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Solar Module Monitoring and Data Logging System Storing Data Locally and Remotely Over LoRa

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Abstract: *The Solar Module Monitoring and Data Logging System is designed to enhance the efficiency, reliability, and maintainability of solar power installations by providing real-time monitoring and data management capabilities. The system continuously measures key parameters such as voltage, current, power output, temperature, and irradiance from solar panels using appropriate sensors. The collected data is processed by a microcontroller and stored locally on an SD card for backup and offline analysis. Simultaneously, data is transmitted remotely over a LoRa (Long Range) communication network, enabling low-power, long-distance wireless communication between remote solar modules and a central monitoring station. This dual-storage approach ensures data redundancy and accessibility even in the absence of internet connectivity. The remotely received data is visualized on a monitoring dashboard or cloud platform for performance evaluation, fault detection, and predictive maintenance. This system offers a cost-effective, scalable, and energy-efficient solution for smart solar farms and distributed photovoltaic systems, contributing to sustainable and data-driven energy management.*

Keywords*:* Renewable Energy, Solar Array, PV, Monitoring System, Lora, Battery, Operating Conditions and Modes etc

I. INTRODUCTION

The Solar Module Monitoring and Data Logging System storing data locally and remotely over LoRa is an innovative project aimed at improving the performance, reliability, and maintenance of solar power systems. As solar energy systems are often deployed in remote or large-scale installations, continuous monitoring of their performance is essential for efficient energy management and fault detection. This system utilizes sensors to measure important parameters such as voltage, current, power, temperature, and light intensity from solar panels. The collected data is processed by a microcontroller or IoT node, which stores it locally on an SD card for backup and later analysis. At the same time, the data is transmitted remotely via LoRa (Long Range) communication technology to a central server or monitoring station. LoRa offers the advantage of low power consumption, long-range communication, and reliable data transfer, making it ideal for rural or off-grid solar applications. The remotely received data can be visualized and analyzed in real time through a dashboard, helping users to detect faults, predict maintenance needs, and optimize energy production.

Overall, the system provides an efficient, low-cost, and scalable solution for smart solar energy monitoring and management. Agriculture must modernize to support the rapidly growing global population, projected to reach 9.7 billion by 2050. To improve efficiency and productivity, farms are increasingly adopting IoT-based smart systems that use sensors and actuators for real-time monitoring of soil, crops, machinery, and environmental conditions. LoRa (Long Range) technology, a low-power, long-distance wireless communication system, is emerging as an ideal solution for agricultural IoT due to its ow cost, reliability, and suitability for rural areas lacking cellular or broadband access.

LoRa enables the creation of wireless sensor networks (WSNs) powered by renewable energy sources like solar or wind. Research shows that these smart, automated systems significantly enhance efficiency, production, and resource optimization in agriculture, with applications in weather, soil moisture, irrigation, security, and crop health monitoring

II. LITERATURE REVIEW

D. P. De Assis et al. (2025) This research proposes a real-time, cost-effective photovoltaic (PV) monitoring system using ESP32 microcontrollers with LoRa modules and precision sensors to track parameters like temperature, solar irradiance, humidity, and wind speed. The system transmits data over long distances to an IoT platform for real-time analysis, enabling anomaly detection and maintenance optimization. It is designed for remote or infrastructure-limited areas, supporting performance evaluation and preventive maintenance of PV systems.

Cuenca-Enrique C et al. (2025) This study presents a hybrid monitoring system for Solar Home Systems (SHS) that integrates LoRa and mobile networks to enable real-time, low-power, and cost-effective performance tracking. Implemented in Panama's Ngäbe Buglé region, it monitored parameters like energy use, battery level, and solar generation while maintaining connectivity in areas with weak mobile coverage. The mesh network minimized mobile data use, lowering costs and improving efficiency. The system is scalable, compatible with existing SHS, and future upgrades will include plug-and-play features and bidirectional communication for better control and interaction.

