

IOT BASED SUN TRACKING SOLAR PANEL MONITORING & SOLAR POWER MANAGEMENT SYSTEM

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Abstract: *The increasing global demand for clean and renewable energy has positioned solar photovoltaic (PV) technology as one of the most sustainable energy generation methods. However, the effectiveness of solar panels is highly dependent on their orientation with respect to the sun's position. To address this limitation, this project presents the design and implementation of an IoT-based solar tracking and power management system. The proposed system employs an ESP8266 microcontroller and servo motor to continuously adjust the solar panel's position for maximum sunlight exposure, thereby improving energy conversion efficiency. The designed model demonstrates significant improvements in energy generation efficiency and operational reliability when compared to traditional fixed solar panels.*

KEYWORD: IoT, Sun Tracking System, Solar Panel Monitoring, Renewable Energy, Dual-Axis Tracking, ESP8266, Light Dependent Resistor (LDR), DHT11 Sensor, Servo Motor Control, Solar Power Management, Real-Time Monitoring, Cloud

Computing, Embedded Systems, Photovoltaic (PV) System, Smart Energy Systems.

I. INTRODUCTION

The demand for sustainable and renewable energy resources is rapidly increasing due to global concerns over fossil fuel depletion, climate change, and carbon emissions. Among all renewable energy sources, solar energy remains the most abundant, clean, and environmentally friendly option. The challenge, however, lies in efficiently harnessing this energy, as the output of a solar panel is heavily dependent on the intensity and angle of sunlight incident on its surface. Fixed solar panels fail to capture optimal sunlight throughout the day because their orientation does not change with the sun's movement. Consequently, their energy generation capacity remains below potential efficiency levels. To overcome these limitations, Sun-tracking systems have been developed to ensure that the solar panel remains aligned with the sun from sunrise to sunset. The project contributes to advancing renewable energy utilization, particularly in off-grid and remote applications where energy efficiency,

II. LITERATURE SURVEY

A comprehensive review of existing research in solar tracking systems and IoT-based energy management reveals continuous advancements toward improving solar panel efficiency, automation, and real-time monitoring. The literature highlights the role of embedded systems, wireless communication technologies, and cloud-based data analytics in transforming traditional photovoltaic (PV) setups into intelligent energy systems. Researchers have widely explored solar tracking mechanisms to maximize energy harvesting. Studies comparing single-axis and dual-axis trackers have shown that active tracking systems can increase energy efficiency by 20–40% compared to fixed installations. Dual-axis systems, though more complex and expensive, offer superior accuracy by maintaining the panel's perpendicular orientation to sunlight throughout the day. Single-axis trackers, in contrast, provide a cost-effective compromise suitable for smaller applications. Recent developments have incorporated IoT platforms to enhance the monitoring and control of solar systems. Integration of ESP8266 and ESP32 microcontrollers with Thingspeak and Blynk cloud platforms has enabled real-time data acquisition, remote supervision, and intelligent fault detection. These systems facilitate automated analysis of voltage, current, and environmental data to predict performance trends and ensure reliable operation. For instance, several studies have demonstrated IoT-based solar monitoring using ESP8266 modules connected to the Thingspeak platform, where data such as temperature, humidity, and power output are stored and visualized through interactive dashboards. This allows users to access real-time performance metrics from any location via the internet. Additionally, research has explored hybrid systems combining machine learning and IoT to predict sunlight intensity and optimize panel orientation proactively.

In the field of battery management, IoT-based monitoring using current and voltage sensors enables accurate assessment of charging and discharging cycles, ensuring prolonged battery life and preventing overcharging. The use of cloud computing and MATLAB analytics on platforms like Thingspeak further enhances the ability to analyze stored data for system optimization and predictive maintenance. Overall, the literature indicates a strong trend toward merging IoT technology with renewable energy systems, enabling automation, remote access, and improved energy efficiency. The insights from prior research form the foundation for developing the proposed IoT-based solar tracking and power management system, which aims to combine automatic tracking with comprehensive real-time monitoring.

III. BLOCK DIAGRAM

The block diagram of IOT based sun tracking solar panel monitoring and solar power management system consists of the following.

