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Research Article

A HYBRID MICROGRID USING A NODEMCU MICROCONTROLLER

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S. Prakash*, T. Divya, J. Raji

Abstract:

Backgorund of study: Access to reliable electricity remains a major issue in remote, hilly, and island areas where conventional power infrastructure is lacking. These communities often face limited energy options, hindering development and quality of life. Renewable energy, particularly when harnessed in hybrid systems, presents an opportunity for sustainable and decentralized solutions.

Aims and scope of paper: This study develops a solar-wind hybrid system with battery storage to deliver clean, reliable power to off-grid areas, focusing on design, conversion, optimization, and real-time monitoring.

Methods: The system combines solar and wind energy, stabilizes output with boost-buck converters, converts DC to AC via an inverter, uses ESP32 NodeMCU for real-time monitoring through Blynk, and applies MPPT to maximize energy efficiency.

Result: The system successfully delivers a stable power supply in off-grid settings by improving energy harvesting efficiency through the MPPT algorithm. Real-time monitoring enhances user interaction and system management. The combination of solar and wind energy supported by battery storage ensures a continuous and dependable power flow.

Conclusion : The study confirms that the hybrid microgrid system developed is an efficient, scalable, and environmentally sustainable solution for communities with limited electricity access. It also demonstrates the potential of such technologies to reduce reliance on fossil fuels while promoting clean energy adoption in underserved areas.

Keywords: Electric Bicycle; GPS Location; IOT Security; Microgrid; Nodemcu Microcontroller

1. INTRODUCTION

The Access to reliable electricity remains a significant challenge in many rural, hilly, and island regions where traditional power infrastructure is either unavailable or difficult to implement. These limitations negatively affect essential services like education, healthcare, communication, and economic development. To solve this issue, we've developed a hybrid renewable energy system that integrates solar and wind power with battery storage. This setup is designed to deliver a clean, consistent, and cost-effective power supply for off-grid and remote communities.

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The system uses solar panels (20V, 2A) and a compact wind turbine (3 feet in diameter, 4V, 4A) as the primary sources of renewable energy

Because the output from these sources can vary, a DC-DC boost converter is used to increase the wind turbine's voltage to 13.1–13.5V DC, while a buck converter regulates the solar panel's voltage to a stable 13.5V DC.

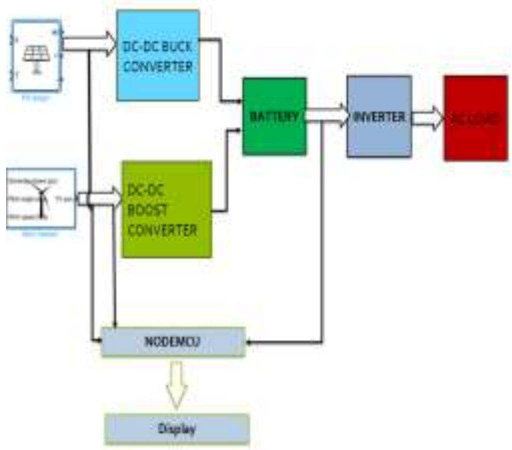

Figure 1. Block Diagram

Energy is stored in two 12V, 14Ah batteries connected in parallel. An inverter converts the stored DC energy into 220–240V AC, making it compatible with household appliances and commercial equipment.

To ensure optimal energy harvesting, MPPT (Maximum Power Point Tracking) is implemented for both solar and wind sources. A NodeMCU (ESP32) microcontroller continuously monitors voltage, current, battery level, and power usage. This real-time data is displayed on an LCD and transmitted to the Blynk App via Wi-Fi, allowing remote monitoring and control. This smart, scalable, and sustainable system offers a practical solution for delivering clean energy to underserved areas and plays a key role in promoting energy independence and environmental responsibility (Rokach & Maimon, 2005)

As PV adoption grows, grid congestion becomes a concern, particularly in areas with high PV penetration. Preventing overloading and maintaining stable operation require strategic upgrades to grid infrastructure and thoughtful system planning (Narang et al., 2023). Government policies and regulatory frameworks significantly influence PV grid integration. Clear technical standards, investments in grid modernization, and incentives for energy storage adoption are critical to supporting solar energy expansion. PV grid integration is a multifaceted process that demands innovation, policy support, and comprehensive planning.

