

**LOW POWER IOT BASED SOLAR PANEL HEALTH MONITORING SYSTEM***Sayali Ghatule**UG Student, Department of Electronics and Telecommunication Engineering
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vaibhav.godase@sknscoe.ac.in***Abstract:**

The rapid expansion of solar energy systems has heightened the demand for efficient maintenance strategies to guarantee peak performance. A primary factor influencing solar panel efficiency is the buildup of dust and dirt on the surface, which diminishes sunlight absorption and results in substantial power loss. To address this challenge, a Low Power IoT-Based Solar Panel Cleaning System featuring an automatic cleaning mechanism is proposed. The developed system combines an ESP32 microcontroller with a motorized cleaning assembly that includes a wiper, a rotating brush, and a water spray mechanism. The cleaning process runs automatically according to preset control logic, removing the need for regular manual oversight. Limit switches ensure the safe movement of the cleaning mechanism, while the motor driver facilitates the controlled operation of the DC gear motor. Powered by solar energy with a battery backup, the system offers energy efficiency and is well-suited for remote and off-grid applications. The proposed design emphasizes simplicity, affordability, and dependable performance. Furthermore, integrating IoT technology paves the way for future improvements in remote monitoring and system control. Implementing this system aids in keeping panels clean, boosting energy generation efficiency, and lowering maintenance requirements. In summary, the proposed solution provides a practical and scalable method for improving solar power system performance via automation and intelligent design.

Keywords: Solar Health Monitoring, IoT, Automatic Cleaning System, Low Power Design, Renewable Energy, Remote Monitoring.



1. INTRODUCTION

The surging demand for renewable energy has spurred a rapid expansion in the installation of solar photovoltaic (PV) systems across diverse sectors. Because solar energy is a clean, sustainable, and abundant resource, it is regarded as a primary solution for decreasing reliance on traditional fossil fuels. However, preserving the efficiency of solar panels remains a critical challenge, particularly in areas where environmental factors like dust, dirt, and pollution are common. One of the primary factors influencing solar panel performance is the buildup of dust on their surfaces. This dust layer diminishes the sunlight reaching the photovoltaic cells, which in turn lowers the total power output. Research indicates that even a thin layer of dust can lead to a substantial drop in energy generation efficiency. Issues become more pronounced in dry, dusty conditions, necessitating regular cleaning to ensure peak performance.

Traditional cleaning approaches primarily depend on manual labour, which is often time-consuming, expensive, and prone to inconsistency. In large-scale solar installations and remote locations, regular manual cleaning is often impractical. Furthermore, incorrect cleaning methods can cause physical damage to the panels, thereby reducing their lifespan and efficiency. These constraints underscore the necessity for an automated and dependable cleaning method.

Recent breakthroughs in embedded systems and Internet of Things (IoT) technologies have made it possible to create intelligent maintenance systems for solar panels. Microcontrollers like the ESP32 offer efficient control of mechanical and electrical components while maintaining low power consumption. By combining automation with sensor-based or time-based control logic, solar panel cleaning systems can function autonomously and guarantee consistent maintenance.

In this context, the proposed Low Power IoT-Based Solar Panel Cleaning System with Automatic Cleaning Mechanism seeks to tackle dust accumulation by employing an efficient and automated solution. The system employs a motorized cleaning assembly featuring a rotating brush, wiper, and water spray to effectively eliminate dirt. It runs on solar power with battery backup, offering a self-sustaining and energy-efficient solution. The main goal of this project is to enhance the performance and reliability of solar panels by automating their regular cleaning. The proposed system is engineered to be straightforward, cost-efficient, and flexible, making it suitable for a wide range of installations from residential rooftops to large-scale solar farms. By combining automation with embedded technology, the system boosts energy production and facilitates sustainable energy use.

2. LITERATURE SURVEY

B. G. Chikte and P. B. Agrawal [1] proposed an IoT-based solar energy monitoring system to observe key parameters such as voltage, current, and power output. The system allows real-time data access through internet connectivity, improving system transparency and enabling early fault detection. Their work highlights the importance of continuous monitoring for enhancing system reliability and maintenance efficiency.