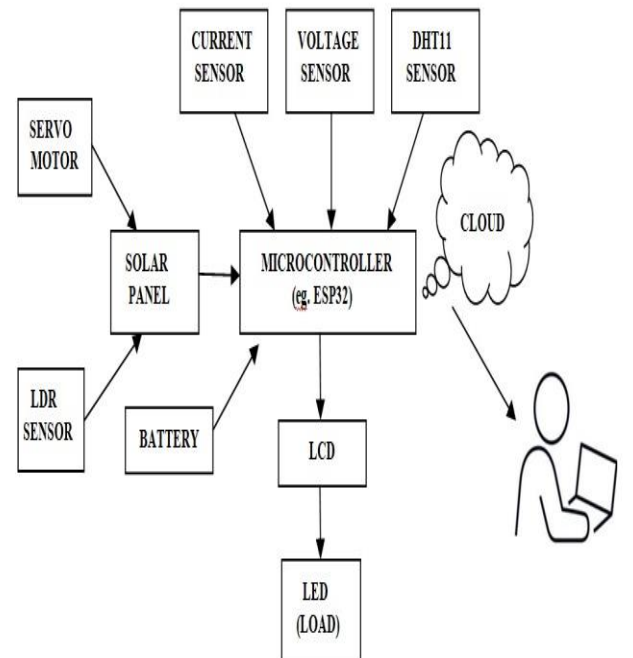


Fig 1: Block Diagram

VI. FLOWCHART

The flow chart of sun tracking solar panel monitoring and solar power management system consists of the following:

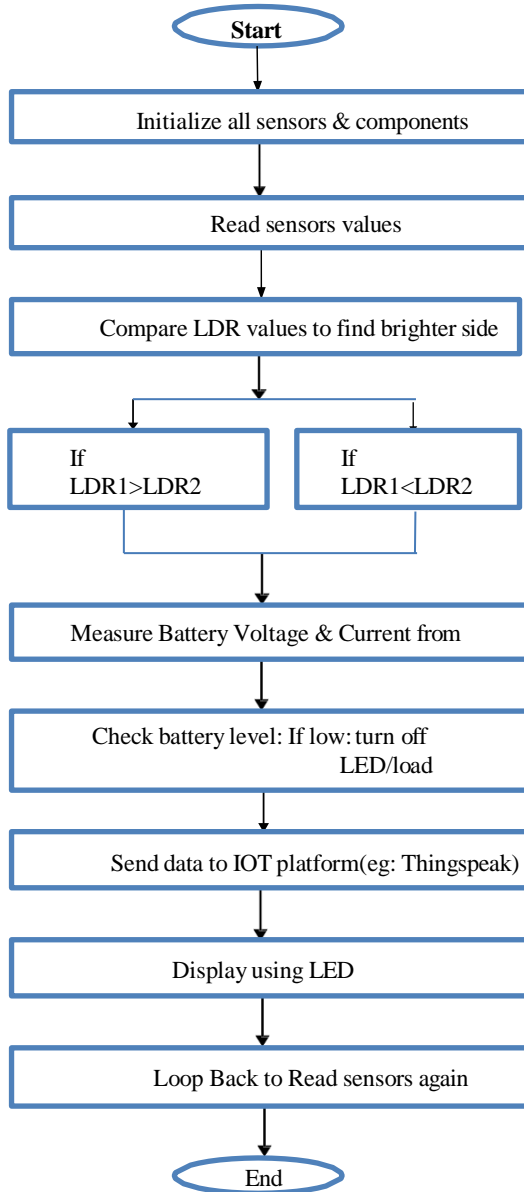


Fig 2: Flow Chart

IV. METHODOLOGY

1. Hardware Components:

The components that are required for the implementation of IOT based sun tracking solar panel monitoring and solar power management system consists as follows:

➤ Solar Panel:



Fig 3: Solar Panel

The solar panel, a vital component within Solar Tracking and IoT Battery Monitoring systems with ESP8266, stands as the primary mechanism for harnessing solar energy. Employing the photovoltaic effect, it converts sunlight into electrical energy through arrays of interconnected solar cells. These panels vary in size, efficiency, and capacity, offering flexibility to tailor energy generation to specific project requirements. Integrated within the solar tracking system, the solar board dynamically adjusts its orientation to align with the sun's position, optimizing energy capture throughout the day.

