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Smart Energy Harvesting from Roadside Winds: Vertical Axis Wind Turbine with Solar Integration

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Abstract

This study deals with the design and fabrication of a Roadside Vertical Axis Wind Turbine (VAWT) to harness wind energy caused by passing vehicles in the urban centers. The design involves two different materials for blades manufacturing by using hand layup technique. Thermosetting epoxy was used for the fabrication of glass fiber reinforced polymer and carbon fiber reinforced polymer blades. Additionally, a solar panel was installed with the base of wind turbine at an angle of 45o. the VAWT was tested using different wind speeds near to a road. The wind speed was measured using a speedometer, and a motor-type generator coupled with bearings was employed to generate electricity in the form of current (amperes). The results showed that at a wind speed of 2.78 m/s, a power output of 0.5 W was produced using carbon fiber blades in combination with solar energy, while 0.3 W was generated using glass fiber blades. The maximum power outputs recorded were 7.5 W and 6.8 W for carbon fiber and glass fiber composite blades, respectively, at a wind speed of 11.11 m/s, producing 10.29% higher power. These findings demonstrate the potential to provide more consistent energy for various applications, such as powering streetlights, sensors, or microcontrollers along roadsides. The study concludes that well-designed and properly integrated small-scale VAWTs, combined with solar systems, can serve as a reliable and sustainable energy source for roadside applications.

Keywords: Vertical Axis Wind Turbine (VAWT), Hybrid Energy System, Glass Fiber Reinforced Polymer (GFRP), Sustainable Energy Solutions.

1. Introduction

The need for sustainable and renewable energy sources has increased globally due to the limitations posed by fossil fuels [1], increasing energy costs and environmental degradation. Among the various renewable energy technologies, wind energy has emerged as a promising option because it is clean, abundant and increasingly cost-effective [2,3]. However, traditional horizontal-axis wind turbines (HAWTs) are not ideal for dense urban settings where space is limited and wind flow is inconsistent. This problem calls for alternative designs that would be more efficient in utilizing low speed turbulent winds [4]. Vertical Axis Wind Turbines (VAWTs) are a viable alternative since they are compact, omnidirectional and easy to maintain compared to HAWTs [5,6]. Savonius-type VAWT has shown great potential in harvesting low-speed, multi-directional winds, such as those generated by passing vehicles [9-11]. Highways and city roads with heavy traffic have constant air flows due to the natural wind and passing vehicles. By harvesting the wind generated by speeding vehicles, we can harness this wasted kinetic energy to produce electrical power. Large Eddy Simulations were used by Rahai [12] to show that moving vehicles produce enough wake energy to power small-scale VAWTs, while Lee and Kim [17] verified that convective wind usage is feasible. In highway conditions, hybrid setups that include solar and wind systems have demonstrated increased dependability and efficiency [13], [16]. Through machine learning-based design enhancements and aerodynamic optimization, Su et al. [14] and Liu and James [15] significantly improved VAWT performance, assisting in the ongoing development of effective hybrid roadside turbines. The potential of vehicle-induced wind for roadside energy collecting has been investigated in numerous research studies but there is a still gap to investigate the performance of different composites blades for generating higher power. Therefore, the preset study is an effort to investigate the comparison of power generation using different composites blades with hybrid system. Table 1 presents the findings of previous research studies.

Table 1. Summary of Literature Review on VAWT

Researcher / Year	Focus / Contribution	Key Findings	Limitations / Gaps
Saha et al. (2008) [1]	Tested VAWT beside highways (vehicle-induced wind)	Generated 5 to 15W power from traffic wind	No hybrid or smart control; efficiency dependent on traffic
Rehman et al. (2012) [2]	Developed hybrid wind–solar system	Continuous energy generation day & night	No real-time data monitoring or compact design
Paraschivoiu (2002) [3]	Studied aerodynamic performance of Savonius-type VAWT	Worked well in low and turbulent winds	Used metallic blades, heavy and inefficient
Islam et al. (2013) [4]	Compared Darrieus vs. Savonius turbines	Savonius performs better at low speeds and self-starts easily	Lower Cp than Darrieus
Altan et al. (2008) [5]	Introduced helical (twisted) Savonius design	Improved torque, smoother rotation, Cp = 0.32	Aluminum blades increased cost and weight

