

LoRa Operated Solar Module Monitoring

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DOI: 10.5281/zenodo.19291693

ABSTRACT

This project presents the design and implementation of a Solar Module Monitoring and Data Logging System capable of storing operational data both locally and remotely using Long Range (LoRa) wireless communication. The primary objective of the system is to continuously monitor key electrical and environmental parameters of solar photovoltaic (PV) modules, such as voltage, current, power output, temperature, and irradiance, to ensure efficient performance and early fault detection. The system employs a microcontroller-based sensing unit integrated with appropriate sensors to acquire real-time data from the solar module. The collected data is stored locally on a memory device such as an SD card, enabling offline access, historical analysis, and reliability in locations with limited connectivity. For remote monitoring, the system utilizes LoRa technology, which offers long-range, low-power, and cost-effective wireless communication, making it suitable for solar installations in remote and rural areas. The sensor node transmits the monitored data over LoRa to a central gateway, where it can be forwarded to a cloud server or remote database for visualization and analysis. The proposed system ensures low power consumption, scalability, and robustness, allowing multiple solar modules to be monitored simultaneously. By providing both local and remote data logging, the system enhances data security and accessibility while reducing maintenance efforts. Overall, this solution improves the operational efficiency, performance assessment, and management of solar power systems, contributing to the reliable deployment of renewable energy infrastructure.

Keywords : - Solar Module Monitoring, Data Logging System, LoRa Communication, Remote Monitoring, Local, Data Storage, Photovoltaic (PV) System, Wireless Sensor Network, Renewable Energy etc

1. INTRODUCTION

The rapid growth in the adoption of solar photovoltaic (PV) systems has increased the need for efficient monitoring and management solutions to ensure optimal energy generation and long-term system reliability. Solar modules are often installed in remote or widely distributed locations, where continuous supervision and maintenance become challenging. Variations in environmental conditions, aging of components, dust accumulation, and electrical faults can significantly affect the performance of solar panels. Therefore, a reliable solar module monitoring and data logging system is essential to track real-time performance, identify faults at an early stage, and support informed decision-making for maintenance and optimization. A solar module monitoring and data logging system is designed to measure key operational parameters such as voltage, current, power output, module temperature, and ambient conditions. By continuously collecting these parameters, the system provides valuable insights into the health and efficiency of the solar PV installation. Data logging plays a crucial role in analyzing long-term trends, comparing expected and actual performance, and assessing the impact of environmental factors on energy generation.

However, conventional monitoring systems often rely on wired communication or high-power wireless technologies, which may not be suitable for remote or large-scale solar plants due to high installation costs and power consumption. To address these challenges, Long Range (LoRa) wireless communication technology has emerged as an effective solution for solar monitoring applications. LoRa offers long-distance communication with very low power consumption, making it ideal for solar-powered sensor nodes. It enables reliable data transmission over several kilometers, even in rural or hard-to-reach areas, without the need for complex network infrastructure. By integrating LoRa into the solar monitoring system, real-time data from multiple solar modules can be transmitted to a central gateway for remote observation and analysis.

In addition to remote communication, local data storage is an important feature of modern solar monitoring systems. Local data logging, typically using SD cards or onboard memory, ensures continuous data availability even during communication failures or network outages. This dual approach of storing data locally and remotely enhances system reliability, data security, and accessibility. Users can retrieve historical data directly from the local storage while also benefiting from remote monitoring through cloud platforms or centralized servers. The

Solar Module Monitoring and Data Logging System with local and remote storage over LoRa provides a scalable, cost-effective, and energy-efficient solution for managing solar PV installations. By combining real-time sensing, local data backup, and long-range wireless communication, the system supports improved performance analysis, predictive maintenance, and efficient utilization of renewable energy resources. This approach is particularly suitable for standalone solar plants, rooftop installations, and large solar farms, contributing to the sustainable and reliable operation of solar power systems.

1.1 OBJECTIVE

- To monitor key parameters of solar modules such as voltage, current, power, and temperature.
- To store data locally for backup and offline analysis.
- To transmit data remotely using LoRa communication for long-range monitoring.
- To analyze and visualize solar performance data in real time.
- To detect faults and inefficiencies early for better maintenance.
- To develop a low-cost, energy-efficient, and scalable solar monitoring solution.
- To enhance reliability and performance of solar power systems through smart data management..

