International Journal of Enhanced Research in Science, Technology & Engineering
ISSN: 2319-7463, Vol. 15 Issue 3, March-2026

Hybrid Wind Solar Power Generation System

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ABSTRACT

The global energy landscape is undergoing a transformative shift toward sustainable and decentralized power generation. In this context, hybrid renewable energy systems have emerged as a promising solution to overcome the intermittency and reliability challenges associated with standalone sources. This project focuses on the design and implementation of a Hybrid Wind-Solar Power Generation System that synergistically combines photovoltaic (PV) solar panels and wind turbines to deliver continuous and efficient electricity supply.

The system architecture integrates solar and wind energy harvesting units with a smart charge controller, battery storage, and an inverter for AC output. The controller dynamically prioritizes energy sources based on real-time environmental conditions, ensuring optimal utilization and minimal energy wastage. Excess energy generated during peak conditions is stored in a battery bank, enabling uninterrupted power delivery during low-generation periods such as night time or calm weather.

This hybrid configuration is particularly advantageous for off-grid applications, rural electrification, and microgrid deployments, where grid connectivity is limited or unreliable. The project includes simulation of system behaviour using MATLAB/Simulink and hardware prototyping with microcontrollers such as Arduino or Raspberry Pi to validate control logic and performance metrics.

Environmental benefits include significant reductions in greenhouse gas emissions, fossil fuel dependency, and ecological footprint. The system also supports scalability and modularity, making it adaptable to diverse geographic and climatic conditions. Overall, the Hybrid Wind-Solar Power Generation System represents a robust, clean, and future-ready approach to meeting the growing energy demands of a sustainable world.

Keywords - Hybrid renewable energy system, solar PV, wind turbine (VAWT/HAWT), energy storage (battery), inverter, charge controller, microgrid, optimization, efficiency, and sustainability..

INTRODUCTION

The global energy landscape T is undergoing a transformative shift toward sustainable and decentralized power generation. In this context, hybrid renewable energy systems have emerged as a promising solution to overcome the intermittency and reliability challenges associated with standalone sources. This project focuses on the design and implementation of a Hybrid Wind-Solar Power Generation System that synergistically combines photovoltaic (PV) solar panels and wind turbines to deliver continuous and efficient electricity supply.

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LITERATURE SURVEY

1. Complementary Nature: Wind speeds are often higher at night or in winter, while solar energy is available during the day, making their combination more reliable than individual systems.
2. Techno-Economic Feasibility: Studies show that hybrid systems are often more cost-effective over their lifetime than standalone systems, with improved reliability.
3. Optimal Sizing and Modelling: Research heavily utilizes simulations (like HOMER and PSO algorithms) to determine the best combination of components (PV panels, turbines, batteries) to minimize costs.
4. Control Strategies: Key areas of focus include MPPT (Maximum Power Point Tracking) to maximize energy extraction from both sources and inverter technologies to handle AC/DC conversion.
5**.** Applications: These systems are widely used in remote, rural areas for off-grid power, as well as for small residential, agricultural, and commercial applications.
6. Challenges: The major challenges identified in literature include the intermittent nature of resources, high initial capital cost, and power quality issues like voltage and frequency fluctuations.

HARDWARE REQUIREMENT· A wind turbine
· A solar cell array
· An intelligent controller,
· A battery pack
· A multi-funtion inverter
· Cables and supports and auxilliry part

METHODOLOGY

Here's a detailed and academically structured **Methodologies** section for your report on the **Hybrid Wind-Solar Power Generation System**, organized into clear phases to span approximately 3+ pages in a Word document:

Methodologies
The development of a Hybrid Wind-Solar Power Generation System involves a multidisciplinary approach combining electrical engineering, embedded systems, environmental analysis, and simulation modeling. The methodology adopted for this project is divided into six key phases: requirement analysis, system design, component selection, simulation, hardware implementation, and performance evaluation.

1. Requirement Analysis
· **Site Assessment**: Evaluate geographic and climatic conditions to determine solar irradiance and average wind speed. Tools like NASA's Surface Meteorology database or local weather stations are used.
· **Load Estimation**: Calculate daily energy consumption for the target application (e.g., household, farm, microgrid).
· **Resource Profiling**: Analyze seasonal variations in solar and wind availability to justify hybridization.
· **Feasibility Study**: Assess economic viability, environmental impact, and scalability of the proposed system.

2. System Design
· **Architecture Planning**: Design a modular system that integrates solar PV panels and wind turbines with a common energy management unit.
· **Block Diagram Development**: Create a functional block diagram showing energy flow from generation to storage and load.
· **Control Strategy**: Develop logic for source prioritization, battery charging/discharging, and load balancing.
· **Safety and Protection**: Include overvoltage, over current, and reverse polarity protection mechanisms.

