled VAWTs

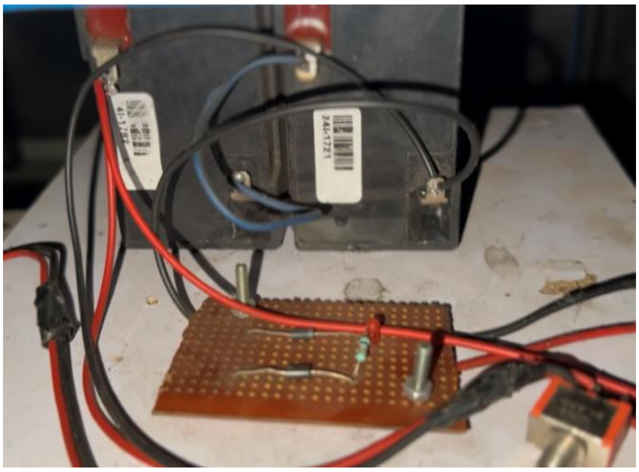

Fig 5- Battery and Rectifier setup

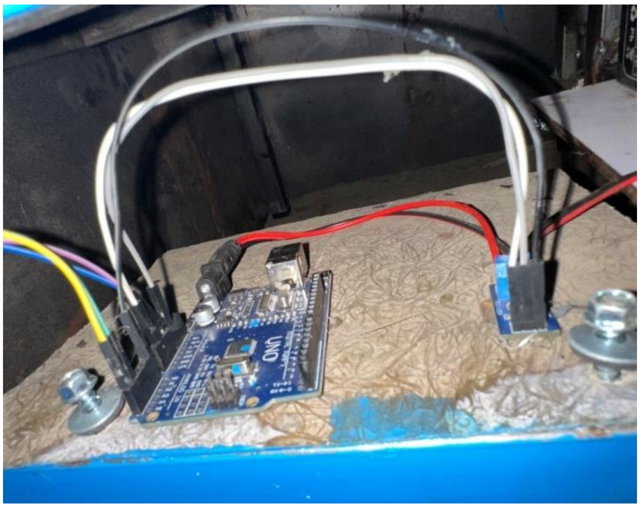

Fig 5- Arduino with Voltage sensor setup

5. PERFORMANCE EVALUATION AND TESTING

5.1. Wind Speed & Power Output Measurement

5.1.1 Wind Speed & Power Output Measurement at 10 km /hr

To test the wind speed and power output of a 12V, 12Ah battery system with a 12V DC dynamo generator connected to a P-N junction diode bridge rectifier, the wind speed was first checked using a weather app. The app provided the wind speed in units like m/s, km/h, or mph. If the wind speed was in units other than m/s, it was converted using the appropriate formula. For example, if the app provided the wind speed in km/h, it was converted to m/s by multiplying by 1000/3600. This provided a more accurate measurement for calculating wind power.

Once the wind speed was obtained, the available wind power was calculated. For instance, if the wind speed reported by the weather app was 10 km/h, it was first converted to m/s.

Wind speed (m/s) = 10 km /h x (1000/3600)

= 2.78 m/s

Next, calculate the swept area of the turbine, which depends on the turbine diameter. Given the turbine diameter is 370mm (or 0.37 meters), you can calculate the swept area using the formula:

$$A = \pi \times \left(\frac{0.37}{2}\right)^2 = 0.1075\ \mathbf{m^2}$$

Then, calculate the available wind power using the formula:

$$P_{wind} = \frac{1}{2}\ \rho \times A \times V^3$$

Where:

ρ is the air density (approximately 1.225 kg/m^3 at sea level),

A is the swept area (0.1075 m^2),

V is the wind speed (2.78 m/s).

