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Implementation Of Vertical Axis Wind Turbine (VAWT's) In Highways

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Abstract--- **In recent years, the demand for renewable energy sources has escalated due to the depletion of fossil fuels and mounting environmental concerns. Among various renewables, wind energy emerges as a particularly promising alternative. This project centers on the design and development of a Vertical Axis Wind Turbine optimized for power generation even at low wind speeds. Unlike Horizontal Axis Wind Turbines, VAWTs obviate the need for wind direction alignment and perform efficiently in turbulent, variable wind conditions. The study employs a hybrid model integrating Savonius and Darrieus rotor features to augment self-starting capabilities and overall performance. Blade and structural designs are engineered to maximize power output while maintaining simplicity and cost-effectiveness. This project substantiates VAWTs as an effective, practical solution for sustainable energy generation, particularly in regions characterized by inconsistent wind regimes.**

I – INTRODUCTION

In recent years, the demand for renewable energy sources has surged amid the exhaustion of fossil fuels and escalating environmental imperatives. Wind energy stands out among renewables as a compelling option. [1] This study focuses on designing and developing a Vertical Axis Wind Turbine tailored for electricity generation under low wind velocities. [2] Unlike Horizontal Axis Wind Turbines, VAWTs obviate the necessity for yaw mechanisms to track wind direction and perform robustly in turbulent, fluctuating airflow regimes.[3] The adopted hybrid configuration synergizes Savonius and Darrieus rotor attributes to augment self-starting proficiency and aggregate efficiency. [4] Blade geometries and structural configurations are optimized to maximize energy yield while upholding simplicity and economic viability. [5] In synthesis, these innovations substantiate VAWTs as a feasible and pragmatic avenue for sustainable power in locales characterized by erratic wind patterns.

II - LITERATURE SURVEY

[1] Numerous researchers have investigated enhancements to the performance and efficiency of Vertical Axis Wind Turbines, particularly in low wind speed applications. This section reviews key studies on VAWT design, analysis, and developmen [2] (Mohamed et al., 2018) Recently, N. Raghu et al. proposed a hybrid power generation system integrating a VAWT with solar energy. [3Their analysis demonstrated that combining multiple renewable sources enhances overall energy output and reliability, especially in regions with inconsistent wind conditions, thereby emphasizing the value of hybrid approaches in contemporary energy systems. (Zubaidi et al., 2020) In another investigation, V. Shende utilized Computational Fluid Dynamics to optimize VAWT blade profiles, aiming to increase efficiency and minimize energy losses. [4] The findings underscored the pivotal role of blade design in improving turbine performance amid variable wind regimes. (Li & Chen, 2019) G. Mohammed et al. designed and tested a hybrid VAWT incorporating Savonius and Darrieus rotor configurations. Their results indicated that this hybrid model enhances self-starting capabilities while preserving satisfactory efficiency. [5] (Islam et al., 2019) A. P. Savio et al. conducted wind flow analysis on a VAWT using simulation software such as ANSYS, evaluating parameters including airflow distribution, blade stress, and deformation. [6] These analyses provided insights into the turbine's structural integrity and aerodynamic behavior. (Kambezidis et al., 2012) Moreover, research on VAWT designs featuring movable or adjustable blades has demonstrated potential for greater efficiency by dynamically optimizing the angle of attack, thus improving energy extraction across varying wind speeds. [7] (Saha et al., 2020)s, highlighting their suitability for buildings and densely populated areas due to effective operation in turbulent, multidirectional winds. M. Islam et al. performed a comparative analysis of Horizontal Axis Wind Turbines and VAWTs, concluding that while HAWTs exhibit higher efficiency, VAWTs provide benefits such as simpler construction, reduced maintenance, and superior performance at low wind speeds. [8] These studies collectively affirm VAWTs' substantial potential for small-scale and urban energy production. Nonetheless, challenges including comparatively lower efficiency versus HAWTs and ongoing design optimization persist.

