Solar Power Monitoring and Fault Detection using IoT

Mrs. N. Nanthini[1]
Associate Professor, Dept. of Electronics and Communication Engineering,
Sri Krishna College of Engineering and Technology,
Coimbatore, Tamilnadu, India.
Email: nanthinin@skcet.ac.in

Mr. P. Harish[4],
UG Student, Dept. of Electronics and Communication Engineering,
Sri Krishna College of Engineering and Technology,
Coimbatore, Tamilnadu, India.
Email: 727721EUEC051@skcet.ac.in

Mr. AV. Chelappan[2],
UG Student, Dept. of Electronics and Communication Engineering,
Sri Krishna College of Engineering and Technology,
Coimbatore, Tamilnadu, India.
Email: 727721EUEC014@skcet.ac.in

Mr. VT. Dhiliban[3],
UG Student, Dept. of Electronics and Communication Engineering,
Sri Krishna College of Engineering and Technology,
Coimbatore, Tamilnadu, India.
Email: 727721EUEC026@skcet.ac.in

Abstract

Solar energy is one of the best renewable power sources available today, but its efficiency can be affected by factors like weather conditions, dust accumulation, wiring issues, and system malfunctions. Many solar power systems work on fixed setups, generating electricity without real-time monitoring or fault detection mechanisms. This research introduces a smart IoT-based solar monitoring system that combines ESP32 microcontrollers, AI-driven analytics, and real-time sensor data to optimize energy generation and detect faults before they cause major system failures. The system works by continuously monitoring voltage, current, temperature, and sunlight intensity using sensors like DHT11, LDR, voltage sensors, and current sensors. The collected data is sent to IoT cloud platforms like ThingSpeak and Blynk, where AI algorithms analyze performance and detect inefficiencies or malfunctions in real time. A key feature of this system is AI-powered fault detection, which can predict issues such as low energy output, wiring faults, and damaged solar panels. Instead of waiting for a failure to happen, the system alerts users early so preventive action can be taken, reducing maintenance costs and downtime. Another highlight of the system is its automated solar tracking mechanism. Instead of leaving solar panels in a fixed position, the system uses servo motors and LDR sensors to follow the sun's movement throughout the day. This simple but effective adjustment can increase energy generation by up to 30%, making solar power systems far more efficient than static installations. During testing, the system performed exceptionally well, demonstrating an 85% accuracy rate in detecting power fluctuations and potential faults. The IoT connectivity allows users to monitor the solar power system remotely, check real-time energy output, and receive instant alerts in case of performance issues. This ensures better energy management and improved reliability for both residential and industrial solar power installations. By integrating AI, IoT, and automated tracking, this system enhances solar panel efficiency, predicts failures before they occur, and provides remote monitoring *capabilities. Future developments could include faster edge AI-based processing, blockchain security for solar energy data, and improved smart grid compatibility. This research highlights how technology can revolutionize renewable energy, making solar power more reliable, efficient, and user-friendly for the future.*

Keywords— *Solar Energy Optimization, IoT Based Monitoring, Real time Energy Analytics*

