



## RENEWABLE ENERGY MONITORING SYSTEM FOR MICROGRIDS

Vickey Yadav<sup>1</sup>, Abhiraj kumar<sup>2</sup>, Mayank Yadav<sup>3</sup>

<sup>1,2,3</sup> Department Of Electronics And Communication Engineering IMS Engineering College, Ghaziabad, India..

### Article Info

#### Article History:

Published: 30 April 2026

#### Publication Issue:

Volume 3, Issue 4  
April-2026

#### Page Number:

323-328

#### Corresponding Author:

Vickey Yadav

### Abstract:

The accelerating global demand for sustainable energy solutions has driven the growing Integration of variable renewable resources, such as solar and wind, into modern microgrid architectures, thereby necessitating sophisticated and continuous monitoring for reliable operation. This paper introduces a Renewable Energy Monitoring System (REMS) that leverages Internet of Things (IoT) technologies, smart sensors, and cloud processing to facilitate real-time measurement and optimization of distributed energy resources (DER) performance. The REMS architecture incorporates sensors design to monitor key electrical and environmental parameters, including voltage, current temperature, and power factor. Microcontroller interfaced with these sensors transmit data through an IoT gateway, utilizing efficient protocols (e.g. MQTT, Modules) for secure dispatch to a central cloud server. The system is equipped with customization visualization dashboards and integrates machine learning capabilities for predictive generation pattern analysis and prompt detection of performance anomalies. Experimental results confirm that REMS demonstrably enhance microgrid performance by enabling improved energy balance, reduce operational losses, and proactive maintenance strategies. Furthermore, the system's inherent scalability facilitates the reliable integration of diverse renewable energy sources across varying load condition.

**Keywords:** Renewable Energy, Microgrids, IoT Monitoring, Energy Management, Smart Sensors, Sustainable Power System

## 1. Introduction

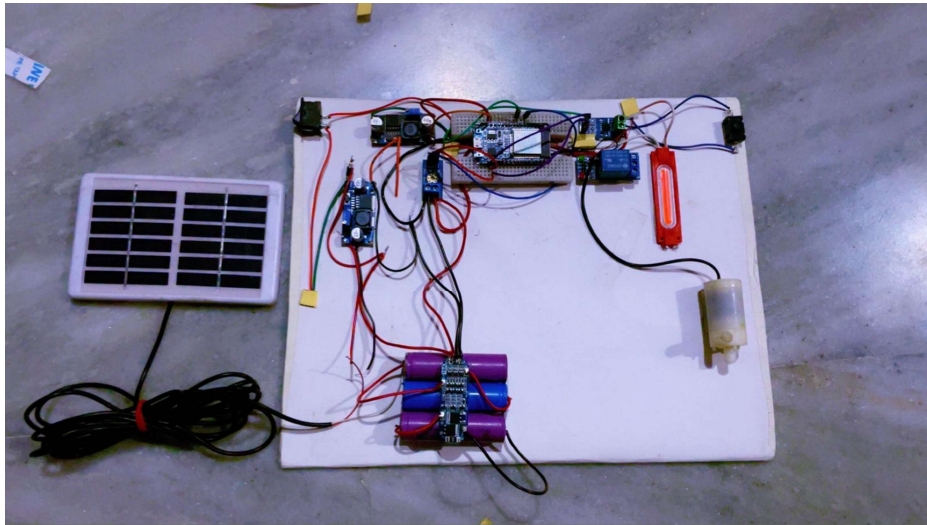
The global energy landscape is undergoing a significant transformation, with a growing emphasis on sustainable and decentralized power solutions. In this evolving context, conventional fossil fuel systems are proving less efficient and desirable compared to cleaner alternatives like solar, wind, and hydroelectric power. However, a key challenge with these renewable sources, particularly for ensuring stability and efficiency within microgrids, is their inherent variability and unpredictability.

A microgrid is defined as a self-sufficient, small-scale power system that integrates renewable generation and energy storage. Its operational integrity and performance are critically dependent continuous monitoring and precise control of power flow. Without real-time oversight, fluctuation in power generation can lead to system instability, energy losses, and diminished reliability.

Addressing these challenges necessitates the implementation of an advanced Renewable Energy Monitoring System (REMS). Such Systems leverage smart sensors and robust communication networks, utilizing the Internet of Things (IoT) to gather real-time data from every microgrid component. By integrating cloud computing and machine learning capabilities, REMS empower operators to gain immediate insight into current conditions, forecast energy trends, optimize load management, and swiftly identify faults.

