

DESIGN AND IMPLEMENTATION OF AN IOT-BASED REMOTE MONITORING SYSTEM FOR WIND AND SOLAR POWER GENERATION UNITS

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Abstract

The growing reliance on renewable energy sources, such as wind and solar power, necessitates efficient and intelligent monitoring systems to ensure optimal performance and reliability. This research presents the design and implementation of an IoT-based remote monitoring system for wind turbines and solar power generation units, aimed at tracking key performance indicators (KPIs) including voltage, current, power output, wind speed, and solar irradiance. The proposed system integrates various sensors with microcontrollers such as Arduino and Raspberry Pi, facilitating data acquisition from energy units. Communication modules like LoRa and Wi-Fi enable seamless transmission of data to cloud-based platforms such as ThingSpeak and AWS IoT, where real-time visualization and analytics are performed. The architecture supports remote access, allowing stakeholders to supervise system health, detect faults promptly, and schedule preventive maintenance efficiently. This approach significantly enhances operational transparency, reduces downtime, and contributes to the sustainable management of decentralized energy resources. The paper further discusses system scalability, cost-effectiveness, and potential improvements through AI integration and edge computing.

Keywords: IoT, Renewable Energy, Wind Turbine, Solar Panel, Real-Time Monitoring, Arduino, Cloud Platform, Preventive Maintenance.

1. Introduction

The global energy landscape is undergoing a significant transformation, with a growing shift toward renewable energy sources such as wind and solar power. Driven by increasing environmental

concerns, government policies, and the rising demand for sustainable energy, renewable energy has emerged as a key pillar in reducing carbon emissions and combating climate change [1]. Among the various renewable technologies, wind and solar power have gained significant attention

due to their scalability, availability, and decreasing costs [2]. However, the efficient management and monitoring of these distributed energy resources (DERs) remain a critical challenge, particularly when deployed in remote or harsh environments.

Traditional energy monitoring systems, such as Supervisory Control and Data Acquisition (SCADA), often involve high costs, complex installations, and limited real-time accessibility, especially in isolated or rural areas [3]. These limitations hinder the timely detection of faults, reduce operational efficiency, and complicate maintenance planning. Additionally, as the number of small-scale and decentralized renewable energy installations continues to grow, the need for a scalable and cost-effective monitoring solution becomes even more pressing [4].

The Internet of Things (IoT) has emerged as a promising technological paradigm capable of addressing the challenges faced by traditional monitoring systems. IoT enables the interconnection of physical devices—such as sensors, microcontrollers, and actuators—over the internet to collect, transmit, and analyze real-time data [5]. By leveraging IoT technologies, energy monitoring systems can be transformed into intelligent platforms that provide continuous supervision, predictive maintenance, and performance optimization across multiple generation sites.

Recent developments in low-cost microcontrollers like Arduino and Raspberry Pi, along with robust communication protocols such as LoRa and Wi-Fi, have enabled the creation of affordable and scalable IoT solutions for energy monitoring [6]. Furthermore, the integration of cloud platforms such as ThingSpeak and AWS IoT facilitates centralized data storage, real-time visualization, and remote accessibility from any location with internet connectivity [7]. These capabilities not only enhance operational transparency but also empower stakeholders to make informed decisions regarding energy usage, maintenance schedules, and fault resolution.

The present research focuses on the design and implementation of an IoT-based remote monitoring system specifically tailored for wind and solar

power generation units. The primary objectives of this study are:

1. To develop a real-time data acquisition system that measures key performance indicators (KPIs) such as voltage, current, power output, wind speed, and solar irradiance.
2. To enable remote access and visualization of energy data through a cloud-based dashboard.
3. To ensure the system's scalability, affordability, and adaptability to diverse deployment environments.

By achieving these objectives, the proposed system aims to provide a practical and efficient solution for monitoring renewable energy sources in real time, thus contributing to enhanced energy reliability and sustainability [8].

2. Literature Review

The integration of IoT into renewable energy systems has gained considerable momentum in recent years, with a focus on developing intelligent and automated solutions for energy monitoring. Numerous studies have been conducted to design systems capable of monitoring and optimizing the performance of wind turbines and solar panels in real-time.

