"Smart Solar Micro-grid Monitoring and Fault Prediction System using IoT"

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ABSTRACT - *The Smart Solar Micro-Grid Monitoring System is an advanced solution developed to improve the efficiency, reliability, and sustainability of solar power systems. This system uses* ***Internet of Things (IoT)*** *technology to continuously monitor important parameters such as voltage, current, power generation, battery condition, temperature, and dust accumulation on solar panels.*

Dust sensors help detect dirt on panels, which can reduce efficiency, while temperature sensors monitor overheating conditions that may damage components. The system collects real-time data and uses machine learning techniques to identify unusual patterns and predict possible faults.

A centralised dashboard displays live data, alerts, and historical records, allowing users to monitor and control the system remotely. This solution is especially useful in rural and remote areas, as it ensures a stable power supply, reduces maintenance costs, and increases system lifespan.

1. INTRODUCTION

In today's world, energy plays a very important role in our daily lives. With the increasing demand for electricity and the rapid depletion of conventional energy resources such as coal and petroleum, there is a strong need to shift towards renewable and sustainable energy sources. Among all renewable energy options, solar energy is one of the most widely used and environmentally friendly sources. It is clean, abundant, and freely available, making it an ideal solution for meeting future energy needs.

Solar power systems, especially solar micro-grids, are becoming increasingly popular in rural and remote areas where access to traditional electricity grids is limited or unavailable. A solar microgrid is a small-scale power system that generates and distributes electricity locally using solar panels, batteries, and other components. These systems provide an efficient and cost-effective way to supply electricity to off-grid locations such as villages, farms, campuses, and isolated industrial areas.

However, despite their advantages, solar micro-grid systems face several challenges. One of the major problems is the lack of proper monitoring and maintenance. Factors such as dust accumulation on solar panels, overheating, battery issues, and electrical faults can significantly reduce system efficiency and performance. In traditional systems, monitoring is often done manually, which is time-consuming and inefficient. Problems are usually detected only after they cause serious damage, leading to increased maintenance costs, reduced system life, and unreliable power supply.

To overcome these challenges, the concept of a Smart Solar Micro-Grid Monitoring System using Internet of Things (IoT) has been introduced. This system aims to provide a modern, automated, and intelligent solution for monitoring and managing solar power systems. It uses **IoT sensors** to continuously track important parameters such as voltage, current, power generation, battery status, temperature, and dust levels on solar panels.

The collected data is processed using a microcontroller and transmitted to a cloud-based platform through the internet. A centralized dashboard displays real-time information, graphical analysis, and system alerts, allowing users to monitor the system from anywhere. This not only improves convenience but also helps in making quick and informed decisions.

One of the key features of this system is its ability to detect problems at an early stage. For example, dust sensors can identify dirt accumulation on solar panels, which reduces their efficiency. Similarly, temperature sensors can detect overheating conditions that may damage system components. By providing timely alerts, the system enables preventive maintenance, reducing downtime and improving overall performance.

In addition, the integration of machine learning techniques makes the system even more powerful. By analysing historical data and identifying patterns, the system can predict potential failures and suggest corrective actions. This approach not only enhances system reliability but also extends the lifespan of components such as batteries and solar panels.

Overall, the Smart Solar Micro-Grid Monitoring System is a smart and efficient solution for modern energy management. It combines renewable energy with advanced technologies like IoT and machine learning to create a sustainable and reliable power system. This project is especially beneficial for rural electrification, smart cities, and remote applications, where a continuous and efficient energy supply is essential.

2. NOVELTY

The Smart Solar Micro-Grid Monitoring System using IoT is not just a basic solar monitoring system; it introduces several innovative and unique features that make it different from traditional solutions.

One of the main novel aspects of this project is the integration of **dust sensing technology** along with solar monitoring. In many existing systems, only electrical parameters like voltage and current are monitored. However, this project focuses on a real-world problem—dust accumulation on solar panels—which directly reduces efficiency. By detecting dust levels and generating alerts for cleaning, the system helps maintain maximum energy output.

Another important innovation is the combination of **temperature monitoring with predictive analysis**. Instead of just displaying temperature values, the system analyses abnormal increases in temperature and provides early warnings. This prevents overheating and protects the components from damage, which increases the overall lifespan of the system.

