A Study of IOT Based Real-Time Monitoring Multiple Solar Power Remote Monitoring

Dipali E. Bhatkar
Department of Electrical Power System
GCOEA

ABSTRACT

This paper presents the design and implementation of an IoT-based real-time remote monitoring system for multiple solar power sources using the ESP32 microcontroller. The system is developed to monitor and compare the performance of two solar panels-one monocrystalline and one polycrystalline-under similar environmental conditions. Voltage and current sensors are integrated with each panel to accurately measure electrical output. The ESP32 collects data from the sensors and transmits it via Wi-Fi to the ThingSpeak cloud platform, where it is visualized and analyzed in real time. This setup enables users to remotely track and evaluate the efficiency, stability, and behavior of both solar panel types. The system offers a scalable and cost-effective solution for solar energy monitoring, supporting further research and practical applications in renewable energy optimization and management.

Keywords: IoT, ESP32, Solar Power Monitoring, Monocrystalline Solar Panel, Polycrystalline Solar Panel, Voltage Sensor, Current Sensor.

The increasing demand for renewable energy has made solar power one of the most widely adopted and environmentally friendly alternatives to traditional energy sources. As solar panel installations grow in both residential and commercial sectors, the need for efficient monitoring and management systems becomes crucial to ensure optimal performance and early detection of faults.

Monitoring solar energy systems in real time provides valuable insights into energy production, panel efficiency, and overall system health. Among the various available technologies, Internet of Things (IoT) has emerged as a powerful solution for enabling remote and continuous monitoring of energy systems. By integrating sensors with IoT-enabled microcontrollers, solar panel performance can be tracked and analyzed in real time from virtually anywhere.

This study focuses on the development of an IoT-based real-time monitoring system using the ESP32 microcontroller. The system compares two types of solar panels—monocrystalline and polycrystalline—by measuring their voltage and current outputs using dedicated sensors. Data from each panel is transmitted via Wi-Fi to the ThingSpeak cloud platform, where it is logged, visualized, and analyzed for performance evaluation.

The main objective of this system is to provide a low-cost, scalable, and accessible solution for remote solar monitoring, enabling users to make informed decisions about energy usage and system maintenance. Furthermore, the comparative analysis between monocrystalline and polycrystalline panels offers insights into the practical performance differences between the two technologies under real-world conditions.

2. METHODOLOGY

The methodology involves the design, development, and implementation of a real-time solar monitoring system using IoT technology. The system architecture includes two types of solar panels, voltage and current sensors, an ESP32 microcontroller, and the ThingSpeak cloud platform for data visualization. The primary aim is to acquire, transmit, and analyze data to compare the performance of monocrystalline and polycrystalline solar panels. System Architecture

The monitoring system comprises the following components:

ESP32 Microcontroller: Serves as the central unit, collecting sensor data and transmitting it to the cloud via Wi-Fi. Solar Panels: *Monocrystalline*: Known for higher efficiency and performance in limited space, *Polycrystalline*: Cost-effective with slightly lower efficiency.

Voltage Sensors (x2): Measure the output voltage from each solar panel.

Current Sensors (x2): Measure the current flowing from each panel to the load.

ThingSpeak Cloud Platform: Receives and displays data in real-time using visual graphs.

Data Acquisition: Each solar panel is connected to a dedicated set of voltage and current sensors: Voltage is measured using voltage divider-based sensors suitable for the ESP32's ADC input. Current is measured using sensors such as ACS712, which provide analog output proportional to the current flow. The ESP32 reads analog voltage and current values using its built-in ADCs. These raw readings are converted into meaningful electrical values (volts and amps) through calibration and scaling formulas.

Data Transmission: The ESP32 is programmed using the Arduino IDE. It connects to a Wi-Fi network and periodically sends the sensor data to the ThingSpeak platform using HTTP POST requests through the Thing Speak API. Each panel's data is sent to separate fields for clear comparison.

Data Visualization and Analysis:Once the data is uploaded to ThingSpeak: Live graphs are generated for voltage and current of both panels.Comparative analysis is possible by observing trends and variations in output based on environmental conditions. This real-time monitoring allows for performance comparison, fault detection, and insights into energy generation patterns.

Experimental Setup:The system is deployed under similar environmental conditions for both types of solar panels to ensure fair comparison. The setup runs continuously to collect time-series data, which is stored and analyzed through the ThingSpeak platform.

