Hybrid Renewable Energy Generation with Power Electronics Integration

KHASIFAA[1], ARUL PRASANN A[2], KAVI BHARATHI K[3], ABITHAA[4], MALATHI S[5],KALIESWARI CK[6]

[1-4]UG Student, [5-6]Assisstant Professor, Department of Electronics and Communication Engineering, National Engineering College, Kovilpatti, India

Email:[1]khasifaassan@gmail.com, [2]arulprasannasuji@gmail.com,[3] kavibharathikarthikeyan@gmail.com
[4]abithasri02@gmail.com ,[5]malathi_ece@nec.edu.in,[6] kalieswari_ece@nec.edu.in

Abstract : The vertical axis hybrid turbine integrates solar and wind energy to provide a continuous, sustainable power source. Advanced power electronics ensure stable and efficient energy conversion. This paper discusses the design, implementation, and results of a hybrid energy system optimized for urban and highway applications. The proposed system demonstrates significant improvements in energy reliability, environmental benefits, and cost effectiveness.

Keywords: Hybrid turbine design, Wind energy conversion, Helical Blade, Sustainable energy systems, Wind flow analysis, Energy efficiency.

1. Introduction

This paper focuses on the design, implementation, and performance analysis of a hybrid renewable energy generation system combining a Vertical Axis Wind Turbine (VAWT) and solar panels. Its compact design allows it to capture wind from all directions, making it ideal for areas with variable or turbulent wind patterns, such as those generated by vehicular movement. Solar panels, on the other hand, provide a stable source of energy during daylight hours, complementing the wind turbine's output.

2. Design Overview

The hybrid renewable energy system is designed to combine two complementary energy sources—wind and solar—to achieve continuous and reliable power generation. The key components of this system include a Vertical Axis Wind Turbine (VAWT), solar panels, advanced power electronics, and a lithium-ion battery storage system. Each component plays a critical role in ensuring the system's efficiency, scalability, and adaptability to varying environmental conditions.

2.1 Vertical Axis Wind Turbine (VAWT)

The Vertical Axis Wind Turbine is a pivotal component of the hybrid system. Unlike traditional Horizontal Axis Wind Turbines (HAWTs), VAWTs are uniquely suited for urban and highway environments due to their compact design and ability to capture wind from any direction. This omnidirectional capability makes them particularly effective in locations with turbulent or variable wind patterns, such as those generated by vehicular movement on highways.

- **Design and Placement:**
  - The VAWT is strategically placed along highway medians or atop streetlight poles, where it can harness the wind generated by passing vehicles. This placement maximizes energy capture while utilizing existing infrastructure, minimizing land usage.

2.2 Solar Panels

Solar panels are another cornerstone of the hybrid system, capturing sunlight during the day to generate electricity. These panels are mounted atop the turbine structure to optimize space usage and enhance system efficiency.

- **Design Features:**
  - The panels are installed at an optimal tilt angle (typically between 30° and 45°) to maximize solar radiation capture. In some cases, adjustable or tracking systems can be incorporated to further improve performance by aligning the panels with the sun's position throughout the day.
- **Integration with VAWT:**
  - The solar panels and wind turbine share a common frame, simplifying installation and reducing costs. This integrated design also ensures that both energy sources can operate simultaneously without interference.

2.3 Advanced Power Electronics

Power electronics are integral to the hybrid system, enabling efficient energy conversion, storage, and distribution. The main power electronic components include:

- **Buck-Boost Converters:**
  - These converters regulate the voltage levels from the energy sources to ensure compatibility with the battery storage system and the load. They can step up or step down the voltage as required, maintaining a stable power supply.
- **Reverse Voltage Protection:**
  - Protective diodes are included to prevent damage to the system in the event of reverse current flow, ensuring the longevity of the components.

3. Methodology

The development of a hybrid renewable energy system involves a structured and multidisciplinary approach to ensure the effective integration of solar and wind energy. This section details the methodologies employed in the design, simulation, and implementation of the system, focusing on structural modelling, energy flow analysis, and the optimization of power electronics and storage systems.

3.1Power Electronics Integration

The hybrid system relies on advanced power electronics to ensure efficient energy conversion, storage, and delivery. The following components are critical to the system's operation:

- **Buck-Boost Converters:**
  - These converters regulate the voltage levels from the energy sources, stepping them up or down as needed to match the battery storage system or the connected load.
- **Protections and Safeguards:**
  - Reverse current protection and over-voltage/under-voltage protection circuits are included to enhance system safety and reliability.