Kumar et al. [2] developed a real-time solar monitoring system using IoT technology. The system collects performance data from solar panels and transmits it to a remote server for analysis. This approach helps in identifying inefficiencies and supports better decision-making for system optimization.

Priya and S. Kumar [3] introduced a low-power IoT-enabled solar monitoring system designed for energy-efficient operation. The system is suitable for remote locations and focuses on minimizing energy consumption while maintaining effective monitoring capabilities. Their study emphasizes the role of low-power design in sustainable systems.

S. Kale et al. [4] presented an integrated system for solar panel cleaning and monitoring using motorized wipers. The system automates dust removal while allowing remote monitoring through IoT. Their approach improves overall system efficiency by combining cleaning and monitoring functionalities.

R. Majeed et al. [5] conducted an experimental analysis of dust accumulation on photovoltaic panels. Their study shows that dust significantly reduces power output over time. They also proposed a cost-effective cleaning mechanism, highlighting the importance of regular maintenance.

Z. Mahatab Md Sakif et al. [6] proposed a deep learning-based system called “Sol Net” for detecting dust on solar panels. The system uses image processing techniques to identify dirt accumulation, enabling intelligent cleaning decisions. This improves automation and reduces unnecessary cleaning operations.

U. P. Singh and S. Chandra [7] focused on optimizing cleaning schedules using deep learning techniques. Their system determines the most efficient cleaning time based on performance data, reducing water and energy usage while maintaining system efficiency.

M. Abraim et al. [8] developed a photovoltaic soiling monitoring system that measures dust accumulation in real time. The system provides useful data for scheduling cleaning operations effectively, thereby improving overall performance and reliability.

P. Borah, L. Micheli, and N. Sarmah [9] presented a detailed review of soiling losses in solar panels. Their study analyzes environmental factors such as dust, humidity, and wind, and discusses various cleaning methods and mitigation strategies.

O. J. Alshawabkeh et al. [10] proposed an AIoT-based dust detection system using colour recognition and ANFIS techniques. The integration of artificial intelligence with IoT improves detection accuracy and enhances automated cleaning decisions.

M. P. Ndeto et al. [11] designed a self-powered solar panel cleaning system that operates using solar energy. The system is energy-efficient and reduces maintenance costs, making it suitable for practical implementation.



H. A. Khan et al. [12] developed a deep learning-based dust detection system for solar panels. Their system provides accurate detection and ensures timely cleaning, improving energy generation efficiency.

Portelli et al. [13] introduced a sensor-based system to detect dust-related power loss in solar panels. The system directly measures efficiency reduction, helping in better maintenance planning and improving system reliability.

R. Aman et al. [14] proposed a deep learning-assisted performance analysis system for photovoltaic modules. The system analyzes real-time data to predict efficiency loss and supports effective maintenance planning.

S. M. Tewari et al. [15] developed an AI-based solar panel cleaning robot integrated with IoT. The system performs automated cleaning using predictive techniques, reducing manual effort and ensuring consistent performance.

Table 1 Comparative review of Low Power IoT Based Solar Panel Health Monitoring System

Sr. No.	Authors	Year	Title	Journal / Conference	Technology Used
1	M. Mani, C. K. Pillai	2010	Impact of Dust on Solar PV Performance	Renewable & Sustainable Energy Reviews	PV Analysis
2	S. Kurtz et al.	2011	Effect of Soiling on PV Module Performance	NREL Report	Monitoring System
3	H. Jiang, L. Lu, K. Sun	2011	Impact of Airborne Dust on PV Modules	Atmospheric Environment	Experimental Analysis
4	A. Sayigh	2012	Effect of Dust on Solar Energy Systems	Renewable Energy	Environmental Study
5	M. J. Adinoyi, S. A. M. Said	2013	Effect of Dust on Power Output of PV Modules	Renewable Energy	Performance Analysis
6	S. I. Sulaiman et al.	2014	Effects of Dust on PV Panels	WASET	Experimental Study
7	A. Sayyah et al.	2014	Energy Loss due to Dust Deposition	Solar Energy	Efficiency Analysis
8	K. S. Rao et al.	2015	Automated Cleaning System for Solar Panels	IJAREE	Motorized Cleaning
9	D. Sharma et al.	2016	Automatic Solar Panel Cleaning System	IJERA	Microcontroller + Motor
10	B. G. Chikte, P. B. Agrawal	2017	IoT-Based Solar Monitoring System	IJIRSET	IoT + Sensors
11	Kumar et al.	2018	IoT-Based Solar Monitoring	IJET	IoT + Cloud
12	Priya, S. Kumar	2019	Low-Power IoT Solar Monitoring System	IJSER	Low Power IoT