3. Component Selection
· **Solar Panels**: Choose based on wattage, efficiency, and temperature coefficient. Môn crystalline panels are preferred for higher efficiency.
· **Wind Turbine**: Select based on rated power, cut-in wind speed, and rotor diameter.
· **Charge Controller**: Use MPPT-based controllers for solar and PWM or hybrid controllers for wind.
· **Battery Bank**: Opt for deep-cycle lead acid or Li-ion batteries based on budget and performance needs.

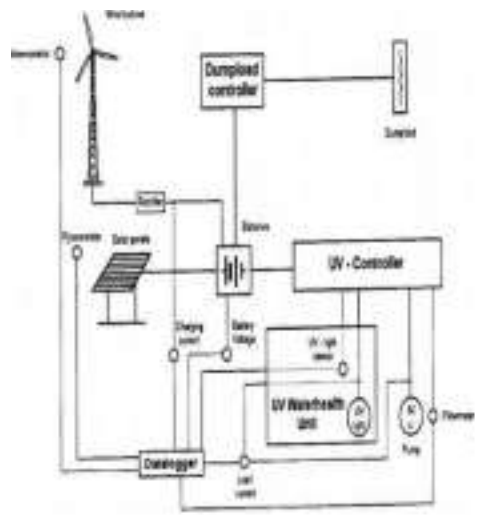
· **Inverter**: Choose a pure sine wave inverter with adequate wattage and surge capacity.
· **Microcontroller**: Use Arduino Uno or Raspberry Pi for control logic and data acquisition.

4. Simulation and Modelling
· **Software Tools**: Use MATLAB/Simulink or Proteus to simulate system behaviour under varying conditions.
· **Solar Modelling**: Simulate PV output using irradiance and temperature data. · **Wind Modelling**: Model wind turbine output using wind speed profiles and turbine characteristics.
· **Hybrid Control Logic**: Implement algorithms for source switching, battery management, and fault detection.
· **Performance Metrics**: Analyze efficiency, reliability, and energy yield across different scenarios.

5. Hardware Implementation
· **Prototype Assembly**: Build a scaled down version of the system using selected components.
· **Sensor Integration**: Install voltage, current, temperature, and wind speed sensors for real-time monitoring.
· **Control Unit Programming**: Code the microcontroller to execute control logic, display data, and log performance.
· **Power Routing**: Connect generation units to the charge controller, battery bank, and inverter.
· **Load Testing**: Connect resistive and inductive loads to test system response under real-world conditions.

6. Performance Evaluation
· **Data Logging**: Record voltage, current, power output, and battery status over time.
· **Efficiency Analysis**: Calculate conversion efficiency for solar and wind subsystems.
· **Reliability Testing**: Evaluate system uptime and response to source failure or low-resource conditions.
· **Environmental Impact**: Estimate carbon offset and reduction in fossil fuel usage.
· **Economic Analysis**: Compare cost per kWh with conventional and standalone renewable systems.

7. Documentation and Reporting
· **Technical Documentation**: Prepare schematics, wiring diagrams, and control flowcharts.
· **Simulation Reports**: Include graphs, tables, and performance summaries from modeling tools.
· **User Manual**: Provide operational guidelines for installation, maintenance, and troubleshooting.
· **Academic Reporting**: Structure findings into IEEE-style sections for publication or academic submission.



Circuit diagram:
Here's a detailed and academically structured **Components** section for your report on the **Hybrid Wind-Solar Power Generation System**, organized by function and technical relevance:

Components of the Hybrid Wind-Solar Power Generation System
The proposed system integrates multiple hardware and software components to ensure efficient energy generation, storage, and distribution. Each component plays a critical role in maintaining system reliability, optimizing performance, and enabling intelligent control.

1. Solar Photovoltaic (PV) Panels
· **Function**: Convert solar irradiance into direct current (DC) electricity.

· **Type**: Monocrystalline or polycrystalline panels.
· **Specifications**:
o Rated power: 100W–300W per panel
o Efficiency: 15–22%
o Operating voltage: 12V or 24V
· **Mounting**: Adjustable tilt frames for optimal sun exposure.

2. Wind Turbine
· **Function**: Converts kinetic energy from wind into electrical energy.
· **Type**: Horizontal-axis wind turbine (HAWT) preferred for higher efficiency. · **Specifications**:
o Rated power: 300W–1kW
o Cut-in wind speed: 3–4 m/s
o Rotor diameter: 1–2 meters
· **Mounting**: Elevated tower (6–10 meters) for unobstructed airflow.

3. Battery Bank
· **Function**: Stores excess energy for use during low-generation periods.
· **Type**: Deep-cycle lead-acid or lithium ion batteries.
· **Specifications**:
o Voltage: 12V/24V
o Capacity: 100Ah–200Ah per unit
o Configuration: Series or parallel based on load requirements
· **Protection**: Battery Management System (BMS) for safety and longevity.

