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Integration of Horizontal and Vertical Axis Wind Turbines for Optimized Renewable Energy

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Abstract – The efficient extraction of wind energy in environments characterized by fluctuating wind speed and direction remains a major limitation of conventional wind turbine systems. Horizontal Axis Wind Turbines (HAWTs) achieve high efficiency under steady wind conditions, whereas Vertical Axis Wind Turbines (VAWTs perform more effectively in low-speed, turbulent, and multidirectional winds but generally exhibit lower standalone efficiency. To overcome these individual drawbacks, this study presents the design, fabrication, and experimental evaluation of a compact hybrid wind energy system integrating both HAWT and VAWT configurations within a single structural framework.

A laboratory-scale prototype was developed using cost-effective materials, and experimental testing was conducted under controlled wind conditions. Performance parameters such as wind velocity, rotational speed, and generated voltage were measured using an anemometer, tachometer, and digital multimeter. The results demonstrate that the hybrid configuration extends the operational wind range and improves power generation consistency compared to individual turbine systems. While the HAWT contributed higher output at moderate wind speeds, the VAWT ensured stable generation under low and variable wind conditions. The study confirms the suitability of hybrid wind turbine systems for decentralized renewable energy applications in urban and semi-urban environments.

1. INTRODUCTION

Conventional wind energy systems primarily employ either Horizontal Axis Wind Turbines or Vertical Axis Wind Turbines. HAWTs are widely used in commercial wind farms due to their high aerodynamic efficiency and superior power coefficients under steady wind conditions. However, their performance significantly deteriorates in low-speed or highly turbulent wind environments, and they require yaw mechanisms to align with wind direction. In contrast, VAWTs can operate efficiently in omnidirectional and turbulent wind flows, making them suitable for urban and semi-urban installations, although their standalone power output is generally lower.

This study focuses on the development and experimental analysis of a compact hybrid wind turbine system that integrates HAWT and VAWT configurations. The proposed system aims to improve power generation stability and efficiency, particularly in environments characterized by unpredictable wind behavior.

Recent research has demonstrated increasing interest in hybrid wind energy systems due to their ability to mitigate the limitations of single-turbine configurations. Didane et al.., reviewed modern hybrid wind energy systems and highlighted the advantages of combining VAWT and HAWT structures. Their analysis reported improvements in energy stability, reduced cut in wind speeds, and higher capacity factors compared to single turbine configurations.[1]

Kumar et al.., Kumar and colleagues evaluated the performance of compact HAWTs designed for rooftop installations. Their study showed that lightweight rotor designs with optimized tip speed ratios can increase efficiency in medium speed wind zones.[2]

Zhang & Yoon.., Zhang and Yoon explored hybrid wind systems combining HAWT and VAWT structures. Their work demonstrated a 15–20% improvement in total energy generation due to the complementary nature of the two turbines. The study also emphasized reduced power variability, making hybrid wind systems suitable for decentralized renewable energy setups.[3]

Kashif Ali a, Zhenzhou Zhao.., Hybrid wind turbine system that places small VAWT around the tower of a HAWT to improve overall power production. The performance of a single VAWT was tested at different positions around the with a fixed 5.4 m spacing and a constant wind speed of 8 m/s. The 3D simulations showed that the tower creates both high speed flow regions and stagnation zones. VAWT placed in high-speed regions produced more power Placing small turbines on both sides at 90° also slightly increased the main HAWT's power by 0.83%.[4]

Qusay Hassan a, Sameer Algburi.., Hybrid power plants that pair wind turbines with PV and batteries are increasingly favored for utility and off-grid applications because complementary resource profiles daytime PV vs. variable wind plus storage reduce intermittency and levelized cost of energy LCOE. Recent reviews and case studies discuss optimal sizing, MPPT and coordinated control strategies to maximize combined output and grid services.[5]

George Daniel Chirita1, Viviana Filip.., The proposed 3 m hybrid wind–photovoltaic rotor with pivoting PV-coated blades and a lightweight rigidizing rim can be deployed as a single mast micro generator for remote farms, off grid cabins, and smart grid street lighting poles where roof or ground area is limited. By harvesting wind energy at night and photovoltaic power during the day or simultaneously in moderate winds, the unit delivers a higher annual energy yield per square meter than separate small wind or rooftop PV systems, while requiring only one foundation and one power electronics package.[6]

Paul Bayron a, Richard Kelso.., Counter-rotating and multi rotor concepts including contra rotating VAWT and tandem co axial arrangements have shown notable performance gains in experiments and CFD studies by recovering wake energy and improving tip speed utilization. Several recent experimental CFD papers report higher power coefficients for carefully spaced counter rotating assemblies.[7]

Alberto Ghigo, Emilio Faraggiana.., Floating VAWT and hybrid arrangements e.g., arrays of VAWT or VAWT+HAWT on floating platforms are being studied as an alternative to conventional floating HAWT because VAWT can be simpler mechanically and less sensitive to yaw. Reviews highlight prototype projects and the need for hydrodynamic aero coupling studies.[8]

2. PROBLEM STATEMENT AND OBJECTIVES

2.1 PROBLEM STATEMENT

The Wind energy is a key renewable resource however, its effective utilization is restricted by continuously changing wind speed, direction, and site-specific conditions. Conventional wind power systems predominantly employ either Horizontal Axis Wind Turbines or Vertical Axis Wind Turbines, each of which performs efficiently only under certain wind environments. Horizontal axis turbines are suitable for locations with steady and high wind speeds, while vertical axis turbines are more adaptable to low-speed and turbulent wind conditions but offer lower standalone efficiency.