Sr. No.	Authors	Year	Title	Journal / Conference	Technology Used
13	S. Kale et al.	2020	IoT-Based Cleaning & Monitoring System	Journal of Smart Systems	IoT + Wiper
14	R. Majeed et al.	2021	Soiling Loss Analysis & Cleaning System	Renewable Energy Systems	Cleaning Mechanism
15	Z. M. M. Sakif et al.	2022	CNN-Based Dust Detection (SolNet)	IEEE Access	AI + Image Processing
16	U. P. Singh, S. Chandra	2023	Optimization of Cleaning Schedule	IJ Renewable Energy	AI + Optimization
17	M. Abraim et al.	2023	PV Soiling Monitoring System	Solar Energy Journal	Monitoring System
18	P. Borah et al.	2023	Review of Soiling Loss in PV Modules	Sustainability	Review Study
19	O. J. Alshawabkeh et al.	2024	AIoT-Based Dust Detection System	IEEE Access	AI + IoT
20	M. P. Ndeto et al.	2024	Self-Powered Cleaning System	Renewable Energy	Solar + Automation
21	H. A. Khan et al.	2024	Deep Learning Dust Detection	Sustainability	ML + Detection
22	Portelli et al.	2025	Dust-Related Power Loss Sensor	Solar Energy Materials	Sensor System
23	R. Aman et al.	2025	Deep Learning PV Performance Analysis	IEEE Trans. Energy	AI + Monitoring
24	S. M. Tewari et al.	2025	AI-Based Solar Cleaning Robot	JETIR	Robotics + IoT

3. METHODOLOGY

The system is engineered to boost solar panel efficiency by combining an automated cleaning mechanism with embedded controls and IoT-based monitoring. The methodology adopts a structured approach encompassing system design, hardware implementation, software development, and system integration to ensure reliable and efficient operation.

The following diagram shows the methodology of the Low-Power IoT-Based Solar Panel Health Monitoring System.

