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Renewable Energy Microgrid Monitoring System

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***Abstract*-- The increasing demand for sustainable and renewable energy solutions has accelerated the adoption of renewable energy microgrids. Effective monitoring and management of such systems are essential to ensure efficient power generation, storage, and distribution. This paper presents the design and implementation of a Renewable Energy Microgrid Monitoring System using the ESP32 microcontroller. The proposed system integrates solar energy generation, wind energy simulation, voltage and current sensing, battery monitoring, relay-based load control, and IoT-enabled wireless communication. Real-time electrical parameters are monitored using sensors and transmitted to a cloud-based dashboard through Wi-Fi connectivity. The system provides remote monitoring, automatic load management, fault detection, and improved energy efficiency. Experimental results demonstrate reliable performance, accurate monitoring, and cost-effective implementation suitable for rural electrification, smart homes, and small-scale renewable energy applications.**

***Keywords*-- ESP32, Renewable Energy, Microgrid, IoT, Solar Energy, Wind Energy, Smart Monitoring, Energy Management.**

I. Introduction

The growing demand for electricity and environmental concerns associated with fossil fuel-based power generation have increased the importance of renewable energy systems. Renewable energy microgrids, which combine solar and wind energy sources with energy storage systems, offer a sustainable solution for decentralized power generation. However, efficient operation of these systems requires continuous monitoring of electrical parameters and intelligent energy management.

This research presents an IoT-based Renewable Energy Microgrid Monitoring System using ESP32. The system enables real-time monitoring of voltage, current, battery status, and load conditions while providing remote access through a web-based dashboard. The proposed solution improves system reliability, reduces maintenance efforts, and enhances renewable energy utilization.

II. Problem Statement

Most existing renewable energy microgrids lack efficient real-time monitoring and control mechanisms.

Manual monitoring methods often result in energy losses, delayed fault detection, increased maintenance costs, and reduced system efficiency. Industrial monitoring systems are expensive and unsuitable for small-scale applications. Therefore, there is a need for a low-cost, IoT-enabled monitoring system capable of real-time supervision, remote access, and automatic load control.

III. Objectives

The objectives of the proposed system are:

1. To develop an IoT-based renewable energy monitoring system using ESP32.
2. To monitor solar and wind energy generation in real time.
3. To measure voltage, current, and battery parameters continuously.
4. To provide remote monitoring through a cloud dashboard.
5. To implement relay-based automatic load control.
6. To improve energy efficiency and system reliability.
7. To reduce maintenance costs and operational downtime.

IV. System Methodology

The proposed system consists of solar panels, a wind energy simulation unit, voltage and current sensors, a rechargeable battery, relay module, and ESP32 microcontroller. The ESP32 continuously acquires data from sensors and processes the information. The collected data is transmitted through Wi-Fi to an IoT dashboard where users can monitor system performance remotely.

The relay module allows automatic switching of electrical loads based on predefined conditions. Battery status monitoring ensures proper energy storage management, while fault detection mechanisms improve operational safety and reliability.

V. Hardware Components

The system consists of the following components:

- ESP32 Development Board
- Solar Panel

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- DC Motor (Wind Energy Simulation)
- Voltage Sensor Module
- ACS712 Current Sensor
- Relay Module
- Rechargeable Battery
- Breadboard/PCB
- Wi-Fi Communication Network

VI. Results And Discussion

The developed system was tested under various operating conditions. Experimental observations showed accurate voltage and current measurements, stable Wi-Fi communication, reliable relay operation, and successful remote monitoring. The IoT dashboard displayed real-time values including solar voltage, current consumption, battery level, wind energy status, and load conditions.

The system achieved:

- High monitoring accuracy
- Reliable wireless communication
- Real-time dashboard updates
- Efficient fault detection
- Automatic load management

The results indicate that the proposed system effectively supports renewable energy monitoring and smart energy management.

VII. Advantages

- Real-time monitoring and control
- Low-cost implementation
- Remote accessibility through IoT
- Hybrid solar and wind energy support
- Improved energy efficiency
- Automatic load control
- Easy installation and maintenance
- Environment-friendly operation

VIII. Limitations

- Dependence on weather conditions
- Requirement of stable Wi-Fi connectivity
- Limited power generation in prototype setup
- Sensor calibration requirements
- Suitable mainly for small-scale applications

IX. Future Scope

Future enhancements may include:

- Artificial Intelligence-based energy prediction
- Cloud data analytics and storage
- Mobile application integration
- Smart grid connectivity
- Advanced battery management systems
- GSM and GPS integration
- Enhanced cybersecurity mechanisms
- Large-scale industrial deployment

X. Conclusion

The Renewable Energy Microgrid Monitoring System using ESP32 successfully demonstrates the integration of renewable energy sources, IoT technology, and smart monitoring techniques into a single platform. The system provides real-time monitoring, remote accessibility, automatic load control, and improved energy management. Its low-cost design, ease of implementation, and reliable performance make it suitable for rural electrification, educational applications, and small-scale renewable energy systems. The project contributes toward sustainable energy development and supports future smart grid initiatives.