Novateur Publications
International Journal of Innovations in Engineering Research and Technology [IJIERT]
ISSN: 2394-3696 Website: ijiert.org
Volume 13, Issue 5, May – 2026

SOLAR-POWERED MICROGRID FOR RURAL ELECTRIFICATION USING IOT-BASED MONITORING AND LOAD MANAGEMENT

Mr. Rahul Nalla 1
Mr. Tushar Thokal 2
Mr. Sudarshan Salgaonkar 3
Miss. Shruti Nilange 4
Prof. Metkari A. S. 5
Department of Electrical Engineering
Vidya Vikas Prathisthan Institute of Engineering & Technology, Solapur
1 rahulnalla0704@gmail.com
2 tusharthokal87@gmail.com
3 Sudarshan.salegaonkar@gmail.com
4 shrutinilange2004@gmail.com
5 archanametkari@gmail.com

Article History: Received on: 8/03/2026
Accepted on: 15/05/2026

DOI: https://doi.org/10.26662/ijiert.v13i5.pp1-6

Abstract

The Solar-Powered Microgrid for Rural Electrification using IoT-Based Monitoring and Load Management is designed to provide a reliable and sustainable power solution for rural and remote areas where conventional electricity supply is limited or unavailable. The system uses solar energy as the primary power source along with battery storage for continuous electricity supply during low sunlight and nighttime conditions.The project uses the Espressif Systems ESP32-WROOM module for IoT-based monitoring of parameters such as solar panel voltage, battery status, load conditions, and power availability. An LDR module is used for dust detection on the solar panel surface to monitor cleanliness and maintain efficient power generation.

A dedicated website has been developed for the project to provide a user-friendly platform for real-time monitoring and management of the solar microgrid system. The website displays live electrical parameters, battery conditions, dust detection status, energy availability, and load information, enabling users to monitor the system remotely through the internet. This improves accessibility, remote supervision, and smart energy management.

The system also includes smart load management that automatically controls non-essential loads during low power conditions, improving energy efficiency and preventing overload. The proposed system provides an eco-friendly, cost-effective, and efficient solution for rural electrification by combining renewable energy, IoT technology, dust monitoring, and web-based management systems.

Keywords: Solar-Powered Microgrid, Rural Electrification, IoT Monitoring, Smart Load Management, ESP32-WROOM, Renewable Energy, Dust Detection, LDR Sensor, Web-Based Monitoring, Battery Storage, Energy Management, Solar Energy, Smart Grid, Remote Monitoring, Sustainable Energy.

I. INTRODUCTION

Access to reliable electricity remains one of the major challenges in rural and remote areas where conventional power infrastructure is either unavailable or unreliable. Frequent power interruptions and lack of proper energy management affect the development of rural communities, agriculture, healthcare, and education. To overcome these challenges, renewable energy-based microgrid systems have emerged as an effective and sustainable solution for rural electrification.

The proposed project, **"Solar-Powered Microgrid for Rural Electrification using IoT-Based Monitoring and Load Management,"** is designed to provide a smart, reliable, and eco-friendly electricity system using solar energy as the primary power source. The system stores excess solar energy in batteries to ensure uninterrupted power supply during nighttime and low sunlight conditions.

The project uses the Espressif Systems ESP32-WROOM module for real-time monitoring and management of important electrical parameters such as solar panel voltage, battery status, load conditions, and power availability. An LDR module is integrated for dust detection on the solar panel surface to maintain efficient power generation and improve overall system performance.

A dedicated website has been developed to provide a user-friendly platform for real-time monitoring of the microgrid system. The website displays live system information including energy availability, battery condition, load status, and dust detection data, allowing users to monitor and manage the system remotely through the internet.

The system also includes smart load management, where non-essential loads are automatically controlled during low power conditions to improve energy efficiency and prevent system overload. By combining renewable energy, IoT technology, dust monitoring, and web-based management, the proposed system offers a cost-effective and sustainable solution for rural electrification and smart energy management.

