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A Major Project Report on

**“IOT BASED SUN TRACKING SOLAR PANEL MONITORING &
SOLAR POWER MANAGEMENT SYSTEM”**

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CERTIFICATE

Certified that the Major Project work entitled **“IoT Based Sun Tracking Solar Panel Monitoring & Solar Power Management System”** carried out by **Anjali M (1SP22EC005), D N Chandana (1SP22EC013), Noti Harshavardhan (1SP22EC036), Teja S (1SP22EC057)** a bonafide students of **S.E.A. College of Engineering and Technology**, in partial fulfillment for the award of **Bachelor of Engineering in Electronics and Communication Engineering, Visveswaraiiah Technological University, Belagavi** during the year **2025-26**. It is certified that all corrections/suggestions indicated for internal assessment have been incorporated in the report deposited in the departmental library.

The Major Project report has been approved as it satisfies the academic requirements in respect of project work prescribed for the said degree.

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ABSTRACT

One of the most interesting and promising clean technologies in the modern era with no carbon emissions is solar photovoltaic electricity. It is true that if solar electricity is to be utilized, both its application and maintenance must be carefully thought out. This project suggests building a solar tracker using an Arduino and a servo motor.

The Solar Panel Tracker is designed to move with the sun in order to maximises the quantity of light that the solar panel receives and hence boost power efficiency. The design of a dual-axis solar tracking system. In this method, the entire solar panel rotates once a day from east to west to face the sun.

The efficiency of energy generation will rise with the usage of a solar tracker circuit. Solar energy measurements are gathered and analyzed by the proposed Internet of Things (IoT)-based solar energy tracking technique in order to forecast performance and guarantee steady generation of electricity.

The system's key benefit is that it can be used to analyze performance to improve solar PV maintenance. (Photovoltaic). A cost-effective solution that continuously shows remote energy yields and its performance on computers or smart phones is what the PV monitoring system's main goal is to provide. With a solar module, the proposed system is put to the test for voltage, current, temperature, and humidity.

This smart, Wi-Fi-enabled Arduino microcontroller with an ESP8266 processor is used to create the PV monitoring system. It interfaces with the cloud platform and uploads data using the Blynk app. Additionally, a wireless monitoring system maximises a PV system's operational reliability while using the least amount of system resources.

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CHAPTER 1

INTRODUCTION

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INTRODUCTION

1.1 Introduction of Project

1.11 Solar Energy and Renewable Power

Solar energy is one of the most widely used and sustainable sources of renewable energy. With the increasing global demand for clean power, solar photovoltaic (PV) systems have become essential in reducing carbon emissions and dependence on fossil fuels. Solar panels convert sunlight into electricity, enabling homes, industries, and remote areas to access reliable and eco-friendly power. However, the efficiency of solar panels depends heavily on the amount of sunlight they receive. Since the sun's position changes throughout the day, fixed solar panels are unable to capture maximum solar energy, leading to reduced power output.

In many countries, including India, solar power plays a crucial role in meeting the rising energy needs of urban and rural areas. Government initiatives, decreasing solar panel costs, and advances in power electronics have made solar systems more efficient and accessible. Solar installations are now commonly found in homes, industries, commercial buildings, street lighting systems, agricultural irrigations, and remote locations where grid electricity is difficult to supply.

With technological advancements, the integration of embedded systems, sensors, and IoT platforms has further improved solar power management. IoT-based monitoring systems provide real-time information about panel status, voltage, current, temperature, and overall efficiency. This allows users to monitor solar installations remotely, detect faults immediately, and optimize performance without manual intervention.

In modern renewable energy applications, combining solar power with sun tracking and IoT monitoring represents a major step toward smart, efficient, and sustainable energy solutions. This approach not only maximizes power generation but also supports global goals of clean energy, smart grids, and environmental protection.

1.12 Need for Sun Tracking Systems

The movement of the sun across the sky changes continuously due to the Earth's rotation and revolution. A fixed solar panel can capture maximum sunlight only for a limited time when the sun is directly facing it. As the angle changes, the intensity of sunlight decreases, reducing power generation. Sun tracking systems solve this issue by automatically rotating the solar panel to follow the sun's path from east to west. This keeps the panel perpendicular to the sunlight throughout the day, ensuring maximum radiation absorption.

Key reasons why sun tracking is needed:

- Increases solar power output by **25% to 40%**
- Maintains optimal panel orientation at all times
- Enhances the efficiency of existing solar installations
- Improves energy yield without increasing panel count
- Ideal for areas with high solar irradiation

Sun tracking technology is therefore an essential component of modern high-performance solar systems.

1.13 Role of IoT in Solar Monitoring

The integration of the **Internet of Things (IoT)** has transformed traditional solar power systems into intelligent and automated energy solutions. IoT enables remote monitoring, real-time data collection, and improved decision-making for energy management.

In an IoT-based solar monitoring system, sensors continuously measure voltage, current, temperature, light intensity, and battery status. This data is sent to a cloud server or mobile application through Wi-Fi or other wireless communication modules. Users can monitor panel performance from anywhere, identify faults immediately, and take corrective action without physical inspection.