The use of a single turbine type results in partial utilization of available wind energy, particularly in urban, semi-urban, and mixed wind environments where wind behaviour is highly unpredictable. This limitation leads to inconsistent power output, reduced system efficiency, and underperformance of wind energy installations.

Hence, the core problem is the lack of an integrated wind energy system capable of efficiently operating across diverse wind conditions. Hybrid wind power system that combines the strengths of both horizontal and vertical axis turbines to enhance energy capture, improve power output stability, and increase the reliability of wind-based renewable energy generation.

2.2 OBJECTIVES

- To design a compact hybrid wind turbine structure that combines the operational advantages of both HAWT and VAWT configurations.
- To fabricate a laboratory-scale prototype using locally available and cost-effective materials suitable for experimental evaluation.
- To experimentally analyse the performance of individual HAWT and VAWT units by measuring wind speed, rotational speed, and generated voltage under controlled conditions.
- To compare the electrical output of horizontal and vertical axis turbines operating at identical wind speeds.
- To study the feasibility of hybrid wind systems for applications in low wind speed, turbulent, and urban environments.
- To evaluate the reliability and consistency of power generation from the hybrid configuration compared to standalone turbine systems.
- To promote the use of sustainable and renewable energy technologies by demonstrating a simple and scalable hybrid wind energy solution.
- To assess the reliability and maintenance requirements of the hybrid wind turbine system.

3. MATERIALS AND COMPONENTS

3.1 COMPONENTS USED

- **Dynamo:** A wind turbine dynamo also known as generator is a critical component that converts the mechanical energy from rotating blades into usable electrical energy through the principle of electromagnetic induction.
  Total dynamos used :3 no's
  Type : Permanent magnet AC dynamos
  Speed : 600 RPM
  Power output : 30–80 watts
- **HAWT and VAWT Blades:**
  Blade size : Dia 600mm,
  thickness : 5 mm
  Blade Guage : 80 grits
  Main support tube : 50 × 25 mm, 16 gauge
  Blade mounting tube : 20 × 20 mm, 16 gauge
  Shaft size : 10 mm
  Hole in shaft plate : 10 mm
  Mounting plate : Dynamo plate
  Bolts : M6 (plate), M10 (blade)
- **Frames and Plate Materials Used:** It's a square tube structure supporting the turbines to stand. Made of Mild steel.

Figure 1: Final Model

4. METHODOLOGY

The methodology adopted in this study involves the design, fabrication, and experimental evaluation of a hybrid wind turbine system. Separate shafts were employed for the HAWT and VAWT to independently assess their performance while operating under the same wind conditions.

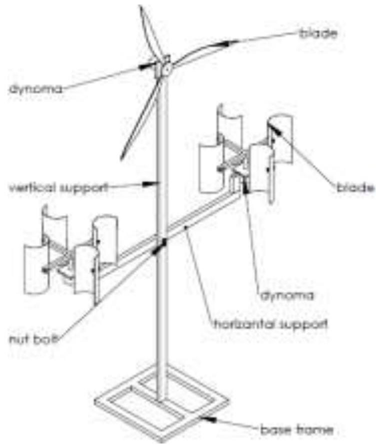

Figure 2: Proposed CAD Model

4.1. METHODOLOGY FLOW CHART

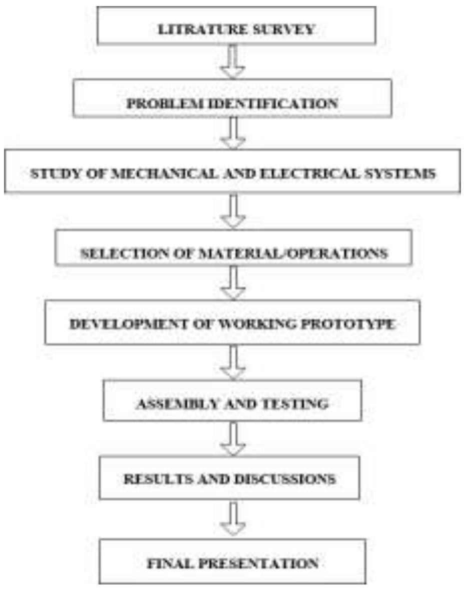

Figure 3: Methodology Flowchart

5. RESULTS AND DISCUSSION

The present model of HAWT and VAWT are placed on the different shaft to find the voltage for the same wind speed. Where the cut in wind speed required to rotate HAWT starts from 0.8m/s and for VAWT starts from 2.5m/s. The voltage generated from both the dynamos connected to the turbine is noted down with wind speed.

