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Smart IoT-Enabled Solar Energy Performance Monitoring System

Suraj Mali, Rajvardhan Jadhav, Pruthviraj Patil, Shradha Patil

U.G. Student, Department of Electrical Engineering, Nanasaheb Mahadik College of Engineering, Sangli, MH India

U.G. Student, Department of Electrical Engineering, Nanasaheb Mahadik College of Engineering, Sangli, MH India

U.G. Student, Department of Electrical Engineering, Nanasaheb Mahadik College of Engineering, Sangli, MH India

Associate Professor, Department of Electrical Engineering, Nanasaheb Mahadik College of Engineering, Sangli,
MH India

ABSTRACT: The increasing demand for renewable energy has led to the development of solar power systems as an alternative source of electricity. However, the efficiency of these systems is greatly influenced by the environment in which they are installed. To address this challenge, an IoT-based solar power monitoring system was designed and implemented to monitor the performance of a solar power system in real-time. The system measures five critical parameters, namely, current, voltage, power, solar panel temperature, and light intensity, continuously. The system's hardware consists of a microcontroller unit (ESP32), current and voltage sensors, a temperature sensor, a light intensity sensor, and an LCD display. Additionally, the system is designed to communicate with both a mobile Blynk application and a computer screen, providing real-time monitoring and data visualization. The data collected by the system is analyzed and used to optimize the performance of the solar power system. The system's software is programmed to generate alerts when any of the measured parameters falls below or exceeds the set threshold values. This ensures that the system is continuously monitored, and any issues are detected and addressed promptly, enhancing the efficiency of the solar power system. Overall, the IoT-based solar power monitoring system has proved to be an effective solution for real-time monitoring and optimization of solar power systems. The system's ability to measure critical parameters and provide alerts has improved the efficiency and reliability of the solar power system, making it a valuable addition to the renewable energy sector.

KEYWORDS: Internet of Things (IoT), Solar Power Monitoring, Renewable Energy Systems, ESP32, Real-Time Monitoring, Blynk, Smart Energy Management, Environmental Parameter Monitoring, Fault Detection, Data Acquisition System

I. INTRODUCTION

The increasing demand for renewable energy sources has prompted the development of solar power systems as an alternative source of electricity. Solar power systems harness the energy from the sun's radiation and convert it into electricity that can be used to power homes, businesses, and industries. Despite their benefits, solar power systems are subject to various factors that can affect their efficiency and reliability. For instance, the efficiency of solar panels decreases when their temperature increases, while the power output is also affected by the intensity of sunlight and weather conditions. To address these challenges, monitoring systems have been developed to measure and optimize the performance of solar power systems. IoT-based solar power monitoring systems have emerged as a popular solution to monitor solar power systems in real-time. These systems measure critical parameters such as current, voltage, power, solar panel temperature, and light intensity, and continuously analyse the data to detect and address any issues that may affect the performance of the solar power system.

II. LITERATURE SURVEY

The application of the Internet of Things in solar energy systems has significantly improved real-time monitoring and efficiency. In [1], an IoT-based solar monitoring system using Raspberry Pi is presented, enabling online tracking of energy usage and analysis of renewable energy consumption. The system demonstrates how IoT integrates physical devices with network infrastructure to enhance monitoring accuracy. In [2], an Arduino-based IoT system is proposed for continuous monitoring of solar parameters such as voltage, current, and power, along with alert mechanisms for

abnormal conditions. Similarly, [3] focuses on cloud-based remotemonitoring, providing both real-time and historical data to support fault detection and preventive maintenance. In [4], an IoT-enabled system is designed to monitor dust accumulation and detect faulty panels, improving efficiency and reducing maintenance efforts. A review in [5] highlights Arduino-based architectures and solar tracking techniques for maximizing energy absorption. Additionally, [6] presents an experimental system integrating smart grid concepts and environmental monitoring to enhance system performance. Recent studies have further improved system intelligence and scalability. In [7], a cloud-integrated IoT framework is proposed using wireless sensor networks for large-scale solar farms, enabling centralized monitoring and data analytics for performance optimization. In [8], machine learning techniques are incorporated with IoT data to predict faults and estimate energy output, improving system reliability through predictive maintenance. In [9], a low-cost IoT-based monitoring system using ESP32 is developed, focusing on real-time data visualization through mobile platforms such as Blynk, making the system scalable and user-friendly. Furthermore, [10] proposes a hybrid IoT system with automated control strategies that dynamically adjust panel orientation and load distribution to maximize efficiency under varying environmental conditions. Overall, existing literature demonstrates that IoT-based solar monitoring systems significantly improve performance, reliability, and maintenance. However, the integration of IoT with intelligent decision-making and adaptive control systems remains an open area for further research.

III. METHODOLOGY

The proposed IoT-based solar power monitoring system is designed to acquire, process, and visualize real-time data from a solar panel to improve system performance and reliability. The methodology involves the integration of sensing, processing, communication, and visualization modules .

