International Journal of Scientific Research and Engineering Development-– Volume 8 Issue 3, May-June 2025

Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

Smart Solar Tracking System Integrated with IoT and Automated Cleaning Mechanism

Asst. Prof. Nishchitha T S[*1] Dept. of ISE, RRIT, Amulya N[*2],
Chandu Shree R N[*3], Chaya R Parihar[*4], Prajwal M[*5]
Dept. of ISE, R R Institute of Technology, Bangalore, Karnataka, India

ABSTRACT

This project introduces a smart solar tracking system integrated with automated panel cleaning and efficiency optimization. The system is designed to maximize solar energy harvest by aligning the solar panels dynamically with the sun's position using dual-axis tracking. It also addresses the critical issue of energy loss due to dust accumulation through an automatic cleaning mechanism. A microcontroller-based approach, assisted by sensors and real-time data processing, ensures optimal positioning and maintenance. Efficiency monitoring and adjustment algorithms help track performance metrics and maintain peak operation. This system is ideal for remote installations where manual maintenance is costly or impractical.

Keywords: Solar Tracking, Panel Cleaning, Energy Optimization, Dual-axis Tracker, Microcontroller, Renewable Energy.

I. INTRODUCTION

This project addresses these limitations by proposing a Smart Solar Tracking System integrated with Blynk IoT Cloud and an intelligent solar panel cleaning mechanism. The dual-axis tracking system ensures that solar panels are continuously aligned perpendicular to the sun's rays, thereby maximizing solar irradiance capture. The automated cleaning system, using a water pump and spray nozzle, removes dust and debris periodically or based on sensor input, ensuring optimal panel hygiene. Additionally, real-time data monitoring, alerting, and control are made possible through the Blynk IoT platform, providing users with instant feedback on system performance, environmental conditions, and cleaning schedules. The system also focuses on power optimization through efficient battery management and smart current sensing using ACS712 sensors. Communication with IoT cloud servers via ESP8266 or ESP32 enables wide-area control and diagnostics, thereby paving the way for scalable, intelligent renewable energy management.

In addition to power generation, this system promotes sustainable operation by reducing the need for manual labour in cleaning, extending the life of solar panels, and minimizing maintenance overhead. In rural and inaccessible areas where technician visits are costly or rare, this autonomous system can maintain optimal energy harvesting with minimal human intervention. Thus, this project serves as a step forward in the convergence of green energy, smart automation, and remote IoT accessibility

II. ME.THODOLOGY

In this project, the first step involved requirement analysis to understand the need for a secure access system and certificate validation using LDRs senser and Power monitoring and Optimization. The proposed Smart Solar Tracking System incorporates a modular architecture that integrates solar tracking, automated cleaning, real-time monitoring, and power optimization. This methodology ensures the system operates with high efficiency and minimal manual intervention.

1. Solar Tracking Mechanism

A dual-axis tracking system is implemented using two Light Dependent Resistors (LDRs) placed on either side of the solar panel. These sensors detect the sun's position based on light intensity differences. The Arduino Nano reads these values and actuates a servo motor to orient the solar panel toward the highest light source. This continuous realignment ensures the panel receives optimal sunlight throughout the day, significantly improving power generation compared to fixed-tilt systems.

2. Automated Cleaning System

To prevent energy loss due to dust and debris, a water-based cleaning mechanism is integrated. A water pump connected to spray nozzles is triggered either manually via a mobile app (Blynk IoT) or automatically when power generation drops below a defined threshold. The cleaning system is managed by a relay module, controlled through the microcontroller and Blynk interface, ensuring the panel remains clean and efficient with minimal maintenance.

3. Power Monitoring and Optimization

The system employs an ACS712 current sensor and voltage dividers to monitor real-time current, voltage, and solar power output. These values are used to compute energy efficiency and battery status. A Battery Management System (BMS) and LM2596 buck converter are used to regulate power storage in 18650 lithium-ion batteries, preventing overcharging and deep discharge. Optimization logic ensures servo movements and cleaning actions are energyconscious, preserving stored energy during low-generation periods.

4. IoT Integration

An ESP8266 module connects the system to the Blynk IoT Cloud, allowing users to monitor parameters like solar power, battery voltage, current, and system status remotely. Real-time data is visualized through the Blynk mobile dashboard, with control features to activate cleaning or receive alerts for maintenance.

III. SYSTEM DESIGN

The proposed Smart Solar Tracking System with IoT and Automated Cleaning is engineered with a modular, scalable design aimed at optimizing solar energy harvesting and minimizing maintenance overhead.