4. Charge Controller
· **Function**: Regulates voltage and current from solar and wind sources to prevent battery overcharging or deep discharge.
· **Type**: MPPT (Maximum Power Point Tracking) for solar; PWM or hybrid controller for wind.
· **Features**:
· Dual input support
· LCD display for monitoring
· Overload and short-circuit protection

5. Inverter
· **Function**: Converts stored DC power into AC for household or grid-compatible use.
· **Type**: Pure sine wave inverter
· **Specifications**:
o Input: 12V/24V DC
o Output: 220V/230V AC
o Power rating: 500W–2kW
· **Features**: Surge protection, auto switching, and cooling fan.

6. Microcontroller Unit
· **Function**: Controls system logic, data acquisition, and automation.
· **Type**: Arduino Uno, Raspberry Pi, or ESP32
· **Tasks**:
o Sensor data logging
o Source prioritization logic
o Display and alert systems
· **Connectivity**: USB, GPIO, I2C, and Wi Fi (optional)

7. Sensors and Monitoring Devices
· **Function**: Measure environmental and electrical parameters.
· **Types**:
o Voltage and current sensors
o Temperature sensors
o Wind speed anemometer
o Solar irradiance sensor
· **Output**: Real-time data for performance analysis and fault detection

8. Load Units
· **Function**: Represent actual power consumption (e.g., lights, fans, appliances).
· **Type**: Resistive and inductive loads · **Purpose**: Testing system response and efficiency under varying demand

9. Supporting Hardware
· **Mounting Structures**: Frames for solar panels and towers for wind turbines.
· **Wiring and Connectors**: Copper cables, MC4 connectors, terminal blocks.
· **Protection Devices**: Fuses, circuit breakers, surge protectors.
· **Cooling Systems**: Passive or active cooling for inverter and batteries.

10. Software Tools

· **Simulation**: MATLAB/Simulink, Proteus for system modeling.
· **Programming**: Arduino IDE, Python for control logic.
· **Monitoring Interface**: LCD displays or web dashboards for real-time data visualization.

CONCLUSION

The Hybrid Wind-Solar Power Generation System developed in this project represents a significant step toward achieving sustainable, decentralized, and reliable energy solutions. In the face of growing global energy demands and increasing environmental concerns, the integration of renewable energy sources has become not only desirable but necessary. This project addresses the critical limitations of standalone solar and wind systems—namely, their intermittency and dependence on weather conditions—by combining them into a hybrid configuration that ensures continuous power generation.

Through careful design, simulation, and hardware implementation, the system successfully demonstrates how solar and wind energy can complement each other to provide a stable and efficient power supply. Solar panels generate electricity during daylight hours, while wind turbines contribute during cloudy or nighttime conditions, especially when wind speeds are favorable. The intelligent charge controller plays a pivotal role in managing energy flow, prioritizing sources, and protecting the battery bank from overcharging or deep discharge. The inclusion of a battery storage system further enhances reliability by storing excess energy for use during low-generation periods.

The simulation phase, conducted using MATLAB/Simulink, validated the theoretical performance of the system under varying environmental scenarios. It allowed for optimization of control algorithms, particularly the Maximum Power Point Tracking (MPPT) for solar input and dynamic switching logic between sources. The hardware prototype, built using Arduino and real-world components, confirmed the system's practical viability. Real-time monitoring, sensor integration, and load testing provided valuable insights into operational efficiency, energy yield, and fault tolerance.

One of the most impactful outcomes of this project is its potential application in off-grid and rural areas. In regions where grid infrastructure is weak or nonexistent, this hybrid system can serve as a standalone power solution, improving quality of life through access to electricity. It can power basic household appliances, agricultural equipment, and even small-scale community services such as lighting, communication, and refrigeration. Moreover, the system's modular design allows for scalability, making it adaptable to different energy demands and geographic conditions.

From an environmental perspective, the system contributes to carbon emission reduction and promotes the use of clean energy. Unlike diesel generators or coal-based power plants, the hybrid system operates with zero emissions during use, aligning with global climate goals and sustainable development targets. Its deployment can help reduce reliance on fossil fuels, mitigate air pollution, and support ecological preservation.

Economically, the system offers long-term cost benefits. While initial setup costs may be higher than conventional alternatives, the absence of fuel expenses, minimal maintenance requirements, and extended component lifespans result in favorable lifecycle economics. The project also highlights the importance of local manufacturing, community involvement, and policy support in scaling renewable energy technologies.

Educationally, this project provides a rich learning experience in interdisciplinary engineering. It combines principles of electrical design, embedded systems, environmental science, and data analysis. Students and researchers gain hands-on exposure to system integration, simulation modeling, and real-world testing, fostering innovation and technical competence.

In conclusion, the Hybrid Wind-Solar Power Generation System is a robust, efficient, and environmentally responsible solution to modern energy challenges. It exemplifies how technological innovation can be harnessed to create sustainable infrastructure, empower communities, and protect the planet. The success of this project lays the groundwork for future enhancements, including IoT-based monitoring, AI-driven optimization, and smart grid integration. With continued research, investment, and collaboration, hybrid renewable systems like this can play a transformative role in shaping the future of energy.

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