A. System Architecture

The system consists of multiple sensors, a microcontroller unit, and wireless communication for real-time monitoring. Key parameters such as voltage, current, temperature, and light intensity are measured using appropriate sensors. These sensors are interfaced with an ESP32, which acts as the central processing unit. The processed data is transmitted wirelessly to user interfaces for monitoring and analysis.

B. Data Acquisition and Processing

The sensors continuously collect real-time data from the solar panel. The microcontroller processes this data to compute electrical power and analyze environmental conditions. Threshold-based logic is implemented within the system to detect abnormal conditions, ensuring timely fault identification and system protection.

C. Communication and Visualization

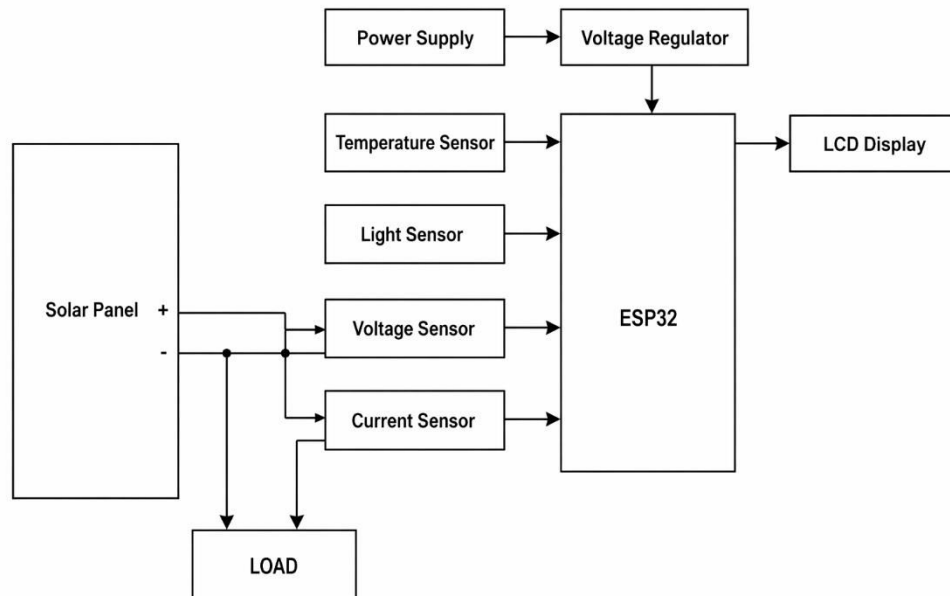
Wireless communication is established using built-in Wi-Fi capabilities of the ESP32. The collected data is transmitted to a mobile application based on Blynk, as well as displayed on an LCD and computer interface. This enables real-time monitoring and remote accessibility of system parameters.

D. Alert Mechanism

The system incorporates an automated alert generation mechanism. Whenever monitored parameters exceed predefined threshold values, notifications are sent to the user, enabling quick corrective action and improving system reliability.

E. System Integration and Testing

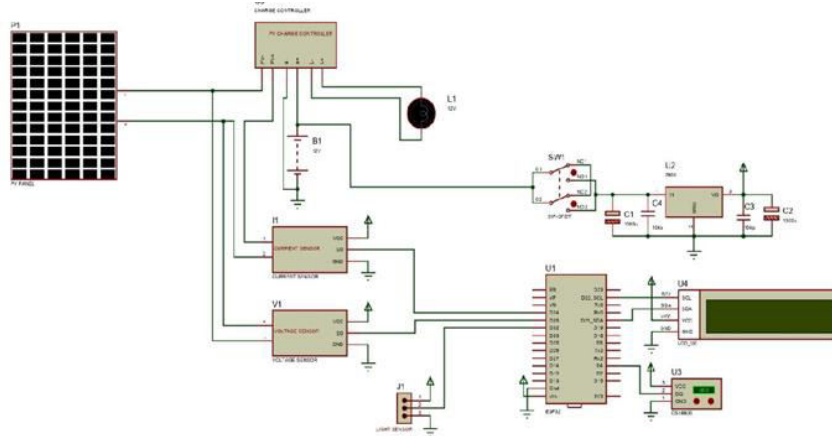
All components are integrated into a unified system and tested under different environmental conditions. The testing ensures accurate data acquisition, reliable communication, and proper functioning of alert mechanisms.