Substituting these values:

$$P_{wind} = \frac{1}{2} \times 1.225 \times 0.1075 \times 2.78^3 = 1.41 \text{ watts}$$

This gave the available wind power of approximately 1.41 watts at a wind speed of 10 km/h. Next, a multimeter was used to measure the DC voltage and current output from the dynamo generator, ensuring it operated around 12V. The voltage and current going into the 12V, 12Ah battery were measured, confirming that it matched the battery's charging specifications. To calculate the power output, the formula was used:

P = V x I

P = 12 x 0.02 = 0.24 W

Compare the calculated wind power 1.41 watts to the actual electrical power being generated and stored in the battery. Evaluating the system's overall efficiency by comparing the electrical power output to the available wind energy using formula,

Efficiency = (Electrical Power Output / Available Wind Power)×100

Efficiency = (0.24 / 1.41) / 100

Efficiency = 17.02 %

5.1.2. Wind Speed & Power Output Measurement at 8 km /hr

To test the wind speed and power output of a 12V, 12Ah battery system with a 12V DC dynamo generator connected to a P-N junction diode bridge rectifier, the wind speed was first checked using a weather app. The app provided the wind speed in units like m/s, km/h, or mph. If the wind speed was in units other than m/s, it was converted using the appropriate formula. For example, if the app provided the wind speed in km/h, it was converted to m/s by multiplying by 1000/3600. This provided a more accurate measurement for calculating wind power.

Once the wind speed was obtained, the available wind power was calculated. For instance, if the wind speed reported by the weather app was 10 km/h, it was first converted to m/s.

Wind speed (m/s) = 8 km /h x (1000/3600)

= 2.22 m/s

Next, calculate the swept area of the turbine, which depends on the turbine diameter. Given the turbine diameter is 370mm (or 0.37 meters), you can calculate the swept area using the formula:

$A = \pi \times (\frac{0.37}{2})^2 = 0.1075\ m^2$

Then, calculate the available wind power using the formula:

$P_{wind} = ½\ \rho \times A \times V^3$

Where:

ρ is the air density (approximately 1.225 kg/m^3 at sea level),

A is the swept area (0.1075 m^2),

V is the wind speed (2.78 m/s).

Substituting these values:

$P_{wind} = ½ \times 1.225 \times 0.1075 \times 2.22^3 = 0.72$ watts

This gave the available wind power of approximately 0.72 watts at a wind speed of 10 km/h. Next, a multimeter was used to measure the DC voltage and current output from the dynamo generator, ensuring it operated around 12V. The voltage and current going into the 12V, 9Ah battery were measured, confirming that it matched the battery's charging specifications. To calculate the power output, the formula was used:

P = V x I

P = 12 x 0.01 = 0.12 W

Compare the calculated wind power 0.72 watts to the actual electrical power being generated and stored in the battery. Evaluating the system's overall efficiency by comparing the electrical power output to the available wind energy using formula,

Efficiency = (Electrical Power Output / Available Wind Power)×100

Efficiency = (0.12 / 0.72) / 100

Efficiency = 16.66 %

5.1.3. Wind Speed & Power Output Measurement at 12 km /hr

To test the wind speed and power output of a 12V, 12Ah battery system with a 12V DC dynamo generator connected to a P-N junction diode bridge rectifier, the wind speed was first checked using a weather app. The app provided the wind speed in units like m/s, km/h, or mph. If the wind speed was in units other than m/s, it was converted using the appropriate formula. For example, if the app provided the wind speed in km/h, it was converted to m/s by multiplying by 1000/3600. This provided a more accurate measurement for calculating wind power.

Once the wind speed was obtained, the available wind power was calculated. For instance, if the wind speed reported by the weather app was 10 km/h, it was first converted to m/s.

Wind speed (m/s) = 12 km /h x (1000/3600)

= 3.33 m/s

Next, calculate the swept area of the turbine, which depends on the turbine diameter. Given the turbine diameter is 370mm (or 0.37 meters), you can calculate the swept area using the formula:

$A = \pi \times (\frac{0.37}{2})^2 = 0.1075\ m^2$

Then, calculate the available wind power using the formula:

$P_{wind} = \frac{1}{2} \rho \times A \times V^3$

Where:

ρ is the air density (approximately 1.225 kg/m^3 at sea level),

A is the swept area (0.1075 m^2),

V is the wind speed (2.78 m/s).

