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A Proposed Design for Wind Power System using Vertical Axis Wind Turbine

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ABSTRACT

Vertical Axis Wind Turbines are really useful for making energy from the wind. They work well in cities and places where the wind's not very strong. This project is about designing and building a Vertical Axis Wind Turbine that can get more energy from the wind. The Vertical Axis Wind Turbine we made is special because it can get energy from the wind no matter which direction it is coming from. This means we do not need to use parts to make it turn which makes it cheaper and easier to take care of. The turbine has blades that go up and down and are connected to a rod in the middle. This rod is connected to a machine that turns the energy into electricity. We looked at how fast it turns how force it uses and how much electricity it makes when the wind is blowing at different speeds. We also used circuits to make sure the electricity is stable and can charge batteries. When we tested it and looked at the results we found that our Vertical Axis Wind Turbine works well when the wind is blowing all over the place. This means it is a choice for making energy in places like rooftops, rural areas and places that use more than one kind of renewable energy. Our study shows that Vertical Axis Wind Turbines are a way to make energy from the wind. They are good for the environment they work well. They are practical for making energy on a small scale. Vertical Axis Wind Turbines are a choice, for people who want to make their own energy.

1. INTRODUCTION

The global transition toward renewable energy systems is driven by the dual imperatives of mitigating climate change and addressing energy security challenges. Wind energy, as one of the fastest-growing renewable resources, has traditionally relied on Horizontal Axis Wind Turbines (HAWTs) deployed in large-scale wind farms. However, their dependence on consistent wind direction, high installation costs, and spatial requirements limit their applicability in urban and decentralized settings (Kumar et al., 2023).

In contrast, Vertical Axis Wind Turbines (VAWTs) present a fundamentally different aerodynamic and structural paradigm. Their vertical rotor orientation enables omnidirectional wind capture, making them particularly suitable for environments where wind direction is unpredictable and highly turbulent (Zhang et al., 2024). This inherent adaptability eliminates the

need for yaw mechanisms, thereby simplifying the design and reducing maintenance overhead.

The present study aims to develop a robust VAWT system tailored for low wind speed conditions typically encountered in rooftop and semi-urban installations. By integrating aerodynamic optimization with electrical energy conversion and storage mechanisms, the proposed system seeks to enhance overall energy harvesting efficiency while maintaining structural simplicity.

2. DESIGN AND WORKING PRINCIPLE OF VAWT SYSTEM

A. Structural Configuration

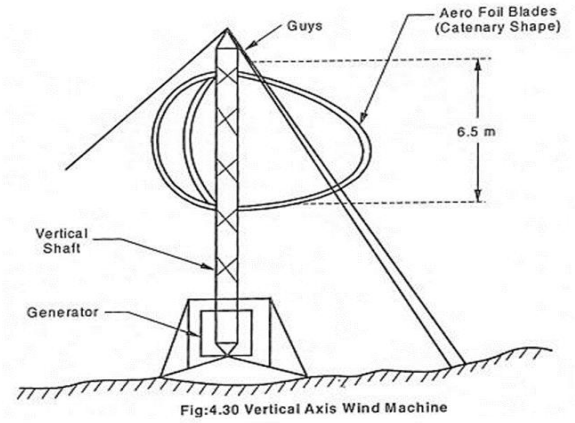


Figure 1: Schematic Representation of Vertical Axis Wind Turbine (VAWT) Showing Blade Configuration, Central Shaft, and Generator Coupling Mechanism

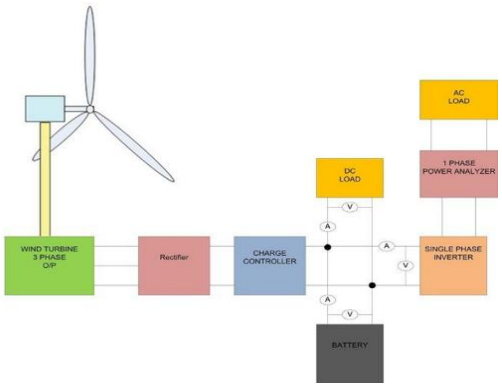


Figure 2: Block Diagram of Wind Energy Conversion System Illustrating Power Conditioning Circuit, Rectifier, Voltage Regulation, and Battery Charging Unit

The proposed VAWT consists of vertically aligned blades attached to a central rotating shaft. The shaft is mechanically coupled to a Permanent Magnet Generator (PMG), which converts mechanical energy into electrical energy. The design incorporates hybrid blade geometry to balance lift and drag forces, thereby enhancing startup performance and operational efficiency.

