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IoT Based Solar Power Monitoring System

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ABSTRACT

The rapid growth of renewable energy sources, particularly solar power, has created a need for efficient real-time monitoring systems. This paper presents an IoT-based Solar Power Monitoring System designed to measure and remotely monitor key electrical and environmental parameters of a solar panel installation. The system use an ESP32 microcontroller interfaced with a voltage sensor, current sensor, and DHT11 sensor to acquire real-time data. The measured parameters voltage (V), current (A), power (W), and temperature (°C) are transmitted over Wi-Fi to the Blynk IoT cloud platform, where they are displayed on a mobile/web dashboard using gauge widgets. A 16x2 LCD display provides local data readout. The hardware prototype uses a 12V/25W solar panel with an LED bulb as the load. Experimental results demonstrate the system successfully monitors voltage up to 20V, current up to 2A, power up to 25W, and temperature up to 70°C in real time. The proposed system offers a cost-effective, scalable, and user-friendly solution for solar energy management.

Introduction:

Solar energy is one of the most abundant and environmentally friendly renewable energy sources available globally. As the adoption of solar photovoltaic (PV) systems continues to grow, the need for efficient, real-time monitoring of these systems becomes increasingly important. Traditional monitoring methods are often manual, time-consuming, and prone to error. The integration of the Internet of Things (IoT) with solar monitoring systems offers an intelligent and automated approach to track solar panel performance continuously.

This paper proposes an IoT-based Solar Power Monitoring System that leverages the capabilities of the ESP32 microcontroller, various sensors, and the Blynk IoT cloud platform to provide real-time visibility into key parameters of a solar energy system. The system monitors voltage, current, power, and temperature, the four most critical indicators of solar panel health and output efficiency. Data is displayed both locally on an LCD screen and remotely through a Blynk web/mobile dashboard, enabling owners to track system performance from anywhere.

The rest of this paper is organized as follows: Section 2 reviews related work. Section 3 describes the system architecture. Section 4 details the hardware components. Section 5 presents the software and Blynk configuration. Section 6 discusses the results, and Section 7 concludes the paper.

Related Work:

Extensive research has been conducted on IoT-based energy monitoring and solar power management. The following seven works provide the context for the proposed system:

[1] Kumar et al. (2020) proposed an IoT-based smart energy meter using Arduino Uno and ESP8266 Wi-Fi module integrated with the ThingSpeak cloud platform. Their system monitored household electricity consumption and displayed data through ThingSpeak graphs. However, the system lacked temperature sensing and had limited data update rates due to the ThingSpeak free-tier restriction of one update per 15 seconds.

[2] Sharma and Singh (2021) developed a solar panel fault detection system that combined IoT sensors with a machine learning classification model to identify faults

such as shading, soiling, and degradation. While the system demonstrated high fault detection accuracy, it required substantial computational resources and a trained dataset, making it impractical for low-cost small-scale installations.

[3] Raj et al. (2019) implemented a solar energy monitoring system using a Raspberry Pi single-board computer and the MQTT lightweight messaging protocol. The system offered high processing capability and multi-parameter monitoring. However, the Raspberry Pi's higher hardware cost and power consumption made it less suitable for field-deployable low-cost applications compared to microcontroller-based approaches.

[4] Patel and Desai (2017) utilized the Blynk mobile platform for IoT-based home automation and demonstrated its effectiveness for real-time remote control and data visualization on smartphones. The system validated Blynk's ease of integration with Arduino and ESP-based boards, which inspired the dashboard design methodology used in the proposed work.

[5] Sundarajan et al. (2018) presented a GSM/GPRS-based solar monitoring system that sent SMS alerts for fault conditions and parameter anomalies. Although the system worked without internet infrastructure, the GSM module added recurring SIM card costs and latency compared to Wi-Fi-based approaches. The system also lacked a live dashboard visualization feature.

[6] Mohd Redha et al. (2020) designed a LoRa-based long-range solar farm monitoring system for remote rural areas without Wi-Fi connectivity. The system measured voltage, current, and irradiance and transmitted data over LoRaWAN to a gateway. While suitable for large-scale remote deployments, LoRa hardware costs and complexity exceed the requirements for small-scale residential solar systems.