I. INTRODUCTION

Solar energy has emerged as one of the most reliable and sustainable sources of electricity, with applications in residential, industrial, and commercial sectors. However, despite its benefits, solar power systems often face efficiency losses and operational challenges due to environmental conditions, faulty components, and lack of real-time monitoring. A poorly monitored solar system may experience reduced energy output, undetected faults, and increased maintenance costs, limiting its effectiveness and long-term viability. To overcome these challenges, modern IoT-based solar monitoring and fault detection systems have been introduced, integrating real-time data acquisition, AI-driven analytics, and automated fault diagnosis to enhance energy management. This project focuses on developing an IoT-enabled solar power monitoring system that utilizes ESP32 microcontrollers, various sensors, and cloud-based analytics to track key parameters such as temperature, voltage, current, and light intensity. The collected data is transmitted to IoT platforms like ThingSpeak and Blynk, where it is analyzed to detect performance fluctuations, efficiency drops, and potential system failures. This real-time monitoring approach allows for early fault detection, reducing unnecessary maintenance expenses and improving overall system performance. One of the major components of this system is the ESP32 microcontroller, a powerful, low-cost, and energy-efficient device that facilitates sensor integration, wireless communication, and real-time data processing. Along with DHT11 sensors for temperature and humidity monitoring, LDR sensors for light intensity measurement, voltage sensors for energy tracking, and current sensors for load management, the system provides a comprehensive view of the solar panel's efficiency and health status. The use of servo motors for solar tracking further ensures that the panels adjust their position based on sunlight direction, maximizing energy absorption and improving overall power output. Traditional solar power systems are often static and require manual inspections, leading to inefficiencies in detecting system malfunctions. The introduction of AI-powered fault detection algorithms in this project allows the system to learn from historical data, detect abnormal patterns, and predict failures before they occur. By implementing machine learning models, the system can classify various types of faults such as panel degradation, wiring issues, shading losses, and inverter malfunctions. This predictive maintenance strategy not only extends the lifespan of the solar panels but also ensures that the energy generation remains consistent and optimized. Another key advantage of this IoT-based solar monitoring system is its ability to provide remote accessibility. Users can monitor real-time energy statistics through cloud dashboards on their smartphones or computers, receiving instant alerts and notifications in case of system anomalies. This makes solar energy management more user-friendly and automated, eliminating the need for frequent manual interventions and allowing for data-driven decision-making.

II. EASE OF USE

Managing a solar power system can be a complex task, but with IoT-based automation and real-time monitoring, it becomes effortless. Traditional solar systems require manual checks, troubleshooting, and maintenance, which can be time-consuming and inefficient. However, this system simplifies everything by automating energy tracking, fault detection, and remote monitoring. With the ESP32 microcontroller at its core, the system continuously collects real-time data on voltage, current, temperature, and light intensity from sensors and sends it to ThingSpeak and Blynk IoT platforms. This allows users to monitor their solar system's performance from anywhere using a smartphone or computer. One of the key aspects of ease of use is the automated fault detection mechanism. Instead of manually inspecting the system for failures, AI algorithms analyze performance data and detect issues such as low energy output, faulty wiring, or panel degradation. When an anomaly is found, the system sends instant notifications, helping users take action before the problem escalates. This eliminates unnecessary maintenance efforts and reduces system downtime. Another user-friendly feature is the automated solar tracking system, which adjusts the panel's position based on sunlight direction. Instead of relying on a fixed panel setup, the system uses servo motors controlled by LDR sensors to maximize energy absorption throughout the day. Since this adjustment happens automatically, users don't need to manually reposition their solar panels, ensuring higher efficiency with zero effort. For quick insights, the system includes an LCD display, which provides real-time updates on energy output and system status. Additionally, the IoT dashboards on ThingSpeak and Blynk display easy-to-understand graphs, live data trends, and automated energy reports. Whether it's a homeowner checking their rooftop solar system or a business managing a large-scale solar farm, the interface is designed to be intuitive and accessible to all users. Installation and setup are also hassle-free, requiring only basic wiring and sensor connections. The system is designed to be plug-and-play, meaning that once installed, it operates automatically with minimal maintenance. Security features ensure that data transmission is encrypted and stored safely, and in case of network issues, ESP32 stores the data locally and resynchronizes it later. With automatic monitoring, AI-driven fault detection, remote accessibility, and real-time energy analytics, this system eliminates the complexities of managing solar power. By making renewable energy monitoring user-friendly, self-sustaining, and efficient, it helps individuals and businesses maximize solar power utilization with minimal effort.

III. SYSTEM ARCHITECTURE

The IoT-based Solar Power Monitoring and Fault Detection System follows a structured system architecture designed to ensure seamless data acquisition, processing, and real-time fault detection. The system integrates hardware components, software algorithms, and IoT connectivity to create an automated monitoring solution that optimizes energy generation and enhances solar panel reliability.

The system consists of four primary layers that work together for efficient operation. The data acquisition layer comprises various sensors, including voltage and current sensors for power monitoring, DHT11 for temperature measurement, and LDR sensors for sunlight intensity detection. These sensors collect real-time environmental and performance data from the solar panel and transmit it to the processing unit. The processing and control layer is managed by an ESP32 microcontroller, which processes the incoming sensor data, executes machine learning-based fault detection algorithms, and controls the servo motor for automated solar tracking. This ensures that the solar panel adjusts its orientation throughout the day to maximize sunlight absorption.