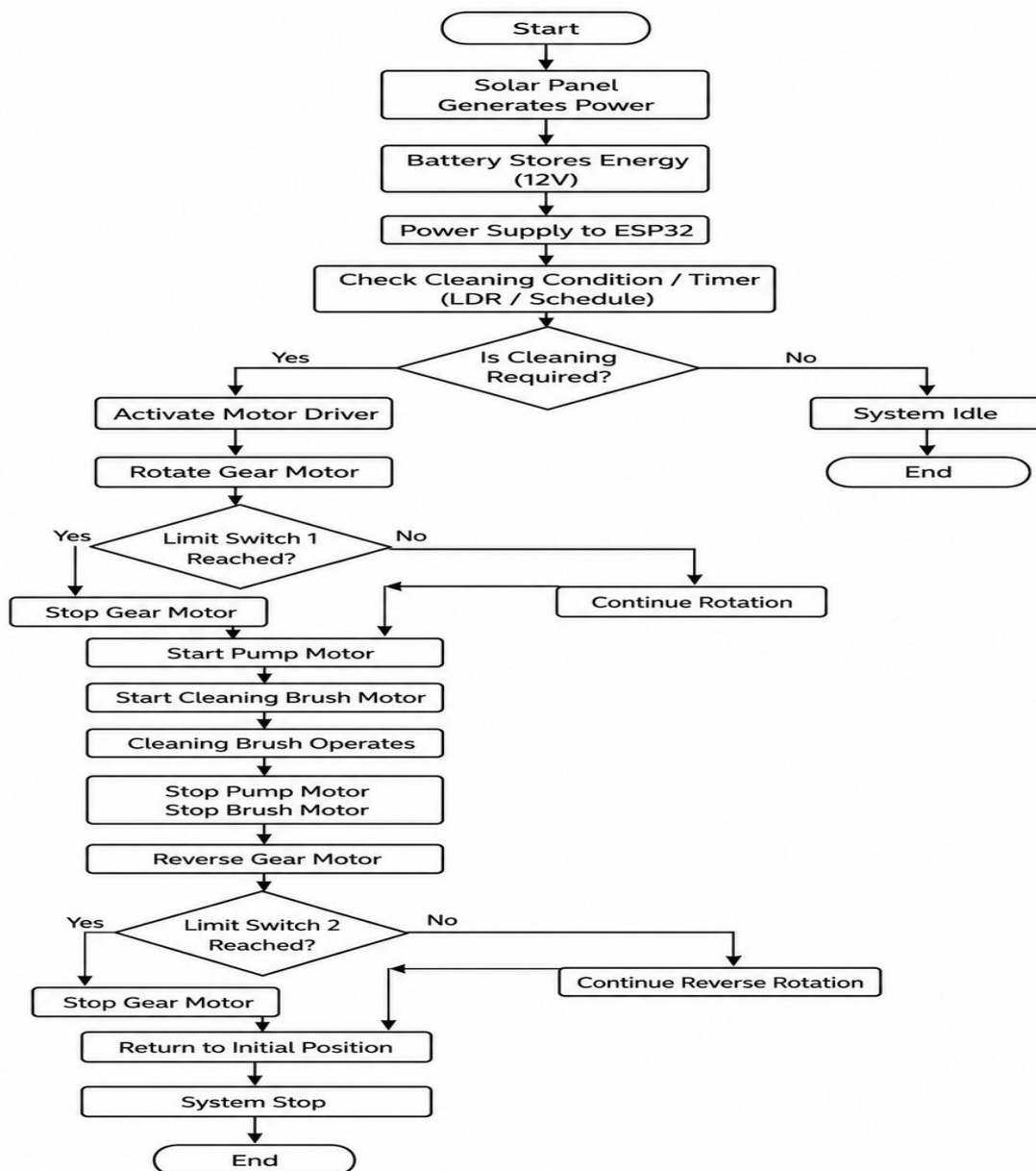


Figure 1 Block Diagram of Low Power IoT-Based Solar Panel Health Monitoring System

The system starts by using solar energy as its main power source. The solar panel converts sunlight into electricity, which is then stored in a rechargeable battery. This stored electricity powers the ESP32 microcontroller, motor driver, water pump, and other components. A voltage regulation unit maintains a stable power supply for all components, ensuring that the system operates smoothly even when environmental conditions change.

The ESP32 microcontroller acts as the main control unit of the system. It is programmed to manage



the cleaning process based on predefined rules, such as time intervals or specific conditions. It sends signals to the motor driver and water pump, ensuring that all components operate together. The ESP32 also has built-in Wi-Fi, which allows future expansion for internet-based monitoring and data collection.

The cleaning process uses a rotating brush and wiper mechanism powered by a DC gear motor. When the cleaning cycle begins, the motor moves the cleaning mechanism across the surface of the solar panel. At the same time, the water pump supplies water to loosen dust and improve the cleaning process. This combination of mechanical movement and water helps remove dust and dirt effectively from the panel surface.

To ensure safe and controlled operation, limit switches are placed at both ends of the panel. These switches send signals to the ESP32 when the cleaning mechanism reaches the edge of the panel. This allows the controller to stop or reverse the motor, preventing mechanical damage and ensuring proper operation of the system.

The system operates in automatic mode and performs cleaning cycles at regular intervals or when predefined conditions are met. The combination of automated control, motorized cleaning, and efficient power utilization minimizes the need for human intervention. The system can also be further enhanced with IoT-based monitoring using a Python backend or cloud platform to track cleaning performance and system operation in real time.

All hardware components and software modules are integrated and tested to ensure proper coordination and reliable operation. The system is evaluated based on cleaning effectiveness, power consumption, and operational stability. The proposed approach provides a cost-effective, energy-efficient, and scalable solution for maintaining solar panel performance under different operating conditions.

4. RESULT AND DISCUSSION

The IoT-based solar panel cleaning system was successfully designed, developed, and tested under different weather conditions. It used an automatic cleaning mechanism with a rotating brush and water sprayer to remove dust, dirt, and other particles from the solar panel surface. After cleaning, a noticeable improvement was observed in the performance and energy output of the solar panel, indicating better sunlight absorption and overall efficiency.