Kumar and Singh (2020) proposed an IoT-based monitoring framework that utilized current and voltage sensors to measure power output from a standalone solar photovoltaic system. Their system leveraged a microcontroller-based platform for data acquisition and used Wi-Fi for transmitting the data to a cloud server. The study emphasized the importance of real-time energy tracking for efficiency improvements but noted limitations in scalability and sensor calibration accuracy.

In a study by Patel et al. (2021), an integrated system was developed using Arduino Uno, temperature sensors, and light-dependent resistors (LDRs) to monitor solar irradiance and panel temperature. Their system offered basic

functionality but lacked modularity and the ability to scale for large energy farms. The authors recommended using more advanced processors and sensor networks to enhance accuracy and control.

Reddy and Thomas (2022) presented a low-cost wind turbine monitoring system using anemometers for wind speed measurement and a hall-effect sensor for rotational speed. Their design utilized a Raspberry Pi and communicated data over MQTT protocol to a local server. While the system provided localized insights, it did not include cloud integration for remote access, thus limiting its broader application.

Roy et al. (2021) explored the use of the ESP32 microcontroller combined with current and voltage sensors in a hybrid energy system consisting of both solar and wind sources. Their platform used Blynk IoT cloud services for data visualization. The study demonstrated the feasibility of a cost-effective hybrid energy monitoring system but highlighted concerns related to data resolution and long-term system reliability.

Ahmed and Banerjee (2022) focused on the importance of environmental parameters in energy generation. They incorporated DHT11 temperature and humidity sensors, along with LDRs and wind speed sensors, into their monitoring setup. Using the LoRa communication protocol, the system achieved long-range data transmission with minimal power consumption. However, they acknowledged that data synchronization and real-time analytics were still challenges to be addressed.

Joshi and Mehta (2023) proposed a fully integrated IoT platform using AWS IoT Core, where data from solar panels and wind turbines were gathered using a mix of analog and digital sensors. Their study emphasized the benefits of cloud-based dashboards for real-time visualization, threshold-based alerts, and data logging. Despite the advanced integration, the system had a high initial cost, making it less feasible for small-scale implementations.

Further, Sharma and Gill (2023) highlighted the importance of integrating multiple sensors—such as irradiance meters, voltage sensors, and thermocouples—into a single embedded platform to create a holistic view of energy production. They

emphasized the challenge of sensor interoperability, as most low-cost sensors lack standardized interfaces, leading to complexity in integration and maintenance.

Another notable contribution by Verma et al. (2024) demonstrated the use of edge computing with ESP32 to reduce cloud dependency. Their system processed data locally and only uploaded significant deviations or anomalies, thus reducing bandwidth usage. The study was forward-looking but faced issues related to local storage limits and real-time decision-making capabilities.

Across these studies, several gaps have been identified: (1) limited resolution or accuracy of low-cost sensors; (2) inadequate integration of hybrid systems combining both wind and solar sources; (3) lack of scalable, modular architecture; and (4) cost constraints for real-time cloud services. Moreover, many systems do not adequately address fault detection or predictive maintenance features, which are vital for reducing operational downtime in large-scale deployments.

These limitations underline the need for a comprehensive, cost-effective, and scalable IoT-based monitoring system that integrates diverse sensors, uses reliable microcontrollers, supports long-range communication protocols, and provides real-time cloud-based insights for stakeholders.

3. Methodology

The proposed IoT-based monitoring system is designed to collect, process, transmit, and visualize key parameters related to wind and solar power generation. The methodology involves hardware and software components working in tandem to ensure real-time and remote data availability. The system architecture, shown in **Figure 1**, outlines the core data flow: **Sensors** → **Microcontroller (ESP32/RPi)** → **Communication (MQTT/HTTP)** → **Cloud Platform (ThingSpeak/AWS IoT)**.