2. MATERIAL AND METHODS

Several studies have explored different approaches to e-bike security. Simulation is a vital tool in both industry and academic research, especially for renewable energy systems. It helps engineers design, analyze, and optimize systems without risking hardware damage. In power electronics, simulations complement hardware by modeling system behavior under various conditions. The simulation of a hybrid solar-wind energy system using MATLAB, focusing on power flow, voltage regulation, and energy storage. Key components such as PV arrays, wind turbines, converters, batteries, and inverters are modeled. MPPT algorithms are applied to enhance energy extraction. The simulation results offer insights into the system's efficiency, reliability, and suitability for real-world applications (Kim et al., 2019).

The implementation of the hybrid solar-wind microgrid system was carried out systematically to ensure efficient energy generation, storage, and utilization. The system integrates solar and wind power sources, regulates their outputs, stores energy in a battery, and converts it into usable AC power for electrical loads. The following steps explain the detailed execution of the project.

2.1 SYSTEM ARCHITECTURE

The hybrid solar-wind microgrid system is designed to generate, store, and deliver clean energy efficiently. It combines a 20V, 2A solar panel and a 4V, 4A wind turbine with a Permanent Magnet Generator (PMG), converting renewable sources into DC power. Since the wind output is too low for direct battery charging, a boost converter steps it up to a constant 13.5V. The solar panel's higher voltage is regulated using a buck converter, ensuring both sources provide a stable 13.5V DC for charging two 12V, 7Ah batteries connected in parallel. These batteries store energy for use when generation is low, maintaining system continuity (Rami Reddy et al., 2022).

The stored DC power is then converted into 220V–240V AC using an inverter sourced from a UPS system, allowing the energy to power household or industrial loads. System performance is monitored using voltage and current sensors, with data processed by an ESP32 NodeMCU microcontroller. This IoT-enabled system is ideal for remote and off-grid applications, offering a scalable, smart solution for renewable energy management (Heidari et al., 2013).

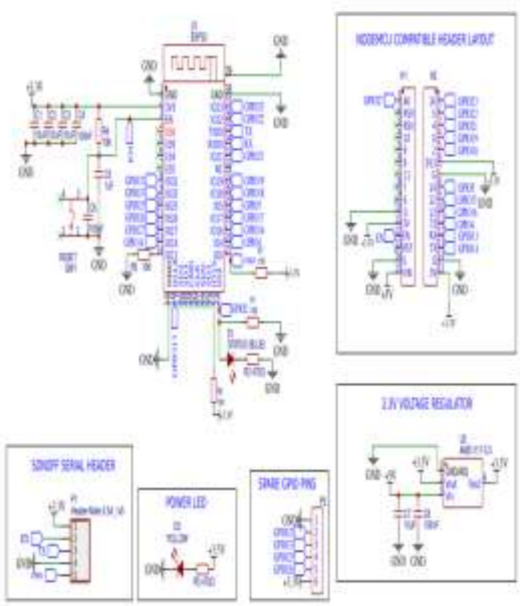

Figure 2. Circuit Diagram

The circuit diagram shows an ESP32 microcontroller setup with a 3.3V regulated power supply, GPIO pin headers, and supporting components. It includes a NodeMCU-compatible header layout for easy interfacing. The ESP32 is powered through a 3.3V voltage regulator (AMS1117-3.3), connected to capacitors for stability. Additional features include reset and power LEDs, a Sonoff serial header for communication, and spare GPIO pin access. Status indication is provided through a blue LED. The layout supports development and debugging of embedded systems, particularly for IoT and automation projects, offering stable voltage, easy pin access, and reliable communication interfaces with peripheral devices.

2.2 WORKING MECHANISM

The hybrid solar-wind microgrid system was systematically implemented to ensure reliable energy generation, regulation, storage, and supply. A 20V, 2A solar panel and a 4V, 4A wind turbine with a Permanent Magnet Generator (PMG) served as the primary energy sources. Since both sources produce fluctuating DC outputs, voltage regulation was achieved using DC-DC converters: a boost converter for the wind turbine and a buck converter for the solar panel, maintaining a constant 13.5V DC for battery charging. Two 12V, 7Ah lead-acid batteries connected in parallel provided energy storage. A DC-AC inverter converted 12V DC into 220V-240V AC, powering standard loads like an AC bulb. Voltage and current sensors ensured real-time monitoring, and the ESP32 NodeMCU microcontroller processed the data, displaying it on an LCD screen and transmitting it wirelessly to the Blynk App. This IoT-enabled setup ensured remote monitoring, system efficiency, and energy availability, making it ideal for off-grid and remote applications.