Rouibah N et al. (2025) This study develops a low-cost IoT-based prototype for remote monitoring of photovoltaic (PV) systems using an Arduino microcontroller. It measures key parameters like temperature, irradiance, voltage, current, and power at the MPPT point, transmitting data via Wi-Fi to a server with real-time display and web access. Using the Incremental Conductance MPPT algorithm, the system efficiently regulates power and operates reliably with low cost and energy use. Although suitable for rural and domestic PV applications, it requires improvements in scalability, shading performance, and cyber security.

Olemukan A. et al. (2025) This project designed a solar-powered, LoRa-based soil moisture monitoring system for smart irrigation in off-grid areas. Using an Arduino Uno, LoRa SX1276 transceiver, and Watermark 200SS sensor, it monitored soil water tension and wirelessly sent data to a gateway without internet. A Python algorithm classified soil conditions and automatically controlled irrigation via a Strega smart valve, optimizing water use. Field tests showed reliable, low-power, and autonomous operation, reducing manual effort and improving efficiency. Future enhancements include better gateway placement, zoned irrigation, and mobile dashboard integration for real-time monitoring.

Bajenaru V.D. et al. (2025) This paper analyzes the efficiency and performance of photovoltaic (PV) systems used to power IoT-based soil monitoring stations. It examines factors affecting solar energy conversion and conducts laboratory tests to optimize the PV system's operating point for reliable power generation. The study also explores how IoT technologies and air-to-ground communication systems can enhance PV performance. Results show that the proposed solar-powered system is well-suited for autonomous, real-time soil monitoring, offering an efficient and sustainable solution for remote IoT applications.

Shyamalagowri M. at al. (2025) This paper presents a precision dual-axis solar tracking system using a PID-controlled servo motor and LoRa-based environmental sensing for real-time monitoring and adaptive performance. The system continuously aligns solar panels with the sun to maximize energy output, overcoming the inefficiencies of fixed panels. LoRa technology enables low-power, long-range communication for remote monitoring of irradiance, temperature, and humidity. Designed for off-grid and remote areas, the system is scalable, IoT-compatible, and offers an efficient, reliable, and intelligent approach to solar energy optimization.

Kutluay et al.(2025), present the results of their experiments to evaluate the performance of the proposed system. They conducted tests on a 12 V lead-acid battery that was charged and discharged at different rates. The results showed that the battery monitoring system was able to accurately measure the battery voltage, current, and temperature, and transmit the data wirelessly to the base station. The authors also noted that the system had a low power consumption and could operate for a long time on a single battery.

Chidolue O. et al. (2024) This study proposes a low-cost wireless monitoring system for solar-powered setups in remote oil wells. Using LoRa-based communication with TTGO LoRa32 SX1276 and Heltec LoRa ESP32 boards, the

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system monitors parameters like battery voltage, PV current, and converter AC output. The LoRa-enabled ESP32 modules enable long-range, real-time data transmission, making the system suitable for isolated locations.

Little M. et al. (2023) This paper presents a low-cost, low-power IoT-based data logging system for remotely monitoring Solar Home Systems (SHS) in off-grid rural areas. The system tracks voltage, current, power, and temperature, storing data locally and transmitting it to the cloud via Wi-Fi or GPRS for real-time access. Field tests in Zambia, Malawi, and the UK showed its effectiveness in detecting faults like low battery charge, supporting preventive maintenance and enhancing SHS reliability, performance, and user satisfaction.

III. HARDWARE DESIGN

Setting up a **LoRa (Long Range)** project involves both **hardware** and **modelling** components. Below is a general guide to what a typical LoRa project setup might look like, including hardware choices and modelling aspects.

LoRa Modules:-

A LoRa module contains a LoRa transceiver chip and microcontroller, giving it all the elements needed for long-range communication. It serves as a building block to connect sensors, actuators and all kinds of IoT edge devices through a LoRa-based network. LoRa modules allow devices to connect to a LoRaWAN network to send and receive data across long distances. LoRa modules are available as readymade standalone components or integrated into development boards and sensors. Common interfaces include UART, SPI and I2C for connecting with external microcontrollers. or onboard sensors. As LoRaWAN gains popularity for LPWAN applications, the ecosystem of affordable LoRa modules has grown exponentially.