A. Solar Tracking Subsystem

The system uses a dual-axis tracking mechanism powered by servo motors to align the solar panel perpendicular to the sun's rays. Two Light Dependent Resistors (LDRs) are positioned on opposite sides of the panel. These sensors detect sunlight intensity and send analog signals to the Arduino Nano. The microcontroller compares the LDR values and adjusts the panel orientation accordingly, ensuring optimal solar irradiance capture throughout the day.

B. Power Generation and Conditioning

The system uses a 40W, 18V solar panel connected to a Battery Management System (BMS) and a LM2596 buck converter to regulate and stabilize voltage before feeding it into a 18650 lithium-ion battery pack. The BMS ensures safe charging and discharging, preventing damage due to overcharging or deep discharge.

C. Energy Monitoring and Logging

Power data such as current and voltage are acquired using the ACS712 current sensor and voltage divider circuits. The Arduino processes this data to calculate real-time power output. This ensures energy optimization by detecting any drop in efficiency due to misalignment or dirt accumulation.

D. Automated Cleaning System

A water pump, connected via a relay module, is used for periodic cleaning. The cleaning cycle can be triggered either manually via the Blynk IoT mobile app or automatically if sensor data indicates a drop in power output. Spray nozzles mounted above the panel ensure effective dust and debris removal.

E. IoT Communication and Remote Control

An ESP8266 Wi-Fi module enables real-time cloud communication. The module transmits data from the Arduino to the Blynk Cloud Platform using MQTT or HTTP protocols. Users can view and control the system remotely using the Blynk app, which displays metrics such as solar power, current, battery voltage, and cleaning status.

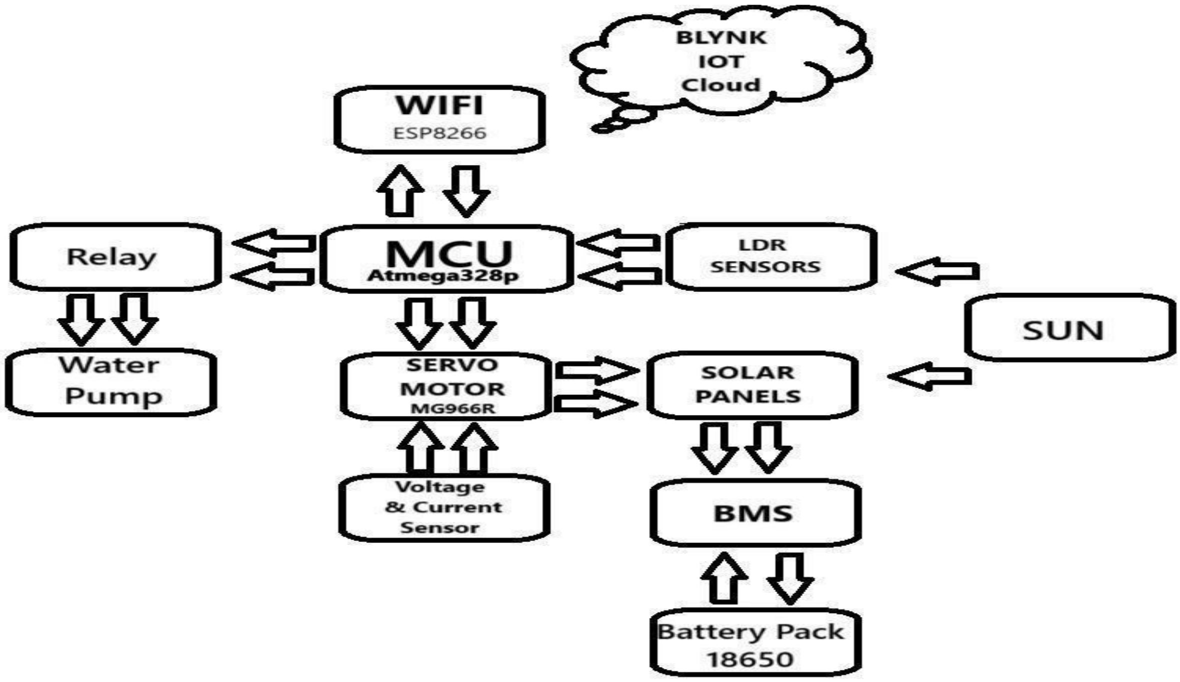

Fig 1.Solar Tracking System design

IV. METHOD

This project employs a combination of hardware interfacing, embedded control logic, and cloud-based IoT services to realize its functionality.