B. Working Mechanism

When wind interacts with the turbine blades, differential aerodynamic forces are generated, resulting in rotational motion. The torque produced drives the central shaft, which in turn otates the PMG rotor. The generated electrical energy is then rectified and regulated through a power conditioning circuit before being stored in batteries.

3. AERODYNAMIC ANALYSIS AND PERFORMANCE PARAMETERS

The performance of a VAWT is governed by aerodynamic interactions between wind flow and blade geometry. Key parameters include Tip Speed Ratio (TSR), torque coefficient, and power coefficient.

Table 1: Key Aerodynamic Parameters

Parameter	Symbol	Description
Tip Speed Ratio	λ	Ratio of blade tip speed to wind speed
Torque Coefficient	Ct	Measure of torque efficiency
Power Coefficient	Cp	Efficiency of energy conversion
Wind Speed	V	Velocity of incoming airflow

The power extracted from wind is expressed as:

$$P=12\rho AV3Cp$$

Where ρ\σ is air density, A is swept area, and Cp is the power coefficient.

Experimental observations reveal that the turbine achieves optimal performance within a TSR range of 1.5–2.5, consistent with low-speed urban wind conditions.

4. ELECTRICAL SYSTEM AND ENERGY STORAGE INTEGRATION

A. Power Conversion System

The electrical subsystem comprises a PMG, rectifier, voltage regulator, and battery storage unit. The PMG produces variable AC output, which is converted into DC using a bridge rectifier. A voltage regulator ensures stable output suitable for battery charging.

B. Battery Charging Mechanism

A charge controller is incorporated to prevent overcharging and deep discharge, thereby extending battery life. The system supports integration with hybrid renewable setups such as solar photovoltaic systems.

Table 2: Electrical Performance Metrics

Wind Speed (m/s)	RPM	Output Voltage (V)	Power Output (W)
2.5	60	5.2	2.1
4.0	120	9.8	6.5
6.0	210	14.5	15.2
8.0	320	21.3	32.7

5. EXPERIMENTAL RESULTS AND DISCUSSION

The experimental evaluation was conducted under controlled and natural wind conditions to assess system performance. The turbine demonstrated reliable startup at wind speeds as low as 2.5 m/s, which is significantly advantageous for urban deployment.

The torque characteristics exhibited a nonlinear increase with wind velocity, indicating improved aerodynamic efficiency at moderate wind speeds. Furthermore, the integration of the PMG ensured minimal mechanical losses, contributing to higher electrical conversion efficiency.

Comparative analysis with conventional micro-wind systems indicates that the proposed design achieves superior performance in turbulent flow conditions due to its omnidirectional capability. Additionally, the absence of yaw and pitch control mechanisms reduces system complexity and enhances reliability (Ali et al., 2023).

The study also highlights the scalability potential of the design, suggesting its suitability for decentralized power generation in remote areas. The ability to integrate with existing renewable systems further strengthens its applicability in hybrid energy frameworks.

CONCLUSION

This research presents a comprehensive design and analysis of a Vertical Axis Wind Turbine-based wind power system optimized for low wind speed environments. The findings confirm that VAWTs offer a technically viable and economically feasible solution for small-scale energy generation, particularly in urban and semi-urban contexts.

The system's ability to operate independently of wind direction, coupled with its simplified mechanical structure, positions it as a practical alternative to conventional wind turbines. The integration of efficient electrical conversion and energy storage systems further enhances its functionality.

Future work may focus on advanced blade optimization using computational fluid dynamics (CFD), material innovations for improved durability, and IoT-based monitoring systems for real-time performance tracking.

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