Fig. 3.1 LoRa Module

NODE MCU esp8266

The NodeMCU (Node Micro Controller Unit) is an open-source software and hardware development environment built around an inexpensive System on- a-Chip (SoC) called the ESP8266. The ESP8266, designed and manufactured by Espressif Systems, contains the crucial elements of a computer: CPU, RAM, networking (Wi-Fi), and even a modern operating system and SDK. That makes it an excellent choice for Internet of Things (IoT) projects of all kinds.

Fig. 3.2 Node MCU esp8266 Development Board

NodeMCU is an open-source firmware for which open-source prototyping board designs are available. The name “NodeMCU” combines “node” and “MCU” (micro-controller unit). The term“NodeMCU” strictly speaking refers to the firmware rather than the associated development kits.

LCD Display 16*2:-

The term LCD stands for liquid crystal display. It is one kind of electronic display module used in an extensive range of applications like various circuits & devices like mobile phones, calculators, computers, TV sets, etc. These displays are mainly preferred for multi-segment light-emitting diodes and seven segments. The main benefits of using this module are inexpensive; simply programmable, animations, and there are no limitations for displaying custom characters, special and even animations, etc.

Fig. 3.3 LCD Display

DHT 11 Sensor:-

The **DHT11** is a commonly used **Temperature and humidity sensor that** comes with a dedicated NTC to measure temperature and an 8-bit microcontroller to output the values of temperature and humidity as serial data. The **DHT11 sensor** can either be purchased as a sensor or as a module. Either way, the performance of the sensor is same. The sensor will come as a 4-pin package out of which only three pins will be used whereas the module will come with three pins as shown above. The only difference between the sensor and module is that the module will have a filtering capacitor and pull-up resistor inbuilt, and for the sensor, you have to use them externally if required.

Fig. 3.4 DHT 11 Sensor

DS18B20 sensor:-

This is a pre-wired and waterproofed version of the DS18B20 sensor. Handy for when you need to measure something far away, or in wet conditions. While the sensor is good up to 125°C the cable is jacketed in PVC so we suggest keeping it under 100°C. Because they are digital, you don't get any signal degradation even over long distances. These 1-wire digital temperature sensors are fairly precise (±0.5°C over much of the range) and can give up to 12 bits of precision from the onboard digital-to-analog converter.

Fig. 3.5 DS18B20 Sensor

LDR Sensor:-

LDR (Light Dependent Resistor) as the name states is a special type of resistor that works on the photo conductivity principle means that resistance changes according to the intensity of light. Its resistance decreases with an increase in the intensity of light.

Fig. 3.6 LDR Sensor

It is often used as a light sensor, light also known as a meter, Automatic street light, and in areas where we need to have light sensitivity. LDR is Light Sensor. LDR are usually available in 5mm, 8mm, 12mm, and 25mm dimensions. It works on the principle of photoconductivity whenever the light falls on its photoconductive material.

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Wiring and Connectors

Cables and connectors are necessary to link the components, such as the power supply, motor, pump, valves, and the receiver unit. Proper insulation and weatherproofing are important for maintaining safety and reliability.

Fig. 3.7 Wiring

Wiring and connectors are crucial components in electrical and electronic systems, enabling the transfer of power, signals, or data between different parts of a circuit or device. They play an essential role in ensuring the smooth, efficient, and safe operation of electrical systems, from small household gadgets to complex machinery like hydraulic jacks and remote control systems

IV. EXISTING SYSTEM

In the existing solar module monitoring systems, the performance of solar photovoltaic (PV) panels is generally monitored using conventional wired data acquisition systems or basic wireless modules such as Wi-Fi or GSM. These setups are primarily focused on local measurement and storage of parameters such as voltage, current, power output, and temperature. The collected data is either displayed on an LCD or stored locally in a microcontroller's memory or SD card for offline analysis. In most of these systems, real-time remote monitoring is limited due to constraints in communication range, power consumption, and network dependency. For instance, Wi-Fi-based or GSM-based systems require internet connectivity and higher power, which makes them unsuitable for remote or rural solar installations where network availability is poor and power efficiency is crucial.