The present study is about the design and fabrication of a Roadside Vertical Axis Wind turbine integrated with a solar panel. Two types of composite blades were developed, namely Glass Fiber Reinforced Polymer (GFRP) and Carbon Fiber Reinforced Polymer (CFRP), by employing the hand layup technique. The hybrid system was intended to increase reliability by supplementing wind power with solar energy to ensure sufficient and continuous power output for low-power applications such as streetlights, traffic sensors and microcontrollers. The integration of small-scale roadside VAWTs with solar systems provides a sustainable, cost-effective, and reliable energy solution for urban environments, as demonstrated by the theoretical, computational, and experimental results taken together.

2 Materials and Methods

2.1 Design and Fabrication

Carbon and glass fiber using thermosetting and thermoplastics epoxy was used to develop the blades of VAWT and purchased from Tei Composites, Taiwan. The Longi Solar Panels of 30 Watt was used for hybrid system. Ball bearing, gear drive, 24V shaft, battery, and DC dynamo were also used as main components for the fabrication of VAWT. The blades were manufactured using the hand lay-up technique with Glass Fiber Reinforced Polymer (GFRP) and Carbon Fiber Reinforced Polymer (CFRP) composites bonded with epoxy resin. The assembly included a central shaft, hub, and bearings mounted on a steel frame for structural stability. The specifications of components of the Roadside VAWT are given in table.2.

Table 2: Specifications of components of the Roadside VAWT

Parameters	Values
Blade Height	152.4 cm
Blade Radius	76.2 cm
Height of Wind Turbine	198.12 cm
Dimensions of Solar Pannel	45.72 cm x 30.48 cm
Materials of Blades	Glass Fiber and Carbon fiber
Diameter of Bearings	6 cm
Speed of Generator	120 rpm
Solar Panel Power	30 Watt

Initial estimates of the height of the blades, rotor diameter, rotor swept area, and estimated wind velocities along the roadside perfected the rotor design. The final design had its rotor radius of 76.2 cm and its swept area of approximately 1.83 m^2 and height of the blades is 152.4 cm. To create the necessary blade geometry, a semi-cylindrical mold was first created using a release agent. Fiber mats were then placed one after the other, and resin was applied. Following 24 to 36 hour curing period in a controlled ambient environment to increase strength, the blades underwent surface polishing. To ensure uniformity for comparing performance, CFRP and GFRP blades were both made using the same process. Figure 1 represents the manufacturing of different composites blades.

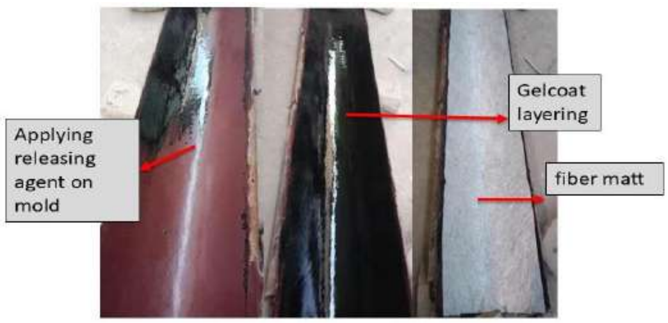


Figure 01: Blade Manufacturing

To reduce the frictional loss, the prepared blades were fixed in the middle rotor shaft that was supported by ball bearings. It was a direct-drive system, and the shaft was attached to a generator. The iron frame used reduced vibrations and provided structural rigidity in the process. Figure 02 represents the final assembly of VAWT.

