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

Dipali E. Bhatkar
Department of Electrical Power System
GCOEA

Abstract: The growing adoption of solar energy as a clean and renewable power source demands efficient monitoring systems to ensure optimal performance. This paper presents a study on the design and implementation of an IoT-based real-time solar power monitoring system. The proposed system uses ESP32 microcontroller, voltage and current sensors, and Wi-Fi connectivity to monitor and transmit data from solar panels. The collected data such as voltage, current, and power output is uploaded in real-time to the ThingSpeak IoT platform, enabling continuous remote monitoring and analysis. The system helps identify faults, assess performance, and manage energy usage effectively. This low-cost, scalable, and real-time solution enhances the reliability, maintenance, and efficiency of solar power systems, making it highly suitable for both urban and remote applications.

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

1. Introduction

Solar energy is one of the most abundant and sustainable sources of energy available on Earth. It is a clean, renewable alternative to fossil fuels and plays a crucial role in reducing greenhouse gas emissions, mitigating climate change, and promoting energy independence. As global energy consumption continues to rise, the need for environmentally friendly and cost-effective energy solutions becomes more urgent. Solar power offers a scalable and decentralized option for both urban and rural energy demands. One of the key advantages of solar energy is its accessibility-sunlight is available almost everywhere, and solar panels can be installed in remote locations without reliance on traditional power grids. Additionally, solar energy systems have low operating and maintenance costs, making them suitable for long-term energy planning. Understanding the differences in output and behavior of these panels under real-world conditions is essential for optimal system design and energy planning.[1]

This project contributes to that understanding by implementing a real-time monitoring system that compares the voltage, current, and power output of both monotype and polytype solar panels. By using IoT technologies such as the ESP32 microcontroller and the ThingSpeak cloud platform, this study demonstrates how solar energy performance can be continuously monitored, analyzed, and optimized. The insights gained not only help improve the efficiency of existing systems but also support smarter decision-making in future solar energy deployments.[2]

2. Hardware Requirements

A. ESP32 Microcontroller

The ESP32 is a powerful, low-cost, low-power microcontroller developed by Espressif Systems that has become increasingly popular in embedded systems and Internet of Things (IoT) applications. It features a dual-core Tensilica LX6 processor, integrated Wi-Fi and Bluetooth capabilities, and a rich set of peripherals, making it a versatile platform for a wide range of real-time data acquisition and control tasks. One of the key reasons for its adoption in modern IoT projects is its ability to handle both edge-level computing and cloud communication seamlessly, without the need for additional hardware. In the context of a solar energy monitoring system, the ESP32 plays a central role as the primary controller and data processor.

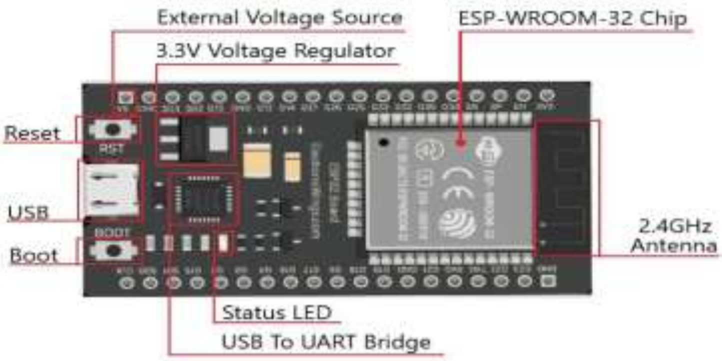

Fig: 1. ESP32 Microcontroller

B. Monocrystalline Solar Panel

Monocrystalline solar panel is made from a single continuous crystal structure of high-purity silicon. The manufacturing process involves slicing wafers from a cylindrical silicon ingot, which gives the cells their characteristic rounded edges and dark black appearance. Because of their uniform crystal structure, electrons move more freely within the cells, resulting in higher energy conversion efficiency typically ranging from 18% to 22%. In a solar monitoring system, monocrystalline panels offer superior performance, especially in low-light or cloudy conditions, where consistent energy generation is critical. Their higher efficiency also means they require less space to produce the same amount of power compared to other panel types.