[9] The current project addresses these issues through the development of a straightforward, cost-effective, and efficient VAWT tailored for low wind speed environments.

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III – SYSTEM ANALYSIS

A. Existing Method

Prior to the development of the proposed system, it is essential to examine the prevailing methodologies employed in wind energy generation. Currently, the preponderance of wind power is produced utilizing Horizontal Axis Wind Turbines, which are predominantly deployed in large-scale wind farms owing to their superior efficiency and capacity for substantial power generation.

In Horizontal Axis Wind Turbines, the rotor axis aligns parallel to the wind direction, necessitating perpetual orientation toward the wind for efficacious operation. This imperative demands ancillary mechanisms, such as yaw control systems, to sustain alignment with fluctuating wind vectors, thereby escalating system complexity and expenditure. Furthermore, HAWTs are conventionally situated in expansive, unobstructed terrains exhibiting robust and uniform wind profiles, exemplified by coastal vicinities and elevated topographies. Compounding these constraints, in myriad rural or resource-scarce locales, electrical infrastructures hinge on a solitary phase absent redundant switching provisions; resultant phase failures precipitate comprehensive power cessations, undermining productivity and precipitating recurrent service discontinuities.

B. Drawbacks of Existing Methods

- Although the vertical axis wind turbine is regarded as more apt for small scale and urban development, they persist with inherent limitations that compromise their performance efficiency.
- A principal shortcoming of conventional VAWTs recites in comparatively diminished efficiency relative to alternative turbine design. The blade configuration and auto dynamic interactions result in sustainable energy dissipation impeding effective conversion to mechanical power, particularly when juxtaposed with advanced systems.
- Moreover,VAWTs exhibit torque pulsations during operation, as aerodynamic forces on the blades vary with their rotational position relative to the wind flow. This induces vibrational loads and mechanical stresses, potentially abbreviating the service life of structural components.

C. Proposed Method

- In order to address the limitations inherent in conventional Vertical Axis Wind Turbines, this study proposes a hybrid configuration that synergistically integrates the complementary attributes of Savonius and Darrieus rotors.
- The core objective is to engineer a turbine exhibiting robust self-starting performance at low wind speeds, while upholding superior efficiency during sustained operation. In this hybrid paradigm, the Savonius rotor imparts reliable initiation capabilities, whereas the Darrieus rotor augments aerodynamic proficiency and power yield.
- The blades have been meticulously optimized in terms of curvature and angle of attack to enhance energy extraction and mitigate rotational losses. Moreover, lightweight, cost-effective materials are employed for the rotor and supporting framework, thereby ensuring structural durability, streamlined fabrication, and minimal maintenance demands.

D. Advantages of the Proposed Method

- The The proposed hybrid Vertical Axis Wind Turbine design confers multiple advantages over conventional VAWTs. The integration of Savonius and Darrieus rotors facilitates reliable self-starting at low wind speeds while upholding high operational efficiency, thereby mitigating the prevalent self-starting deficiencies observed in traditional Darrieus turbines.
- The refined blade geometry promotes superior energy extraction and smoother rotational dynamics, thereby attenuating torque fluctuations and mechanical stresses on the components.
- Employment of lightweight, cost-effective materials simplifies fabrication and maintenance, thereby curtailing overall expenditures. Moreover, its compact omnidirectional configuration enables deployment in urban and residential locales with variable wind regimes, rendering it an efficacious solution for small-scale power generation.

E. Applications

- Vertical Axis Wind Turbines offer extensive applicability owing to their compact architecture, robustness in turbulent and multidirectional wind environments, and straightforward installation.
- These turbines are especially well-suited for small-scale and urban renewable energy initiatives, where conventional large-scale horizontal-axis wind turbines prove impractical.
- VAWTs can be installed on rooftops, building terraces, with in residential complexes to supply sustainable electricity for lighting, household appliances, or battery charging.