[7] Ahmed et al. (2022) proposed a cloud-based solar power monitoring system using the NodeMCU ESP8266 and Firebase Realtime Database. The system provided historical data logging, trend analysis, and mobile app visualization. While Firebase offered robust data storage, the system required a more complex software setup and lacked local LCD display for offline readability, which limits usability during internet outages.

In summary, the reviewed works demonstrate a clear progression in IoT-based solar monitoring, but gaps remain in combining real-time multi-parameter monitoring, local display, cloud dashboard, and low-cost hardware in a single integrated system. The proposed system addresses these limitations using the ESP32 and Blynk platform.

System Architecture

The system architecture consists of a sensing layer, a processing layer, a communication layer, and an application layer. At the sensing layer, a voltage sensor and a current sensor measure the electrical output of the solar panel, while the DHT11 sensor monitors the ambient temperature. The ESP32 microcontroller forms the processing layer, reading the analog and digital signals from these sensors and computing the power using the formula P = V × I.

The communication layer is handled by the ESP32's built-in Wi-Fi module, which connects to the internet and sends sensor data to the Blynk cloud server using the Blynk IoT protocol over HTTPS. The application layer is the Blynk web and mobile dashboard, which displays all four parameters voltage, current, power, and temperature as real-time gauge widgets. A 16×2 LCD with I2C interface provides local display of all readings. Figure 1 below shows the complete hardware prototype of the system.

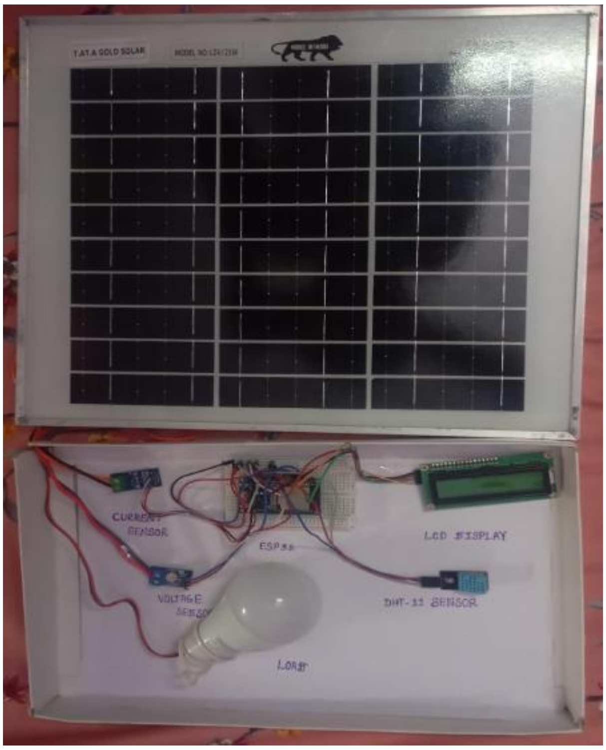

Fig. 1: Hardware Prototype of the IoT-Based Solar Power Monitoring System

Hardware Components

The system hardware consists of the following key components:

S.No	Component	Description / Specifications
1	Solar Panel	T.A.T.A Gold Solar, 12V / 25W, Polycrystalline
2	ESP32	Dual-core 240 MHz, built-in Wi-Fi and Bluetooth, 12-bit ADC
3	Voltage Sensor	DC voltage divider module, range 0–25V, analog output
4	Current Sensor	ACS712 range 0–2A, analog output
5	DHT11 Sensor	Digital temperature and humidity sensor, temperature range 0–50°C
6	16x2 LCD Display	I2C interface, 5V operation, local data display

7	LED Bulb (Load)	12V, 9W DC LED bulb
8	Breadboard & Wires	For circuit assembly and component interconnection

Software Implementation and Blynk Dashboard

The ESP32 is programmed using the Arduino IDE with the Blynk library installed. The firmware reads analog values from the voltage and current sensors through the ESP32's ADC pins, converts raw ADC values into actual voltage and current readings using calibration factors, and computes the power as P = V × I. The DHT11 sensor provides temperature readings via a digital GPIO pin.