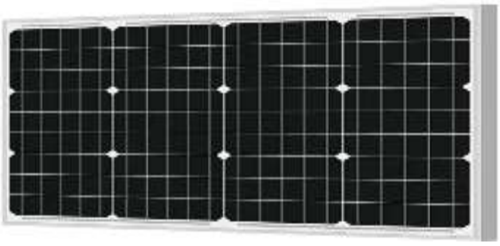

Fig:2. Monocrystalline Solar Panel

C. Polycrystalline Solar Panel

Polycrystalline solar panel is made by melting and casting multiple silicon crystals together, which are then cut into square wafers. These panels have a distinctive bluish hue and grainy texture, indicating the presence of multiple silicon fragments. Because the electrons encounter more resistance as they pass through the various crystal boundaries, polycrystalline panels have slightly lower efficiency, typically ranging from 15% to 17%. Despite their lower efficiency, polycrystalline panels are more cost-effective to produce, making them a popular choice for large-scale installations where space constraints are less of a concern. They also exhibit good performance under standard sunlight conditions, though they may be slightly less effective in low-light or high-temperature environments compared to monocrystalline panels.

Fig:3. Polycrystalline Solar Panel

D. Current Sensor

A current sensor is an essential component in an IoT-based solar monitoring system, responsible for measuring the flow of electric current from the solar panels to the load or storage system. In a photovoltaic (PV) setup, monitoring the

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current output is crucial because it directly correlates with the amount of electrical power being generated by the solar panels. The current measurement, when combined with voltage data, allows for the accurate calculation of power output, efficiency, and system performance. Current sensors operate on various principles depending on their type, but in solar monitoring applications, the most commonly used are Hall-effect sensors such as the ACS712.

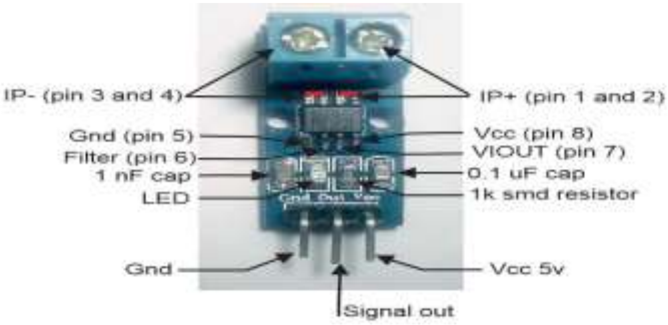

Fig:4. Current Sensor

E. Voltage Sensor

A voltage sensor is a critical component in the monitoring system of a solar photovoltaic (PV) setup. It is designed to measure the electrical potential difference across two points in an electrical circuit in this case, the output voltage from the solar panels. Accurate voltage measurement is essential for calculating the real-time power output, assessing the efficiency of energy conversion, and diagnosing potential faults in the system. In solar energy applications, voltage sensors typically function by scaling down the high voltage produced by the solar panels to a level that is safe and readable by a microcontroller like the ESP32. This is done using voltage divider circuits or specialized sensor modules.

Fig:5. Voltage Sensor

3. SOFTWARE REQUIREMENTS

A. ThingsSpeak Cloud Setup

ThingsSpeak is an open-source IOT platform application, which offers different services, that are only focused on building IOT applications. It is an API that stores and retrieves the information from the sensor or the objects/things associated with the system through the internet that utilizes Hypertext Transfer Protocol (HTTP) from the local network to the cloud. All the information logs that are received from the sensors will get updated by ThingsSpeak cloud platform application, tracking the location applications, and the status application providing to the clients(users) and taken from the clients. To use the ThingsSpeak application, the client needs to create an account which contains various channels aimed at observing the various parameters in the framework or in monitoring the parameters in a remote device. This cloud allows the administrator(user) to envision the information in graphical representation. Energy yield information is transferred to a router with internet-based monitoring, making it accessible through the online interface. Your solar panel output information can be accessed from anywhere you can get an internet connection, which is the primary benefit of frameworks like these.

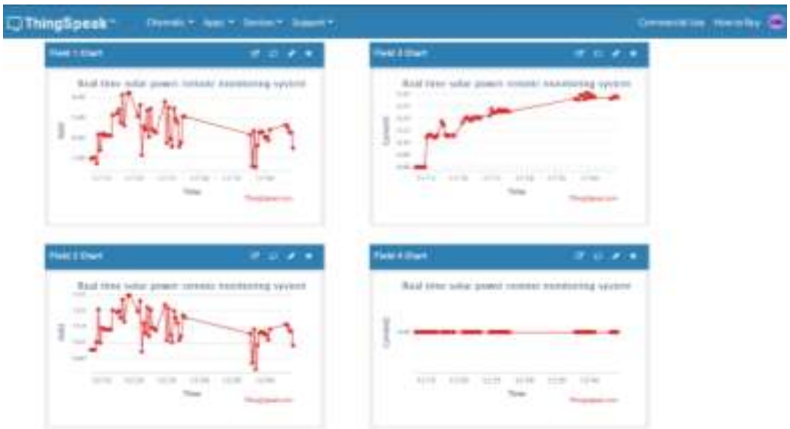

Fig: 6. ThingSpeak Cloud Setup

B. Arduino Integrated Development Environment (IDE)

Arduino IDE is the open-source development platform compatible for Mac OS X, windows and Linux (both 32 and 64bits) operating system. This software is mainly used for editing, compiling and uploading the code into the Arduino device. Both C and C++ programming languages are supported in this environment. It is easy to install. You can easily add libraries according to the hardware module. And also, software update will be available from time to time.

