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WSN-IOT based smart solar energy monitoring system

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ABSTRACT
The rapid adoption of renewable energy systems, especially solar power, necessitates efficient and intelligent monitoring solutions to ensure optimal performance and reliability. This paper presents a Wireless Sensor Network (WSN) and Internet of Things (IoT) based smart solar energy monitoring system designed to remotely track and manage key parameters of a solar power setup. The system integrates various sensors to measure solar panel voltage, current, temperature, irradiance, and battery status, and transmits real-time data to a cloud platform using an IoT module. The WSN enables decentralized data collection and enhances scalability for larger solar farms. Users can access data remotely through a web or mobile dashboard, enabling real-time performance tracking, fault detection, and preventive maintenance. This smart system promotes efficient energy utilization, system longevity, and supports sustainable energy initiatives by providing transparent, data-driven insights for solar infrastructure.
***Key Words**: Wireless Sensor Network (WSN),Internet of Things (IoT), Smart Solar Monitoring, Renewable Energy, Real-time Data Acquisition, Solar Panel Efficiency, Remote Monitoring.*

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I. INTRODUCTION

The increasing global demand for clean and sustainable energy has led to widespread adoption of solar energy systems. While solar power is reliable and eco-friendly energy source, its performance is heavily influenced by environmental conditions and system health. Traditional monitoring methods often lack real-time feedback, making it difficult to detect faults, inefficiencies, or abnormal behavior promptly.

With the advancement of Wireless Sensor Networks **(WSN)** and the Internet of Things (IoT)**,** it is now possible to create intelligent and connected solar energy monitoring systems. WSN enables distributed data collection using sensor nodes deployed across the solar installation, while IoT facilitates communication between devices and cloud-based platforms for remote access.

This paper proposes a WSN-IoT based smart solar energy monitoring system that continuously measures parameters such as voltage, current, temperature, solar irradiance, and battery condition. These data are transmitted wirelessly to a central gateway and uploaded to a cloud server for visualization and analysis. The system allows users to monitor solar performance in real-time**,** receive alerts for abnormalities, and plan maintenance activities efficiently.The integration of WSN and IoT not only enhances the operational efficiency of solar power plants but also supports smart grid applications and contributes to sustainable energy goals.

II. Objectives

The primary objectives of this research are:

➢ To design and implement a smart monitoring system for solar energy installations using Wireless Sensor Networks (WSN) and Internet of Things (IoT) technologies.

➢ To collect real-time data on key parameters such as solar panel voltage, current, temperature, irradiance, and battery status.

➢ To enable wireless transmission of sensor data to a central gateway for cloud-based monitoring and analysis.

➢ To provide a user-friendly interface (web/mobile dashboard) for remote access, visualization, and control of solar system performance.

➢ To detect faults or anomalies in solar power generation and alert users instantly for quick corrective actions.

- To support preventive maintenance by analyzing historical performance data and identifying trends or deviations.
- To promote efficient energy usage and management by optimizing solar energy output and reducing downtime.
- To contribute to sustainable energy initiatives by integrating smart technology into renewable energy infrastructure.

III. PROPOSED BLOCK DIAGRAM

The block diagram of the WSN-IoT based smart solar energy monitoring system illustrates the integration of various hardware and communication components to enable real-time monitoring of a solar power setup. At the core of the system is a solar panel, which generates DC electricity from sunlight. A set of sensors is connected to the solar panel to measure critical parameters such as voltage, current, temperature, solar irradiance, and battery level. These sensors feed the collected data into a microcontroller unit (such as Arduino, ESP32, or PIC), which processes and formats the data for transmission.

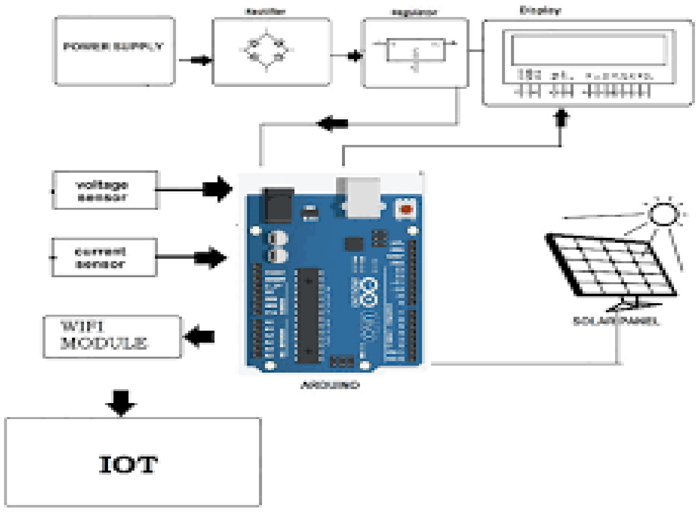

Figure.1 Proposed block diagram

The system uses a Wireless Sensor Network (**WSN)** module like ZigBee or LoRa to transmit data wirelessly from remote sensor nodes to a central gateway. In addition, an IoT communication module (e.g., Wi-Fi-based ESP8266 or NodeMCU) connects the system to the internet, enabling data to be uploaded to a cloud server or IoT platform. This server stores and analyzes the data, making it accessible through a user interface, such as a web portal or mobile application. Users can remotely view real-time and historical performance data, receive alerts in case of system faults, and make informed decisions for maintenance and optimization. This integrated system enhances the reliability, efficiency, and usability of solar energy installations.

