

Revolutionizing Renewable Energy: Harnessing Highway Wind for Sustainable Power Generation

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Abstract— This research introduces an innovative approach to sustainable energy generation through the integration of vertical windmills strategically placed along highways. Our design incorporates metal sheets that rotate with the wind generated by passing vehicles, providing a unique solution for harnessing kinetic energy. Experiments and simulations demonstrate the notable efficiency of our vertical windmill design, particularly in dynamic and open highway environments. Our findings indicate the potential for substantial contributions to the renewable energy landscape, specifically within the context of highways. The design's adaptability to existing infrastructure enables the capture of wind energy from moving vehicles, aligning with global efforts to reduce carbon emissions. This work offers a practical and innovative solution, showcasing the potential for integrating renewable energy systems into everyday transportation networks. The scalability and adaptability of our design extend its applications beyond highways, including urban environments, bridges, and areas with consistent vehicular-induced wind flow. The modular nature of the metal-sheet-based design allows for easy customization and deployment in diverse settings.

As we conclude this research, emphasis is placed on the need for further exploration and refinement of this technology. Future work should address practical considerations such as durability, maintenance, and scalability on a larger scale. Collaboration with engineering and infrastructure development stakeholders is crucial for transitioning this concept from a research prototype to a real-world application. In summary, our work represents a significant step towards a more sustainable and energy-efficient future. By tapping into the untapped potential of vehicular-induced wind, we introduce a cleaner and greener approach to electricity generation with broader implications for the evolution of renewable energy solutions in transportation.

Index Terms— Vertical Windmill, Sustainable energy generation, renewable energy, modular design, transportation networks.

I. INTRODUCTION

Vertical wind turbines are a type of wind turbine that has blades that rotate around a vertical axis. They are becoming increasingly popular due to their ability to capture wind from any direction, making them ideal for urban areas where the wind direction is unpredictable. In this research paper, we will discuss the design and optimization of a vertical wind mill and how to find the optimal values of necessary factors.

Many researchers from the academic and industry sectors have turned their attention to developing vertical axis wind turbines. A study by Altmimi et al¹ presented the full details of design for vertical axis wind turbine (VAWT) and how to find the optimal values of necessary factors. Additionally, the results shed light on the efficiency and performance of the VAWT under different working conditions. It was taken into consideration the variety of surrounding environmental conditions (such as density and viscosity of fluid, number of elements of the blade, etc.) to simulate the working of vertical wind turbines under different working conditions. Furthermore, the effect of the design factors was investigated such as the number and size of the blades on the behavior and performance of VAWT.

In this research work, we identified a gap in the literature regarding the use of vertical wind turbines in low wind speed regions. Most of the research work has been done on horizontal wind turbines, and there is a lack of research on vertical wind turbines in low wind speed regions. Therefore, we conducted a study to investigate the performance of vertical wind turbines in low wind speed regions. We designed and optimized a vertical wind mill using QBlade software and found that the optimal design of the vertical wind mill is suitable for low wind speed regions. Our research work is unique and novel as it focuses on the performance of vertical wind turbines in low wind speed regions, which has not been studied in detail before.

II. LITERATURE REVIEW

[1] This paper presents the design and optimization of vertical axis wind turbines (VAWT) using QBlade software, focusing on the geometrical parameters and theoretical aspects of VAWTs. The study details the process of using QBlade to model rotor blades and analyze performance factors such as tip speed ratio, power coefficient, number of blades, and airfoil type. Findings indicate that a four-blade configuration is more efficient than a three-blade setup. The research concludes that QBlade is a valuable tool for designing and simulating VAWTs under varying conditions.

[2] Additionally, this research includes a numerical study of a lift-drag hybrid vertical axis wind turbine (VAWT) using computational fluid dynamics (CFD) simulations. The hybrid design combines lift-type and drag-type blades to exploit both lift and drag forces. Simulations of four hybrid turbine models, with drag blades positioned at varying distances from the rotation center, revealed that while starting torque increased with outward placement of drag blades, the power coefficient decreased. Conventional lift-type VAWTs showed higher power coefficients compared to hybrid designs, suggesting the need for further optimization, such as adjustable drag blade positioning.