2.3 ADVANTAGES OF THE PROPOSED SYSTEM

Reliable Power Supply: Provides continuous electricity even in remote or off-grid locations where conventional infrastructure is unavailable. Hybrid Efficiency: Combines solar and wind energy to ensure power generation in diverse weather conditions—solar during the day and wind at night or cloudy times. Voltage Regulation: Uses buck and boost converters for stable 13.5V DC output, enhancing power quality and protecting system components. Battery Backup: Stores energy in a battery bank for uninterrupted supply during low generation periods. AC Conversion:Converts stored DC power to 220V–240V AC using an inverter for household and commercial use. Smart Monitoring: ESP32/NodeMCU with Wi-Fi enables real-time monitoring via LCD and the Blynk App. Scalable and Modular: System design allows easy expansion with more panels, turbines, or batteries based on demand. Cost-Effective: Replaces expensive controllers like DSPACE DS1104 with affordable microcontrollers like ESP32. Eco-Friendly: Reduces carbon emissions by utilizing renewable energy sources. Educational and Practical: Ideal for research, education, and real-world implementation in rural development projects.

3. RESULT AND DISCUSSION

Result :

Microcontrollers like ESP32 and NodeMCU are crucial in smart renewable energy systems for real-time monitoring, control, and automation. The ESP32, with its dual-core processor, Wi-Fi, and Bluetooth capabilities, supports advanced functions such as MPPT, cloud-based data logging, and remote access via platforms like Blynk and Firebase. NodeMCU offers a cost-effective solution for basic data collection and monitoring. Both microcontrollers ensure efficient power distribution, safety through fault detection, and integration with DC-DC converters. Their use enhances reliability, reduces energy waste, and allows users to track performance remotely, making them ideal for off-grid and hybrid solar-wind applications in rural or remote areas (Lidula & Rajapakse, 2012)

The control board, as shown in Figure 3, displays the physical implementation of the hybrid microgrid system. This includes the DC-DC buck converter, DC-DC boost converter, voltage and current sensors, lead-acid batteries, inverter, transformer, and the AC load. Real-time data monitoring is achieved through the Blynk app, depicted in Figure 4. The app displays key parameters for the solar panel (12.4V, 0.1A, 0.9W), wind mill (3.1V, 0A, 0.1W), and battery (11.1V, 13.2A, 145.7W).

The hybrid simulation model, presented in Figure 5 , integrates the windmill source with a boost converter and the solar panel source with a buck converter, feeding into the battery and ultimately to the load. The results of this simulation model are shown in Figure 6.

Discussion :

Access to reliable electricity remains a significant challenge in remote, hilly, and island areas lacking conventional infrastructure, which negatively impacts essential services and economic development. To address this, the study developed a hybrid renewable energy system integrating solar and wind power with battery storage to provide sustainable electricity for off-grid communities. This system is designed to deliver a clean, consistent, and cost-effective power supply.

The system utilizes solar panels (20V, 2A) and a compact wind turbine (3 feet in diameter, 4V, 4A) as primary energy sources. Due to the fluctuating output from these sources, a DC-DC boost converter is employed to increase the wind turbine's voltage to 13.1–13.5V DC, while a buck converter regulates the solar panel's voltage to a stable 13.5V DC. This voltage regulation is crucial for stabilizing the output and protecting system components. Energy is stored in two 12V, 14Ah batteries connected in parallel , or two 12V, 7Ah batteries connected in parallel , ensuring an uninterrupted supply during periods of low generation. An inverter converts the stored DC power into 220–240V AC, making it compatible with household appliances and commercial equipment.

To optimize energy harvesting, the Maximum Power Point Tracking (MPPT) algorithm is implemented for both solar and wind sources. An ESP32 NodeMCU microcontroller continuously monitors voltage, current, battery level, and power usage. This real-time data is displayed on an LCD and transmitted to the Blynk App via Wi-Fi, allowing remote monitoring and control. This IoT-enabled setup makes the system ideal for remote and off-grid applications.

The proposed system offers several advantages, including providing a reliable power supply even in remote locations , hybrid efficiency by combining solar and wind energy for diverse weather conditions , and smart monitoring capabilities. It is scalable and modular, allowing for easy expansion with more panels, turbines, or batteries. Furthermore, it is cost-effective by replacing expensive controllers with affordable microcontrollers like ESP32 , eco-friendly by reducing carbon emissions , and has educational and practical value for research and rural development projects.

