



IOT Based Solar Power Measurement System Using Arduino Uno With Solar Tracking

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Abstract: Solar energy is one of the most important renewable energy sources used for clean and sustainable power generation. Photovoltaic (PV) systems convert sunlight into electrical energy using semiconductor materials. However, the performance of solar panels varies due to environmental conditions such as sunlight intensity, temperature, and dust. Therefore, real-time monitoring of PV systems is essential for improving efficiency and detecting faults.

This paper presents an IoT-based solar panel monitoring system that measures important parameters such as voltage, current, temperature, and output power in real time. The system uses sensors and an Arduino/ESP32 microcontroller to collect data and transmit it wirelessly to an Android smartphone through IoT technology. The proposed system provides remote monitoring, easy maintenance, low cost, and improved performance analysis of solar panels. Experimental results show that the system is reliable and suitable for residential and small-scale solar power applications.

Keywords: Solar Energy, Photovoltaic System, IoT, Solar Panel Monitoring, Arduino, Wireless Communication, Renewable ENERGY.

I. INTRODUCTION

Solar energy is one of the fastest growing renewable energy sources in the world due to the increasing demand for clean, reliable, and sustainable electricity generation. Among various renewable energy technologies, photovoltaic (PV) systems are widely used because they directly convert sunlight into electrical energy through the photovoltaic effect. A photovoltaic panel is made up of semiconductor materials, mainly silicon, which generates electrical current when exposed to sunlight. PV systems offer several advantages such as low maintenance cost, high reliability, noiseless operation, and zero environmental pollution. These benefits make solar energy suitable for residential, commercial, and industrial applications.

The performance of solar panels mainly depends on environmental factors such as solar irradiance, temperature, dust accumulation, shading, and the direction of sunlight. Variations in these conditions cause fluctuations in the output voltage, current, and power generated by the PV system. Therefore, continuous monitoring of solar panel parameters is necessary to improve efficiency, detect faults, and ensure proper operation of the system. Manual monitoring methods are difficult, time-consuming, and less accurate for large-scale installations.

With the development of Internet of Things (IoT) technology, smart monitoring systems have become more efficient and reliable. IoT-based solar monitoring systems can collect real-time data from sensors and transmit it wirelessly to

cloud platforms or mobile applications for remote monitoring and analysis. These systems help users monitor the performance of solar panels from any location, reduce maintenance efforts, and improve energy management.

II. LITERATURE REVIEW

[1] S. H. Sajjad, M. Erfanul Haque Sajib, M. N. Hasan and M. Abdur Razzak developed an IoT-based solar power monitoring system using ESP32 microcontroller and cloud technology in 2023. The system was designed to monitor solar panel voltage, current, temperature, and power in real time. The collected data was transmitted to a mobile application for remote monitoring and analysis. The proposed system reduced manual supervision and improved the efficiency of photovoltaic systems. The authors concluded that IoT technology provides a reliable and cost-effective solution for solar energy monitoring.

[2] B. E. Demir and E. Gül proposed a low-cost IoT-based monitoring system for photovoltaic energy systems in 2023. The system used sensors and wireless communication modules for real-time data acquisition and transmission. The monitored parameters included voltage, current, temperature, and solar irradiance. The study also implemented machine learning techniques to estimate solar power generation and improve prediction accuracy. Experimental results showed improved system efficiency and reliable monitoring performance.

[3] N. Rouibah, A. Hamidat and M. Benyoucef presented a smart IoT prototype for photovoltaic system monitoring in 2025. The proposed system used wireless communication and cloud storage to monitor PV system performance remotely. The monitoring platform provided real-time graphical visualization of solar parameters through a web-based interface. The authors highlighted that the system helped in quick fault identification and reduced maintenance cost.

[4] C. Krishna Rao and P. Sahoo designed an intelligent smart energy monitoring system for solar PV generation using IoT technology in 2024. The system continuously measured electrical parameters such as voltage, current, and output power using sensors connected to a microcontroller. The collected data was transmitted to a cloud server for storage and analysis. The proposed model improved energy management and system reliability in solar applications.

[5] A. Ftirich, M. El Ghzizal and H. Bennis implemented a low-cost real-time monitoring system for building-integrated photovoltaic systems in 2024. The monitoring system was designed using IoT technology and wireless sensors to collect environmental and electrical parameters. The proposed system successfully monitored PV panel performance and provided accurate data analysis for energy optimization. The authors emphasized that the system can be effectively used in residential and industrial applications.

[6] Gaurav Khambalkar, Atharva Wasurkar, Ritesh Jibhakate, Suraj Dongare and Vijay Chikhalonde proposed an IoT-based solar power monitoring system in 2023. The system used sensors to monitor voltage, current, and power generation of solar panels. The measured data was displayed on a mobile application through wireless communication. The study concluded that the proposed system improved monitoring accuracy and reduced maintenance complexity.