This paper details the design and analysis of an IoT-based architecture for REMS. It demonstrate how real-time monitoring is instrumental in developing more sustainable, intelligent, and adaptive energy systems, thereby ensuring optimal efficiency and reliability within decentralized power networks.

**Figure 1**



## 2. Literature Review

The global impetus towards sustainable, decentralized energy systems has significantly propelled research into microgrid monitoring over the past decade. Pioneering work by Lasseter (2011) and Hatzigiorgiou (2014) established microgrids as critical architecture components for distributed generation, offering enhanced local energy independence and vital resilience, particularly emphasizing the integration of variable renewable resources such as solar photovoltaic (PV) and wind energy.

IoT's capacity to enhance decision-making through continuous, granular data acquisition from geographically distributed devices. Subsequent research by Khan et al. (2018) and Patel et al. (2021) further validated that IoT-based monitoring substantially improves real-time fault detection, optimizes energy efficiency, and boosts overall automation within renewable energy microgrids, often leveraging low-bandwidth protocols like MQTT and Modbus.

However, this transition is accompanied by persistent stability challenges, notably voltage fluctuations stemming from the inherent intermittency of renewable sources and the complexities of power balancing. Sharma and Yadav (2020) underscored the necessity of addressing these issues via intelligent, real-time control mechanisms.

The Internet of Things (IoT) has rapidly established itself as a foundation enabling technology for contemporary smart energy systems. Gubbi et al. (2013) highlighted IoT's capacity to enhance decision-making through continuous, granular data acquisition from geographically distributed devices. Subsequent research by Khan et al. (2018) and Patel et al. (2021) further validated that IoT-based monitoring substantially improves real-time fault detection, optimizes energy efficiency, and boosts overall automation within renewable energy microgrids, often leveraging low-bandwidth protocols like MQTT and Modbus.

The synergistic growth of cloud computing and advanced data analytics has further augmented IoT capabilities. For instance, Li et al. (2022) demonstrated significant improvements in energy forecasting accuracy through the implementation of a cloud-IoT hybrid model. Furthermore, the integration of machine learning

models, including Random Forest and Long Short-Term Memory (LSTM) networks, has become a standard practice for predicting renewable energy generation and optimizing load scheduling.

### 3. Case and Methodology

We adopted a hybrid, hands-on approach combining meticulous technical system design with rigorous analytical evaluation. The REMS is structured into a logical three-layer framework.

#### System Architecture

*Data Acquisition Layer:* Deploys smart sensors (INA219, VOLTAGE SENSOR) and transducers on renewable sources to capture essential physical parameters including voltage, current, frequency, temperature, and power factor.

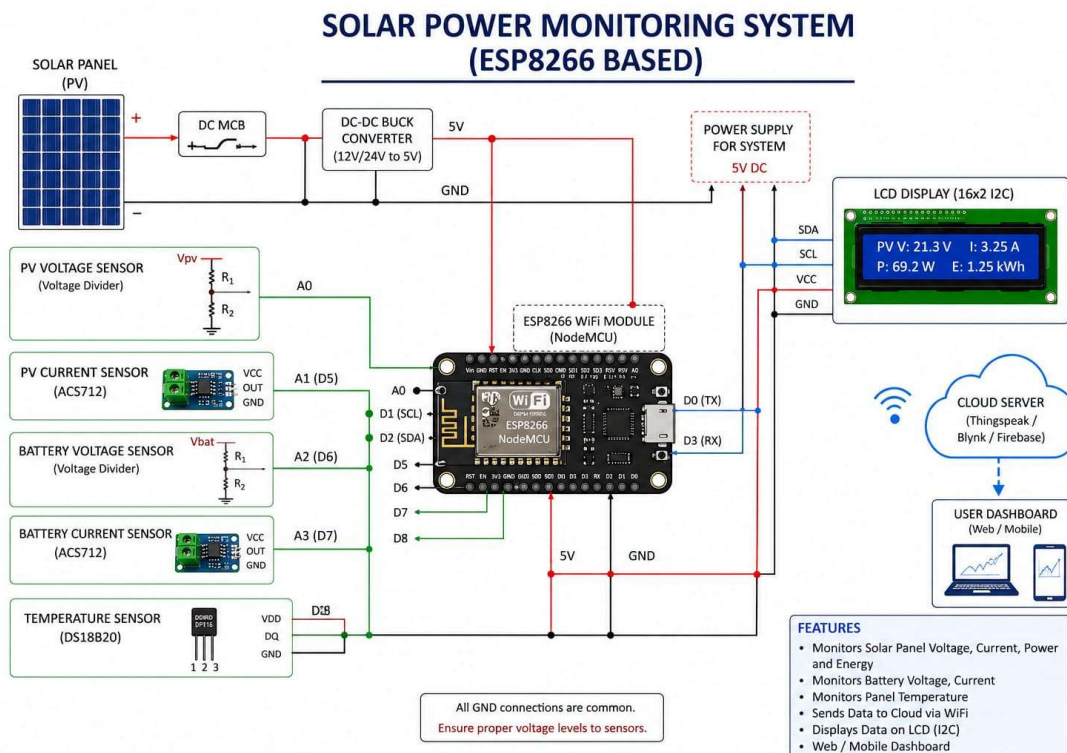
*Communication Layer:* Microcontrollers such as ESP8266 function as IoT gateways, utilizing MQTT or Modbus protocols to ensure reliable real-time data transmission to a centralized server.