➤ Current sensor:

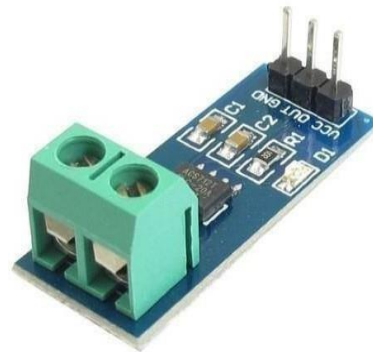


Fig 4: Current Sensor

It is used to measure the amount of current generated by the solar panel and flowing toward the battery or load. In this project, an ACS712 current sensor is used, which operates on the Hall- effect principle to detect current without making direct contact with the high-power circuit. The sensor provides an analog voltage output proportional to the current flowing through it. This output is connected to an analog input pin (GPIO34) of the ESP8266 microcontroller, which reads and converts the signal into current values using its ADC (Analog-to-Digital Converter).

➤ **LCD Display:**

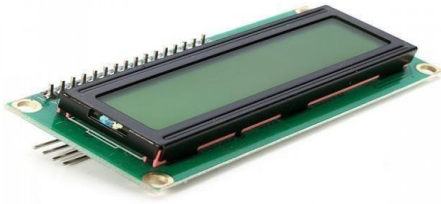


Fig 5: LCD Display

In this project, a 16x2 I2C LCD display is used to present real-time data to the user in a simple and readable format. The LCD is connected to the ESP32 microcontroller using the I2C communication pins — SDA (GPIO21) and SCL (GPIO22) — which reduce wiring complexity and make the system more efficient. It displays important parameters such as solar panel voltage, current, temperature, humidity, and system status, allowing users to observe performance instantly without needing a computer or mobile device.

➤ **Microcontroller (WIFI Module):**

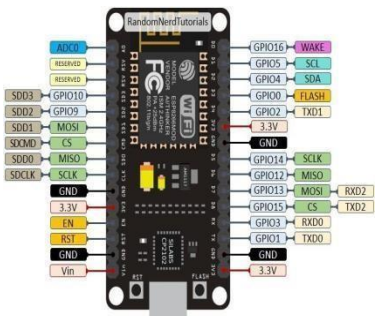


Fig 6: ESP8266 WIFI Module

The ESP8266 is a low-cost Wi-Fi microchip with full TCP/IP stack and microcontroller capability, widely used in IoT applications for wireless data transmission. In the IoT-based Sun Tracking Solar Panel Monitoring and Power Management System, the ESP8266 is used to send real-time sensor data (voltage, current, temperature, humidity, sunlight intensity) from the microcontroller to a cloud platform like Thingspeak or Blynk.

The ESP8266 is a low-cost Wi-Fi microcontroller widely used in IoT projects for wireless communication. In the sun tracking solar panel system, the ESP8266 is responsible for sending real-time sensor data, such as voltage, current, temperature, and humidity, to cloud platforms like Thingspeak or Blynk. It allows remote monitoring and control of the solar panel system, enabling users to track performance, detect faults, and manage energy efficiently. The ESP8266 is popular due to its built-in Wi-Fi module, compact size, low power consumption, and ease of programming, making it ideal for smart solar energy management applications.

➤ **LDR Sensor:**

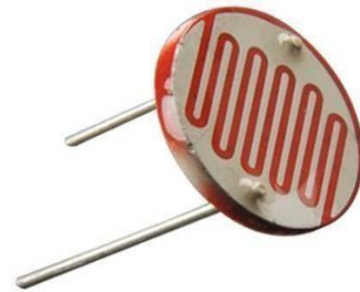


Fig 7: LDR Sensor

The LDR (Light Dependent Resistor) is a sensor whose resistance varies according to the intensity of light falling on it. In the sun tracking solar panel system, LDRs are used to detect the direction of sunlight. Typically, four LDRs are positioned at the corners of the panel, and the microcontroller compares the light intensity readings from each sensor to determine the direction receiving the most sunlight. Based on this information, the motors adjust the panel's orientation to align with the sun, ensuring optimal energy generation.

➤ **DHT 11 Sensor:**

The DHT11 is a digital temperature and humidity sensor widely used in IoT-based monitoring systems. It measures the ambient temperature and relative humidity of the environment, which are important parameters affecting the efficiency of solar panels.