4. WORKING PROCESS

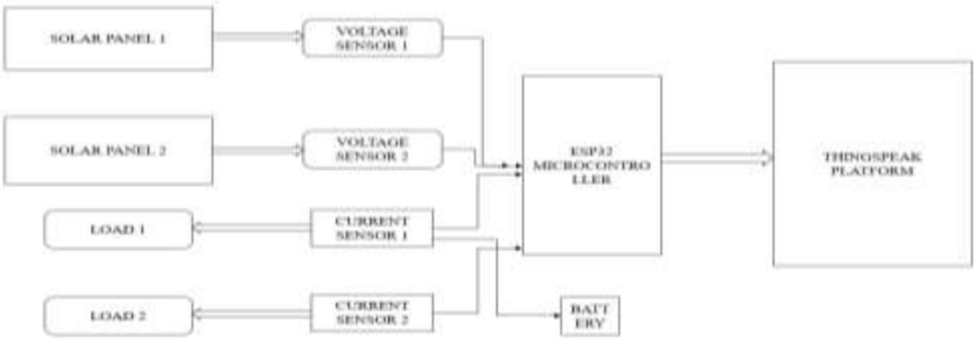

Fig:7. Block Diagram Of Study Of IoT Based Real Time Solar Power Monitoring System

The block diagram illustrates an IoT-based real-time solar power monitoring system that uses two solar panels to generate electricity, each monitored by a voltage sensor. The power generated is supplied to two separate loads, with current sensors measuring the current drawn by each load. All sensor data voltage and current is sent to the ESP32 microcontroller, which is powered by a battery to ensure uninterrupted operation. The ESP32 processes this data and transmits it via Wi-Fi to the ThingSpeak platform, where it is stored, visualized, and analyzed in real time. This setup enables continuous remote monitoring of the solar system's performance, improving efficiency, fault detection, and maintenance planning.

5. RESULT AND DISCUSSION

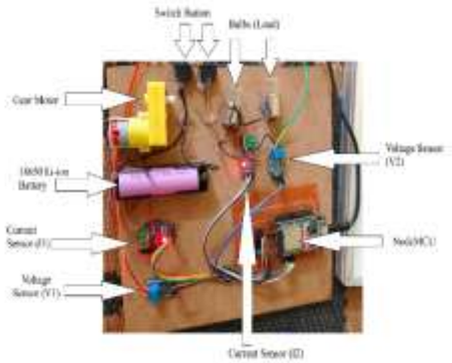

Fig:8. Circuit Board of Solar Monitoring System

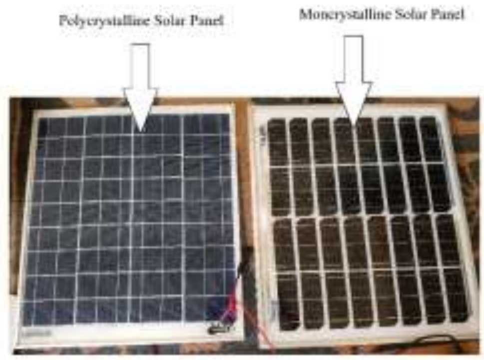

Fig:9. Solar Panels

At Morning Session

The graph displays real-time monitoring data of a solar power system using ThingSpeak, showing voltage and current readings from two solar panels. In Field 1 and Field 2 charts, both voltage outputs initially start around 2V, then rise and fluctuate between 3.5V to 4V, indicating active solar generation. A sudden drop in Voltage 2 suggests a possible brief disconnection or shadowing. The current output in Field 3 (Current 1) increases steadily to about 0.5A and remains relatively stable, while Field 4 (Current 2) shows mostly low current with a single sharp spike, possibly due to a momentary load or sensor anomaly. Overall, the data reflects effective solar energy generation with minor fluctuations and highlights the importance of real-time monitoring for detecting irregularitiesas shown in fig.5(a).

Fig.5(a) Recorded data in the morning (Field1)Voltage1 Vs Date/Time graph,(Field2) Voltage2 Vs Date/Time graph,(Field3) Current1 Vs Date/Time,(Field4) Current2 Vs Date/Time.

