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IoT-Based Solar Grid Parameters Monitoring System

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Abstract: *The rapid expansion of solar photovoltaic systems has created a strong demand for advanced monitoring and optimization techniques to ensure maximum efficiency and reliability. Conventional monitoring systems are limited in their capability to provide real-time insights, predictive analysis, and multi-parameter correlation, leading to energy losses and inefficient system performance. This paper presents an IoT-based intelligent solar power monitoring system integrated with mathematical modelling and predictive optimization techniques. The system continuously measures key parameters such as voltage, current, temperature, and irradiance, and transmits the data to a cloud platform for real-time analysis. An analytical framework is developed to evaluate system efficiency, loss mechanisms, and performance degradation. The proposed approach enhances monitoring accuracy, enables predictive maintenance, and improves overall system efficiency. The system is scalable, cost-effective, and suitable for modern smart energy applications.*

Keywords: IoT, Photovoltaic System, Solar Monitoring, Predictive Maintenance, Smart Energy Systems

I. INTRODUCTION

The growing global demand for clean and sustainable energy has significantly increased the adoption of solar photovoltaic systems. Solar energy offers an environmentally friendly alternative to conventional fossil fuels; however, the performance of solar panels is highly dependent on environmental conditions such as temperature, irradiance, dust accumulation, and shading effects.

In practical applications, solar panels rarely operate at their rated efficiency due to these external factors. An increase in temperature results in a decrease in output voltage, thereby reducing the overall power output. Similarly, variations in solar irradiance directly affect current generation, leading to fluctuations in power output.

Traditional monitoring systems lack real-time data analysis and predictive capabilities, which results in delayed fault detection and inefficient utilization of energy resources. With the advancement of Internet of Things technology, intelligent monitoring systems can be developed to overcome these limitations. IoT enables continuous data acquisition, remote monitoring, and real-time decision-making.

This paper proposes an IoT-based intelligent solar monitoring system that integrates real-time data acquisition with analytical modelling to improve system efficiency and reliability. The system provides predictive insights and enhances operational performance in solar energy systems.

II. LITERATURE REVIEW

Existing research emphasizes the importance of monitoring and analysis in solar photovoltaic systems. Studies by Madeti and Singh have highlighted the need for continuous monitoring to detect faults in solar installations. Research by Mellit and Kalogirou demonstrated the effectiveness of artificial intelligence techniques in improving solar energy prediction accuracy. Other works have proposed IoT-based monitoring systems; however, they often lack detailed analytical modelling and predictive frameworks.

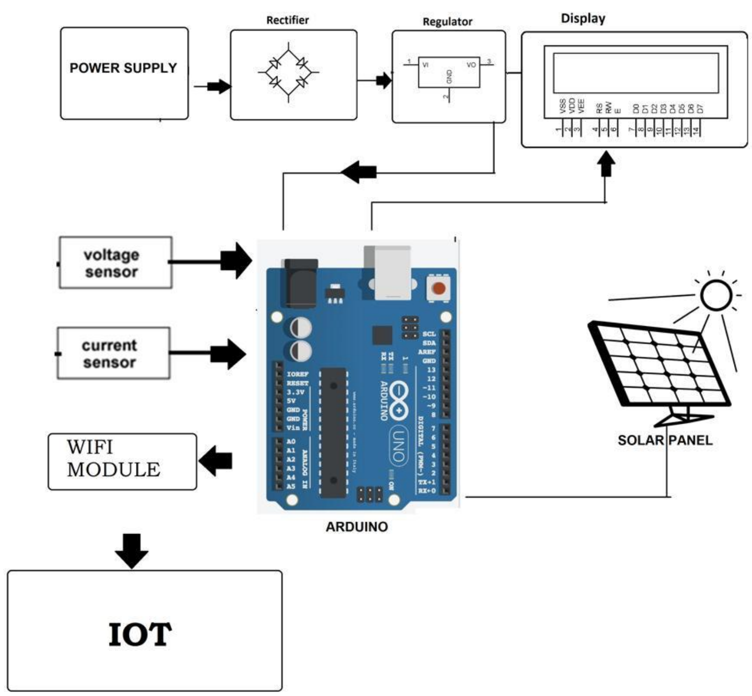
A critical analysis of existing systems reveals that most approaches focus primarily on data acquisition without integrating performance modelling. There is limited emphasis on correlating environmental parameters with electrical output, and predictive maintenance features are often absent. This paper addresses these limitations by combining IoT monitoring with mathematical modelling and analytical evaluation to provide a comprehensive solution.

III. SYSTEM ARCHITECTURE AND DESIGN

FUNCTIONAL OVERVIEW

The proposed system consists of multiple layers including sensing, processing, communication, and visualization. Sensors are used to measure electrical and environmental parameters, which are processed by a microcontroller and transmitted to a cloud platform. The system ensures continuous monitoring and real-time data availability for analysis.