High temperatures can reduce solar panel efficiency, while humidity may indicate environmental conditions that could affect the system's performance. The sensor combines a thermistor for temperature measurement and a resistive humidity sensor. It sends data in a digital format via a single-wire communication protocol to a microcontroller such as Arduino or Node MCU. The microcontroller processes this data and transmits it to an IoT platform (like Thingspeak or Blynk) for real-time monitoring and analysis. the DHT11 sensor plays a critical role in enhancing solar power system efficiency by providing accurate environmental data for smart energy management.

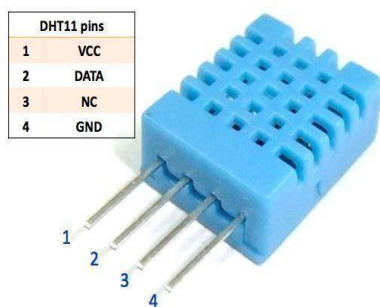


Fig 8:DHT11 Sensor

➤ Servo Motor:



Fig 9: Servo Motor

The servo motor plays a crucial role in the sun-tracking. A servo motor is an electromechanical device used for precise control of angular position. In the IoT-based sun tracking solar panel system, servo motors are employed to rotate the solar panel accurately toward the sun based on the signals received from the LDR sensors. Servo motors are preferred in such applications due to their precision, reliability, and ease of interfacing with microcontrollers.

They help maximize the solar panel's energy capture while keeping the system compact and efficient. It is widely used in automation and robotics, including solar tracking systems.

➤ Battery:

The battery is an essential component of the IoT-based solar panel system, responsible for storing the electrical energy generated by the solar panel. During daylight, the solar panel charges the battery through the charge controller, allowing the system to operate even when sunlight is not available. The stored energy is later used to power the ESP8266 microcontroller, sensors, LCD display, and servo motor during nighttime or cloudy conditions. This ensures continuous monitoring and system operation. The battery also helps maintain a stable power supply, preventing fluctuations that could affect the electronic components. By effectively managing charging and discharging, the system ensures longer battery life and efficient energy utilization.



Fig 10: Lithium Ion Battery

➤ LED:

The LED (Light Emitting Diode) is used in this project as a visual indicator to show the operational status of the system. It is connected to the ESP8266 microcontroller, which controls when the LED turns ON or OFF based on system conditions. When the LED is glowing, it indicates that the solar panel system is functioning normally and power is being generated or monitored. This LED operates in reverse of photodiode, which converts light into electricity.

In case of faults, low battery, or any abnormal conditions, the LED can blink or remain OFF to alert the user. This simple yet effective component helps in quickly identifying the working state of the system without needing to check the IoT dashboard or LCD screen. Overall, the LED provides an easy and reliable way to monitor system status in real-time.



Fig 11: LED

➤ **Voltage Sensor:**

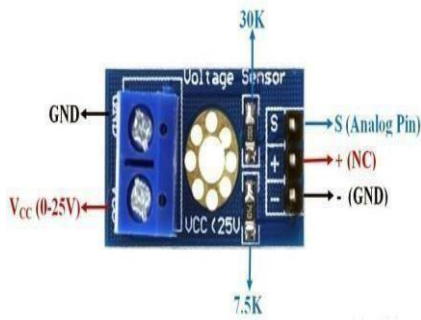


Fig 12: Voltage Sensor

The voltage sensor is used in this project to measure the voltage output of the solar panel and battery in real time. It works by scaling down the high voltage from the solar panel to a safe level that can be read by the ESP8266 microcontroller's analog input pin. The ESP8266 then processes this analog signal to calculate the actual voltage value. This data is displayed on the LCD screen and also sent to the IoT dashboard for remote monitoring. By continuously tracking voltage levels, the system ensures that the solar panel is generating proper output and that the battery is charging efficiently. The voltage sensor helps in detecting any voltage drops or faults in the system, making it an important component for safe and efficient solar power management. A voltage sensor is a device that measures and monitors voltage levels within

a system, detecting both AC and DC voltage. It is used in various applications, including industrial machinery, power systems, and consumer electronics, to ensure that equipment operates efficient. The measured voltage is then displayed on the IoT platform for remote monitoring.