II. LITERATURE SURVEY

1. **Solar Microgrid Systems:**
   Solar microgrids are widely used for rural electrification because they provide clean, renewable, and decentralized energy solutions for remote areas.

2. **IoT-Based Energy Monitoring:**
   IoT technology helps in monitoring electrical parameters such as voltage, battery status, and load conditions in real time for efficient energy management.

3. **Dust Detection in Solar Panels:**
   Dust accumulation on solar panels reduces power generation efficiency. LDR-based dust monitoring systems help maintain better performance by detecting dirt on panel surfaces.
4. **Smart Load Management Systems:**
   Load management techniques automatically control non-essential loads during low power conditions to improve energy efficiency and prevent overload.

5. **Web-Based Monitoring Systems:**
   Web applications enable remote monitoring and management of renewable energy systems through live data visualization and internet connectivity.

6. **III. BLOCK DIAGRAM**

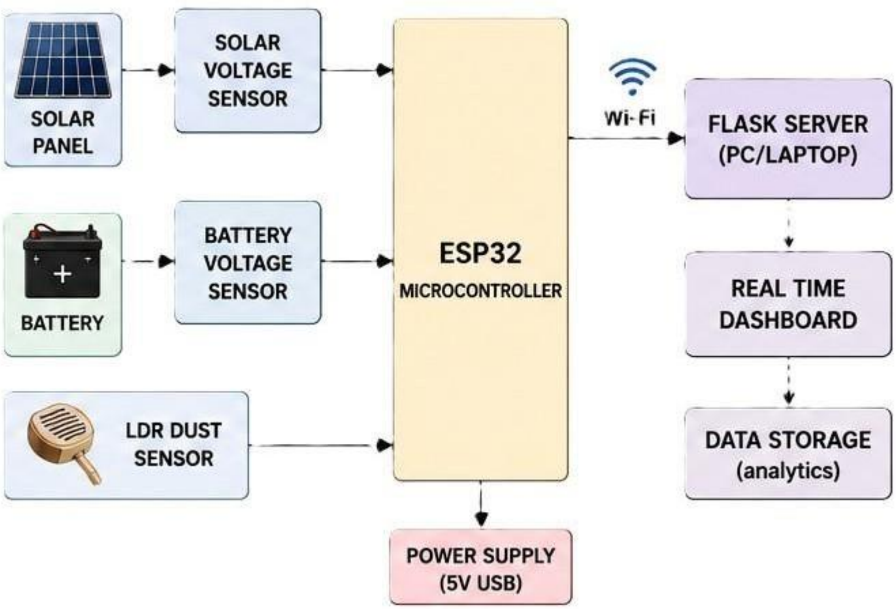

Fig No.1

IV. PROBLEM IDENTIFICATION

Many rural areas still suffer from poor electricity supply and unstable power infrastructure. Traditional power systems are expensive and difficult to maintain in remote locations. Solar panels are an effective solution, but their efficiency decreases due to dust accumulation and poor energy management. Lack of real-time monitoring also makes maintenance difficult.

This project addresses these issues by developing a solar-powered microgrid with IoT-based monitoring, dust detection, smart load management, and website-based remote supervision.

V. METHODOLOGY

1. Solar panels generate electrical energy from sunlight.
2. The charge controller regulates battery charging and protects the battery.
3. The battery stores excess solar energy for backup power.
4. ESP32-WROOM monitors voltage, battery status, and load conditions.
5. The LDR module detects dust accumulation on solar panels.
6. Relay modules control electrical loads automatically.
7. Live data is displayed on the developed website for remote monitoring.
8. Smart load management disconnects non-essential loads during low power conditions.

