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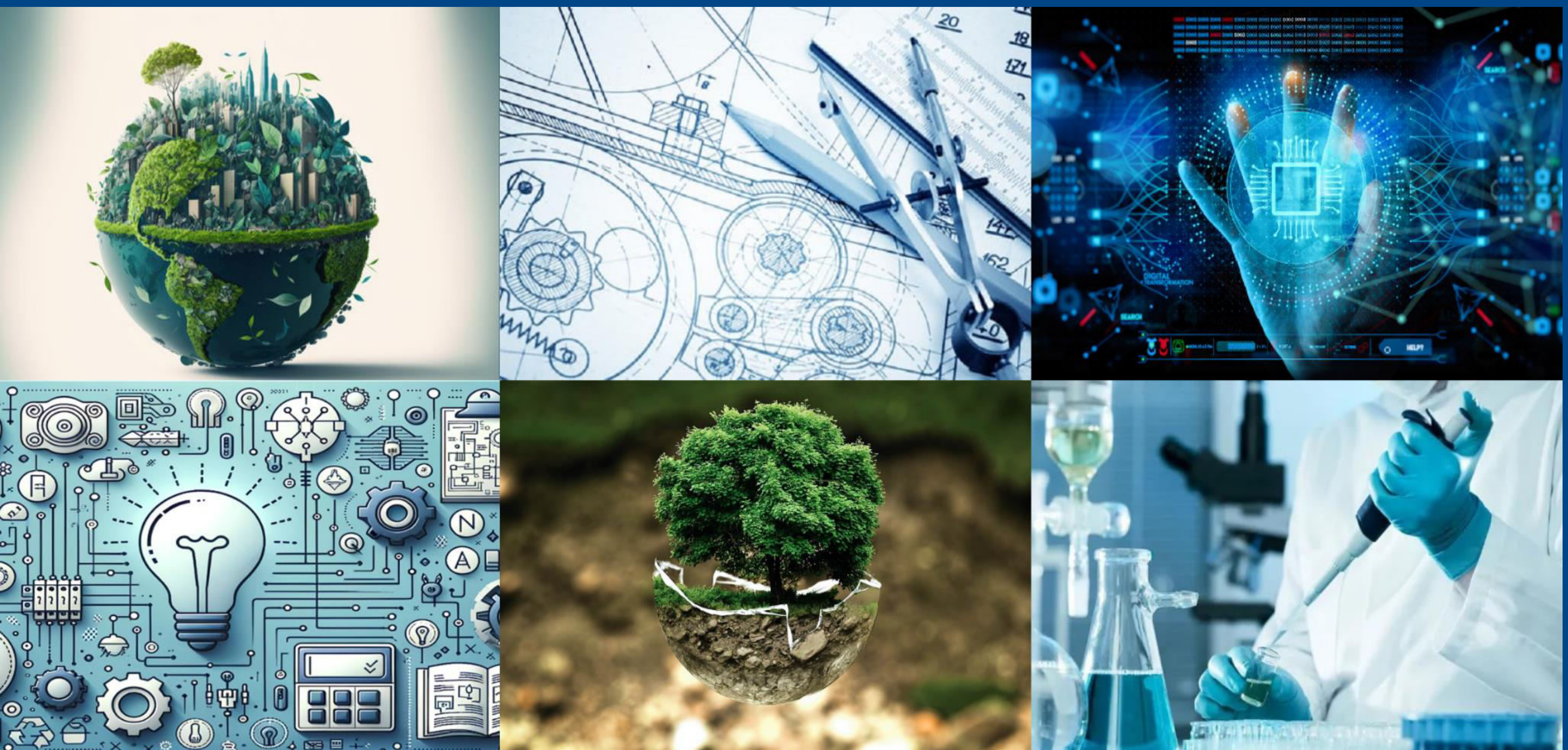

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Fault Detection in Solar PV system

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ABSTRACT: Solar energy has received great interest in recent years, for electric power generation. Furthermore, photovoltaic (PV) systems have been widely spread over the world because of the technological advances in this field. However, these PV systems need accurate monitoring and periodic follow-up to achieve and optimize their performance. The PV systems are influenced by various types of faults, ranging from temporary to permanent failures. A PV system failure poses a significant challenge in determining the type and location of faults to maintain the required performance of the system quickly and cost-effectively without disturbing its normal operation. Therefore, a suitable fault detection system should be enabled to minimize the damage caused by the faulty PV module and protect the PV system from various losses. In this work, different classifications of PV faults and fault detection techniques are presented. Specifically, thermography methods and their benefits in classifying and localizing different types of faults are addressed. In addition, an overview of recent techniques using different artificial intelligence tools with thermography methods is also presented.