➤ **Jumper Wires:**

Jumper wires are essential components used to make electrical connections between the various modules and the ESP32 microcontroller in the project. They are flexible, insulated wires with connector pins at both ends, allowing easy connection without soldering. In this project, jumper wires connect sensors (like LDR, DHT11, voltage and current sensors), the LCD display, LED, servo motor, and battery to the ESP32. They help transmit power and signals between components reliably. Jumper wires simplify prototyping, reduce circuit complexity, and allow easy modifications or troubleshooting during system setup. Overall, they are a convenient and essential tool for building and testing the IoT- based solar tracking and monitoring system.



Fig 13: Jumper Wire

➤ **Thingspeak Platform:**

Thingspeak is a cloud-based IoT platform that enables real-time monitoring and data visualization from connected devices. In the sun tracking solar panel system, Thingspeak is used to display live readings from sensors such as voltage, current, temperature, and humidity. The microcontroller, such as an ESP32 or ESP8266, sends sensor data to Thingspeak via the internet, allowing users to access and analyze the information remotely. With features like graphical charts, data logging, and alerts, Thingspeak helps

in monitoring the performance of the solar panel system, detecting faults, and making informed decisions for efficient energy management. Its simplicity, reliability, and compatibility with popular microcontrollers make it ideal for IoT-based solar projects.

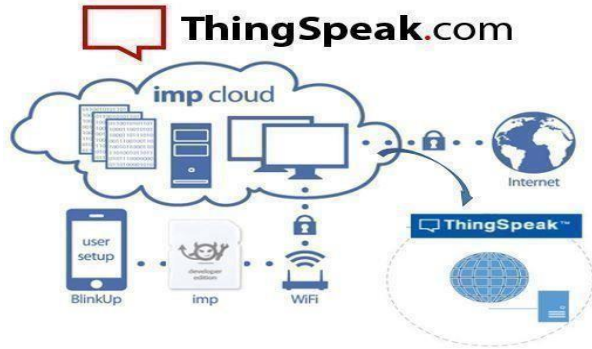


Fig 14: Thingspeak Platform

2. Circuit Connections:

Here are the steps to connect the circuit:

1. The solar panel is connected to the battery charging circuit, with its positive terminal linked to the charging module input and the negative terminal to GND. This setup powers the system and charges the battery.
2. Current & Voltage Sensors: Connect current sensor OUT to GPIO34 and voltage sensor OUT to GPIO35 of ESP32; both sensors get VCC from 3.3V/5V and GND.
3. LCD Display: Connect VCC to 3.3V, GND to GND, SDA to GPIO21, SCL to GPIO22 to display voltage, current, and environmental data.
4. LED(Load): Connect the LED's anode to GPIO23 and cathode to GND to indicate system status.
5. DHT11 Sensor: Connect VCC to 3.3V, GND to GND, and DATA to GPIO19 to monitor temperature and humidity.
7. LDR (Light Sensor): Connect one leg of the LDR to 3.3V and the other leg directly to GPIO36. The ESP32 reads sunlight intensity to control the servo motor for sun tracking.
8. Servo Motor: Connect the signal wire to GPIO18, VCC to 5V, and GND to GND. The ESP8266 rotates the solar panel based on LDR readings.

Once we have completed these steps, the circuit is ready to use. ESP8266 monitors the solar panel's voltage and current and checks the battery level. The DHT11 provides temperature and humidity data, while the LDR senses sunlight intensity. Based on LDR readings, the ESP8266 rotates the servo motor to align the solar panel toward maximum sunlight.

The LCD displays voltage, current, temperature, and humidity for easy monitoring, and the LED shows system status. All data is sent to an IoT dashboard for remote tracking, ensuring efficient solar power management.

Setting up Thingspeak:

Setting up Thingspeak for IoT-based data logging and visualization is a straight forward process. Thingspeak is an IoT platform that allows you to collect, analyze, and visualize sensor data in real-time. Here's a step-by-step guide to setting up

Thingspeak:

▪ Install Arduino IDE:

Download and install the Arduino IDE software on your computer from the official Arduino website.

▪ Add ESP8266 Board to Arduino IDE:

Open Arduino IDE → Go to File → Preferences → Paste the following URL in the "Additional Board Manager URLs":

https://arduino.esp8266.com/stable/package_esp8266com_index.json

Then go to Tools → Board → Boards Manager, search for "ESP8266" and click Install.