IV. Methodology

The development of the WSN-IoT based smart solar energy monitoring system follows a structured methodology that includes hardware design, software development, data transmission, and user interface integration.

First, hardware components are selected and interfaced. These include the solar panel**,** voltage and current sensors**,** temperature sensor**,** light (irradiance) sensor**,** and a battery level sensor. These sensors are connected to a microcontroller (such as Arduino, ESP32, or NodeMCU), which acts as the central unit for data acquisition and control. The microcontroller reads analog and digital signals from the sensors and converts them into meaningful digital data.

Next, the system uses a Wireless Sensor Network **(WSN)**, such as ZigBee or LoRa, for long-range, low-power wireless communication between the sensor nodes and a central hub. Additionally, an IoT module (e.g., ESP8266 or built-in Wi-Fi in ESP32) is used to upload the collected data to a cloud-based platform via the internet.

In the software phase, embedded code is developed using Arduino IDE or other microcontroller programming environments to read, process, and transmit sensor data. A cloud server or IoT dashboard (such as Thingspeak, Blynk, or Firebase) is used to store and visualize data in real-time. This platform can also trigger automated alerts or notifications if abnormal values are detected.

Finally, a user-friendly interface is developed, which can be accessed via smartphone or web browser. This interface provides live monitoring, graphical data representation, system status updates, and analytics to help users make informed decisions.Overall, the methodology ensures seamless integration of WSN and IoT technologies to provide a real-time, efficient, and smart solar energy monitoring solution.

V. RESULTS AND DISCUSSION

The implemented WSN-IoT based smart solar energy monitoring system was tested under real environmental conditions to evaluate its performance and effectiveness. The system successfully monitored key parameters such as solar panel voltage, current, temperature, solar irradiance, and battery level in real-time. The sensor data was accurately collected by the microcontroller and transmitted via the wireless network to the cloud platform.

The results showed that the system could detect variations in solar output based on weather conditions, panel orientation, and time of day. For instance, during peak sunlight hours, the voltage and current values increased, while during cloudy conditions, a drop in irradiance was observed, leading to a proportional decrease in output power. The temperature sensor helped identify thermal losses, which are critical in assessing the efficiency of the panel. The battery monitoring system ensured that charging and discharging cycles remained within safe limits, preventing overcharging or deep discharge.

The cloud-based IoT dashboard provided clear and intuitive visualizations, including graphs and alerts, enabling users to remotely monitor the system from a smartphone or computer. Historical data trends helped in analyzing long-term performance and planning maintenance schedules.

From the discussion, it is evident that integrating WSN and IoT technologies provides an efficient and scalable solution for solar energy monitoring. It not only ensures real-time visibility but also helps in fault detection, preventive maintenance, and optimizing energy output. The system is cost-effective, easy to install, and adaptable for both residential and commercial solar installations. Overall, it contributes to improving the efficiency, reliability, and sustainability of solar energy systems.

a) Discussion

The performance of the smart solar monitoring system is evaluated by measuring several key parameters. These parameters are crucial for understanding the efficiency, safety, and reliability of the solar installation. The following table lists and explains the observed parameters, along with their significance:

Table: Key Parameters and Their Significance

S.No	Parameter	Measured Unit	Description	Significance
1	Solar Panel Voltage	Volts (V)	Output voltage generated by the solar panel.	Indicates power generation and helps in power calculations.
2	Solar Panel Current	Amperes (A)	Output current flowing from the solar panel.	Required for calculating total power output ($P = V \times I$).
3	Temperature	°C	Temperature of the solar panel surface.	Higher temperatures reduce panel efficiency; helps in performance optimization.
4	Solar Irradiance	Lux / W/m²	Intensity of sunlight falling on the panel surface.	Affects the amount of energy generated; helps compare output to solar input.
5	Battery Voltage	Volts (V)	Voltage level of the storage battery.	Ensures battery health, prevents overcharging/discharging.
6	Charging/Discharging Status	Percentage (%)	Indicates battery charge level.	Helps in energy management and backup planning.
7	Fault Detection Alerts	Boolean / Status	Detects abnormal values in voltage, temperature, etc.	Ensures system safety by alerting about overvoltage, overheating, etc.

During testing, the system recorded data at regular intervals and uploaded it to the cloud. The voltage and current readings fluctuated throughout the day, increasing during peak sunlight and reducing in the early morning or late evening. Temperature readings helped in identifying thermal effects that could degrade the panel's output. Solar irradiance was directly proportional to the power output, verifying the panel's response to light levels. The battery status and voltage data confirmed that the system was efficiently storing and supplying energy.This parameter-based analysis enables real-time tracking, fault detection, and system optimization. It ensures higher operational reliability and maximizes the performance of the solar power system.

VI. CONCLUSION

The proposed WSN-IoT based smart solar energy monitoring system effectively demonstrates how modern technologies can enhance the efficiency, reliability, and intelligence of renewable energy installations. By integrating Wireless Sensor Networks (WSN) with the Internet of Things (IoT), the system enables continuous real-time monitoring of key solar parameters such as voltage, current, temperature, irradiance, and battery status.

The implementation results show that the system can accurately collect and transmit data, detect faults early, and provide meaningful insights through cloud-based dashboards accessible remotely. This promotes predictive maintenance, improves energy output, and prevents system failures, ultimately extending the lifespan of the solar infrastructure.

The system is scalable, cost-effective, and adaptable to both small-scale residential and large-scale commercial solar installations. It empowers users with real-time visibility and data-driven control, contributing to smarter energy management and supporting the global move toward sustainable and green energy solutions.

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