I. INTRODUCTION

The global shift towards renewable energy sources has accelerated the deployment of solar PV systems. However, these systems are susceptible to various faults that can degrade performance and efficiency. Traditional maintenance approaches often react to failures after they occur, leading to increased downtime and maintenance costs. The integration of Internet of Things (IoT) technology offers a proactive solution, enabling real-time monitoring and fault detection. This project focuses on developing an IoT-based fault detection and diagnosis system for solar PV panels using the ESP32 microcontroller. The system monitors critical parameters such as voltage, current, and temperature to detect anomalies indicative of faults. Incorporating MPPT ensures optimal energy extraction, while an automated cleaning mechanism addresses efficiency losses due to soiling. A custom mobile application provides users with real-time data and control capabilities, enhancing user engagement and system reliability.

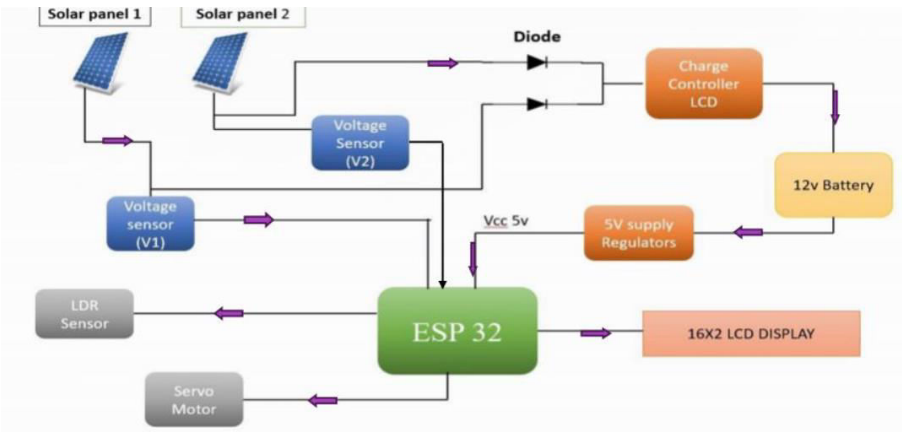

Fig 1: Block diagram of fault detection in solar PV system

The block diagram outlines an IoT-based fault detection and monitoring system for a solar PV setup, where the ESP32 microcontroller serves as the central processing unit for managing and analyzing data. The system starts with two solar panels that convert sunlight into electrical energy, which is then monitored for performance and faults. Voltage sensors

(V1 and V2) are strategically placed to measure the output from each solar panel individually and the combined voltage from both, sending real-time data to the ESP32 for analysis. The ESP32 processes this information to detect any anomalies or faults in the system, such as underperformance or failures. Diodes are used to protect the panels from reverse current flow, ensuring the safety of the system components. The charge controller regulates the flow of electricity into a 12V battery, which stores excess energy for use during periods of low sunlight. The charge controller features an LCD that provides a real-time display of the charging status. A 5V supply regulator ensures that the ESP32 and other sensitive components receive a stable 5V power supply, stepping down from the 12V battery voltage. Finally, the ESP32 not only handles fault detection and system control but also facilitates wireless communication with a mobile app, enabling remote monitoring and alerting of any detected issues in the solar PV system, ensuring efficient operation and proactive maintenance.

II. LITERATURE REVIEW

Yang et al. (2019) proposed a fuzzy rule-based diagnostic system for photovoltaic arrays. Their approach leverages fuzzy logic to model and analyze uncertain or imprecise data collected from solar panels. The study reported a diagnosis accuracy exceeding 90%, indicating its practical effectiveness. However, the authors emphasized that the system's reliability is strongly influenced by the quality of sensor data, making sensor calibration and data filtering critical components.

Alam et al. (2020) conducted a comprehensive review of Internet of Things (IoT) applications in solar PV systems. Their research highlighted the advantages of incorporating IoT, such as enhanced system reliability, real-time monitoring, remote diagnostics, reduced system downtime, and more efficient maintenance planning. The paper established IoT as a transformative tool in modernizing solar energy infrastructure.

Soni et al. (2019) introduced a deep learning-based method for fault detection and classification in solar PV systems. The model used multi-sensor data and neural networks to accurately categorize different fault types. Their system achieved a classification accuracy of over 95%, demonstrating the potential of AI-driven models in improving solar PV fault analysis and offering more targeted and automated maintenance solutions.