▪ Select the ESP8266 Board and Port:

Go to Tools → Board → ESP8266 Boards → Node MCU 1.0 (ESP-12E Module). Then choose the correct COM port under Tools → Port.

▪ **Connect Components to ESP8266:** Interface sensors (LDR, DHT11, voltage and current sensors), LCD, LED, servo motor, and battery as per the circuit connections.

- **Write or Upload the Code:**

Open your project code in Arduino IDE. The code should include sensor libraries (like DHT.h and Servo.h) and Thingspeak library for IoT data upload.

- **Enter Wi-Fi and Thingspeak Details:**

In the code, update your Wi-Fi SSID, password, and Thingspeak API key to enable internet connectivity and data uploading.

- **Compile and Upload the Code:**

Click on Verify to compile and check for errors, then click Upload to transfer the code to the ESP8266 microcontroller.

Open the Serial Monitor in Arduino IDE to view real-time data such as voltage, current, temperature, humidity, and LDR readings. The same data will appear on your Thingspeak dashboard for remote monitoring.

That's it! Your code should now be running on the ESP8266 board. You can disconnect the board from your computer and power it with an external power source if needed. Remember to select the correct board and COM port each time you upload a sketch to the ESP8266.

← → ↺ thingspeak.com/channels/new

ThingSpeak™ Channels Apps Devices Support

New Channel

Name: Room temp

Description: Get room temperature on a graph

Field 1: Temperature ☒

Field 2: ☐

Field 3: ☐

Field 4: ☐

Field 5: ☐

Field 6: ☐

ThingSpeak™ Channels Apps Support

Channel ID: 862680 direction of the chair

Author: pratiknani123

Access: Private

Private View Public View Channel Settings Sharing API Keys

Write API Key

Key: MQEXF4FUQTR8LC0J

Generate New Write API Key

Read API Keys

Key: AXEZW27Y3ALILFXA

Note:

V. EXISTING SYSTEM AND PROPOSED SYSTEM

a. Existing System:

In the existing solar panel setups, most systems use fixed panels that remain stationary throughout the day. These panels are positioned at a fixed angle and cannot adjust to the changing position of the sun, which reduces the efficiency of solar energy capture. Monitoring of panel performance is usually manual or done with basic local displays, making it difficult to track real-time energy production and detect faults remotely. Power management is often limited, with little automation for battery charging or energy distribution, leading to inefficient utilization of generated solar power.

b. Proposed System:

The proposed system introduces a smart and automated solution using sun tracking, IoT-based monitoring, and solar power management.

In this system: Sun Tracking: LDR sensors detect sunlight direction, and motors automatically adjust the solar panel to face the sun, maximizing energy capture. IoT Monitoring: Sensors continuously measure voltage, current, temperature, and humidity. Data is sent to a cloud platform like Thingspeak or Blynk for real-time remote monitoring. Solar Power Management: The system manages energy storage in batteries and distributes power efficiently to connected loads. Automation ensures maximum utilization of generated energy while protecting batteries from overcharging or deep discharge. This proposed system significantly improves energy efficiency, automation, and remote accessibility compared to conventional setups, making solar power systems more reliable and intelligent.

VI. RESULT

The IoT-based sun tracking solar panel system successfully demonstrates automatic solar tracking, where the servo motor adjusts the panel's

position based on sunlight intensity detected by LDR sensors, ensuring maximum energy capture throughout the day. The ESP8266 continuously monitors voltage and current from the solar panel, providing real-time electrical data, while the DHT11 sensor measures temperature and humidity, which is displayed on the 16x2 LCD for easy local monitoring. The LED indicator efficiently shows system status, to normal operation or potential issue.

