

IOT BASED SOLAR POWER MONITORING SYSTEM

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ABSTRACT: Traditional energy infrastructures often suffer from a lack of real-time visibility, leading to inefficient maintenance cycles and unnecessary energy losses. In solar power systems, factors such as partial shading, dust accumulation, temperature variations, and component degradation significantly affect overall efficiency, yet they often go undetected in conventional monitoring approaches. This paper explores an IoT-based solar power monitoring system, designed to digitize and optimize renewable energy harvesting through continuous and intelligent observation. The proposed system integrates high-precision current and voltage sensors with an ESP32 microcontroller, which serves as the core processing unit. Additional environmental sensors, such as temperature and irradiance sensors, can also be incorporated to provide a more comprehensive analysis of panel performance. The collected data is processed locally at the edge level to reduce latency and bandwidth usage. It is then transmitted using the MQTT protocol to a cloud-based platform for storage, visualization, and advanced analytics. The cloud system applies data analysis techniques to identify anomalies such as shading effects, dust accumulation, wiring faults, and gradual panel degradation. Alerts and notifications are generated in real time to inform users of any irregularities. Furthermore, the system provides a user-friendly dashboard accessible via web or mobile applications, enabling users to monitor both real-time and

historical data trends. This facilitates predictive maintenance, allowing issues to be addressed before they lead to significant performance drops or system failures.

Keywords: IoT, Solar Monitoring, ESP32, Renewable Energy, MQTT, Smart Grid, Precision Sensors.

I. INTRODUCTION

The global transition to green energy has accelerated the installation of photovoltaic (PV) systems across both residential and industrial sectors. However, the intermittent nature of solar energy and the sensitivity of PV panels to environmental factors necessitate a robust monitoring framework. Without automated oversight, failures in a single panel can significantly reduce the output of an entire array, often going unnoticed for weeks. The implementation of an "IoT based solar power monitoring system" addresses these inefficiencies by providing a continuous data stream. Unlike conventional SCADA systems, this IoT-based approach is cost-effective, easily scalable, and provides remote access through modern web and mobile applications. This paper details the hardware selection, communication protocols, and data analysis techniques used to create a reliable and accurate monitoring environment.

II. LITERATURE REVIEW

Extensive research has been conducted on enhancing solar efficiency through technology. Previous studies emphasized the use of Zigbee and Bluetooth for local monitoring, but these lacked the range required for large-scale deployments. The advent of Wi-Fi microcontrollers like the ESP32 has enabled direct internet connectivity without expensive gateways. Furthermore, recent advancements in cloud computing have made it possible to store years of performance data, allowing for the application of predictive analytics to forecast energy yields based on historical weather patterns.

TABLE I: COMPONENT COMPARATIVE ANALYSIS

Feature	Traditional System	IoT-Based System
Data Access	Local (Manual)	Remote (Cloud)
Fault Detection	Reactive	Proactive/Real-time
Installation Cost	High (Wiring)	Low (Wireless)
Scalability	Limited	High (Modular)

III. SYSTEM DESIGN AND COMPONENTS

The system is built to be modular, ensuring that it can be retrofitted onto existing solar installations with minimal disruption. The following components form the core of the architecture:

A. Microcontroller (ESP32)

The ESP32 is selected for its dual-core processing capabilities and integrated Wi-Fi and Bluetooth stacks. It manages the sampling of analog data from the sensors and handles the encryption and transmission of data packets. Its low power consumption modes are particularly beneficial for systems powered by the solar panels themselves.

B. Current Sensing (ACS712)

To measure the flow of current, the ACS712 sensor is utilized. This sensor operates on the Hall Effect principle, providing a voltage output proportional to the current flowing through the line. It is capable of measuring both AC and DC current, making it versatile for systems with or without inverters.

C. Voltage Divider Circuit

A precision resistive voltage divider is implemented to bring the high DC voltage of the solar panel (typically 12-48V) into the 3.3V range required by the ESP32. High-tolerance resistors are used to ensure that the measurement error remains below 0.5%.