Substituting these values:

$P_{wind} = \frac{1}{2} \times 1.225 \times 0.1075 \times 3.33^3 = 2.43$ watts

This gave the available wind power of approximately 2.43 watts at a wind speed of 10 km/h. Next, a multimeter was used to measure the DC voltage and current output from the dynamo generator, ensuring it operated around 12V. The voltage and current going into the 12V, 9Ah battery were measured, confirming that it matched the battery's charging specifications. To calculate the power output, the formula was used:

$P = V \times I = 12 \times 0.03 = 0.36$ W

Compare the calculated wind power 2.43 watts to the actual electrical power being generated and stored in the battery. Evaluating the system's overall efficiency by comparing the electrical power output to the available wind energy using formula,

Efficiency = (Electrical Power Output / Available Wind Power)×100

Efficiency = (0.36 / 2.43) / 100

Efficiency = 14.81 %

5.1.4. Average Efficiency

Calculating the average efficiency, we need to take the efficiencies for each wind speed (10 km/h, 8 km/h, and 12 km/h) and find the mean. Here are the efficiencies you provided:

At 10 km/h: 17.02%

At 8 km/h: 16.66%

At 12 km/h: 14.81%

Now, to calculate the average efficiency:

Average Efficiency = (17.02+16.66+14.81) / 3

Average Efficiency = 16.16 %

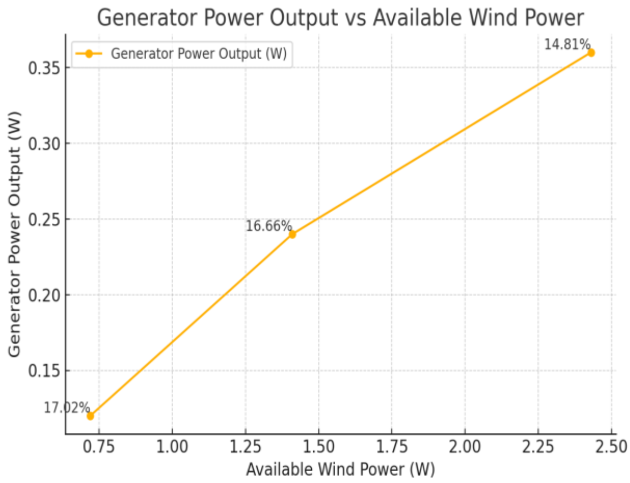

Chart 2- Efficiency Chart

5.2. Rotation & Mechanical Testing

Rotation & Mechanical Testing checks for resistance, misalignment, and wear by rotating the turbine, inspecting bearings, and measuring speed. It helps identify faults, improve efficiency, and reduce maintenance.

5.3 Visual Inspection

Visual inspection of a VAWT checks for damage, wear, and misalignment in key components like blades, tower, wiring, bearings, and foundation. Regular inspections prevent failures, reduce maintenance costs, and extend the turbine's lifespan.

5.4. Electrical System Testing

Electrical system testing in wind turbines involves measuring voltage, current, and power output to assess the dynamo, rectifier, battery, and circuitry. It ensures efficient AC to DC conversion, prevents overcharging, and evaluates system efficiency for optimal performance. A battery indicator is also used to monitor the battery's voltage levels, providing real-time feedback on its charging status and ensuring proper functioning.

5.5. Vibration & Noise Testing

Vibration and noise testing in wind turbines ensures mechanical stability and acoustic compliance. Using accelerometers, vibrations in the turbine's structure, blades, and generator are measured to detect issues like misalignment or imbalance. Noise testing checks sound levels to ensure they meet environmental standards. These tests help minimize vibrations and noise, enhancing the turbine's lifespan, performance, and regulatory compliance.

6. APPLICATION OF VATWs

Residential Energy Generation: Used for small-scale energy production, particularly in urban or suburban areas with limited space.

Marine Applications: Suitable for offshore and marine environments, including boats and offshore platforms, where wind direction is highly variable.

Agricultural Applications: Powering water pumps for irrigation in areas where wind resources are available.

Roadways: VAWTs can be integrated into roadway infrastructure, such as along highways or roads, to harness wind energy from passing vehicles or prevailing winds, contributing to roadside power generation.

Urban Wind Energy Solutions: VAWTs are ideal for installation on building rooftops, parking lots, or other urban spaces, where they can harness wind energy from the surrounding turbulent conditions.

7. CONCLUSION

This journal highlights the potential of Savonius-based Vertical Axis Wind Turbines (VAWTs) as an efficient, sustainable energy solution for small-scale applications. The design optimization, material selection, and performance testing have shown promising results in terms of power output, efficiency, and durability. VAWTs are adaptable for various applications, including residential, agricultural, urban, and roadway energy generation. While challenges remain, ongoing research can improve efficiency and durability, making VAWTs a competitive option for decentralized renewable energy, particularly in areas with variable wind conditions.

8. REFERENCE

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