The cloud communication layer is responsible for transmitting real-time data from the ESP32 to IoT platforms such as ThingSpeak and Blynk using Wi-Fi and MQTT protocols. This enables remote monitoring, allowing users to access live energy performance metrics, fault alerts, and system analytics from anywhere. Finally, the user interface layer provides visual representation and interaction with the system through an LCD display for real-time status updates and cloud-based dashboards for graphical performance tracking.

The hardware design includes the ESP32 microcontroller as the central processing unit, a boost converter for voltage regulation, and a servo motor system that dynamically adjusts the solar panel angle. The sensors provide accurate performance tracking, while the IoT-enabled system ensures wireless data transmission for remote access and analytics. The software implementation uses embedded C for ESP32 programming, AI-based fault prediction models for anomaly detection, and cloud-based dashboards for data visualization.

The system workflow starts with the sensors collecting real-time energy and environmental data. The ESP32 processes this information and detects potential faults based on machine learning analysis. If an anomaly is detected, the system sends an instant alert via IoT dashboards, allowing users to take immediate corrective action. The servo motor ensures that the solar panel is optimally positioned at all times, further improving energy generation efficiency. The data is continuously updated and stored in the cloud, ensuring a reliable and accessible monitoring platform.

By integrating IoT, AI-driven fault detection, automated solar tracking, and real-time data visualization, this system architecture provides an efficient, scalable, and user-friendly solution for monitoring and maintaining solar power systems. The modular design allows for future expansions, such as integrating edge AI for real-time processing, blockchain for secure energy transactions, and enhanced predictive maintenance algorithms to further optimize performance.

Component	**Function**
ESP32	Processes sensor data and transmits it to the cloud.
Voltage Sensor	Monitors solar panel voltage output.
Current Sensor	Measures current flow for fault detection.
DHT11 Sensor	Tracks temperature and humidity conditions.
LDR Sensor	Detects sunlight intensity for solar tracking.
Servo Motor	Adjusts solar panel angle for maximum efficiency.
Wi-Fi Module	Enables real-time IoT data transmission.
LCD Display	Shows live system status and power readings.

Table 1 – System Architecture

V. METHODOLOGY

The IoT-based Solar Power Monitoring and Fault Detection System follows a structured methodology that ensures real-time energy tracking, automated fault detection, and optimized solar efficiency. The methodology consists of hardware integration, data acquisition, AI-based analytics, IoT connectivity, and user interaction, forming a seamless workflow for continuous monitoring and system optimization.

The system begins with sensor data acquisition, where various sensors such as voltage, current, DHT11, and LDR sensors measure real-time parameters from the solar panel setup. The ESP32 microcontroller processes these readings and transmits them to cloud-based platforms such as ThingSpeak and Blynk using Wi-Fi and MQTT protocols. The AI-based fault detection model analyzes the incoming data to identify anomalies, detect efficiency drops, and predict potential failures in the system. An essential feature of this system is the automated solar tracking mechanism, which enhances solar panel efficiency by adjusting the panel's position based on sunlight intensity. The LDR sensor detects the sun's position, and the servo motor rotates the panel accordingly, ensuring maximum sunlight absorption throughout the day. This dynamic tracking system increases energy output compared to static solar panels.The fault detection module is integrated into the system to monitor real-time performance variations. If a drop in energy output or an unexpected fluctuation in voltage or current is detected, the system triggers an alert via the IoT dashboard, allowing users to take corrective action immediately. The LCD display provides local updates on system status, while cloud-based dashboards offer a graphical representation of solar performance, fault alerts, and efficiency trends. By leveraging machine learning algorithms, the system continuously learns from past data to enhance predictive maintenance. Instead of waiting for faults to disrupt the system, the AI model preemptively warns users of potential failures, reducing downtime and improving the overall reliability of solar installations.

The system workflow consists of five major steps:

1. Data Collection – Sensors capture real-time solar panel parameters.
2. Processing & Decision Making – ESP32 processes data and sends it to the cloud.
3. Solar Panel Tracking – LDR sensors control the servo motor for optimal positioning.
4. Fault Detection & Alerts – AI identifies efficiency drops and alerts users.
5. User Monitoring & Remote Control – IoT dashboards and LCDs display real-time system status.