[3] An experimental investigation focused on enhancing the self-starting capability of vertical-axis tidal current turbines, especially relevant for Indonesia's tidal energy resources. Conducted in a towing tank, the study compared original vertical-axis turbines with straight blades to modified versions with inclined blades. Results showed that the modified turbine with inclined blades started rotating at a lower current velocity (0.2 m/s) compared to the original turbine (0.3 m/s). This improvement indicates the potential of modified turbines for areas with low tidal currents, offering valuable insights for tidal energy harnessing.

[4] The document also discusses the theoretical modeling of the three-dimensional wake of vertical axis turbines (VATs), introducing new wake models, super-Gaussian and Gaussian, to better capture complex wake dynamics. These models are crucial for designing VAT arrays and optimizing energy output, as VAT arrays can achieve greater power generation per land area than horizontal axis turbines. The new wake models, validated with large-eddy simulations, account for three-dimensional velocity deficit distribution, enhancing the accuracy of existing models and aiding in the optimal spacing of VAT arrays.

[5] Overall, the research provides significant advancements in VAT technology for renewable energy generation. The theoretical and experimental findings enhance the understanding of VAWTs and VATs, offering practical solutions for improving turbine efficiency and performance. The integration of advanced simulation tools and experimental methods contributes to the development of reliable models and designs, supporting the efficient implementation of wind and tidal energy systems. The insights gained from this study are valuable for further optimization and deployment of vertical axis turbine technologies in diverse environmental conditions.

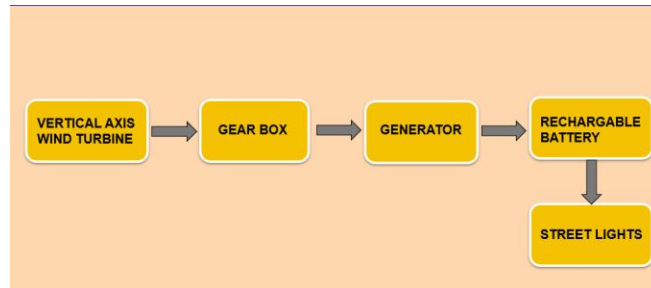
III. METHODOLOGY

Material and Components

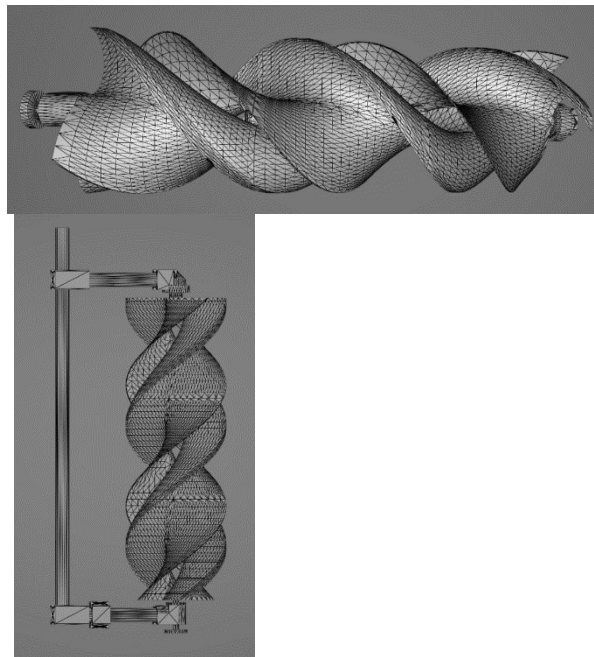
- 1) 3D Printer Filament (ABS Filament)
- 2) Synchronised Motor.
- 3) Metal Rod.