VI. COMPONENTS DESCRIPTION

1. Solar Panel - Converts sunlight into electrical energy.

2. Battery - Stores electrical energy for backup supply.

3. ESP32-WROOM - Used for IoT-based monitoring and control.

4. LDR Module - Detects dust on the solar panel surface.

5. Voltage Sensor - Monitors solar panel and battery voltage.

6. Website - Displays live system data and monitoring information.

VII. RESULT AND IMPLEMENTATION

Fig No.2

Parameter	Status
1. Solar Voltage	12.5 V
2. Battery Level	85%
3. Battery Backup	5 Hour
4. Dust Status	Dust Detected
5. Load Status	ON
6. Energy Availability	Normal
7. System Condition	Active

The developed system successfully generates electricity using solar energy and provides continuous power through battery backup. The ESP32-WROOM monitors system parameters and sends live data to the developed website. The LDR module detects dust on solar panels, helping maintain better efficiency.
The website displays real-time information such as battery status, energy availability, load condition, and dust detection status. Smart load management improves energy efficiency by automatically controlling loads during low power conditions.

VIII. ADVANTAGES

1. Eco-friendly energy solution.
2. Suitable for rural electrification.
3. Real-time monitoring through website.
4. Smart load management.
5. Improved solar panel efficiency using dust detection.
6. Cost-effective system.
7. Reliable backup power supply.
8. Remote supervision and management.

IX. APPLICATIONS

1. Rural villages
2. Smart homes
3. Farms and irrigation systems
4. Remote healthcare centers
5. Educational institutions
6. Disaster relief power systems

X. FUTURE SCOPE

1. **Automatic Solar Panel Cleaning System**
   An automatic cleaning mechanism can be added to remove dust from solar panels and improve power generation efficiency.

2. **Mobile Application Integration**
   A mobile application can be developed for easier real-time monitoring and control of the microgrid system.

3. **AI-Based Energy Prediction**
   Artificial Intelligence and Machine Learning algorithms can be used to predict energy generation and consumption patterns.

4. **Hybrid Renewable Energy System**
   The system can be expanded by integrating other renewable energy sources such as wind or hydro power.

5. **Advanced Fault Detection System**
   Smart fault detection and alert systems can be implemented for faster maintenance and improved reliability.

6. **Smart Energy Billing System**
   A digital energy meter and billing system can be added for energy usage tracking and cost management.

7. **Remote Load Control**
   Users can control electrical loads remotely through the website or mobile application.

8. **Large-Scale Rural Deployment**
   The proposed system can be implemented on a larger scale for smart villages and rural community electrification projects.

REFERENCES

1. A. Sharma and P. Gupta, "Solar Powered Microgrid System for Rural Electrification," International Journal of Renewable Energy Research, vol. 10, no. 3, pp. 145–150, Mar. 2022.
2. S. Kumar and R. Singh, "IoT-Based Smart Energy Monitoring System Using ESP32," IEEE International Conference on Smart Electronics and Communication, pp. 210–214, 2021.
3. M. Patel and K. Shah, "Web-Based Monitoring and Control of Solar Energy Systems," International Journal of Engineering Research and Technology (IJERT), vol. 9, no. 5, pp. 102–106, May 2020.
4. V. Rao and P. Kulkarni, "Smart Load Management in Renewable Energy Microgrids," IEEE Access, vol. 8, pp. 65432–65440, 2020.
5. R. Mishra and A. Verma, "Performance Analysis of Solar Panels under Dust Conditions Using LDR Sensors," International Journal of Advanced Research in Electrical Engineering, vol. 7, no. 4, pp. 78–83, Apr. 2021.
6. Espressif Systems, "ESP32-WROOM-32 Datasheet," Espressif Systems, 2023. [Online]. Available: ESP32 Official Documentation.
7. "Solar Energy and Rural Electrification," National Renewable Energy Laboratory (NREL), accessed May 2026.
8. A. Joshi and S. Patil, "Design and Development of IoT-Based Smart Microgrid for Rural Applications," International Journal of Scientific Research in Engineering and Management, vol. 6, no. 8, pp. 1–6, 2022.