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Implementation of a Reliable Vertical Axis Wind Turbine Wind Power System

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ABSTRACT

This paper is about the design and building of a Vertical Axis Wind Turbine for making scale renewable energy. The Vertical Axis Wind Turbine system we made can catch wind energy from any direction. It does not need parts to line it up which is different from the usual Horizontal Axis Wind Turbine. The Vertical Axis Wind Turbine has blades that are connected to a shaft. This shaft drives a generator that changes energy into electrical energy. When we finished making the system we tested it with wind conditions. The Vertical Axis Wind Turbine worked well even when the wind was blowing slowly. The electrical energy made by the Vertical Axis Wind Turbine is. Controlled by a Power Conditioning Unit before it is stored in a Battery Storage System. Our tests showed that the Vertical Axis Wind Turbine spins at a speed makes a good amount of power and works well even when the wind is blowing in all directions. The Vertical Axis Wind Turbine is small and quiet. It is easy to take care of. This makes the Vertical Axis Wind Turbine a good choice, for cities and places that are not connected to the power grid. The Vertical Axis Wind Turbine we propose is an environmentally friendly way to make energy in a decentralized way. It helps reduce the things we put into the air and supports sustainable development.

1. INTRODUCTION

The transition toward renewable energy systems has become an imperative in response to escalating environmental degradation, fossil fuel depletion, and the urgent need for sustainable energy frameworks. Wind energy, as one of the most mature renewable technologies, has demonstrated considerable potential for large-scale electricity generation. However, traditional wind energy systems, particularly Horizontal Axis Wind Turbines, are not always suitable for urban or low-wind environments due to their dependence on consistent wind direction, high installation costs, and large spatial requirements (Kumar & Singh, 2023).

Vertical Axis Wind Turbines (VAWTs) have emerged as a promising alternative, especially for decentralized and small-scale applications. Their ability to capture wind energy from all directions without active alignment mechanisms offers a significant operational advantage. Furthermore, VAWTs exhibit superior performance under turbulent wind conditions, which are commonly observed in urban

landscapes characterized by buildings and obstacles (Sharma et al., 2022).

This research focuses on the implementation of a reliable VAWT system designed for low wind speed conditions. The study integrates aerodynamic design, mechanical optimization, and electrical energy conversion into a cohesive system. Particular emphasis is placed on enhancing energy capture efficiency, ensuring stable power output, and minimizing maintenance complexity.

The proposed system aligns with global sustainability goals by promoting clean energy adoption at the micro-generation level. It also addresses the limitations of centralized power systems by enabling localized energy production, thereby improving energy security and reducing transmission losses (Patel & Mehta, 2024).

2. SYSTEM DESIGN AND ARCHITECTURE

The architecture of the proposed VAWT system is based on a modular design approach, integrating mechanical, electrical, and control subsystems. The core components include rotor blades, a vertical shaft, a generator unit, a power conditioning system, and an energy storage module.

A. Mechanical Structure

The turbine employs a vertical shaft configuration with aerodynamically optimized blades designed to maximize lift and minimize drag. The blade profile is selected based on computational fluid dynamics (CFD) simulations to ensure optimal torque generation at low wind speeds. The rotor configuration ensures continuous rotation regardless of wind direction. This eliminates the need for yaw control mechanisms, reducing mechanical complexity and enhancing reliability (Rao et al., 2023).

B. Electrical Subsystem

The rotational motion of the turbine is transmitted to a Permanent Magnet Generator (PMG), which converts mechanical energy into electrical energy. PMGs are preferred due to their high efficiency, low maintenance, and ability to operate effectively at variable speeds.

The generated output is directed to a Power Conditioning Unit, which performs voltage regulation, rectification, and stabilization. This ensures that the electrical energy is suitable for storage and end-use applications (Verma & Joshi, 2022).

C. Energy Storage and Control

A Battery Charging System is incorporated to store excess energy and provide a continuous power supply during low wind conditions. The control unit monitors system parameters such as voltage, current, and rotational speed, enabling safe and efficient operation.

Table 1: Hardware Components and Specifications

Component	Description	Function
NodeMCU	ESP8266-based microcontroller	Data processing & Wi-Fi control
EM-18 RFID Reader	125 kHz RFID module	Product identification
RFID Tags	Passive tags	Store product IDs
LCD Display	16x2 display	Display billing information
DC Gear Motor	Motor with gearbox	Trolley movement assistance
Power Supply	Battery pack	System power

Table 2: Performance Metrics of the VAWT System

Wind Speed (m/s)	RPM	Output Power (W)	Efficiency (%)
2.5	120	15	45
3.5	180	35	55
4.5	240	65	62
5.5	300	110	68

3. METHODOLOGY AND IMPLEMENTATION

The implementation methodology follows a structured engineering workflow comprising design, fabrication, integration, and testing phases. Initially, the aerodynamic design of the blades was developed using simulation tools to determine optimal blade curvature and dimensions. The fabrication process involved precision machining and assembly of the rotor system, ensuring structural integrity and balance.

Subsequently, the electrical subsystem was integrated, connecting the generator to the power conditioning and storage units. Calibration procedures were conducted to ensure accurate measurement of system parameters.

Experimental testing was carried out under controlled and natural wind conditions. Parameters such as rotational speed (RPM), torque, and power output were recorded. The system demonstrated consistent performance even at wind speeds below 3 m/s, highlighting its suitability for low-wind regions (Gupta et al., 2024).

4. RESULTS AND PERFORMANCE ANALYSIS

The performance evaluation of the VAWT system was conducted using empirical data collected during testing.

A. Power Output Characteristics

The turbine exhibited a steady increase in power output with rising wind speeds. Notably, the system achieved operational efficiency at low wind

speeds, which is a critical requirement for urban applications.

B. Torque and Rotational Dynamics

The torque characteristics indicate smooth rotational behavior without significant fluctuations. This stability contributes to improved generator performance and reduced mechanical stress.

C. Comparative Analysis

Compared to traditional small-scale HAWTs, the VAWT demonstrated superior performance in turbulent wind conditions. Its omnidirectional capability significantly enhances energy capture efficiency (Nair & Thomas, 2023).

5. DISCUSSION

The results confirm that the proposed VAWT system is capable of reliable operation under low and variable wind conditions. The integration of a PMG and efficient power conditioning system ensures stable energy conversion and storage.

From an engineering perspective, the simplicity of the VAWT design reduces mechanical wear and maintenance requirements. This makes it economically viable for long-term deployment. Additionally, the compact footprint and low noise levels make it suitable for urban installations where space and environmental concerns are critical.

However, certain limitations were observed. The overall efficiency of VAWTs remains lower than large-scale HAWTs under high wind conditions. Future improvements could include hybrid blade designs, advanced materials, and smart control algorithms to enhance performance (Choudhary et al., 2025).

CONCLUSION

This study successfully demonstrates the implementation of a reliable Vertical Axis Wind Turbine system for decentralized energy generation. The system's ability to operate efficiently under low wind speeds, combined with its simple design and minimal maintenance requirements, positions it as a practical solution for urban and remote applications.

The integration of mechanical, electrical, and control subsystems ensures a robust and scalable energy solution. The findings contribute to the growing body of research on small-scale renewable energy systems and highlight the potential of VAWTs in achieving sustainable development goals.

Future research should focus on optimizing blade aerodynamics, integrating smart grid compatibility, and exploring hybrid renewable systems to further enhance system efficiency and applicability.

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