BLOCK DIAGRAM DESCRIPTION



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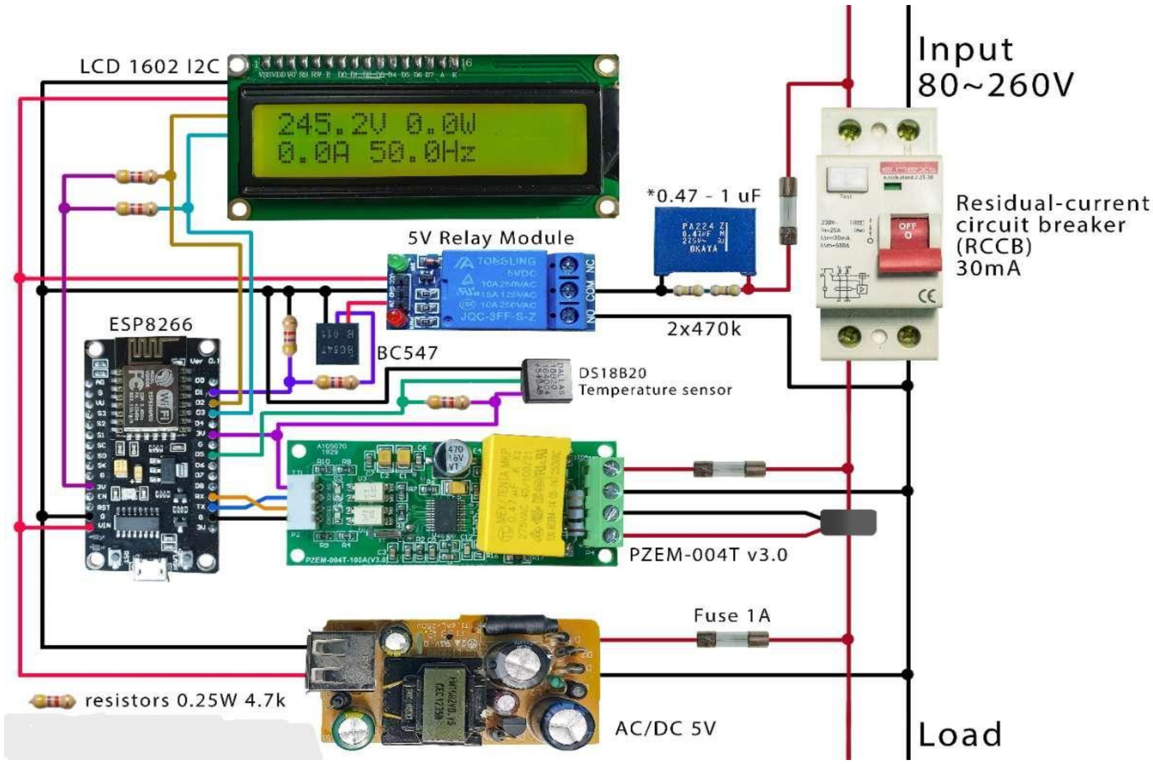

The block diagram illustrates the interaction between system components. The solar panel generates electrical energy, which is measured using sensors for voltage, current, temperature, and irradiance. The microcontroller processes the data and sends it to a cloud platform through a communication module. The cloud system stores and visualizes the data for real-time monitoring.

IV. MATHEMATICAL MODELLING AND ANALYSIS

The performance of the solar system is evaluated using fundamental electrical equations. The output power of the solar panel is calculated using the relation between voltage and current.

$$P = V \times I$$

The input solar power depends on irradiance and panel area, which determines the available energy from sunlight.

$$Pin = G \times A$$

The efficiency of the solar panel is calculated as the ratio of output power to input power.

$$\eta = (Pout / Pin) \times 100$$

Temperature has a significant effect on panel performance. As temperature increases, efficiency decreases according to the temperature coefficient relation.

$$\eta T = \eta ref\,[1 - \beta\,(T - Tref)]$$

The total system losses are determined by the difference between input and output power. This helps in identifying inefficiencies and optimizing performance.

$$Loss = Pin - Pout$$

These equations provide a comprehensive framework for analyzing system performance and identifying factors affecting efficiency.

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V. HARDWARE IMPLEMENTATION

The hardware implementation of the system includes an ESP8266 microcontroller, which acts as the central processing and communication unit. Sensors such as the ACS712 current sensor and voltage divider are used to measure electrical parameters. A DHT11 sensor is used to measure temperature, while a light-dependent resistor is used to estimate solar irradiance.

The microcontroller collects data from all sensors, processes it, and transmits it to the cloud using Wi-Fi communication. This integration of hardware components enables real-time monitoring and efficient system operation.

VI. SOFTWARE AND ALGORITHM DESIGN

The system is implemented using Arduino IDE and cloud platforms such as Blynk for visualization. The software algorithm continuously reads sensor data, calculates power and efficiency, and uploads the data to the cloud. The system compares real-time values with predefined thresholds to detect abnormal conditions. In case of any deviation, alerts are generated to notify the user. This automated process ensures efficient monitoring and predictive fault detection.

VII. RESULTS AND PERFORMANCE ANALYSIS

Experimental observations indicate that the output power of the solar panel decreases with an increase in temperature due to voltage reduction. Maximum power is achieved at high irradiance levels, as current generation is directly proportional to solar radiation. The efficiency of the system varies depending on environmental conditions such as temperature and shading. The implementation of IoT-based monitoring significantly improves system performance by enabling continuous data acquisition and early fault detection. The system reduces downtime and enhances operational efficiency. Analytical evaluation shows that efficiency can be improved by approximately ten to fifteen percent through optimized monitoring and predictive maintenance.

VIII. APPLICATIONS

The proposed system has wide applications in modern energy systems. It can be used in large-scale solar power plants for real-time monitoring and efficiency optimization. In smart grid systems, it supports energy management and integration of renewable sources. It is also suitable for residential and commercial solar installations, providing remote monitoring and efficient energy utilization. In rural and off-grid areas, the system enhances reliability and ensures continuous power supply.

IX. CONCLUSION

This paper presents an IoT-based intelligent solar monitoring system that integrates real-time data acquisition with analytical modelling. The system effectively addresses the limitations of conventional monitoring methods by providing continuous monitoring and predictive analysis. The results demonstrate that environmental factors significantly affect system performance, and the proposed system successfully captures these variations. The integration of predictive techniques enables early fault detection and improved maintenance. The system enhances efficiency, reliability, and scalability, making it suitable for modern solar energy applications.

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