Khan et al. (2020) developed an IoT-based solar PV monitoring and fault detection system. The proposed architecture involved the use of sensors to continuously collect data on parameters such as voltage, current, and temperature, which were transmitted to a cloud-based server for advanced analytics and fault identification. This system laid the foundation for scalable, cloud-integrated PV monitoring solutions.

Dhar et al. (2020) proposed a similar IoT-enabled architecture for solar PV performance monitoring and anomaly detection. Their system employed distributed sensors and microcontrollers to detect variations in performance metrics and alert users about faults. They demonstrated that IoT can play a critical role in enabling predictive maintenance, thereby reducing manual inspections and improving operational efficiency.

III. METHODOLOGY OF PROPOSED SURVEY

System Design and Simulation

The project began with designing and simulating a basic solar PV system model to understand its behavior under different environmental and electrical conditions. The simulation allowed analysis of variations in voltage, current, temperature, and irradiance. These simulations provided valuable insights into how faults might affect real-time performance and helped in establishing fault detection thresholds. This phase laid the groundwork for hardware development and algorithm logic.

Hardware Architecture

At the core of the system is the ESP32 microcontroller, chosen for its dual-core processing capability, integrated Wi-Fi/Bluetooth, and compatibility with multiple sensors. Voltage sensors were used to monitor output from both the solar panels and battery, while current sensors tracked the flow of power through the system. Temperature sensors detected overheating scenarios such as hot spots, and LDRs (Light Dependent Resistors) were used to measure solar irradiance.

An automated cleaning mechanism driven by a servo motor was integrated to clear dust and debris from the panel surface. Additionally, a 16×2 LCD was included for displaying real-time voltage, system status, and fault notifications.

Data Acquisition and Processing

The ESP32 continuously receives data from the connected sensors, monitoring voltage, current, and temperature at regular intervals. This data is compared to predefined threshold values to identify anomalies. For instance, sudden drops in voltage could indicate soiling or shading, while irregular current patterns might suggest short-circuits or loose connections. Temperature readings help detect hot spots or thermal degradation. All data is processed in real-time to enable immediate response and minimize performance losses.

Fault Detection Algorithm

The embedded software on the ESP32 includes logic for recognizing common PV faults. These include open-circuit faults, short-circuit faults, ground faults, and over-temperature events. When certain fault conditions are met, the system responds accordingly triggering warnings, recording the event, or activating the cleaning mechanism. The algorithm ensures proactive identification of issues before they escalate into system failure, enhancing reliability and minimizing manual intervention.

IoT Integration and Mobile Interface

The ESP32's Wi-Fi module allows the system to transmit data wirelessly to a custom-developed mobile application. Through the app, users can view live performance data including voltage and current levels, fault alerts, and temperature readings. The app also allows users to manually activate or schedule the cleaning system remotely. This enhances user control and provides an intuitive interface for maintenance without requiring physical access to the installation.

System Testing and Validation

After completing hardware integration, the system was subjected to rigorous testing under controlled and real-world conditions. Scenarios including partial shading, low irradiance, and fault injection were simulated to evaluate the system's responsiveness. The results showed reliable detection of voltage drops, temperature spikes, and irradiance-related issues. The mobile application successfully received real-time data and control signals from the ESP32, confirming the effectiveness of the IoT communication and remote monitoring features.

IV. CONCLUSION AND FUTURE WORK

This project successfully demonstrates the design and implementation of an IoT-based fault detection and diagnosis system for solar photovoltaic (PV) installations using the ESP32 microcontroller. By integrating voltage, current, temperature, and light sensors, the system enables real-time monitoring of critical parameters and effectively identifies anomalies such as voltage drops, current imbalances, and overheating. The inclusion of Maximum Power Point Tracking (MPPT) ensures optimal energy harvesting, while the automated cleaning mechanism maintains panel efficiency by removing soiling without manual intervention. Wireless connectivity allows for seamless data transmission to a custom mobile application, providing users with real-time updates, alerts, and control functionality. The system was thoroughly tested under various environmental and load conditions, validating its accuracy, responsiveness, and reliability. Although challenges were encountered in achieving stable cloud server integration, the core objectives—fault detection, local visualization via LCD, and remote control—were successfully achieved. Future enhancements will focus on establishing a robust cloud communication platform for long-term data storage and analytics, improving the mobile application interface for better usability, and incorporating machine learning algorithms to enable predictive maintenance. Further expansion will include support for larger PV arrays, advanced weather-based performance forecasting, and adaptive cleaning scheduling based on real-time irradiance data. These improvements will make the system more scalable, intelligent, and suitable for widespread adoption in both residential and commercial solar power applications.

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