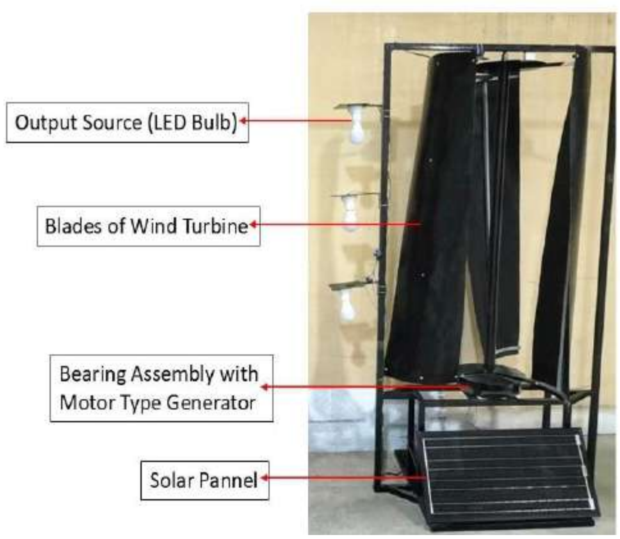


Figure 02: Road Side Vertical Axis Wind Turbine (VAWT)

2.2 Principle of Working

Vehicle induced wind strikes on the blades and the rotor self-starts around 2.78 m/s and spins smoothly in multi directional winds. The rotor shaft directly drives a 3-phase permanent magnet generator. A 3-phase bridge rectifier converts the generator's AC to DC. The charge controller takes DC from both sources (wind and 30 W solar panel), prioritizes what's available, and charges the 12 V, 5 Ah battery using safe stages. The load is powered from the controller's load output. An ESP microcontroller reads DC voltage, RPM and shows live data on the LCD. Low friction bearings and a rigid iron frame reduce losses. Figure 3 presents the working principle of VAWT.

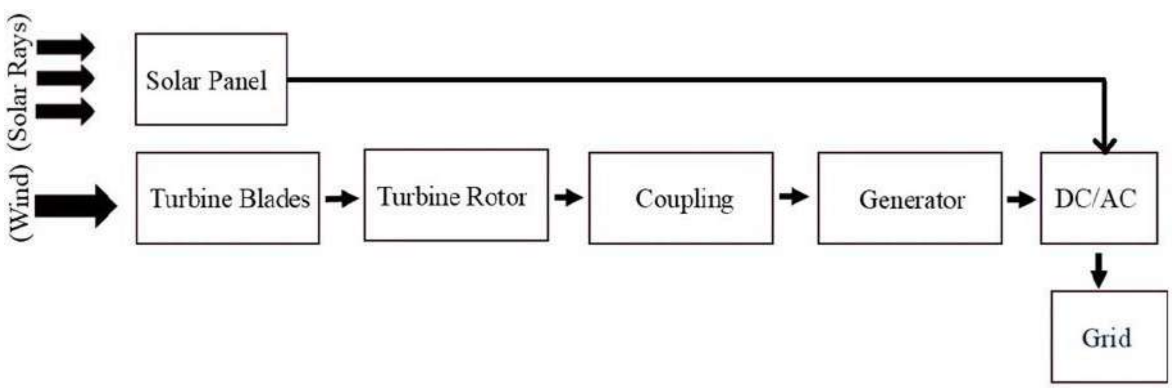
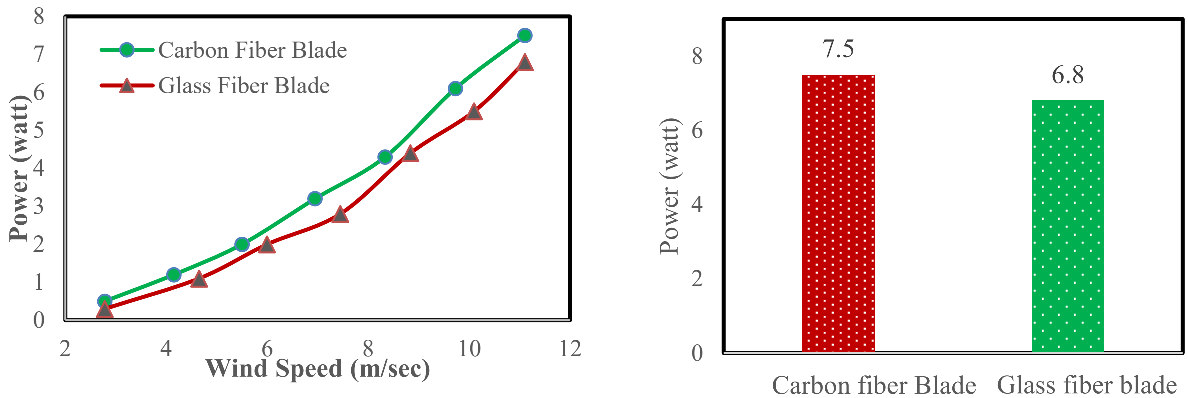