The graph of Voltage vs Speed and Voltage vs Wind Velocity is plotted for both HAWT and VAWT. From this analysis we can say that the efficiency of the generation can be increased. The graph shows that as the wind speed increases the voltage increases after it crosses the cut in wind speed.

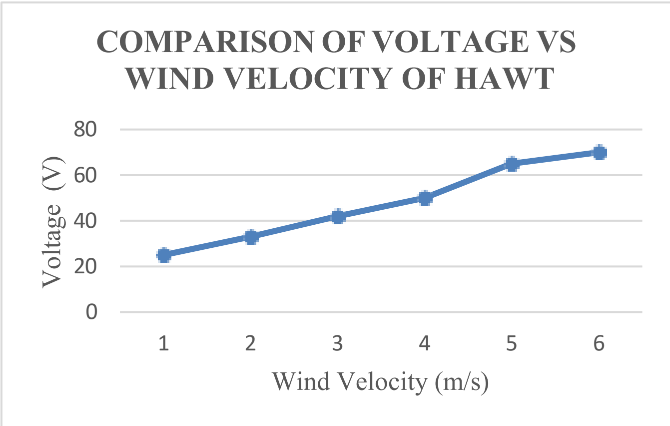

Figure 4: Comparison of Voltage and Wind Velocity of HAWT

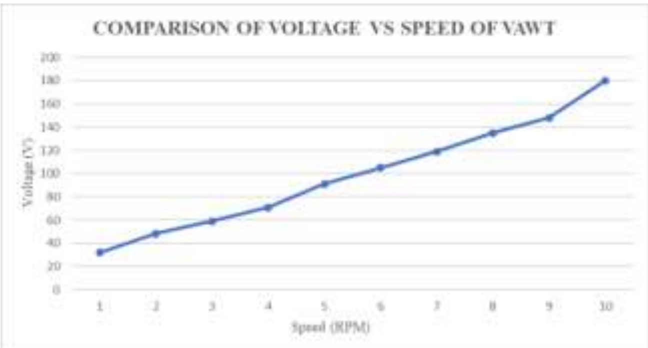

Figure 5: Comparison of Voltage and Speed of HAWT

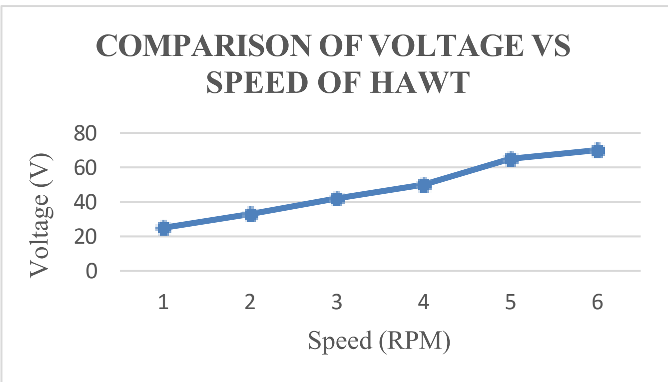

Figure 6: Comparison of Voltage and Wind Velocity of VAWT

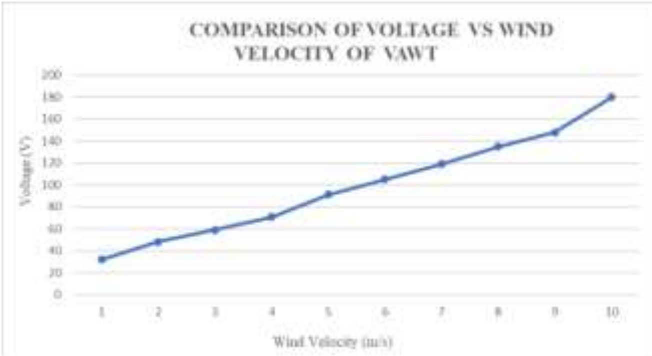

Figure 7: Comparison of Voltage and Wind Velocity of VAWT

CONCLUSION

1. This project successfully demonstrated the design and experimental evaluation of a Hybrid Wind Power System integrating both HAWT and VAWT. The hybrid configuration was developed to address the limitations of standalone wind turbines operating under variable wind conditions.
2. Experimental results obtained using instruments such as an anemometer, tachometer, and digital multimeter showed that both turbine types contribute effectively to energy generation at different wind speeds.
3. The HAWT exhibited higher efficiency at moderate wind velocities, while the VAWT performed reliably at lower and multidirectional wind conditions. This complementary behavior confirms that combining both turbines improves overall system adaptability and power generation consistency.

4. Overall, the project proves that hybrid wind turbine systems can enhance renewable energy utilization, especially in environments where wind characteristics are unpredictable, thereby supporting sustainable energy development.

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