The project also stands out due to its use of **IoT-based real-time monitoring with remote accessibility**. Users can monitor the entire system from anywhere through a dashboard, making it highly convenient and practical, especially for remote or rural areas where physical monitoring is difficult.

A key novelty is the implementation of **basic machine learning techniques for fault prediction**. Unlike traditional systems that react only after a fault occurs, this system can identify patterns in data and predict possible failures in advance. This approach enables predictive maintenance, reduces downtime, and lowers repair costs.

Additionally, the system provides a **centralised dashboard that combines multiple parameters** such as voltage, current, battery status, temperature, and dust levels in one place. This integrated view helps users make better decisions and manage energy more efficiently.

The project is also designed with a focus on **scalability and real-world application**. It can be extended for use in rural electrification, smart homes, agricultural systems, and small industries. Its low-cost components and simple design make it affordable and easy to implement.

In summary, the novelty of this project lies in:

- Integration of dust and temperature monitoring with solar systems
- Real-time IoT-based remote monitoring
- Use of machine learning for early fault prediction
- Smart alert system for preventive maintenance
- User-friendly and centralised dashboard
- Practical and cost-effective design for real-world use

3. LITERATURE SURVEY

3.1 Our Survey:

Before starting the development of the Smart Solar Micro-Grid Monitoring System using IoT, we conducted a detailed survey to understand the existing systems, real-world problems, and possible improvements in solar energy monitoring.

During our survey, we observed that solar energy is widely used in rural and remote areas due to the lack of reliable grid electricity. Many households, farms, and small industries depend on solar power for their daily needs. However, most of these systems do not have proper monitoring facilities. In many cases, users are not aware of the actual performance of their solar panels and batteries.

We also found that traditional solar systems mainly rely on manual checking. Users have to physically inspect the system to identify faults or issues. This process is time-consuming and often leads to delayed problem detection. Common issues such as dust accumulation on solar panels, overheating, and battery problems are usually ignored until they cause significant performance loss.

Through online research and study of existing projects, we came to know that some advanced systems use IoT for monitoring parameters like voltage, current, and battery status. These systems provide real-time data through dashboards. However, most of them do not include important environmental factors like dust and temperature, which directly affect the efficiency of solar panels.

Another important observation from our survey was the lack of predictive analysis in many systems. Most existing solutions only provide monitoring but do not predict future problems. As a result, users can only react after a fault occurs, which increases maintenance costs and system downtime.

We also studied research papers, journals, and case studies related to IoT-based solar monitoring systems. These studies highlighted the importance of real-time data collection, cloud storage, and remote access. Some systems also used machine learning techniques, but they were complex and costly, making them less suitable for small-scale or rural applications.

Based on our survey, we identified the need for a system that is:

- Easy to use
- Cost-effective
- Capable of real-time monitoring
- Able to detect dust and temperature issues
- Supports early fault detection and prediction

To address these gaps, we designed our project by combining IoT technology with smart sensors and basic machine learning techniques. Our system not only monitors electrical parameters but also focuses on environmental factors like dust and temperature. It provides real-time alerts and allows users to monitor the system remotely through a dashboard.

In conclusion, our survey helped us understand the limitations of existing systems and guided us in developing a more efficient, smart, and practical solution. The proposed system aims to overcome the drawbacks of traditional monitoring methods and provide a reliable solar energy management system suitable for real-world applications.

Identified Problems

Based on the field surveys and observations, the following problems were identified:

1. No real-time monitoring of system parameters
2. Dependence on manual inspection
3. Dust accumulation reduces panel efficiency
4. Overheating issues not detected early
5. Delay in fault detection
6. No remote monitoring capability
7. Poor energy management
8. Lack of predictive maintenance
9. High cost of advanced systems

Proposed Solution

- To address the above problems, a Smart Solar Micro-grid Monitoring and Fault Prediction system is being developed.
- Real-time monitoring using IoT
- Dust and temperature detection
- Smart alert and notification system
- Machine learning-based fault prediction
- Remote access through cloud dashboard
- Improved energy management
- Cost-effective and practical implementation.
- The system also supports **energy optimisation and load management.** By analysing real-time and past data, users can make better decisions regarding energy usage, reduce wastage, and improve overall efficiency.
- Finally, the proposed solution is designed to be **low-cost, scalable, and easy to implement.** It can be used in various applications such as rural electrification, agriculture, smart homes, and small industries.