At Afternoon Session

This graph presents real-time monitoring data of a solar power system using ThingSpeak, showcasing voltage and current readings from two separate solar panels. Field 1 and Field 2 charts show the voltage outputs of Panel 1 and Panel 2, respectively. Both voltages initially rise and fluctuate Volt1 between 3.5V to 5.5V and Volt2 between 10V to 12.5V then show a gradual drop after 12:30 PM, possibly due to a change in sunlight intensity or load. Field 3 (Current1) shows a consistent increase from 0 to about 0.25A, indicating efficient current generation by Panel 1. In contrast, Field 4 (Current2) remains nearly flat at 0A throughout, suggesting that Panel 2 is either underperforming or disconnected. Overall, the system demonstrates good performance from Panel 1, while Panel 2 requires inspection due to the absence of current flow as shown in fig.5(b).

Fig.5(b) Recorded data in the morning (Field1)Voltage1 Vs Date/Time graph,(Field2) Voltage2 Vs Date/Time graph,(Field3) Current1 Vs Date/Time,(Field4) Current2 Vs Date/Time.

At Night Session

This graph from ThingSpeak shows real-time monitoring of a solar power system, recording voltage and current data for two solar panels. In Field 1 (Volt1), the voltage initially peaks around 6.5V, then drops sharply and remains near 0V, indicating a possible disconnection or lack of sunlight. Field 2 (Volt2) shows fluctuating voltage between 4V to 7V, with some interruptions, suggesting unstable generation or intermittent load conditions. Field 3 (Current1) shows relatively stable current between 0.45A to 0.50A, confirming consistent output from the first panel, but it drops suddenly at the end. In contrast, Field 4 (Current2) mostly stays near 0A, with only two brief spikes, indicating the second panel is not actively generating current. Overall, the data suggests stable performance from the first panel for a while, while the second panel shows irregular or minimal activity, possibly due to system faults, shading, or poor connection as shown in fig.5(c)

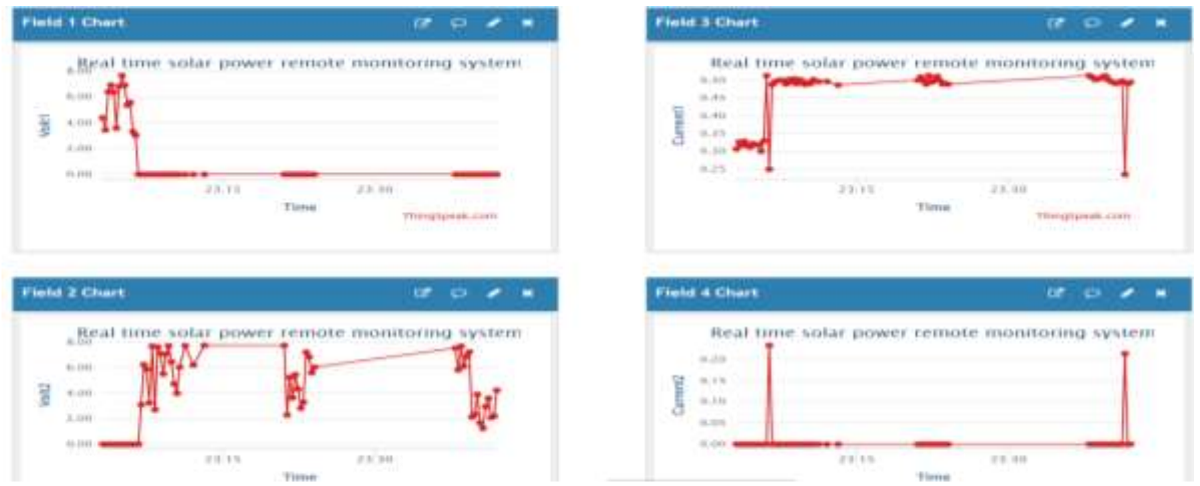

Fig.5(c) Recorded data in the morning (Field1)Voltage1 Vs Date/Time graph,(Field2) Voltage2 Vs Date/Time graph,(Field3) Current1 Vs Date/Time,(Field4) Current2 Vs Date/Time.

6. CONCLUSIONS

In conclusion, the implementation of an IoT-based real-time solar power monitoring system proves to be an effective and efficient solution for continuously observing the performance of solar panels. By integrating sensors and microcontrollers with cloud-based platforms like ThingSpeak, the system enables users to remotely monitor voltage, current, and overall power generation. This real-time access to data not only helps in identifying faults and inefficiencies promptly but also improves system maintenance and energy utilization. The project demonstrates how IoT can enhance the reliability, productivity, and sustainability of solar energy systems, making it a valuable approach for modern renewable energy management.

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