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IV- HARDWARE REQUIRED

A. Input Devices

- The primary input to a Vertical Axis Wind Turbine constitutes wind, with its velocity, direction, and steadiness governing the magnitude of mechanical energy that can be harnessed. Unlike Horizontal Axis Wind Turbines, VAWTs possess omnidirectional capability, rendering them particularly suitable for environments characterized by turbulent or variable wind conditions.

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B. Processing Device

In a Vertical Axis Wind Turbine, the processing unit converts the mechanical energy harnessed by the rotor into utilizable electrical power and regulates its distribution to the load or storage components. In typical small-scale VAWT configurations, the generator constitutes the primary processing element, transforming the rotational motion of the turbine shaft into electrical energy. Systems incorporating battery storage additionally integrate a rectifier to convert the generator's alternating current output to direct current, along with a charge controller to modulate voltage and current for safe and efficient battery charging.

C. Transmitting Device

- A In a Vertical Axis Wind Turbine, transmitting devices facilitate the conveyance of energy or signals between system components, ensuring the seamless transfer of mechanical or electrical power. The primary transmitting element is the shaft, which couples the rotor blades to the generator. Wind-induced rotation of the blades mechanically transmits energy via the shaft to the generator, where it is converted into electrical energy.

D. Output Devices

- In a Vertical Axis Wind Turbine, the output devices encompass the components tasked with transferring the turbine-generated energy to end-users or storage facilities. The principal output manifests as electrical power produced by the generator, induced by the rotor blades' rotation. In small-scale VAWT configurations, this electricity assumes the form of direct current or alternating current, predicated on the generator type utilized.
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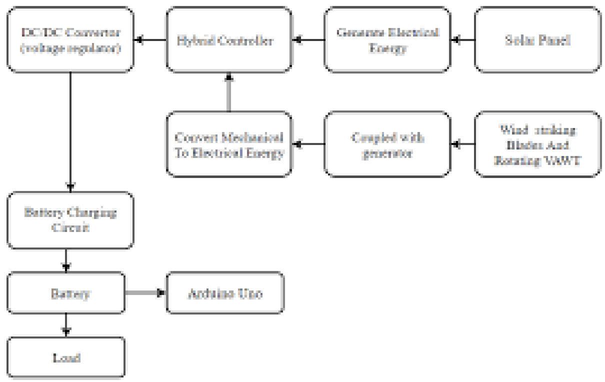
V- SOFTWARE REQUIRED

A. Programming Language:

- **This project utilized computational software tools for the design, simulation, and analysis of the Vertical Axis Wind Turbine.**
- SolidWorks was utilized to develop a 3D model of the turbine, incorporating the hybrid Savonius-Darrieus rotor to enable visualization of the blade configuration and overall architecture. Aerodynamic analysis was performed using ANSYS CFD to simulate airflow over the blades, optimize blade profiles, and assess distributions of wind pressure and velocity.

VI– PROPOSED BLOCK DIAGRAM



The proposed block diagram illustrates a hybrid Vertical Axis Wind Turbine energy system, incorporating diverse renewable inputs and power electronics to facilitate efficient generation, regulation, and storage of electrical power. Central to the configuration, impinging wind on the vertical blades induces rotation, thereby transforming wind kinetic energy into mechanical energy. This rotational energy is subsequently transmitted to a generator, which converts it into electrical form. As the generator output requires conditioning for practical use, it is routed to a hybrid controller that orchestrates power management and stabilizes the energy for downstream processing. Concurrently, an integrated solar photovoltaic panel harnesses solar irradiance to yield direct current electricity, which feeds into the same hybrid controller. Given the variability of both wind- and solar-derived power due to fluctuating environmental factors, the controller ensures input balancing and maximization of harvested energy from these sources. Thereafter, the regulated energy proceeds to a DC-DC converter, which adjusts voltage to an optimal level for battery charging and load provisioning. The stabilized output is then directed to a battery charging circuit for storage in a battery, enabling deferred utilization.