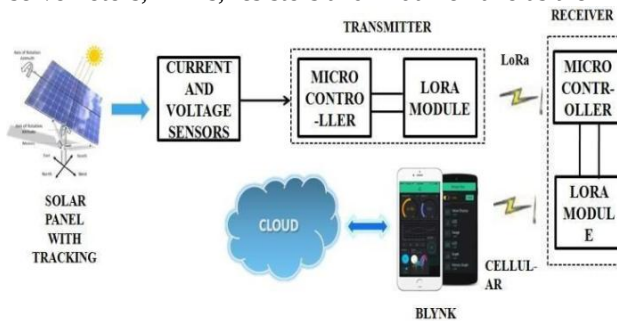
2. LITERATURE SURVEY

- **Shyamalagowri M. et 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 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.
- **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.
- **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.

3. WORKING & IMPLEMENTATION

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 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. 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.

4. WORKING OF SYSTEM

The working of the Solar Module Monitoring and Data Logging System involves continuous sensing, data processing, local storage, and long-range wireless transmission using LoRa technology. The overall operation can be explained in the following stages:

Data Sensing and Acquisition

Sensors are interfaced with the solar module to measure key electrical and environmental parameters such as solar panel voltage, current, output power, module temperature, and ambient conditions. These sensors continuously monitor the real-time performance of the solar panel. The analog signals from the sensors are converted into digital values using the built-in analog-to-digital converter (ADC) of the microcontroller.

Data Processing and Parameter Calculation

The microcontroller processes the acquired sensor data to calculate useful parameters such as instantaneous power and efficiency. The measured values are time-stamped to ensure accurate tracking of performance variations throughout the day. Threshold values can also be set to detect abnormal conditions like over-temperature, voltage drop, or reduced power output, indicating possible faults or degradation.

Local Data Logging

The processed data is stored locally on a memory device such as an SD card or internal flash memory. Local data logging ensures uninterrupted data storage even when wireless communication is unavailable. This stored data can later be retrieved for offline analysis, performance evaluation, and maintenance planning.

LoRa-Based Data Transmission

At predefined time intervals, the microcontroller transmits the monitored data using a LoRa transceiver. LoRa modulation enables long-range, low-power wireless communication, making it suitable for remote solar installations. The data packets are sent to a LoRa gateway or receiver located at a central monitoring station.

Remote Data Reception and Storage

The LoRa gateway receives the transmitted data and forwards it to a remote server or cloud platform via the internet. The received data is stored in a remote database, allowing authorized users to access real-time and historical information from anywhere through a web or mobile interface.

Monitoring, Visualization, and Alerts

The remotely stored data is visualized in the form of graphs, charts, and reports to help users analyze system performance. If any parameter exceeds predefined limits, alert notifications can be generated to inform operators about potential faults, enabling timely maintenance and reducing system downtime.

Power Management

Since the system is typically solar-powered, power management techniques such as sleep modes and low-power operation are implemented in the microcontroller and LoRa module. This ensures minimal energy consumption while maintaining reliable monitoring and communication. Overall, the system provides a reliable and efficient method for monitoring solar module performance by combining real-time sensing, secure local data backup, and long-range remote communication using LoRa technology.

5. CONCLUSIONS

The Solar Module Monitoring and Data Logging System with local and remote storage over LoRa provides an effective, reliable, and energy-efficient solution for monitoring the performance of solar photovoltaic systems. By continuously measuring key electrical and environmental parameters, the system enables real-time assessment of solar module health and operational efficiency. The integration of local data storage ensures uninterrupted data logging and data security even during network failures, while remote data transmission over LoRa allows long-range monitoring with minimal power consumption. The use of LoRa communication makes the system highly suitable for remote, rural, and large-scale solar installations where conventional communication methods are impractical or costly. The ability to access data both locally and through a remote server or cloud platform enhances flexibility, scalability, and ease of maintenance. Furthermore, the system supports early fault detection, performance analysis, and predictive maintenance, which help reduce downtime and improve the overall reliability of solar power generation. In conclusion, this dual-mode monitoring and data logging approach contributes significantly to efficient solar energy management and supports the sustainable deployment of renewable energy systems. With further enhancements such as advanced analytics, IoT integration, and automated control features, the system can play a vital role in the future of smart and intelligent solar power infrastructures.

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