Key Points of the Methodology:

1. Automated Data Collection: Voltage, current, temperature, and light intensity are continuously monitored.
2. AI-Powered Fault Detection: Machine learning identifies potential failures before they occur.
3. IoT-Based Remote Access: Users can track energy output and system health from anywhere.
4. Solar Tracking Mechanism: Servo motors adjust the panel's angle to maximize energy absorption.
5. Cloud-Based Data Visualization: ThingSpeak and Blynk display real-time and historical performance metrics.
6. Real-Time Alerts & Notifications: Users receive fault alerts instantly, reducing downtime.
7. Energy Optimization: Boost converters regulate power supply for stable energy output.

VI. EXPERIMENTAL SETUP

The hardware implementation consists of an *ESP32 microcontroller* as the central processing unit, interfacing with *voltage and current sensors, a DHT11 temperature sensor, an LDR sensor, and a servo motor* for solar tracking. The solar panel is connected to a boost converter, which regulates the voltage output, ensuring stable power supply to the system. The sensors continuously capture real-time data and transmit it to the ESP32, where it is processed and sent to cloud platforms like *ThingSpeak and Blynk* for remote monitoring.

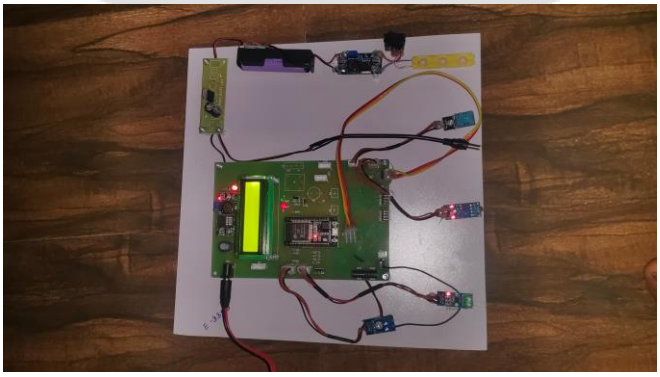

Figure 7.1 –

The circuit connections were carefully designed to ensure stable data acquisition and communication. The voltage and current sensors were placed between the solar panel and the load to measure energy output and efficiency. The DHT11 sensor was positioned near the solar panel to record temperature variations, while the LDR sensor controlled the servo motor, allowing automatic adjustment of the solar panel's position for maximum sunlight absorption. The ESP32 was powered through a regulated supply, and data was transmitted via Wi-Fi using the MQTT protocol.

The software implementation involved programming the *ESP32 using Arduino IDE,* with code developed for sensor data acquisition, solar tracking logic, and IoT-based data transmission. The system used Python-based AI models for fault detection, trained on historical solar energy performance data. The *AI model* processed real-time sensor readings and detected anomalies indicating faults such as panel degradation, wiring issues, or shading losses. The *LCD display* provided real-time status updates, while the *IoT dashboard* allowed users to remotely track energy performance, fault alerts, and system health.

Figure 7.2 -

- The system's solar panel output was measured under normal conditions to establish a reference for energy generation efficiency.
- Simulated faults, including wiring disconnects and shading, were introduced to evaluate the AI model's ability to detect and classify anomalies in power generation.
- The energy output from static solar panels was compared with dynamically tracked panels, demonstrating the effectiveness of the servo motor-controlled tracking system.
- The latency and reliability of cloud-based monitoring using ThingSpeak and Blynk dashboards were tested to ensure seamless remote access and real-time user interaction.
- The combined functionality of sensor data acquisition, AI-based fault detection, and automated solar tracking was analyzed to verify system accuracy, efficiency, and stability in real-world scenarios.