The following diagram shows the project setup of the Low-Power IoT-Based Solar Panel Health Monitoring System.

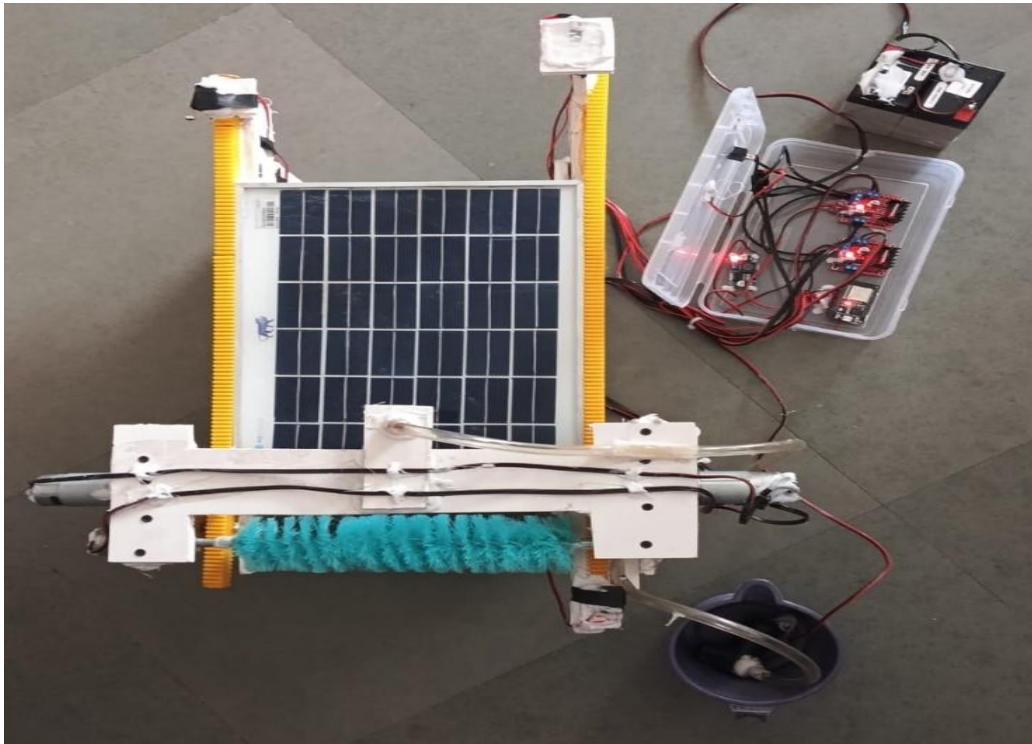


Figure 1 Project Setup

The ESP32 microcontroller worked effectively as the main control unit by coordinating the operation of the DC gear motor and water pump. The cleaning process operated smoothly without interruption, demonstrating reliable coordination between the hardware components. The limit switches helped ensure that the cleaning mechanism remained within the required movement range by detecting when it reached the end of its travel. This prevented excessive movement and improved the safety and durability of the system.

The system also operated with low power consumption and used energy efficiently. It utilized solar energy as the primary power source and included a battery backup to maintain operation when sunlight was unavailable or during nighttime. The automatic cleaning mechanism reduced the need for manual intervention and ensured regular cleaning of the solar panel. This helps maintain the performance and efficiency of solar panels over a longer period.

The following diagram shows the online setup of the Low-Power IoT-Based Solar Panel Health Monitoring System.