3. DESIGN AND IMPLEMENTATION

1.Block Diagram

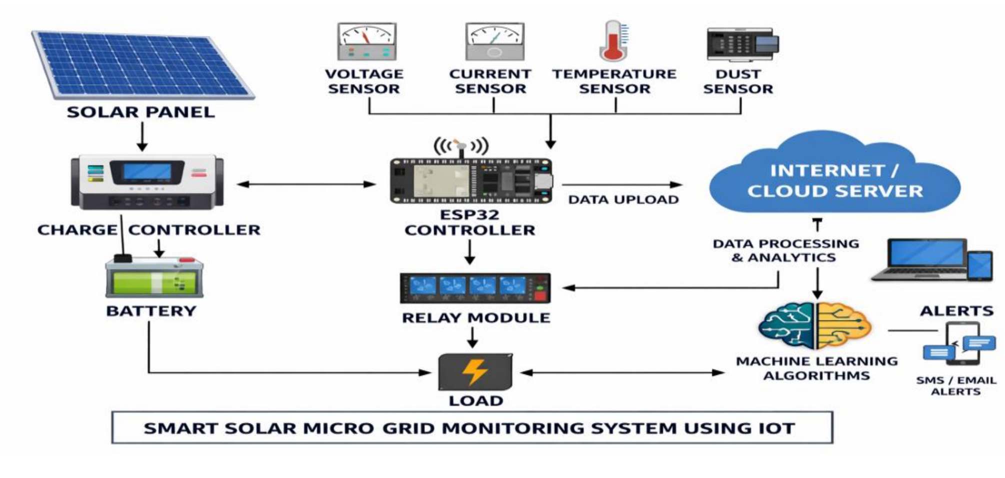


Figure 3.1 Block diagram of the system

2.Level Data Flow Diagram (DFD)

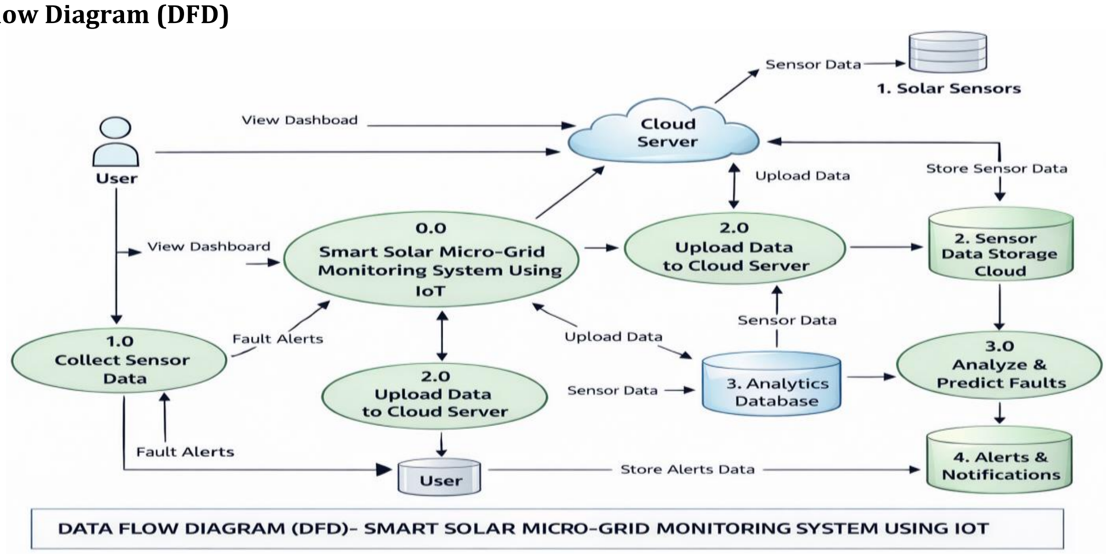


Figure 3.2 Level Data Flow Diagram (DFD)

3. Home Page Design

Home page design of the solar micro-grid monitoring system showing navigation, system overview, and user interface layout:

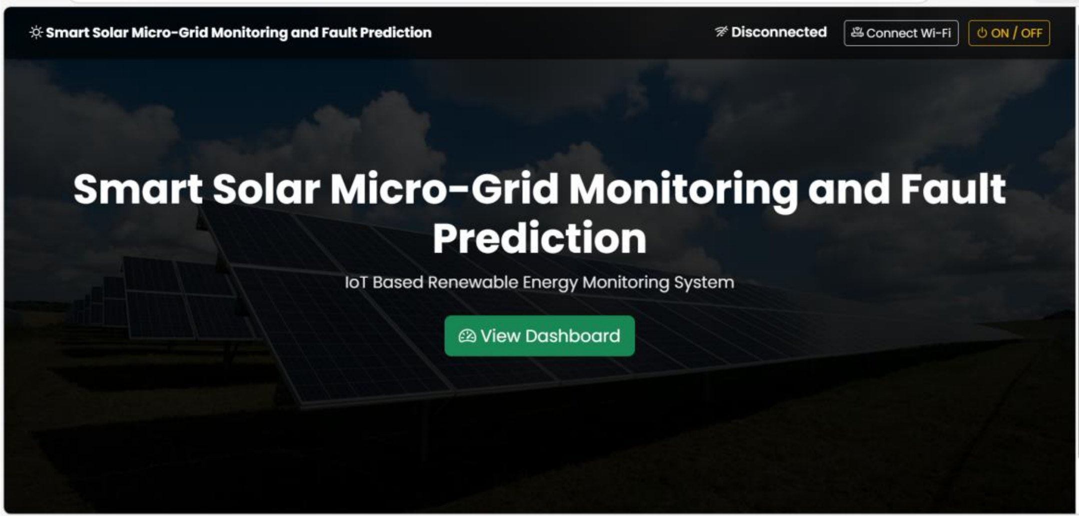


Figure 3.3 Home Page Design

4.User Dashboard Design

User dashboard for visualising real-time voltage, current, temperature, and battery status:

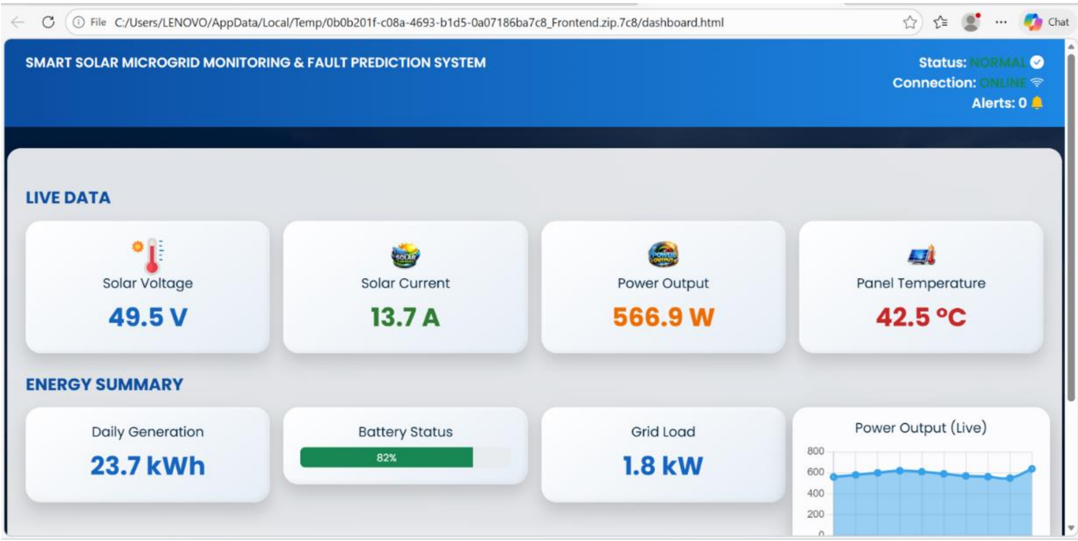
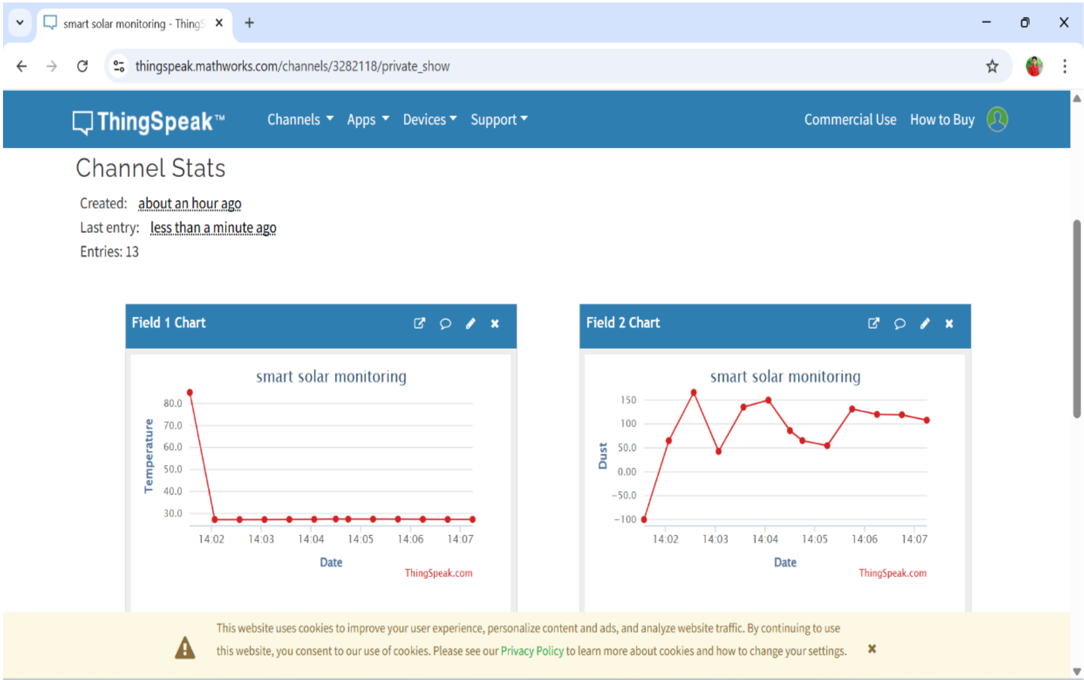