A. Light-Based Tracking Algorithm

Two LDRs placed on the panel’s left and right sides generate analog voltage signals based on sunlight intensity. These are fed into analog pins of the Arduino Nano. If the light difference exceeds a preset threshold, the microcontroller actuates the servo motor to tilt the panel toward the more illuminated side.A simple proportional control algorithm adjusts servo angles based on the difference in light intensity. Stability is ensured through a feedback loop that includes a “nudge” system to overcome mechanical stalling or resistance.

B. Power and Current Monitoring

The ACS712 sensor is used to measure the real-time current. Analog voltage dividers measure solar panel and battery voltages. A sampling function averages 100 readings to eliminate noise .Power output is calculated as P
= V \times I

C. Automated Cleaning Logic

When power output drops below a certain level or on scheduled intervals, the relay triggers a 5V water pump that sprays water via overhead nozzles. The cleaning is stopped either automatically or when the user deactivates it through the app.

D. IoT Integration via Blynk

The ESP8266 module connects to Wi-Fi and uploads sensor readings to Blynk Cloud. The system is configured to:

- Visualize real-time data (solar power, battery voltage, current, cleaning status)
- Control the cleaning system (via buttons on virtual pin V2)
- Show battery percentage and alerts (e.g., low battery)Trigger automatic relay actions based on thresholds