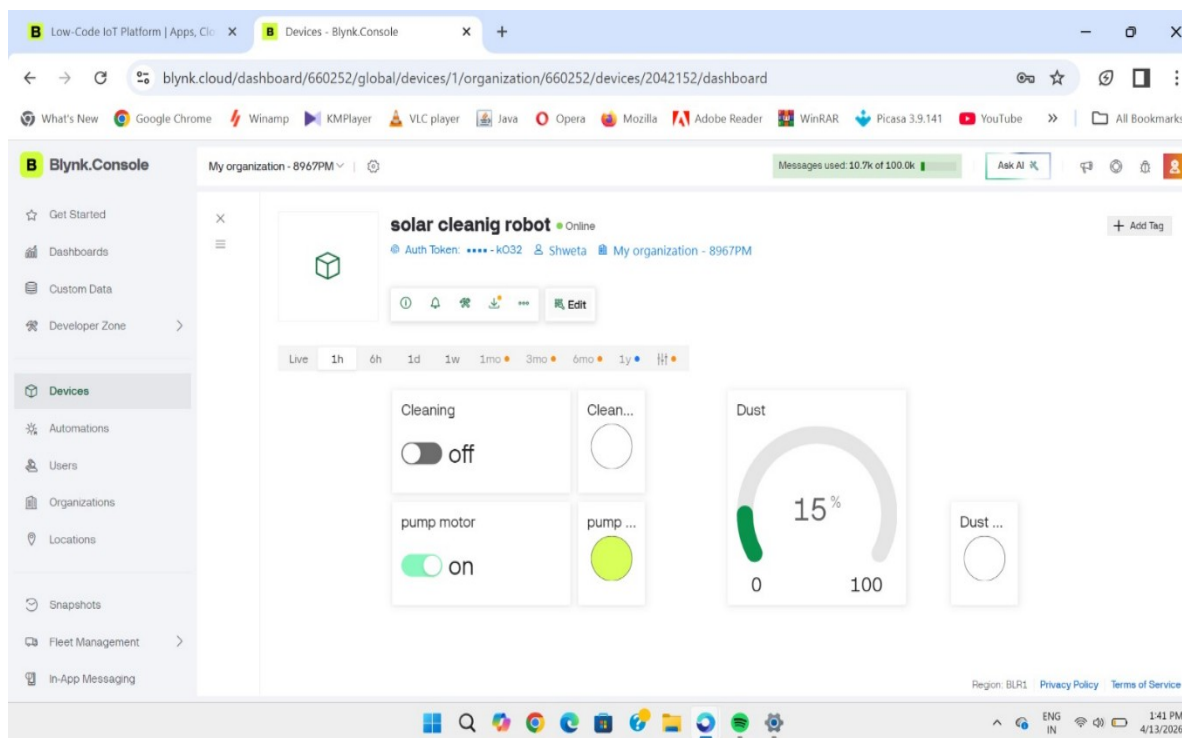


Figure 2 Blynk Status

The tests showed that dust accumulates on solar panels and reduces their energy output. The automatic cleaning system helped maintain the panels regularly without requiring manual cleaning. This improved the overall operation of the system and reduced maintenance and operating costs.

Using the ESP32 microcontroller with IoT-based control made the system more intelligent and flexible. It enabled remote monitoring of the system and provided opportunities for future improvements, such as real-time performance tracking and automatic scheduling of cleaning cycles. The system consumed power only when required, which helped save energy and improve overall efficiency.

The limit switches improved system reliability by controlling the movement of the cleaning mechanism accurately. This helped prevent mechanical damage and allowed the system to operate smoothly for longer periods. The combination of mechanical cleaning methods, such as a rotating brush and wiper, with water spraying made the cleaning process more effective, particularly in dusty environments.

From a cost perspective, the system is affordable due to its simple design, low maintenance requirements, and use of renewable energy. It can be applied in various locations, including residential buildings, offices, and large-scale solar farms. The system can also be adjusted according to different installation requirements and is suitable for areas with high levels of dust and pollution.



Overall, the proposed system provides a practical, efficient, and environmentally friendly approach to improving solar panel performance. It demonstrates how automation and intelligent control can support modern solar energy systems and provides a foundation for further research and development in smart solar panel maintenance solutions.

5. CONCLUSION

The IoT-based solar panel cleaning system offers an effective and automatic way to maintain solar panel performance. It uses a microcontroller-controlled motor to operate the cleaning mechanism, which helps reduce dust accumulation and improves the energy output of the solar panels.

Using solar energy with a battery backup allows the system to operate efficiently with minimal external power requirements, making it suitable for remote locations and large-scale solar installations. Overall, the proposed system reduces the need for manual cleaning, improves solar panel performance, and provides a cost-effective solution for maintaining solar panels.

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