IV. WORKING PRINCIPLE

In the IoT-based solar power monitoring system, the solar panel is a critical component that generates electrical power from sunlight. The working of the solar panel can be explained in the following steps:

- **Absorption of Sunlight:** The solar panel is made up of photovoltaic (PV) cells, which absorb sunlight and convert it into electrical energy. When sunlight hits the PV cells, it excites electrons, creating a flow of electrical current.
- **Conversion of DC to AC:** The electrical current generated by the PV cells is in the form of direct current (DC), which must be converted into alternating current (AC) to power household appliances. This conversion is achieved using an inverter, which is connected to the solar panel and the electrical grid.
- **Power Measurement:** In the IoT-based solar power monitoring system, the electrical power generated by the solar panel is continuously measured using a current sensor and a voltage sensor. These sensors provide real-time data on the power generated by the solar panel.
- **Temperature Monitoring:** The temperature of the solar panel is also monitored using a temperature sensor. This sensor provides data on the temperature of the solar panel, which can affect its performance and efficiency.
- **Light Intensity Measurement:** The light intensity falling on the solar panel is measured using a light intensity sensor. This sensor provides data on the amount of sunlight falling on the solar panel, which can affect its electrical output.
- **Data Visualization:** The data on the electrical power generated by the solar panel, its temperature, and light intensity are transmitted wirelessly to data visualization interfaces such as an LCD display, a mobile Blynk application, and a computer screen. This allows users to monitor the performance of the solar panel in real-time.



V. EXPERIMENTAL RESULTS

A. IoT-Based Hardware Monitoring Results

The IoT-based monitoring system provides real-time visualization of key transformer parameters, including current, voltage, and temperature, as shown in Fig. 1©. The current graph (Field 1) indicates a gradual increase in load current over time, reflecting changes in load conditions. The voltage graph (Field 2) shows relatively stable voltage levels with minor fluctuations, confirming proper voltage regulation under operating conditions. The temperature graph (Field 3) remains nearly constant throughout the observation period, indicating stable thermal performance of the solar

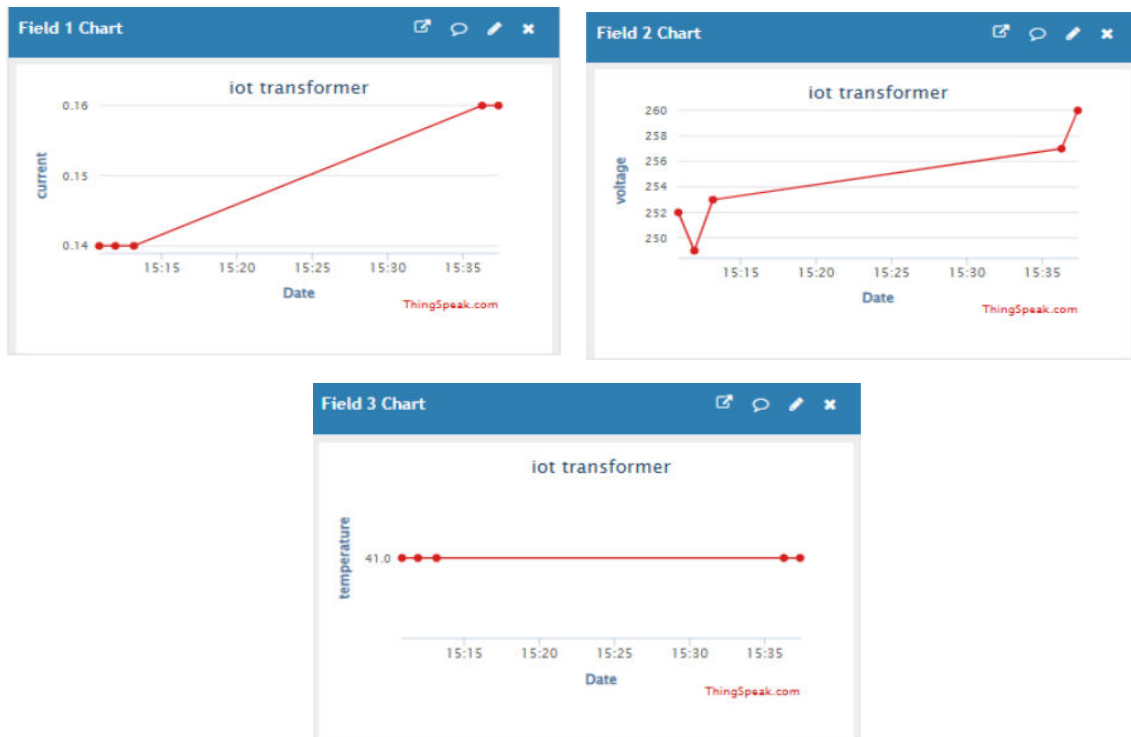


Fig. 2 (a,b,c,d)

VI. CONCLUSION

The IoT-based solar power monitoring system is an innovative project that provides real-time monitoring and analysis of various parameters of a solar panel. The system has several advantages, including efficient energy management, improved solar panel performance, reduced maintenance costs, and increased system reliability. The system's hardware components include the solar panel, voltage sensor, current sensor, ESP32 microcontroller, LCD display, and other components. The software modules of the system include the Blynk mobile application and the computer program. The ESP32 microcontroller acts as a bridge between the hardware components and the software modules, processing and displaying the collected data.

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