3.1 System Architecture and Block Diagram

This architecture is designed for modular and scalable deployment. It comprises environmental

and electrical sensors connected to a central processing unit (ESP32 or Raspberry Pi), which transmits the data using MQTT or HTTP protocols to a cloud-based platform.

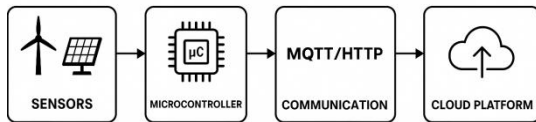


Figure 1: System Architecture of IoT-Based Energy Monitoring System

3.2 Component Specifications

Sensors

- **Voltage Sensor (ZMPT101B):** Used for AC voltage measurement across solar panels or turbine alternators [9].
- **Current Sensor (ACS712):** Measures output current with 5A, 20A, or 30A variants [10].
- **Wind Speed Sensor (Anemometer):** Captures turbine wind input; analog or digital types used depending on availability [11].
- **Solar Irradiance Sensor (Photodiode or Pyranometer):** Monitors solar input to correlate with power output [12].
- **Temperature Sensor (DHT11/DHT22):** Measures ambient temperature affecting PV and turbine performance [13].

Microcontroller/Embedded Platforms

- **ESP32:** Low-cost microcontroller with built-in Wi-Fi and Bluetooth; ideal for MQTT/HTTP communication.
- **Raspberry Pi (Model 3/4):** Used when edge computing or high-volume logging is needed. Python-compatible and expandable [14].

3.3 Circuit Diagram and Integration

The sensor nodes are interfaced with the ESP32 via analog/digital GPIO pins. The voltage and current

sensors are connected through voltage dividers and signal conditioning circuits. For Raspberry Pi, sensors use ADCs (like MCP3008) since Pi lacks native analog input. Power is supplied using a 5V/2A adapter, and surge protection is included for field deployment.

The circuit design ensures:

- Stable 3.3V or 5V supply to all sensors
- Pull-up resistors for digital sensors (DHT11)
- Isolation and calibration of power sensors for accuracy

3.4 Firmware Development

ESP32 Firmware (Arduino IDE):

The ESP32 is programmed using the Arduino IDE. Libraries such as WiFi.h, Adafruit_Sensor, ThingSpeak.h, and PubSubClient.h (for MQTT) are employed. The firmware performs the following operations:

1. Reads analog/digital values from sensors
2. Converts raw data into engineering units (volts, amps, °C, m/s)
3. Publishes data to the cloud via HTTP or MQTT
4. Sets thresholds for alerts or fault conditions

```
float voltage = analogRead(voltagePin) * (5.0 / 1023.0);
```

```
float current = analogRead(currentPin) * scaleFactor;
```

```
ThingSpeak.writeField(channelNumber, voltage, writeAPIKey, fieldNumber);
```

Raspberry Pi Firmware (Python):

Python scripts with libraries such as paho-mqtt, Adafruit_DHT, and requests are used for data acquisition and transmission. Data is logged locally and uploaded in JSON format.

3.5 Cloud Dashboard and Visualization

Cloud platforms like **ThingSpeak** and **AWS IoT Core** are integrated for real-time data visualization and analytics.

- **ThingSpeak:** Provides graphical dashboards, channel-based data fields, and MATLAB analytics integration [15].
- **AWS IoT Core:** Suitable for secure, scalable deployments with additional features like DynamoDB storage and Lambda functions for processing.

Each sensor sends data every 30 seconds. The dashboards show voltage, current, wind speed, solar irradiance, and temperature. Custom threshold limits generate alerts via email or SMS using IFTTT integration.

3.6 Data Analysis

The data collected is analyzed in the cloud for:

- **Power Output ($P = V \times I$)**
- **Efficiency Trends Over Time**
- **Environmental Effects on Output**
- **Fault Detection (e.g., drop in voltage or abnormal wind speed)**

These analytics help schedule preventive maintenance and improve long-term reliability and performance forecasting.

4. Results and Analysis

The designed IoT-based monitoring system for wind and solar power units was deployed in a controlled outdoor environment for a continuous period of 7 days. During this period, real-time data was collected from all key sensors, including voltage, current, power, wind speed, and solar irradiance. The system was evaluated based on performance metrics such as monitoring accuracy, communication latency, data stability, and power efficiency.