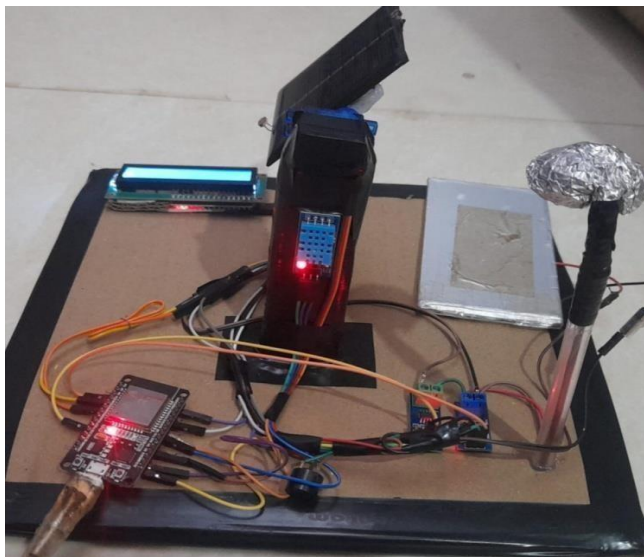


Fig 15 Working Model

Battery charging and the power management are optimized, preventing overcharging or deep discharge, thereby extending battery life. All data is transmitted to an IoT dashboard, allowing remote real-time monitoring of solar panel performance, environmental conditions, and energy storage. The system has proven to increase overall energy generation efficiency compared to the traditional fixed solar panels, while enabling automatic, unattended operation. In addition, the integration of IoT and real-time data analytics provides valuable insights for better maintenance and future scalability of solar power systems. The collected data was displayed on the LCD screen and uploaded to the Thingspeak cloud platform through the ESP32/ESP8266 microcontroller, allowing remote observation of performance and energy statistics. To ensure better management of solar power generation and usage.

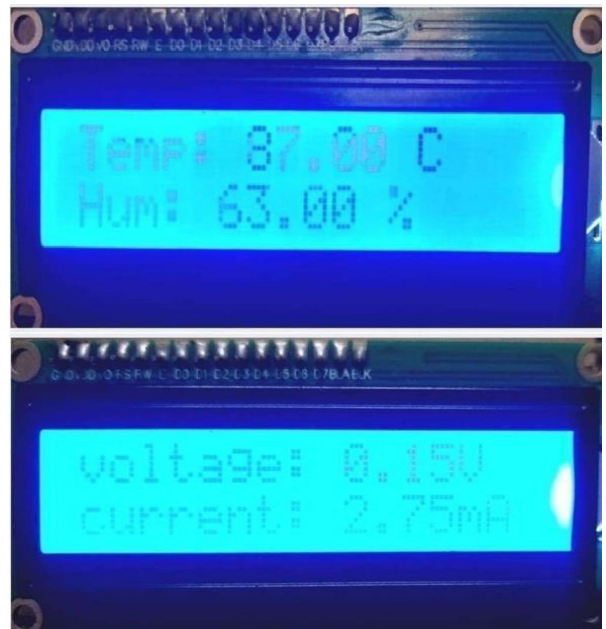


Fig 16: LCD Output

VII. CONCLUSION & FUTURE SCOPE

➤ CONCLUSION

The IoT-based sun tracking solar panel monitoring and solar power management system successfully integrates automation, real-time monitoring, and efficient energy management into a single platform. By continuously adjusting the panel's orientation toward the sun, the system maximizes energy capture, while sensors and IoT modules provide remote monitoring of voltage, current, temperature, and environmental conditions. The inclusion of battery management ensures optimal utilization of stored energy, reducing wastage and enhancing system reliability. Overall, the project demonstrates how combining sun tracking, IoT, and smart power management can significantly improve the performance and efficiency of solar energy systems compared to conventional fixed-panel setups. The inclusion of voltage, current, and temperature sensors (DHT11) allows accurate monitoring of panel performance and environmental conditions, enabling predictive maintenance and smart energy management. Overall, the system represents a cost-effective, reliable, and sustainable solution for modern solar energy applications, demonstrating the practical benefits of combining IoT with solar tracking and monitoring technology.

➤ FUTURE SCOPE

The proposed IoT-Based Sun Tracking Solar Panel Monitoring and Power Management System provides a foundation for intelligent solar energy management. Future developments can further enhance the system's efficiency and functionality:

Artificial Intelligence and Machine Learning: By analyzing sunlight patterns and historical data, AI algorithms can optimize panel movement automatically, improving energy capture throughout the day and across seasons.

Automatic Cleaning Mechanisms: Dust and debris reduce solar panel efficiency; integrating automated cleaning systems can maintain optimal energy generation without manual intervention.

Advanced IoT Integration: Enhanced mobile applications and cloud platforms can provide real-time alerts, detailed performance analytics, and remote control capabilities.

Battery and Energy Management: Smart battery monitoring and energy storage optimization can prevent overcharging, extend battery life, and ensure reliable off-grid power supply.

XI. REFERENCE

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