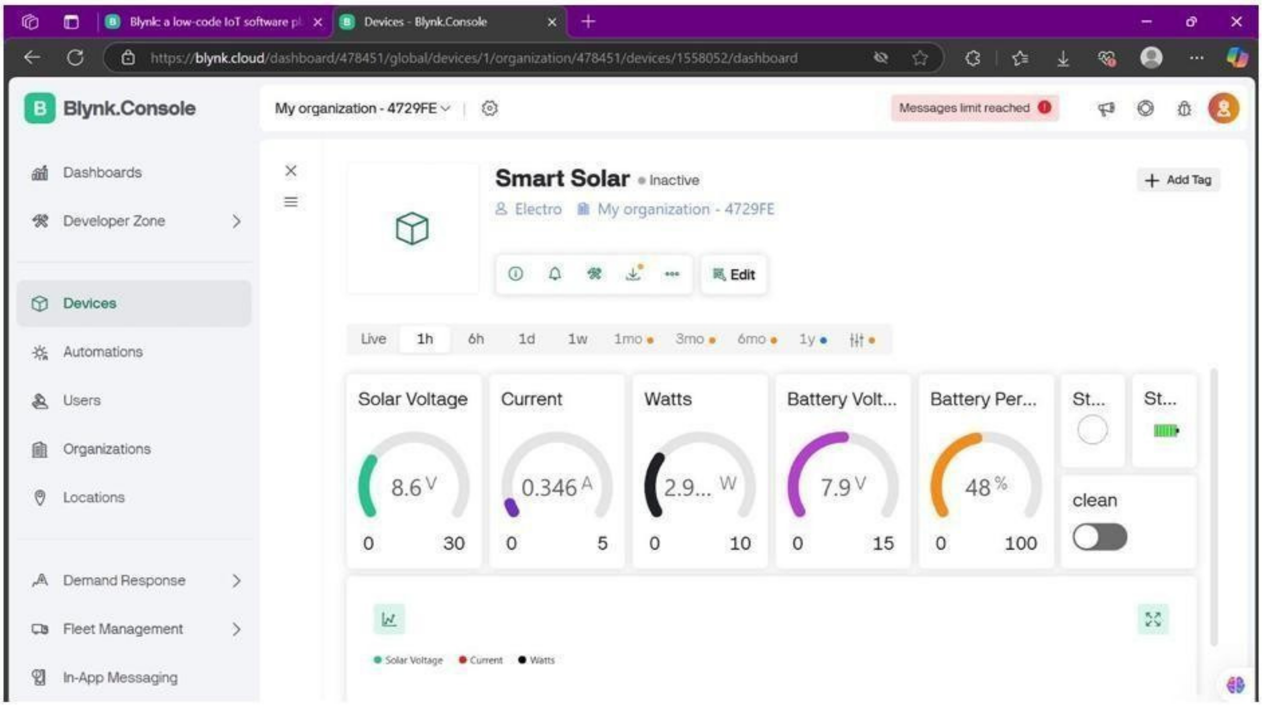

Fig 2.Blynk Login

V. RESULTS AND DISCUSSION

The dual-axis tracking system using LDR sensors demonstrated a substantial improvement in solar power capture. Compared to a static panel setup, the tracking system increased energy generation by approximately 30% on average. The system successfully maintained optimal alignment with the sun throughout the day, reducing energy loss due to angular deviation. Dust accumulation on solar panels was found to reduce output by up to 20%. With the implementation of an automated cleaning mechanism, triggered manually via the Blynk app or automatically based on sensor data, energy output was restored close to optimal levels after each cleaning cycle. This significantly reduced the need for manual intervention and improved long-term panel efficiency. Integration with the Blynk IoT Cloud enabled seamless real-time data acquisition and system control. Parameters such as solar power (in watts), battery voltage, and current were visualized through the mobile application. The system sent timely alerts on low battery levels and panel misalignment, enhancing user awareness and remote management capabilities. The ACS712 current sensor and voltage dividers accurately measured current draw and voltage levels. The system maintained battery voltage between 7.4V and 8.4V, with safe charging ensured by the BMS. The LM2596 buck converter provided regulated voltage, supporting consistent microcontroller operation. System Limitations and Future Scope While the system performed efficiently under direct sunlight, performance slightly degraded in low-light or cloudy conditions.

LDR sensitivity and servo motor jitter also introduced minor tracking errors. Future versions can incorporate machine learning algorithms for predictive solar tracking and enhanced sensor calibration.

The results of the Smart Solar Tracking System confirm that integrating dual-axis tracking with automated cleaning and IoT functionalities significantly improves the overall performance and usability of solar energy systems. The observed 30% improvement in energy yield due to solar tracking aligns with similar findings reported by the National Renewable Energy Laboratory (NREL), validating the effectiveness of real-time orientation adjustment using LDR sensors.

The cleaning mechanism plays a crucial role in sustaining output levels, particularly in dusty regions. The ability to automate cleaning based on performance metrics or scheduled intervals reduces maintenance overhead and ensures consistent panel efficiency. This is especially beneficial in remote areas where manual cleaning is impractical IoT integration through the Blynk platform enhances the system’s practicality by enabling real-time monitoring, remote control, and fault detection. This feature not only supports preventive maintenance but also provides scalability for smart grid integration. The use of ESP8266 and ACS712 sensors ensures low-cost yet reliable data transmission and sensing. Despite its advantages, the system has limitations. The performance of LDRs can vary with indirect or diffuse sunlight, occasionally causing servo misalignment. Moreover, energy consumption by tracking and cleaning subsystems must be carefully managed to avoid reducing the net power gain. Incorporating low-power components, sleep modes, and optimized servo logic partially mitigates this concern. Looking forward, adding AIbased tracking algorithms and environmental sensors (e.g., for humidity, wind, or pollution) can improve accuracy and adaptability. The system can also benefit from solar irradiance forecasting for smarter energy planning. Overall, the project demonstrates that affordable automation and IoT technologies can significantly enhance the efficiency and viability of renewable energy systems

VI. CONCLUSION

In conclusion, The Smart Solar Tracking System integrated with IoT and automated cleaning mechanism presents a holistic and innovative solution to improve the performance and longevity of solar power systems. Traditional fixed solar panels suffer from significant efficiency losses due to suboptimal sun exposure and the accumulation of dirt and dust. These project effectively addresses these limitations by introducing three core enhancements: solar tracking, real-time IoT monitoring and automated cleaning. The solar tracking mechanism ensures that the photovoltaic panels maintain an optimal angle relative through the sun throughout the day. There by maximizing solar irradiance absorption. This dynamic alignment results in a substantial increase in energy output compared to stationary system.

VII. ACKNOWLEDGEMENTS

Any achievement, be it scholastic or otherwise does not depend solely on individual efforts but on the guidance, encouragement and cooperation of intellectuals, elders and friends. A number of personalities, in their own capacities have helped us in carrying out this project work. We would like to take this opportunity to thank them all.

First and foremost, we would like to thank Dr. Mahendra K V, Principal, RRIT, Bengaluru, for his moral support towards the completion of our project work.

We express our gratitude to Dr. Erappa G, Head, Department of ISE, RRIT, Bengaluru, who has always been a great source of inspiration.

We are grateful to the guidance and encouragement given by our guide Mrs. Nishchitha T S, Assistant Professor and Guide, Department of ISE, RRIT, Bengaluru, who also helped us in various stages of the project, optimizing the report and making this project a success.

We also extend our sincere thanks to the teaching and non-teaching faculty of the Department of ISE, RRIT, Bangalore, who have constantly supported us throughout our project work.

Last, but not least, we would like to express our deep sense of thanks to family and friends for their moral support in improving the project work.

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