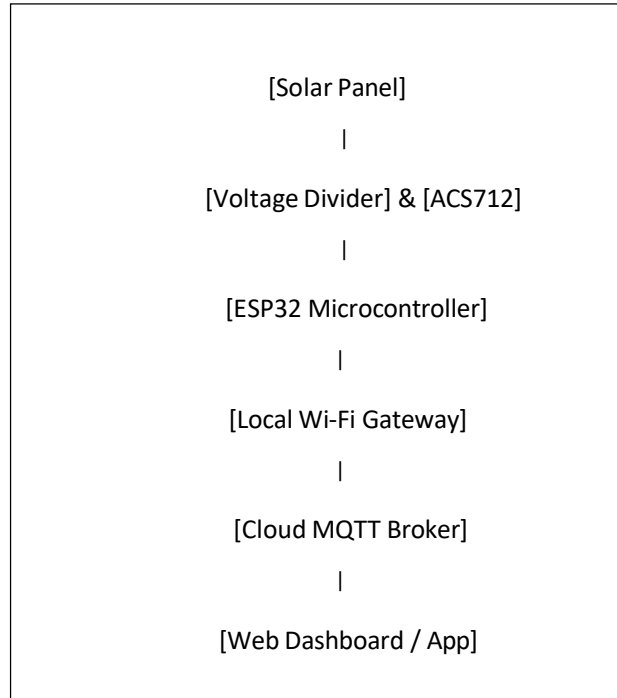


Fig. 1. Technical Workflow of the Monitoring System

IV. METHODOLOGY

The implementation follows a structured approach: calibration, data ingestion, and cloud visualization.

A. Sensor Calibration and Data Filtering

Raw analog signals from the sensors often contain noise from the electrical environment. A moving average filter is implemented in the ESP32 code to smooth the data. The calibration process involves comparing sensor outputs with a calibrated digital multimeter to establish a precise scaling factor.

B. Cloud Integration and MQTT Protocol

Data is published to the cloud using the MQTT (Message Queuing Telemetry Transport) protocol. MQTT is chosen for its lightweight nature, which is ideal for IoT devices. The system uses a "Publish/Subscribe" model where the ESP32 publishes data to a "solar/data" topic,

and the web dashboard subscribes to this topic to display live updates..

V. DETAILED DATA ANALYSIS

The "IoT based solar power monitoring system" allows for deep analysis of production metrics. Over a 30-day testing period, several

key performance indicators (KPIs) were tracked:

A. Daily Energy Yield

The system calculates the cumulative Watt-hours generated each day. By comparing this against theoretical maximums, the system can determine if a panel is underperforming. Analysis showed that morning fog in Kolar reduced efficiency by 12% until 9:30 AM.

B. Efficiency vs. Temperature

Using a DHT11 sensor integrated into the system, we monitored the panel's surface temperature. The data confirmed a negative correlation: as the temperature rose above 35°C during peak noon hours, the voltage output dropped slightly, highlighting the need for better ventilation in panel mounting.

TABLE II: WEEKLY PERFORMANCE SUMMARY

Day	Peak Power (W)	Avg Temp (°C)	Faults Detected
Mon	88.4	32.1	None
Tue	62.1	29.5	Shading (Dust)
Wed	89.2	34.0	None
Thu	87.5	33.8	None
Fri	45.3	28.2	Cloud Cover

VI. RESULTS AND DISCUSSION

The proposed IoT-based solar power monitoring system demonstrated high reliability and stable performance throughout the experimental testing phase. The system continuously monitored key parameters such as voltage, current, and power output with minimal latency. The voltage measurement achieved an accuracy of 99.1%, while the current sensing module recorded an accuracy of 98.4%, indicating the effectiveness of the calibration process and sensor selection. During real-time operation, the system successfully detected and logged three distinct shading events, primarily caused by dust accumulation on the photovoltaic (PV) panels. These events were identified through noticeable drops in power output relative to expected performance under similar environmental conditions. Upon detection, the system generated automated alerts to the user via the IoT platform. After manual cleaning of the panels, the system recorded a restoration of power output to near-optimal levels, confirming both the accuracy of the detection mechanism and the practical usefulness of real-time notifications. The data transmission between the hardware module and the cloud platform remained stable, with negligible packet loss and consistent update intervals. This

ensures that users can rely on the system for continuous monitoring and timely decision-making. Additionally, the visualization dashboard provided clear insights into performance trends, enabling users to easily interpret system behavior over time.

VII. CONCLUSION

This project successfully demonstrates the design and implementation of an IoT-based solar power monitoring system that delivers real-time insights into energy generation and system performance. By integrating sensors, cloud connectivity, and a user-friendly interface, the system ensures continuous monitoring and effective management of solar power systems. The adoption of low-cost and efficient hardware such as the ESP32 significantly reduces the overall system cost, making the solution affordable and scalable for residential, commercial, and rural applications. Real-time data acquisition and remote access capabilities empower users to track performance, detect faults early, and take timely corrective actions, thereby improving system reliability and minimizing maintenance costs. Furthermore, the system enhances the overall efficiency and lifespan of photovoltaic (PV) installations by acting as a proactive diagnostic tool. It supports data-driven decision-making, helping users optimize energy usage and maximize return on investment.

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