The study's results confirm that this system can provide a stable power supply by optimizing energy harvesting through the MPPT algorithm. The implementation has been proven to improve the energy efficiency and reliability of renewable electricity resources. This developed hybrid microgrid system provides an efficient and environmentally friendly solution for communities with limited access to electricity. With an expandable scale, these technologies have the potential to support energy sustainability and reduce reliance on fossil fuels. The system includes overvoltage and undervoltage protection, enhancing safety and reliability, and its scalability offers a sustainable energy solution with continuous power and proactive maintenance through IoT integration.

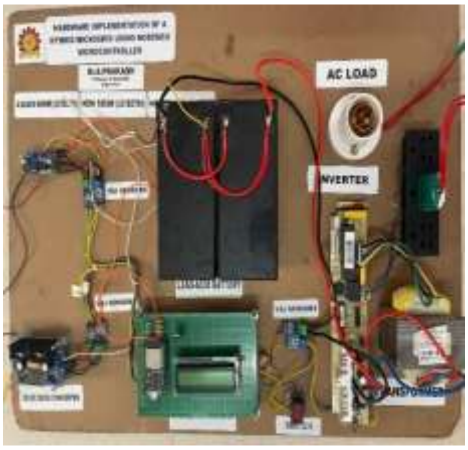

Figure 3. Control Board

Figure 4. Blink App Monitoring

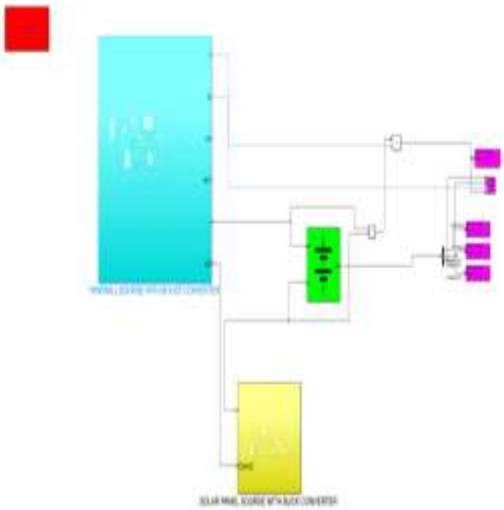

Figure 5. Hybrid Simulation Model

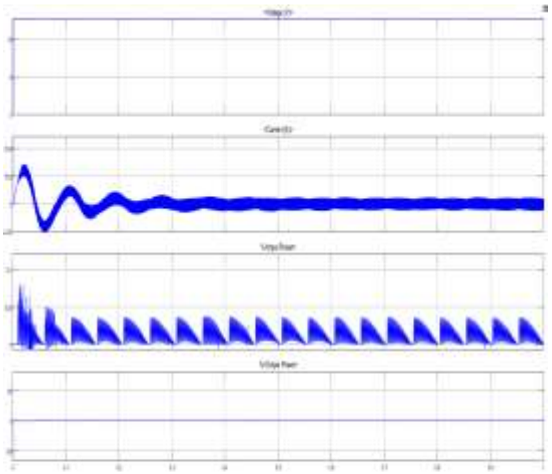

Figure 6. Result of Hybrid Simulation Model

4 CONCLUSION

The hybrid renewable energy system combines solar and wind power to provide reliable, cost-effective electricity for off-grid areas like islands and rural regions. Solar panels generate power during the day, while wind turbines operate at night or in low sunlight. DC-DC converters regulate voltage, ensuring a stable 13.5V DC output for efficient battery charging. An ESP32 microcontroller enables real-time monitoring via the Blynk IoT app, collecting data from voltage and current sensors. The system includes overvoltage and undervoltage protection, enhancing safety and reliability. Scalable and adaptable, it offers a sustainable energy solution with continuous power and proactive maintenance through IoT integration.

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6. AUTHOR CONTRIBUTION STATEMENT

All the authors involved in this study S. Prakash, T. Divya, and J. Raji contributed significantly to the development of the concept, system design, data analysis, and article writing and editing. The authors worked together to ensure that this study provides an innovative solution for hybrid microgrid systems that combine solar and wind power with battery storage. In addition, the author is also active in simulation and testing of systems to improve the efficiency and reliability of renewable energy for people who need sustainable access to electricity.

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