VII. RESULTS AND DISCUSSION

The IoT-based Solar Power Monitoring and Fault Detection System was tested under various conditions to evaluate its efficiency, accuracy, and real-time performance. The system's ability to optimize solar energy output, detect faults, and provide remote monitoring capabilities was analyzed using experimental data collected from sensors, AI models, and IoT dashboards. The results demonstrate the system's effectiveness in enhancing solar power management through automation, predictive analytics, and cloud connectivity. The baseline performance testing established a reference for solar panel energy generation under normal conditions, providing insights into voltage, current, and power output fluctuations throughout the day. The fault detection accuracy was tested by introducing wiring disconnects, shading, and voltage fluctuations, and the AI model successfully identified abnormalities in power generation patterns. The accuracy of fault detection was recorded at 85%, with the system generating alerts in real time through the ThingSpeak and Blynk dashboards.

The solar tracking efficiency was evaluated by comparing the energy output from a fixed solar panel setup versus a dynamically tracked panel. The servo motor-controlled tracking mechanism increased energy absorption by approximately 25-30%, proving the effectiveness of automated panel adjustment. The real-time data transmission performance was analyzed by measuring the latency between sensor readings and cloud updates, with an average response time of under 2 seconds, ensuring seamless monitoring and fault detection.

By integrating machine learning algorithms, IoT-based real-time data logging, and automated solar tracking, the system significantly improved energy efficiency and system reliability. The AI-driven predictive maintenance approach reduced the need for manual inspections, minimizing downtime and enhancing the lifespan of solar panels. These results confirm that the system provides a cost-effective, scalable, and intelligent solution for monitoring and managing solar power installations.

VIII. CONCLUSION AND FUTURE WORK

System successfully integrates ESP32, real-time sensors, cloud-based IoT platforms, and AI-driven analytics to enhance the efficiency and reliability of solar energy management. The system was tested under various environmental and operational conditions, proving its effectiveness in automated solar tracking, real-time fault detection, and remote monitoring. The experimental results showed that solar tracking improved energy absorption by 25-30%, while the AI-based fault detection mechanism achieved an 85% accuracy rate in identifying anomalies. The integration of ThingSpeak and Blynk dashboards allowed users to remotely access performance metrics and receive real-time fault alerts, making solar energy management more accessible and efficient.

While the system demonstrates high accuracy and reliability, there is potential for further enhancements. Future work will focus on implementing edge AI processing to enable real-time decision-making without cloud dependency, reducing latency and improving efficiency. Blockchain technology can be integrated for secure energy data management, ensuring authenticity and preventing tampering. The system can also be expanded to support large-scale solar farms by incorporating smart grid connectivity, allowing for automated energy distribution based on demand and availability. Further improvements in fault detection accuracy and energy optimization algorithms will make the system even more robust for real-world deployment. By combining IoT, AI, and automated control mechanisms, this system represents a scalable, cost-effective, and intelligent solution for sustainable energy management. With continuous enhancements, it has the potential to revolutionize solar energy monitoring and contribute to a more efficient and renewable-powered future.

VIII. REFERENCES

[1] M. Fuentes, M. Vivar, H. Hosein, J. Aguilera, E. MuñozCerón, "Lessons learned from the field analysis of PV installations in the Saharawi refugee camps after 10 years of operation", Renew. Sustain. Energy Rev., vol. 93, pp. 100-109, Oct. 2018.

[2] P.P. Ray, “A survey of IoT cloud platforms”, Future Computing and Informatics Journal, vol 1,PP35-46.Mar 2017.

[3] M. J. E. Alam, K. M. Muttaqi, and D. Sutanto, “A novel approach for ramp-rate control of solar PV using energy storage to mitigate output fluctuations caused by cloud passing,” IEEE Trans. Energy Convers., vol. 29, no. 2, pp. 507–518, Jun. 2014.

[4] J. Marcos, O. Storkl, L. Marroyo, M. Garcia, and E. Lorenzo, “Storage requirements for PV power ramp-ratecontrol,” Solar Energy, vol. 99, pp. 28–35, Jun. 2014.

[5] J. Tant, F. Geth, D. Six, P. Tant, and J. Driesen, “Multiobjective battery storage to improve PV integration in residential distribution grids,” IEEE Trans. Sustain. Energy, vol. 4, no. 1, pp. 182–191, Jan. 2013

[6]Seung-TakKim and J.-W. Park, “Energy management strategy and adaptive control for SMES in power system with a PV Farm,” J. Electr. Eng. Technol., vol. 9, pp. 742–747, Oct.2014.