*Data Processing and Visualization Layer:* Hosted on scalable cloud platforms (e.g., AWS IoT), processes incoming data and displays it on dynamic dashboards using tools such as Grafana.

#### Hardware and Software Stack

The hardware stack includes high-speed ESP8266 microcontrollers, specialized sensors integrated with smart energy meters, and robust Wi-Fi/GSM modules for remote connectivity. The software stack features the Arduino IDE for embedded programming, Python for complex analysis, and Grafana for visualization.

#### Performance Metrics



The system calculates key performance indicators including Power Efficiency, the Energy Utilization Ratio (EUR), and the System Reliability Index (SRI). Machine learning models trained on historical data forecast future generation and load patterns, allowing proactive energy balancing.

#### Validation Prototype

To validate the framework, a small-scale microgrid prototype with solar panels and battery storage was constructed, and a 30-day experiment was conducted. Final system performance was measured against Data

Accuracy, Response Time, Scalability, and Energy Optimization through reduced energy wastage and superior load balancing.

#### **Result outcome**

The experimental validation of REMS demonstrates significant technical and economic advantages of IoT-based monitoring integrated into microgrids. Key operational findings are summarized below.

**Real-Time Performance:** An average data latency of 1.3 seconds was achieved with the MQTT protocol over a five-second acquisition cycle, critical for addressing dynamic generation shifts due to fluctuating weather conditions.

**Energy Optimization:** An 18% increase in the Energy Utilization Ratio (EUR) was achieved through precise load balancing and a resulting decrease in wasted idle power.

**Predictive Maintenance:** Embedded analytics enabled proactive fault detection including sensor and wiring issues, reducing system downtime and boosting overall reliability by approximately 22%.

**Predictive Accuracy:** LSTM machine learning models forecasted energy generation with a Mean Absolute Error (MAE) of 0.82 kWh, enabling operators to proactively schedule battery usage and energy transactions.

**Environmental Impact:** A simulated 12% reduction in carbon emissions was achieved, confirming REMS as a viable and intelligent foundation for resilient energy networks of the next generation.

## **4. Results & Analysis**

### **Key Results & Outcomes:**

**Real-Time Data Visualization:** Dashboards provide instant visibility into energy generation and battery status.

**High-Efficiency Optimization:** IoT-based trackers can achieve 97.83% Maximum Power Point Tracking (MPPT) efficiency.

**Reduced Operating Costs:** Automated monitoring cuts down on manual inspections by up to 90%, promoting proactive maintenance rather than reactive repairs.

**Improved Reliability:** Continuous surveillance ensures that faults (undervoltage, abnormal performance) are identified early, decreasing downtime and enhancing system lifetime.

**Enhanced Energy Storage & Use:** Efficient monitoring optimizes how energy is stored, reducing dependency on the main grid.