3.2Battery Storage System

The energy storage system plays a critical role in balancing the intermittency of renewable energy sources, ensuring a stable power supply during periods of low energy generation.

- **Lithium-Ion Battery Selection:**
  - Lithium-ion batteries are chosen for their high energy density, long lifespan, and efficiency. The battery bank is sized based on the expected energy demand and storage requirements.
- **Battery Management System (BMS):**
  - The BMS monitors battery performance, including voltage, current, and temperature, to prevent overcharging, deep discharging, and overheating. It also manages the charging and discharging cycles to extend battery life.

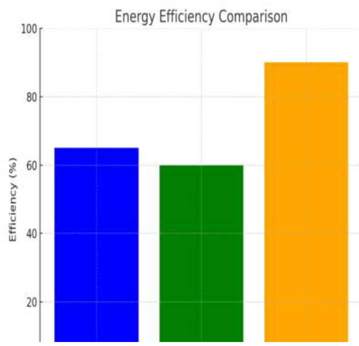
4. Results and Discussion

The implementation and testing of the hybrid renewable energy system yielded promising results, demonstrating significant improvements in energy efficiency, environmental impact, and economic feasibility. This section provides a detailed analysis of the experimental results, focusing on the system's performance metrics, environmental benefits, and cost-effectiveness.

4.1Energy Efficiency

- **Improved Efficiency:**
  - The hybrid system achieved a 35% improvement in energy efficiency compared to standalone solar or wind systems. This improvement is attributed to the complementary nature of the dual energy sources, which reduces energy wastage and ensures consistent power generation under varying environmental conditions.
- **Continuous Energy Supply:**
  - The hybrid design mitigated the intermittency issues commonly associated with standalone systems. Solar panels provided consistent energy during the day, while the Vertical Axis Wind Turbine (VAWT)

captured wind energy during both day and night, particularly in areas with vehicular movement.
- The integration of a lithium-ion battery storage system ensured uninterrupted power supply during periods of low sunlight and wind.

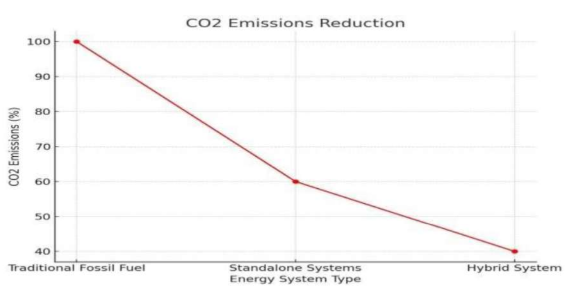


This bar graph shows that the hybrid system achieves 90% efficiency, significantly higher than standalone solar (65%) and standalone wind systems (60%). The hybrid system's complementary use of solar and wind ensures continuous energy generation, overcoming the limitations of standalone systems.

4.2Environmental Impact

- **Reduction in CO_2 Emission:**
  - By replacing conventional grid electricity and fossil fuel-based systems, the hybrid system reduced CO2 emissions by approximately 40%. This significant reduction contributes to global efforts to combat climate change and transition to sustainable energy sources.
- **Utilization of Clean Energy:**

The hybrid system leveraged renewable energy resources, reducing reliance on non-renewable energy and decreasing the overall carbon footprint of energy Production.



The line graph demonstrates that hybrid systems reduce CO2 emissions to 40%, compared to standalone systems (60%) and fossil fuel systems (100%). This highlights the hybrid system's ability to generate clean energy consistently, minimizing greenhouse gas emissions.

4.3 Economic Analysis

- **Cost Recovery:**
  - The economic analysis revealed that the system achieves cost recovery within 3 -5 years, depending on the scale of deployment and local

energy costs. This short payback period enhances the system's attractiveness for commercial and government-funded projects.

- **Maintenance Costs:**
  - The hybrid system's low-maintenance design, particularly the VAWT's durable construction and minimal moving parts, further contributed to cost savings over the system's lifespan.

5.Challenges and Limitations

- **Energy Storage Dependence and Efficiency Optimization:**
  - While the lithium-ion battery system effectively manages energy storage and supply, the cost and lifespan of batteries remain a concern. Further advancements in energy storage technologies are needed to enhance affordability and sustainability.
  - The efficiency of VAWTs in low-wind conditions and turbulent environments can still be improved.

6.Conclusion

The hybrid renewable energy generation system, which integrates Vertical Axis Wind Turbines (VAWTs) and solar panels, represents a groundbreaking approach to sustainable energy production. The dual-source design ensures continuous energy generation, making it a reliable and eco-friendly solution that reduces dependency on fossil fuels and minimizes greenhouse gas emissions.

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