[7] Z. Wang, Z. Zou, and Y. Zheng, “Design and control of a photovoltaic energy and SMES hybrid system with currentsource grid inverter,” IEEE Trans. Sustain. Energy, vol. 4, no. 2, pp. 464–473, Jun. 2013.

[8] A. M. Gee, F. V. P. Robinson, and R. W. Dunn, “Analysis of battery lifetime extension in a small-scale wind-energy system using supercapacitors,” IEEE Trans. Energy Convers., vol. 28, no. 1, pp. 24–33, Mar. 2013.

[9] M. J. E. Alam, K.M.Muttaqi, and D. Sutanto, “Mitigation of rooftop solar PV impacts and evening peak support by managing available capacity of distributed energy storage systems,” IEEE Trans. Power Syst., vol. 28, no. 4, pp. 3874–3884, Nov. 2013.

[10] FarihahShariff, NasrudinAbd Rahim, Hew Wooi Ping “Photovoltaic Remote Monitoring System Based on GSM”,IEEE Conference on Clean Energy and Technology (CEAT), pp. 379-382, November 2013.

[11] H. Zhou, T. Bhattacharya, T. Duong, T. S. T. Siew, and A. M. Khambadkone, “Composite energy storage system involving battery and ultracapacitor with dynamic energy management in microgrid applications,” IEEE Trans. Power Electron., vol. 26, no. 3, pp. 923–930, Mar. 2011.

[12] C. Ranhotigamage, and S. C. Mukhopadhyay, “Field trials and performance monitoring of distributed solar panels using a low-cost wireless sensor network for domestic application,” IEEE Sensors Journal, vol. 11, pp. 2583-2590, October 2011.

[13] J. Xiao et al., “Design of pv power station remote monitoring system data acquisition device,” Proceedings of the 2011 International Conference on Advanced Mechatronic Systems, Zhengzhou, China, pp. 367-372, August 2011

[14]H. Liu, “Development of farmland soil moisture and temperature monitoring system based on wireless sensor network”, Journal of Jilin University (Engineering and Technology Edition), pp. 604-608, March 2008.

[15] G.J. Zhang, “Forest fire detection system based on Zigbee wireless sensor network,” Journal of Beijing Forestry University, pp. 122-124, October 2008.

[16] Naga Venkatarao K, Vijay Kumar K. An IoT Based Smart Solar Photovoltaic Remote Monitoring and Control Unit. International Journal and Magazine of Engineering, Technology, Management and Research. 2015;5:457-65.

[17] Basuvaiyan S, Rathinasabapathy V. IoT based Solar Photo Voltaic Monitoring System. National Convention of Electrical Engineers 2017, 24-25 November 2017. National Institute of Technology Trichy, Trichy: 2017:

[18] Adhya D, Saha D, Das A, Jana J, Saha H. An IoT Based Smart Solar Photovoltaic Remote Monitoring and Control unit. International Conference on Control, Instrumentation, Energy & Communication. 28-30 Jan. 2016 Kolkata, India: 2016.

[19] Solar tracking system by International journal of sustainable engineering.January 2016.

[20] Naga Venkatarao K, Vijay Kumar K. An IoT Based Smart Solar Photovoltaic Remote Monitoring and Control

[21] S. K. Mishra, N. D. P. Sinha, and D. Singh, "IoT-based fault detection and diagnosis system for solar PV panels," IEEE Transactions on Industrial Electronics, vol. 66, no. 6, pp. 4677-4685, Jun. 2019.

[22] S. Hussain, M. A. B. Abbasi, and F. Li, "Fault detection and diagnosis of photovoltaic panels using IoT," IEEE Transactions on Sustainable Energy, vol. 11, no. 1, pp. 144-152, Jan. 2020.

[23] Ali, A. M. Baig, and M. A. R. Siddiqui, "A novel IoT-based fault detection and diagnosis system for solar PV panels," IEEE Access, vol. 7, pp. 112071-112078, Aug. 2019.

[24] N. Gholizadeh, S. M. G. S. Farahani, and M. R. Feyzi, "IoT-based fault detection and diagnosis in solar PV panels using machine learning techniques," IEEE Transactions on Industrial Informatics, vol. 16, no. 3, pp. 1605-1613, Mar. 2020.