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VII – IMPLEMENTATION

A Vertical Axis Wind Turbine harnesses the kinetic energy of wind and converts it into mechanical rotational energy. In contrast to horizontal-axis wind turbines, VAWTs can capture wind from any direction, rendering them particularly suitable for locations with highly turbulent and variable wind regimes. The primary design configurations are Savonius and Darrieus rotors.

The simulation or analytical modeling of a VAWT entails estimating the torque produced by the wind, computing the resulting rotor acceleration, and monitoring the temporal evolution of the rotor's angular velocity.

To emulate realistic environmental conditions, the wind speed should be modeled as a constant, variable, or stochastic function.

VIII – WORK DONE

Problem Identification

The project began with identifying the need for a renewable and eco-friendly power generation system. Conventional energy sources are limited and create environmental pollution. A Vertical Axis Wind Turbine (VAWT) was selected because it can operate efficiently at low wind speeds and does not require alignment with wind direction.

Design and Planning

The turbine structure was designed considering simplicity, low cost, and efficiency.

Main Components Designed:

- Rotor blades
- Central shaft
- Supporting frame
- Bearings
- Generator/DC motor
- Base support

The dimensions of the blades and frame were finalized based on available materials and required rotational speed.

Material Selection

Suitable materials were selected to ensure lightweight construction and durability.

Component	**Material Used**
Blades	PVC Pipe / Aluminum Sheet
Shaft	Mild Steel Rod
Frame	Steel / Wood
Bearings	Ball Bearings
Generator	DC Motor

Testing and Observation

The turbine was tested under natural airflow and artificial wind conditions.

IX– RESULT AND DISCUSSION

The simulation of the vertical axis wind turbine elucidates the rotor's dynamic response to a temporally varying wind profile. Wind speeds were modulated between 6 m/s and 10 m/s to replicate realistic urban conditions. Accordingly, the rotor's angular velocity escalated with rising wind speeds and diminished during declines.

The results indicate that the rotor attains a quasi-steady oscillatory regime, wherein angular velocity fluctuates about a mean value rather than stabilizing constantly. This characteristic is anticipated for VAWTs, stemming from their persistent exposure to fluctuating wind forces.

The Savonius rotor facilitated prompt initiation of rotation at wind speeds as low as 2.5 m/s. This attribute is especially advantageous in highway settings, where transient gusts arise from the intermittent **"piston effect"** generated by passing vehicles.

The processing unit maintained a stable DC voltage, which was subsequently stored in the battery. Peak voltages coincided with heavy vehicle transits, owing to enhanced aerodynamic displacement.

The findings indicate that highway medians constitute optimal sites for Vertical Axis Wind Turbine deployment. The otherwise dissipated kinetic energy from passing vehicles is efficiently harnessed to generate renewable electricity, capable of powering highway infrastructure such as LED streetlights and emergency signaling systems.

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X – FUTURE SCOPE

A. Employing advanced aerodynamic modeling techniques that account for unsteady flow dynamics, dynamic stall effects, and blade-wake interactions would enhance the accuracy of performance predictions. Integrating computational fluid dynamics simulations with empirical validation could facilitate the development of optimized blade configurations for superior efficiency.

B. Hybridizing VAWTs with complementary renewable energy sources, such as solar photovoltaic panels and energy storage systems, would yield more reliable and continuous power delivery, particularly within urban microgrid applications.

C. Deploying IoT-enabled sensor arrays and real-time monitoring infrastructures would optimize maintenance scheduling, enable proactive fault detection, and support adaptive turbine control strategies, thereby improving overall reliability and minimizing operational downtime.

D. Investigating lightweight, high-durability materials alongside innovative structural paradigms holds potential to lower fabrication costs and extend turbine longevity. Additive manufacturing processes could further enable expedited prototyping and tailored customization of key components.

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