Figure 3.4 User Dashboard Design

4. Graphs of Monitoring.

Live monitoring graphs showing real-time performance of the solar micro-grid system:

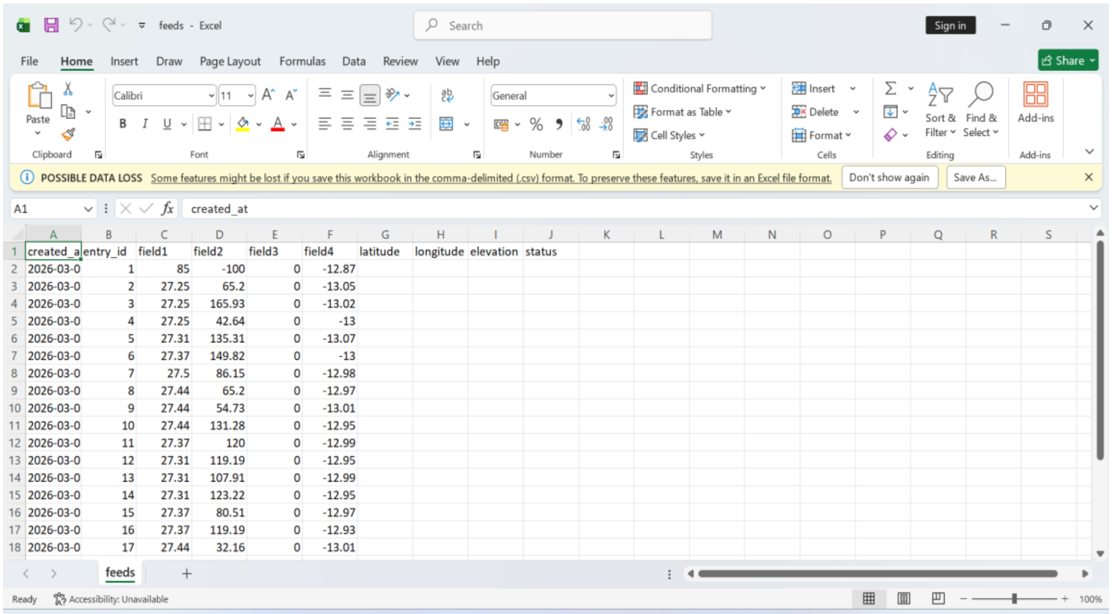


Figure

3.5 Real time Monitoring Graphs Analysis

5. Stored Data of Solar Panel

Recorded solar panel data, including electrical and environmental parameters:



created_at	entry_id	field1	field2	field3	field4	latitude	longitude	elevation	status
2026-03-0	1	85	-100	0	-12.87				
2026-03-0	2	27.25	65.2	0	-13.05				
2026-03-0	3	27.25	165.93	0	-13.02				
2026-03-0	4	27.25	42.64	0	-13				
2026-03-0	5	27.31	135.31	0	-13.07				
2026-03-0	6	27.37	149.82	0	-13				
2026-03-0	7	27.5	86.15	0	-12.98				
2026-03-0	8	27.44	65.2	0	-12.97				
2026-03-0	9	27.44	54.73	0	-13.01				
2026-03-0	10	27.44	131.28	0	-12.95				
2026-03-0	11	27.37	120	0	-12.99				
2026-03-0	12	27.31	119.19	0	-12.95				
2026-03-0	13	27.31	107.91	0	-12.99				
2026-03-0	14	27.31	123.22	0	-12.95				
2026-03-0	15	27.37	80.51	0	-12.97				
2026-03-0	16	27.37	119.19	0	-12.93				
2026-03-0	17	27.44	32.16	0	-13.01				

Figure 3.5 Stored Data of Solar Panel

6.Project Hardware Structure

Physical setup of solar micro-grid system with IoT-based hardware components:

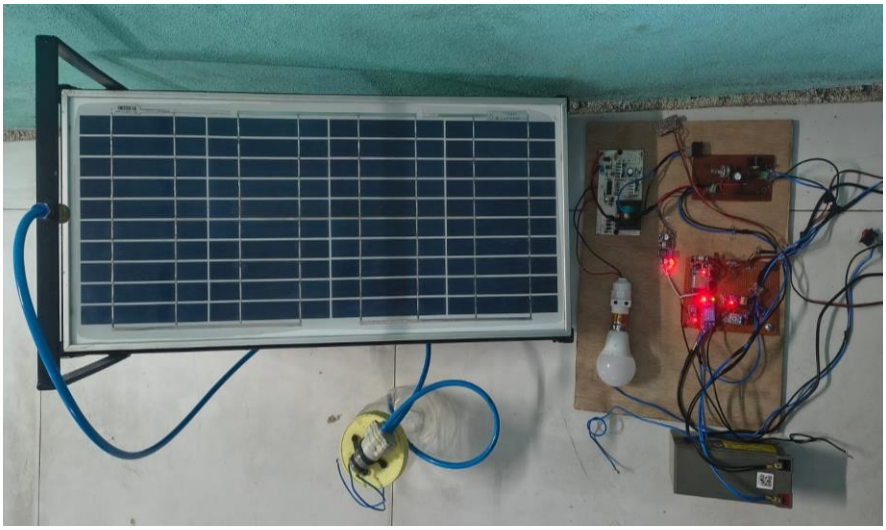


Figure 3.6 Project Hardware Structure

4. INTEGRATION & TESTING

Integration means connecting all the parts of the project so they work as one system. In this project, we connected sensors, an ESP32, a solar panel, a battery, and a cloud dashboard so that data can flow properly and the system can monitor everything in real time.

Testing means checking whether the system is working correctly or not. We tested each component, like sensors and ESP32, and then tested the full system to make sure it shows correct data, sends alerts, and works smoothly without errors.

5. SAFETY & LEGAL COMPLIANCE

In this project, proper safety measures are followed to ensure safe operation of the solar micro-grid system. Electrical components like solar panels, batteries, and wiring are handled carefully to avoid short circuits, overheating, and electric shocks. Protective devices such as charge controllers and proper insulation are used to maintain system safety.

The system is designed to operate within safe voltage and current limits to prevent damage to components and ensure user safety. Regular monitoring through sensors also helps in detecting abnormal conditions like high temperature or voltage fluctuations.

From a legal point of view, the project follows basic standards related to renewable energy systems and electronic devices. It uses approved components and follows general guidelines for safe installation and operation. Data collected from the system is used only for monitoring purposes, ensuring user privacy and security.

6. CONCLUSION

The Smart Solar Micro-Grid Monitoring System using IoT is an effective and practical solution for improving the performance of solar power systems. It helps in real-time monitoring of important parameters like voltage, current, temperature, battery status, and dust levels.

The system can detect problems early and send alerts, which reduces maintenance efforts and prevents major failures. It also allows remote monitoring, making it useful for rural and remote areas. Overall, this project increases efficiency, improves reliability, and supports the use of clean and sustainable energy

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