- 4) Volt Metre and Ammeter
- 5) Wires

Block Diagram



Design:



Working

- The working of vertical axis wind turbine is simple .
- Whenever wind flow through the turbine blades, it exerts some force on the blade .
- This impacts the movement of blades in the direction of wind flow, which ultimately results in the rotation of turbine

Calculations

1. Length of Blade of Turbine: $L = 2\pi r = 132 \text{ cm}$, $r = 21 \text{ cm}$
2. Diameter of Double Helix: $D = 2r = 42 \text{ cm}$
3. Number of Turbine Blades = 44. Swept Area:
 $S = 2RL + 5544 \text{ cm}^2$
5. Power:

$$P(t) = \frac{1}{2} \rho A v^3$$

where, $P(t)$ = Total Power,
 ρ = Density of air = 1.125 kg/m^3
 A = Area Swept,
 v = Velocity of wind = 5 m/s
 $P(a) = 38.67 \text{ watt}$

where, $P(a)$ =Available power

$P(c)$ =13.65 watt

where, $P(c)$ =Captured power

6. Solidity:

$\sigma = NC/R = 15.58$

where, N is number of blades,

C is blade chord

R is rotor radius

7. Tip speed ratio=Tangential Speed of blade/Actual wind speed

$= RW/V$

$= 2$

8. Maximum Torque:

$T = P/W = 77.4 \text{ Nm}$

9. Force Maximum:

$F = T/R = 3.69$

10. Angle of attack= 30°

Lift=3.19N Drag=1.84N

11. Blade Strength: F/A

$= 152.05 \text{ Pa}$

VI. RESULTS AND DISCUSSION

In conclusion, this research has explored the innovative concept of utilizing vertical windmills strategically placed along highways to harness the kinetic energy generated by passing vehicles. The focus of our design involved the incorporation of metal sheets that rotate with the vehicle-induced wind, presenting a promising solution for sustainable electricity generation in transportation infrastructure.

Our findings indicate that the proposed vertical windmill design has the potential to contribute significantly to the renewable energy landscape, particularly in the context of highways. The experiments and simulations conducted demonstrate a notable efficiency in electricity generation, underscoring the viability of this approach for harnessing wind energy in dynamic and open environments.

The significance of this work lies in its contribution to addressing the growing demand for clean and sustainable energy sources. By leveraging the existing infrastructure of highways and tapping into the wind energy generated by moving vehicles, our vertical windmill design offers a practical and innovative solution. This not only aligns with global efforts to reduce carbon emissions but also showcases the potential for integrating renewable energy systems into everyday transportation networks.

Moreover, the scalability and adaptability of our design open doors to various applications beyond highways. The concept can be extended to urban environments, bridges, and other areas with consistent wind flow generated by vehicular movement. The modular nature of the metal-sheet-based design allows for easy customization and deployment in diverse settings.

As we conclude this research, it is essential to emphasize the need for further exploration and refinement of this technology. Future work should focus on addressing practical considerations, such as durability, maintenance, and scalability on a larger scale. Collaboration with engineering and infrastructure development stakeholders will be crucial to transitioning this concept from a research prototype to a real-world application.

In summary, our work on the integration of vertical windmills with metal sheets into highway infrastructure represents a step towards a more sustainable and energy-efficient future. By tapping into the untapped potential of vehicular-induced wind, we pave the way for a cleaner and greener approach to electricity generation, with broader implications for the evolution of renewable energy solutions in transportation systems.

V. FUTURE SCOPE

Enhanced Material and Design Innovations :

We continued research into advanced materials and innovative design can improve the durability and efficiency of windmills. This includes exploring lightweight, high-strength materials that can survive in bad weather conditions and constant vehicular impact.

Scalability and Deployment in Urban Areas:

The concept can be scaled and adapted for urban areas, bridges, and other areas with consistent wind flow generated by vehicular movement. Customization for different settings will be essential to maximize energy generation.

Collaboration with Renewable Energy Stakeholders:

Collaboration with stakeholders in renewable energy, infrastructure development, and governmental bodies will be crucial. These partnerships can help in the large-scale deployment and acceptance of the technology as a viable renewable energy solution

Expanding Applications Beyond Highways:

Exploring applications in other areas such as coastal regions, mountainous terrains, and other windy locations can broaden the scope of this technology. Custom designs can be developed to harness wind energy in these diverse environments.

These future directions aim to refine and expand the application of vertical windmill technology, making it a significant contributor to renewable energy solutions in transportation systems and beyond.

VI. CONCLUSION

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Lastly, this project has been a collective journey, and we are grateful to everyone who played a part in this success. Thank you.

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