Typical Operation of the Existing System

Sensors (voltage and current sensors) are connected to the PV module to measure electrical parameters.
Microcontroller or Arduino-based unit reads these parameters at regular intervals.
Data is stored in a local memory (EEPROM or SD card) for later retrieval and manual inspection.
Some advanced setups use Wi-Fi or GSM modules to upload data to a cloud server for online visualization.
Users or technicians manually visit the site to extract data or check system performance.
The existing solar monitoring systems provide basic functionality such as voltage and current measurement and local data logging. However, they are not optimized for low-power, long-range, and scalable remote monitoring. This limitation highlights the need for a LoRa-based solar monitoring and data logging system, which can efficiently transmit performance data over long distances at low power consumption and store information both locally and remotely for better reliability and accessibility.

V. PROPOSED METHOD

The main objective of our proposed work is to monitor the current and voltage parameters of PV solar power plant by Lora technology. To increase the efficiency of the solar panel dual-axis solar tracking system is also implemented. In this section we present LoRa based photovoltaic solar power monitoring system.

In our proposed method, the solar panel is mounted on the microcontroller based dual-axis solar tracking system which moves according to the position of the sun. The functionality of this tracking system is that it can track the sun in all the four directions i.e. both east-west and north-south directions which helps to increase efficiency. The tracking system consists of servomotors, LDRs, resistors and Arduino nano as the microcontroller. LDRs are used to sense the amount of light falling on them. Four LDRs and resistors are connected in voltage divider fashion and the output is connected to Arduino. In order to track the east-west direction the analog values from top two LDRs and bottom two LDRs are

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compared and servomotors are moved according to the greater values. For north-west tracking, the analog values from left two LDRs and right two LDRs are compared and the servomotors are moved accordingly.

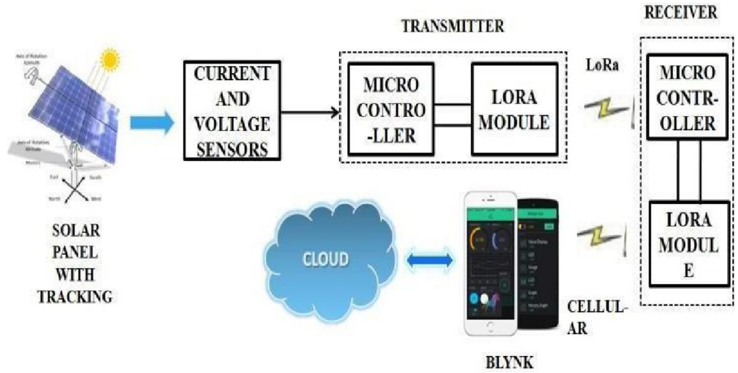

Fig. 5.1 System Block Diagram

The overall system is able to measure and monitor the PV solar panel current and voltage continuously. The voltage is sensed by voltage sensor and current is sensed by Hall-effect current sensor. The obtained data is processed and sent by Lora transmitter in which Arduino nano is interfaced with LoRa module. The data is received by LoRa receiver in which Node mcu Esp8266-integrated wifi module is interfaced with LoRa module. Further the data is processed and uploaded to web server by Esp8266 microcontroller via internet. The data is displayed using Blynk application and the data can be accessed anywhere by the user for monitoring purpose.

VI. CONCLUSION

The Solar Module Monitoring and Data Logging System storing data locally and remotely over LoRa provides an efficient and reliable solution for real-time monitoring of solar power systems. By integrating sensors, a microcontroller, and LoRa communication technology, the system ensures accurate data collection, long-range wireless transmission, and secure local storage. This dual data management approach enhances system reliability and prevents data loss during network interruptions. The remote monitoring capability allows users to analyze performance, detect faults early, and optimize energy output, reducing maintenance costs and downtime. Overall, the project contributes to the development of smart, cost-effective, and sustainable solar energy management systems, promoting the wider adoption of renewable energy technologies.

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