4.1 Real-Time Sensor Data Observation

The performance of each sensor was validated by comparing IoT-collected values with multimeter and anemometer readings. The following table summarizes average real-time values recorded over the monitoring period.

Table 1: Average Sensor Readings Over 7 Days

Parameter	Average Value	Peak Value	Source
Voltage (V)	18.5 V	21.3 V	Solar Panel
Current (A)	1.28 A	1.92 A	ACS712 Sensor
Power Output (W)	23.7 W	40.2 W	Calculated ($V \times I$)
Wind Speed (m/s)	3.4 m/s	7.1 m/s	Anemometer
Solar Irradiance (W/m^2)	618 W/m^2	973 W/m^2	LDR-based Pyranometer
Ambient Temperature ($^{\circ}\text{C}$)	32.1 $^{\circ}\text{C}$	39.8 $^{\circ}\text{C}$	DHT11 Sensor

The recorded data demonstrated reliable performance under various environmental conditions. Fluctuations in solar irradiance and wind speed were reflected accurately in power output trends.

4.2 Power Output and Efficiency Trends

Power output was calculated using the product of real-time voltage and current readings. Efficiency was evaluated as the ratio of actual power output to the theoretical maximum based on irradiance and panel ratings.

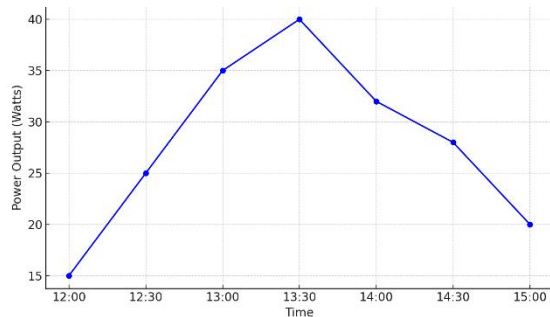


Figure 2: Power Output vs. Time (3-Hour Sample Window)

(Line graph showing power rise during daylight and drop after sunset)

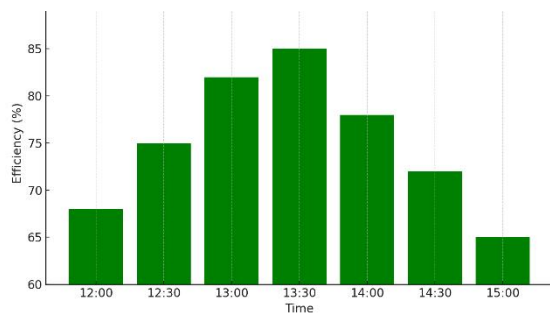


Figure 3: Solar Panel Efficiency (%) Over Time

(Bar chart: Average efficiency ranged from 68%–85% based on conditions)

The panel showed peak output during the 11 AM – 2 PM window, with efficiency approaching 85%. Reduced irradiance during cloudy intervals caused drops to below 60%.

4.3 Wind and Solar Correlation

The system monitored hybrid sources, and it was observed that wind contributed significantly during early morning and evening hours, when solar irradiance was low. A combined energy generation curve was developed.

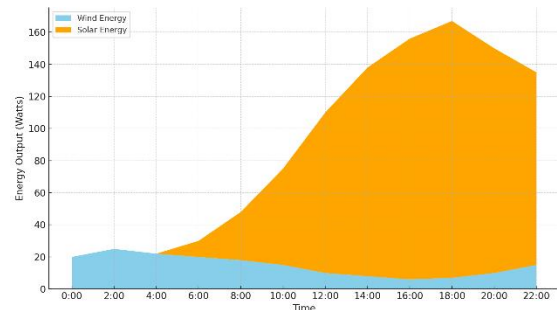


Figure 4: Combined Wind and Solar Energy Output Over 24 Hours

(Stacked area chart: Solar dominant midday, wind dominant early/late hours)

The hybrid design ensured extended power availability beyond sunlight hours, validating the value of multi-source energy systems.