3. MODELING AND ANALYSIS

Modelling and Analysis

The modeling and analysis of the proposed IoT-based solar monitoring system focus on understanding the electrical behavior of two different types of solar panels—monocrystalline and polycrystalline—using real-time voltage and current measurements. The system uses sensor-based modeling to acquire data and cloud-based tools to analyze and compare the performance.

3.1 System Modeling

The system is modeled in two layers: the hardware model for data acquisition and the software/cloud model for data processing and analysis.

3.1.1 Hardware Model

Each solar panel is modeled as an independent DC power source with varying output based on sunlight intensity and panel efficiency. The mathematical relationship used is based on basic electrical power laws:

$P=V\times I$

Each sensor's output is modeled using calibration equations based on their specifications:

Voltage Sensor Output:

$V_{actual}= (V_{ADC}*V_{ref})*\text{scaling factor}$

Current Sensor Output (e.g., ACS712):

$I_{actual}=(V_{sensor}-V_{zero})/\text{sensitivity}$

These values are read by the ESP32's ADC pins and converted into digital data for cloud transmission.

Software/Cloud Model

ThingSpeak is used to model the behavior of the solar panels over time:

Separate channels and fields are created for each panel's voltage and current.

Time-series plots are generated for real-time observation.

Power output is calculated and visualized using custom MATLAB code within ThingSpeak or locally on the ESP32.

3.2 Data Analysis

Once data is collected on ThingSpeak, it is analyzed to compare the performance of the two panel types:

3.2.1 Comparative Analysis

Voltage Comparison: Observes which panel generates a higher voltage under similar conditions.

Current Comparison: Evaluates the load-handling capacity.

Power Output Comparison: Assesses efficiency using calculated power.

3.2.2 Time-Based Trends

Performance during different times of the day is analyzed.

Graphs indicate the effect of sunlight variation on each panel type.

Insights and Observations:

The monocrystalline panel generally produces slightly higher voltage and power output compared to the polycrystalline panel under identical light conditions.

The cloud-based approach allows continuous tracking, storage, and comparative performance analysis.

The system is responsive and effective in capturing small fluctuations in panel behavior, enabling more informed maintenance or energy management decisions.

4.RESULTS AND DISCUSSION

Voltage and Current Output

- Monocrystalline Panel:
  - Voltage: Consistently higher, averaging around 19.5V.
  - Current: Higher current output, especially during peak sunlight hours.
- Polycrystalline Panel:
  - Voltage: Slightly lower, averaging around 18V.
  - Current: Lower current output compared to the monocrystalline panel.

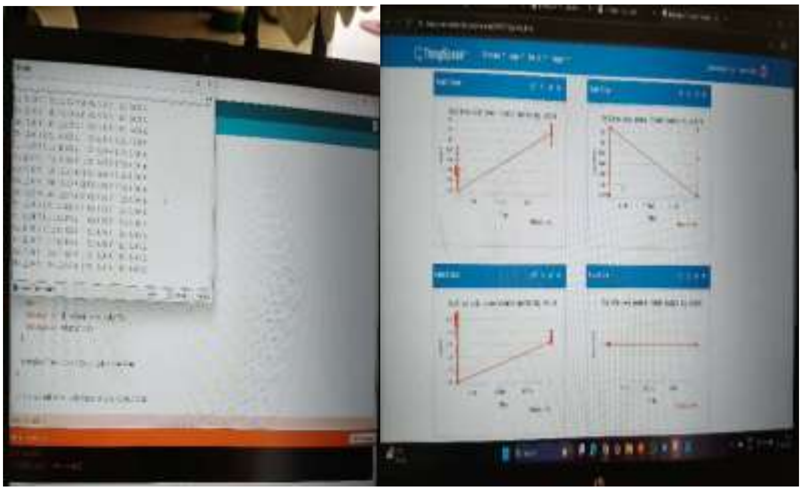

Figure: Results

CONCLUSION

The IoT-based monitoring system effectively demonstrated the superior performance of monocrystalline solar panels over polycrystalline ones under the tested conditions. The integration of ESP32 with ThingSpeak provided a robust platform for real-time data acquisition and analysis, offering valuable insights into solar panel performance metrics.

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