[7] O. Sobhana, G. C. Prabhakar, Amarnadh Reddy Nalamalapu and Rashmi Kapoor developed a smart IoT-based solar monitoring system for environmental sustainability in 2022. The system collected solar panel parameters using sensors and transmitted the data to cloud storage for real-time analysis. Graphical visualization of the monitored data helped users understand system performance effectively. The proposed system contributed to efficient renewable energy utilization.

[8] N. Chamat and M. P. Tellawar designed a solar power monitoring system using IoT technology in 2023. The system monitored solar panel voltage, current, and output power using wireless communication techniques. The monitored data was stored in cloud platforms for remote access and analysis. The proposed system was found to be reliable, cost-effective, and suitable for small-scale photovoltaic systems.

[9] J. H. Syu, M. E. Wu, Gautam Srivastava and Jerry Chun-Wei Lin proposed an IoT-based smart energy management system for solar power generation in 2023. The study focused on predictive analytics and intelligent monitoring techniques for efficient solar energy management. The proposed system improved energy prediction accuracy and optimized solar power utilization using IoT-enabled technologies.

[10] G. Shukla, J. Li, H. Xu and Y. Wang presented a review on IoT-enabled photovoltaic systems for real-time monitoring and predictive maintenance in 2025. The study analyzed recent advancements in IoT technologies, cloud computing, and artificial intelligence for solar energy applications. The authors concluded that IoT-based monitoring systems significantly improve fault detection, system reliability, and energy efficiency in photovoltaic systems.

III. METHODOLOGY

The proposed system is an IoT-based solar panel monitoring system designed to measure and monitor important photovoltaic (PV) parameters in real time. The system mainly consists of a solar panel, voltage sensor, current sensor, temperature sensor, Arduino/ESP32 microcontroller, Wi-Fi communication module, cloud platform, and Android smartphone application. The methodology of the proposed system is divided into different stages including data sensing, data processing, wireless communication, cloud storage, and remote monitoring.

Initially, the photovoltaic panel converts solar radiation into electrical energy using the photovoltaic effect. The output generated from the solar panel depends on environmental conditions such as sunlight intensity, temperature, shading, and dust accumulation. To continuously monitor the performance of the solar panel, different sensors are connected to the PV system. A voltage sensor is used to measure the output voltage of the solar panel, while a current sensor measures the generated current. A temperature sensor is also included to monitor the panel temperature because temperature variations directly affect the efficiency and output performance of the PV system.

The sensor data is continuously collected by the Arduino/ESP32 microcontroller, which acts as the main control unit of the system. The microcontroller processes the received data and converts it into digital values for monitoring and analysis. The processed data is then transmitted wirelessly using Wi-Fi communication technology. The system can use built-in Wi-Fi features of ESP32 or an external Wi-Fi module for internet connectivity.

The transmitted data is sent to a cloud server or IoT platform such as Blynk, ThingSpeak, or Firebase for storage and visualization. Cloud integration enables real-time monitoring and secure storage of solar panel performance data. Users can access the monitored parameters remotely through an Android smartphone application or web interface. The application displays real-time values of voltage, current, temperature, and power generation in graphical and numerical formats.

Mathematical Model

The output power generated by the photovoltaic (PV) panel is calculated using the relation:

$$P = V \times I$$

Where:

P = Output Power (W)

V = Output Voltage (V)

I = Output Current (A)

The efficiency of the solar panel is given by:

$$\eta = \frac{P_{out}}{P_{in}} \times 100$$

Where:

- η = Efficiency (%)
- P_{out} = Output Power
- P_{in} = Input Solar Power

IV. BLOCK DIAGRAM

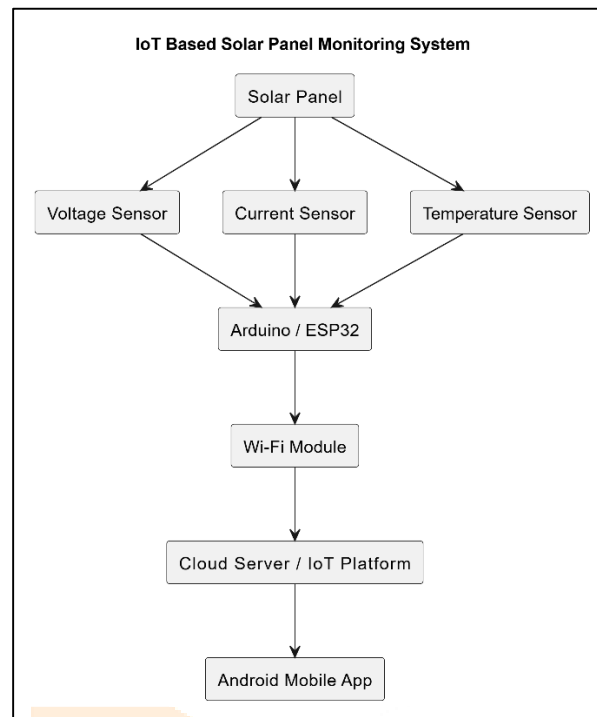


Fig 1 – Block Diagram

V. RESULTS AND DISCUSSION

| Time | Voltage (V) | Current (A) | Temperature (°C) | Output Power (W) | Observation |
|----------|-------------|-------------|------------------|------------------|----------------------------|
| 9.00 AM | 16.5 | 1.8 | 28 | 29.7 | Moderate sunlight |
| 11.00 AM | 18.2 | 2.5 | 32 | 45.5 | Increased power generation |
| 1.00 PM | 19 | 3 | 36 | 57 | Maximum output observed |
| 3.00 PM | 17.4 | 2.3 | 34 | 40 | Slight reduction in power |
| 5.00 PM | 15.2 | 1.5 | 30 | 22.8 | Reduced sunlight intensity |

The experimental results obtained from the proposed IoT-based solar panel monitoring system demonstrate that the system is capable of accurately monitoring photovoltaic parameters in real time. The voltage, current, temperature, and output power values were measured continuously and transmitted successfully to the Android application through wireless communication. The monitored data clearly showed variations in solar panel performance under different environmental conditions such as sunlight intensity and temperature.

From the observed results, it was found that the solar panel generated maximum output power during peak sunlight hours around midday. During morning and evening hours, the power generation decreased due to lower solar irradiance. Temperature also influenced the performance of the photovoltaic panel, where excessive temperature slightly reduced the system efficiency. The proposed monitoring system effectively recorded these variations and provided reliable performance analysis.

The system also demonstrated efficient remote monitoring capability by allowing users to access real-time solar panel data from any location using a smartphone. Cloud-based storage helped maintain historical records for future analysis and troubleshooting.

In addition, the monitoring system can assist in identifying abnormal conditions such as voltage fluctuations, overheating, and reduced power output, which improves system maintenance and reliability.

Overall, the developed system provides a low-cost, reliable, and user-friendly solution for solar energy monitoring. The integration of IoT technology with photovoltaic systems improves energy management, reduces manual monitoring efforts, and enhances the overall efficiency of renewable energy systems.

VI. CONCLUSIONS

The proposed IoT-based solar panel monitoring system was successfully designed and implemented for real-time monitoring of photovoltaic (PV) system parameters. The system continuously measured important parameters such as voltage, current, temperature, and output power using sensors connected to the Arduino/ESP32 microcontroller. The collected data was transmitted wirelessly through Wi-Fi communication and displayed on an Android smartphone application for remote monitoring and analysis.

The experimental results showed that the system accurately monitored the performance of the solar panel under different environmental conditions. The developed system reduced the need for manual supervision and helped in identifying abnormal conditions such as power fluctuations and overheating. The integration of IoT technology improved the efficiency, reliability, and maintenance of the photovoltaic system.

Overall, the proposed monitoring system provides a low-cost, user-friendly, and efficient solution for solar energy management. The system is suitable for residential, commercial, and small-scale industrial applications, contributing to better utilization of renewable energy resources and supporting the development of smart energy systems.

VII. FUTURE SCOPE

The proposed IoT-based solar panel monitoring system can be further enhanced by integrating advanced technologies such as artificial intelligence (AI) and machine learning (ML). These technologies can be used for predictive maintenance, fault detection, and performance forecasting of photovoltaic systems. By analyzing historical sensor data, the system can predict possible failures, identify abnormal operating conditions, and provide early warning alerts to users. This will help in reducing maintenance costs, improving system reliability, and increasing the overall efficiency of solar power generation. In addition, advanced data analytics can be used to optimize energy production based on weather conditions, solar irradiance, and load requirements.

In future, the monitoring system can also be integrated with smart grid and cloud computing technologies for large-scale solar power plant applications. Features such as automatic solar tracking, battery health monitoring, and energy consumption management can further improve the performance of the system. The use of advanced wireless communication technologies such as 5G and Lora WAN can provide faster and more reliable data transmission over long distances. Furthermore, the system can be expanded to support hybrid renewable energy systems by integrating wind and battery storage systems for efficient and sustainable energy management.

VIII. ACKNOWLEDGMENT

We students would like to express their sincere gratitude to the management, department staff, and project guide for their valuable guidance, continuous support, and encouragement throughout the completion of this project work. Their technical suggestions and motivation greatly helped in the successful development of the IoT-based solar panel monitoring system.

We students also thank all faculty members, friends, and researchers whose references and research papers provided important knowledge and support for this study. Finally, heartfelt thanks are extended to everyone who directly or indirectly contributed to the successful completion of this project.

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