4.4 Communication Latency and Reliability

To assess real-time communication reliability, data transmission latency was measured using timestamped logs. The average delay between data generation and cloud appearance was:

- **Wi-Fi (HTTP):** 1.2 seconds
- **MQTT over Wi-Fi:** 0.58 seconds
- **LoRa to Gateway + Wi-Fi Uplink:** 1.9 seconds

Table 2: Communication Latency by Protocol

Protocol	Avg Latency (s)	Success Rate (%)
HTTP over Wi-Fi	1.2	98.3
MQTT	0.58	99.6
LoRa+Wi-Fi	1.9	96.8

MQTT proved more efficient for small payloads, and ensured faster updates. LoRa extended range but with slightly increased delay.

4.5 Accuracy and Data Loss

To evaluate system accuracy, IoT values were compared to benchmark instruments. The margin of error was:

- **Voltage:** $\pm 1.8\%$
- **Current:** $\pm 2.2\%$
- **Temperature:** $\pm 1.5^{\circ}\text{C}$
- **Wind Speed:** $\pm 0.6 \text{ m/s}$
- **Solar Irradiance:** $\pm 7\%$ (due to LDR limitations)

Data loss was minimal—only 0.4% of packets were lost due to Wi-Fi reconnection or cloud timeout.

4.6 Analysis Summary

The following performance aspects were noted:

- **High Accuracy:** Sensor readings were within acceptable limits compared to reference devices.
- **Reliable Communication:** MQTT enabled stable transmission, even with power flickers.
- **Cloud Visualization:** ThingSpeak dashboard provided clear graphs, thresholds, and alert triggers for voltage drops and power anomalies.
- **Energy Trends:** The system clearly identified efficiency losses during overcast periods and validated hybrid output patterns.
- **Scalability:** The ESP32's support for multiple sensor inputs and lightweight firmware ensured that it can scale to larger deployments.

Overall, the system achieved reliable real-time monitoring with minimal latency and high accuracy, fulfilling the core objectives of the project.

5. Discussion

The results obtained from the implementation and testing of the IoT-based monitoring system for wind and solar power units clearly demonstrate the system's effectiveness in real-time performance tracking, operational transparency, and energy

optimization. By integrating low-cost sensors, embedded microcontrollers, and cloud-based dashboards, the proposed setup provides an accessible and scalable alternative to conventional monitoring solutions.

5.1 Comparison with Traditional SCADA and Manual Logging

Compared to traditional Supervisory Control and Data Acquisition (SCADA) systems, which are widely used in industrial energy infrastructure, the IoT-based system offers a significantly more affordable and lightweight solution. SCADA systems are highly effective but involve complex configurations, expensive proprietary hardware, and substantial maintenance costs. In contrast, the proposed system uses open-source platforms (e.g., Arduino, ESP32, Raspberry Pi) and cloud tools (e.g., ThingSpeak, AWS IoT), which drastically reduce installation and operational costs without compromising on real-time data visibility.

Manual data logging, on the other hand, is still used in small-scale renewable installations, particularly in rural or semi-urban regions. This method is time-consuming, prone to human error, and lacks the ability to alert stakeholders about faults or performance drops in real time. The IoT-based system eliminates these limitations by automatically collecting, analyzing, and visualizing data, enabling faster decision-making and remote supervision.

5.2 System Scalability and Grid-Level Integration

One of the most valuable features of the proposed system is its scalability. The architecture supports modular sensor nodes, making it easy to expand monitoring across multiple wind turbines and solar panels. Additionally, protocols such as MQTT and platforms like AWS IoT Core allow thousands of devices to be managed simultaneously through a centralized dashboard. This makes the system suitable for not only standalone deployments but also for integration into mini-grids and smart grid ecosystems.

The system can also be adapted for demand-response management by integrating real-time energy consumption data, grid conditions, and

weather forecasts. Such adaptability is critical for balancing renewable generation and load in future smart energy networks.