Figure 03: VAWT Working Principle

3 Results and Discussion

The propose of the study is to investigate the power generation of VAWT using different composites blades and solar panel along the side of a traffic road. The experimental roadside testing was used to evaluate the performance of VAWT and it was found that the carbon fiber blades performed better than glass fiber blades. The results revealed that at a wind speed of 2.78 m/s, a power output of 0.5 W and 0.3 W was generated using carbon and glass fiber blades, respectively. The maximum power outputs recorded were 7.5 W and 6.8 W for carbon fiber and glass fiber composite blades, respectively, at a wind speed of 11.11 m/s. Overall, the carbon fiber blades generated 10.29% higher power compared to glass fiber at same velocity. Figure 4 (a) and (b) represents the relationship between power generated and wind speed.



(a) **(b)**

Figure 4: (a) Relationship between power produced and wind speed (b) Comparison of Power generation using Carbon and Glass fiber blades

The RPM of carbon and glass fiber at wind speed 2.78 m/sec was recorded 17 and 12 respectively. At maximum velocity of 11.11 m/sec, the carbon fiber blades had a revolution of 120, while the glass fiber blade had a revolution of 112. Carbon fiber blade rpm was 7.14% higher than glass fibers. The relationship between RPM of the blades and Wind Speed is shown in figure .5.

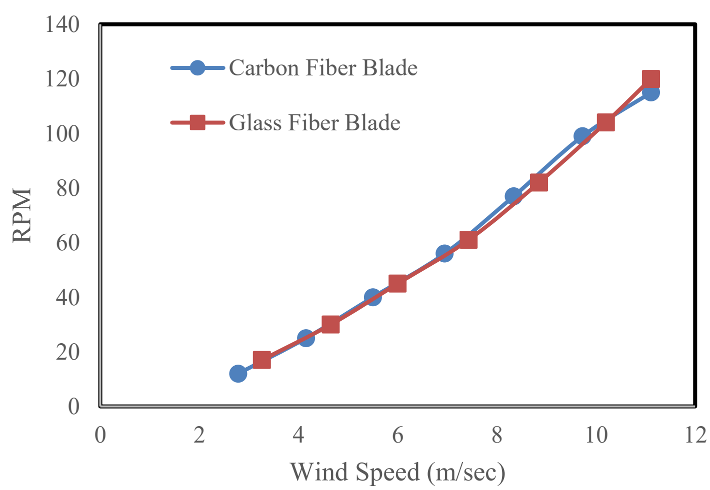


Figure 05: Relationship between RPM and Wind Speed (m/sec)

4 Conclusion

This study successfully demonstrated the design, fabrication, and performance evaluation of a roadside Vertical Axis Wind Turbine (VAWT) integrated with a solar panel to form a hybrid renewable energy system. The rising demand of the decentralized, sustainable and cost-effective energy solutions in urban areas. VAWT was manufactured with the help of composite blades were made of glass fiber reinforced polymer and carbon fiber reinforced polymer, in order to provide aerodynamically optimized, light, and strong performance. The findings revealed at a wind speed of 11.11 m/s, a power output of 7.5 W and 6.8 W was generated using carbon and glass fiber blades, respectively. Carbon fiber blades generated 10.29% higher power compared to glass fiber at same velocity and 7.14% higher RPM as well compared to glass fibers. It also led to the smoother surface, which enhanced the overall conversion efficiency of the energy by lowering the number of drag losses, and increasing the balance in the RPM. The hybrid wind solar system is an effort to overcome the problem associated with the LED in the streets lights.

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