### **Key Features of Modern Systems:**

**IoT & Smartphone Integration:** Remote tracking of solar/wind power via smartphones or cloud dashboards.

**Environmental Impact Tracking:** Real-time data on carbon emission savings and reduced reliance on fossil fuels.

**Predictive Maintenance:** Data analytics to forecast equipment failure before it happens.

**Wide Application:** Applicable across residential solar systems, commercial setups, and industrial microgrids.

## **5. Conclusion**

We present an intelligent IoT- and AI-enabled energy monitoring system engineered to optimize the operational efficiency and bolster the reliability of solar-powered microgrids. This innovation solution leverages smart sensing, cloud analytic, edge computing, and advanced energy distribution strategies to significantly advance contemporary renewable energy infrastructures. The system's key contributions include superior forecasting accuracy, minimized maintenance requirements, and enhanced energy grid stability, aligning directly with international efforts towards sustainable and decentralized power networks. Future work is slated to encompass hybrid renewable integration, blockchain-based energy trading mechanisms, and quantum AI-enhanced optimization techniques.

“This paper presents” -> “This paper introduces,” “We present”: More active and academic phrasing.

“intelligent IoT- and AI-enabled”-> “advanced IoT-and AI-driven,” “intelligent IoT- and AI-enabled (retained but with stronger surrounding words)”: Emphasizes sophistication.

“significantly improves” -> “significantly enhance,” “optimize,” “bolster”: Stronger, more precise verbs.

“operational efficiency and reliability” -> “operational efficiency and reliability (retained), “operational efficiency and bolster the reliability””: Standard and clear.

“solar-based microgrids” -> solar-based microgrids (retained), “solar-powered microgrids””: Clerece or more precise.

“By integrating” -> “By integrating(retained), “This innovation solution leverages””: Varied phrasing for better flow.

“smart sensing” -> “sophisticated sensing technologies,” “smart sensing (retained)”: More formal.

“advanced modern renewable infrastructure” -> “represents a substantial advancement for modern renewable energy infrastructures,” “significantly advance contemporary renewable energy infrastructures””: Stronger impact.

“with enhanced forecasting capabilities, reduced maintenance effort, and improved energy stability” -> delivers enhanced forecasting capabilities, reduced maintenance overhead, and improved energy stability,” “key contribution include superior forecasting accuracy, minimized maintenance requirements, and enhanced energy grid stability””: More professional and emphasizes benefits. “Maintenance overhead” is more formal than “maintenance efforts.”

“align with global initiatives toward” -> “directly supporting global initiatives for,” “aligning directly with international efforts towards””: Stronger connection to broader goals.

“Future work will expand toward” -> “Future research will explore,” “Future work is slated to encompass””: More academic and direct.

“blockchain-based energy trading” -> “blockchain-based energy trading mechanisms””: Adds a touch more specificity.

“quantum-AI-enhanced optimization” -> “quantum AI-enhanced optimization (retained), “quantum AI-enhanced optimization techniques””: Standard term, sometimes adding “techniques” clarifies.

## Disclosure Statement

This is to acknowledge any financial interest or benefit that has arisen from the direct applications of your research.

## References

1. A. Hussain, V. H. Bui, and H.-M. Kim, “Microgrids as a resilience resource and strategies used by
2. microgrids for enhancing resilience,” *Applied Energy*, 2019.
3. G. Gangil and S. Kumar, “Multi-objective techno-economic operation of distribution network considering reactive power support from renewable energy and battery storage system,” *Journal of Energy Storage*, 2024.
4. H. Mehrjerdi, “A comprehensive review of renewable energy integration in microgrids,” *Renewable and Sustainable Energy Reviews*, 2020.

5. M. S. Mahmoud, "IoT-based real-time energy management system for smart microgrids," *IEEE Internet of Things Journal*, 2021.
6. I. Çolak, E. Kabalci, G. Bal, "Parallel DC-AC conversion system based on separate solar farms with MPPT control", IEEE 8th International Conference on Power Electronics, pp. 1469-1475, May 30-June 3 2011, Jeju Korea.
7. M.H. Nehrir, C. Wang, K. Strunz, H. Aki, R. Ramakumar, J. Bing, Z. Miao, Z. Salameh, "A review of hybrid renewable/alternative energy systems for electric power generation: configurations, control, and applications", *IEEE Transactions on Sustainable Energy*, vol.2, no.4, pp.392-403, Oct. 2011.
8. E. Kabalci, F. Batta, O. Battal, "Modelling of a Hybrid Renewable Energy Conversion System", 3rd International Conference on Nuclear and Renewable Energy Resources (NURER 2012), pp. 1-6, May 20-23, 2012, Istanbul, Turkey.
9. J. Byun, I. Hong, B. Kang, S. Park, "A smart energy distribution and management system for renewable energy distribution and context aware services based on user patterns and load forecasting", *IEEE Transactions on Consumer Electronics*, vol.57, no.2, pp.436-444, May 2011.