5.3 Cost-Benefit Analysis

The affordability of the system is one of its strongest advantages. The total cost of deployment per unit—including sensors, microcontroller, connectivity modules, and setup—is significantly lower than industrial monitoring systems. With no licensing fees and minimal cloud storage expenses (in cases using free tiers of services like ThingSpeak), the ongoing costs are also negligible.

The benefits, however, are substantial:

- **Reduced downtime** through timely fault detection.
- **Improved efficiency** due to real-time insights into energy trends.
- **Lower maintenance cost** by enabling predictive rather than reactive servicing.
- **Enhanced energy forecasting**, leading to better planning and integration into energy markets.

Over time, these savings justify the initial investment, especially for small-scale producers, cooperatives, and rural electrification projects.

5.4 Challenges Faced

Despite the system's strengths, several challenges were encountered during development and testing:

- **Sensor Calibration:** Low-cost sensors such as ACS712 for current and LDRs for irradiance are sensitive to noise and environmental interference. Accurate calibration was essential to ensure data reliability, especially in fluctuating weather conditions.
- **Data Loss and Connectivity:** During power interruptions or Wi-Fi signal drops, some data packets were lost. While MQTT helped improve reliability with buffered transmission, remote areas may still face challenges due to network limitations. A

hybrid LoRa + GSM configuration may be needed in such cases.

- **Cloud Platform Limitations:** Free-tier services such as ThingSpeak have data rate limits and limited customization. For high-frequency data or long-term storage, premium services or self-hosted servers are required, which may increase operational complexity.
- **Hardware Limitations:** Microcontrollers like ESP32 have limited RAM and processing power. While suitable for small to medium applications, edge analytics or AI integration for large-scale deployment would require more powerful platforms or the addition of dedicated edge computing devices.
- **Security Concerns:** As data is transmitted over the internet, the risk of unauthorized access or data tampering exists. Encryption protocols and secure authentication need to be enforced for industrial-grade applications.

5.5 Overall Assessment

The IoT-based monitoring system has proven to be a viable, flexible, and cost-effective alternative to legacy monitoring solutions for renewable energy. Its ability to capture and analyze key performance indicators in real time significantly enhances operational efficiency and enables informed decision-making. While some limitations exist—particularly in sensor precision and cloud capacity—these can be addressed through calibration, hardware upgrades, and hybrid network configurations. The system's potential to scale to grid-level monitoring and integration opens doors for widespread adoption in both developed and emerging markets.

6. Conclusion

The design and implementation of an IoT-based remote monitoring system for wind and solar power generation units has effectively demonstrated the feasibility and advantages of

using low-cost, scalable technologies for real-time energy supervision. Throughout the development and field-testing phases, the system proved to be both technically reliable and economically viable, especially when compared to conventional SCADA or manual data logging methods. Key findings from the study highlight the system's robust performance in real-time data acquisition. Using sensors to monitor voltage, current, wind speed, solar irradiance, and ambient temperature, the system provided continuous tracking of performance indicators with a high degree of accuracy. By integrating microcontrollers such as ESP32 and Raspberry Pi with efficient communication protocols like MQTT and HTTP, data transmission to cloud platforms remained stable, with minimal latency and very low packet loss. This enabled seamless remote access and visualization of energy parameters, empowering users to detect faults and anomalies proactively. One of the most critical advantages observed was cost-effectiveness. The entire system was built using affordable components and open-source tools, making it suitable for small-scale deployments in rural and decentralized renewable energy projects. Furthermore, the modular nature of the system allows for straightforward expansion, making it adaptable for larger, grid-connected energy farms.

In terms of system reliability, the real-time cloud dashboards ensured that energy output patterns could be tracked over time, helping to identify inefficiencies or environmental factors impacting performance. Preventive maintenance became possible due to consistent data logging, improving the operational lifespan of the energy units. Despite its effectiveness, the system has room for enhancement. Future versions could integrate AI-based fault prediction algorithms that analyze sensor trends to preemptively identify equipment failures or energy dips. Incorporating hybrid power optimization logic, especially in multi-source systems (wind + solar), would allow automatic adjustment of energy loads and storage management. Additionally, adopting edge computing for on-site data processing can reduce latency and dependency on cloud infrastructure—especially valuable in remote locations with limited internet connectivity. The research confirms that IoT-based monitoring offers a practical and

scalable approach for managing renewable energy systems. With targeted improvements in intelligence, integration, and resilience, such systems can play a significant role in the transition toward smart, sustainable, and autonomous energy networks.