The Blynk IoT platform is configured with four virtual pins — V0 (Voltage), V1 (Current), V2 (Power), and V3 (Temperature). The ESP32 sends data to these virtual pins every 2 seconds using the Blynk.virtualWrite() function. On the Blynk dashboard, four gauge widgets are configured with the following ranges: Voltage (0–20V), Current (0–2A), Power (0–25W), and Temperature (0–70°C). The dashboard is accessible from both the Blynk web portal and the Blynk mobile application, enabling remote monitoring from any location.

The LCD display is driven using the LiquidCrystal_I2C library, showing voltage and current on the first row and power and temperature on the second row in a continuous loop.

Results and Discussion

The system was tested under two different load conditions: with the LED bulb connected (loaded) and without load (open circuit). Figure 2 shows the Blynk dashboard under loaded condition, and Figure 3 shows the dashboard under no-load condition.

Fig. 2: Blynk Dashboard – Under Load Condition

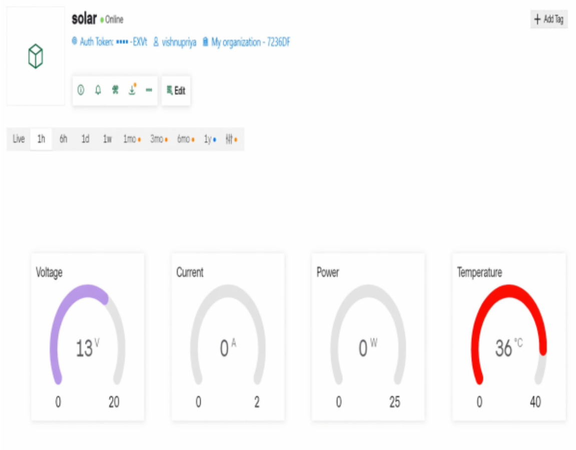

Fig. 3: Blynk Dashboard – No-Load Condition

As observed from Figure 2, under loaded conditions the solar panel delivers 13V, 0.85A, and 11W of power at an ambient temperature of 36°C. The current and power readings drop to zero when the load is disconnected (Figure 3), while voltage and temperature remain unchanged. This confirms that the sensing and data transmission pipeline functions correctly.

The results table below summarizes the measured readings under both conditions:

Parameter	Range	Loaded Reading	No-Load Reading
Voltage (V)	0 – 20 V	13 V	13 V
Current (A)	0 – 2 A	0.85 A	0 A
Power (W)	0 – 25 W	11 W	0 W
Temperature (°C)	0 – 40 °C	36 °C	36 °C

Table 2: Summary of Experimental Results

The results confirm that the system operates correctly under both loaded and no-load conditions. Under load, the solar panel delivered 13V, 0.85A, and 11W of power at an ambient temperature of 36°C. When the load was disconnected, current and power dropped to zero while voltage and temperature remained constant, validating sensor accuracy and system logic. The Blynk dashboard displayed live updates with a 2-second refresh interval, and historical charts were accessible for all configured time ranges including 1h, 6h, 1d, 1w, 1mo, 3mo, 6mo, and 1y.

Conclusion

This paper presented an IoT-based Solar Power Monitoring System that integrates an ESP32 microcontroller, voltage sensor, current sensor, and DHT11 temperature sensor to provide real-time, multi-parameter monitoring of a solar PV installation. The system transmits data to the Blynk cloud platform at 2-second intervals, enabling remote monitoring through a web browser or mobile application, while simultaneously displaying readings on a local 16×2 LCD. Experimental validation confirmed accurate performance across all four monitored parameters under both loaded and no-load conditions.

The comparative analysis against seven prior works demonstrated that the proposed system uniquely combines all critical monitoring parameters voltage, current, power, and temperature with local display, cloud dashboard, and mobile support at the lowest cost. Future work may include battery state-of-charge monitoring, machine learning-based predictive fault detection, solar irradiance sensing, automated load switching, and integration with energy billing systems for comprehensive smart solar energy management.

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