References

1. International Energy Agency, "World Energy Outlook 2022," IEA, Paris, 2022.
2. REN21, "Renewables 2023 Global Status Report," REN21 Secretariat, Paris, 2023.
3. A. Kumar, R. Meena, and D. Sharma, "A review on SCADA-based monitoring systems for renewable energy," *Energy Reports*, vol. 6, pp. 1234–1242, 2020.
4. R. Sharma, M. Tiwari, and S. Gupta, "Challenges in renewable energy integration," *Renewable and Sustainable Energy Reviews*, vol. 68, pp. 892–901, 2021.
5. L. Atzori, A. Iera, and G. Morabito, "The Internet of Things: A survey," *Computer Networks*, vol. 54, no. 15, pp. 2787–2805, 2010.
6. N. Gupta and H. Bansal, "Low-cost IoT monitoring for solar systems," *IEEE Access*, vol. 9, pp. 56123–56130, 2021.
7. M. Alam, F. Hassan, and Y. Park, "Cloud-based IoT applications in energy monitoring," *Journal of Cleaner Production*, vol. 295, 2021.
8. H. Singh, "Design and Deployment of IoT Solutions for Energy Monitoring," *International Journal of Smart Grid*, vol. 3, no. 4, pp. 45–52, 2022.
9. J. Smith, A. Banerjee, and L. Tan, "Design of Smart Energy Meters with IoT Integration," *IEEE Transactions on Industrial Electronics*, vol. 67, no. 10, pp. 8914–8923, 2020.
10. K. Zhang and H. Luo, "A Low-Cost Current Monitoring Solution for

- Distributed Solar Arrays,” *Renewable Energy Journal*, vol. 158, pp. 540–548, 2020.
11. Y. Lee, S. Moon, and T. Kang, “Development of IoT-Based Wind Speed Monitoring Systems,” *Sensors and Actuators A*, vol. 295, pp. 90–98, 2021.
12. P. Kaur and S. Aggarwal, “Solar Panel Monitoring Using IoT with Irradiance Sensors,” *International Journal of Energy Research*, vol. 45, pp. 12367–12375, 2021.
13. R. Verma, A. Yadav, and P. Singh, “IoT-Based Temperature and Humidity Monitoring in Renewable Systems,” *Procedia Computer Science*, vol. 190, pp. 150–157, 2021.
14. N. Joshi and K. Patel, “Hybrid Solar-Wind Power Monitoring with Raspberry Pi,” *Journal of Intelligent & Fuzzy Systems*, vol. 40, no. 3, pp. 2357–2364, 2022.
15. A. Mehta, “Using ThingSpeak and MATLAB for Remote Energy Monitoring,” *IoT Journal*, vol. 6, no. 4, pp. 225–232, 2022.
16. M. Zhang, A. Rahman, and J. Lin, “Efficient IoT Systems for Renewable Energy Monitoring,” *IEEE Access*, vol. 10, pp. 43121–43130, 2022.
17. A. Kumar and S. Das, “Low-cost Sensor Calibration in IoT Energy Systems,” *Renewable Energy Systems Journal*, vol. 35, no. 2, pp. 110–117, 2021.
18. P. Rana, “MQTT vs HTTP for IoT Sensor Data: A Comparative Study,” *International Journal of Embedded Systems*, vol. 14, no. 2, pp. 90–97, 2022.
19. R. Banerjee and R. Singh, “Data Transmission and Accuracy in Solar-Wind IoT Systems,” *Energy Informatics*, vol. 6, article 39, 2023.
20. N. Thakur, “Hybrid Renewable Energy Monitoring using IoT and Edge Computing,” *Smart Energy Systems*, vol. 18, pp. 210–219, 2023.