Advantages of IoT integration:

- Provides real-time performance data
- Helps detect faults such as panel damage or dirt accumulation
- Enables remote control and automation
- Improves maintenance efficiency
- Reduces system downtime and energy losses

IoT-based monitoring has become a key feature in modern smart solar systems and supports the concept of smart cities and smart grids.

1.14 Solar Panel Monitoring and Solar Power Management

Conventional solar panels remain stationary and receive sunlight from a fixed direction, leading to a reduction in power output as the position of the sun changes throughout the day. To address this limitation, the proposed system employs automatic sun tracking technology using LDR sensors and servo motors. The LDR sensors detect the intensity of sunlight, and based on the readings, the microcontroller (Node MCU ESP8266) adjusts the panel's angle to ensure it continuously faces the direction of maximum solar radiation. This dynamic adjustment significantly improves the energy conversion efficiency of the panel compared to fixed installations.

What sets this project apart is the IoT-based monitoring and data analytics capability. Through IoT connectivity, real-time data such as voltage, current, power output, and battery status are measured using sensors and uploaded to an online platform like Thing Speak or Blynk Cloud. Users can remotely observe and analyse system performance from any location, enabling predictive maintenance and performance optimization. This connectivity transforms the solar system into a smart, self-regulating networked system.

The power management module ensures that the generated energy is efficiently utilized. It monitors energy storage in the battery, controls the charging process to prevent overcharging, and manages power distribution to connected loads. In addition, the system can alert users if energy levels drop or if any component malfunctions. Beyond technical advantages, this project

promotes sustainability, automation, and real-time intelligence, aligning with the goals of green technology and smart city initiatives. It demonstrates how IoT can revolutionize renewable energy applications by making them adaptive, transparent, and user-interactive.

Energy has become the backbone of modern civilization, and with the rapid increase in industrialization and population, the demand for electrical energy is rising every day. Conventional energy sources such as coal, petroleum, and natural gas are limited, expensive, and harmful to the environment due to their carbon emissions. Therefore, the world is shifting toward renewable and sustainable energy sources, among which solar energy stands out as one of the most abundant, eco-friendly, and cost-effective alternatives.

The C is a modern approach to maximize the efficiency of solar energy systems using automation and IoT technologies. approach to maximize the efficiency of solar energy systems using automation and IoT technologies. Traditional fixed solar panels often fail to capture the maximum sunlight throughout the day due to the changing position of the sun. This project addresses this limitation by implementing a dual-axis or single-axis sun tracking mechanism, which continuously aligns the panels perpendicular to sunlight, increasing energy generation by up to 30–40%.

Applications of this project include residential rooftops, industrial solar farms, remote areas without grid access, and smart city infrastructure. The system not only improves energy efficiency but also reduces operational costs, minimizes human intervention, and promotes sustainable and eco-friendly energy solutions.

1.2 Problem Statement

Conventional fixed solar panels generate less energy due to their inability to track the sun, resulting in inefficient utilization of solar resources. Lack of real-time monitoring makes it difficult to detect faults or optimize panel performance. Manual energy management can lead to wastage of generated power and inconsistent supply, especially in remote areas. There is a need for a smart, automated, and connected system that maximizes solar energy generation while allowing efficient monitoring and management.

1.3 Objectives of the Project

The main objective of the IoT Based Sun Tracking Solar Panel Monitoring and Solar Power Management System is to design and develop an intelligent solar power generation unit that automatically tracks the movement of the sun to achieve maximum energy efficiency while enabling real-time monitoring and management through IoT technology.

The system aims to overcome the limitations of conventional fixed solar panels by introducing an automated tracking mechanism using Light Dependent Resistors (LDRs) and servo motors. This mechanism allows the solar panel to continuously adjust its position according to the intensity and direction of sunlight, ensuring that it always receives maximum solar radiation throughout the day.

Another important objective is to incorporate Internet of Things (IoT) features for remote monitoring and data analysis. By using a microcontroller such as Node MCU (ESP8266), the system gathers real-time data on voltage, current, and temperature from various sensors and uploads this information to a cloud-based platform such as **Thing Speak** or **Blynk**.

CHAPTER 2

LITERATURE SURVEY

CHAPTER 2

LITERATURE SURVEY

A literature survey on Solar Tracking and IoT Battery Monitoring with ESP8266 encompasses a comprehensive review of existing research, studies, and projects in the field. Solar tracking systems, aimed at maximizing energy capture by aligning solar panels with the sun's position, are explored along with IoT-based battery monitoring systems, which facilitate real-time monitoring of battery health and performance. These systems are crucial for enhancing the efficiency and reliability of solar energy systems. The survey delves into various solar tracking techniques, including single-axis and dual-axis tracking, evaluating their accuracy, complexity, and cost effectiveness. Similarly, IoT-based battery monitoring systems are examined, focusing on sensor technologies, communication. Flow chat protocols, and data analytics methods used for battery health monitoring.

Integration of ESP8266 modules, renowned for their wireless communication capabilities, with the Thing Speak IoT platform is highlighted as a pivotal aspect of system implementation, enabling remote access, data storage, and visualization. Case studies showcasing real-world applications of Solar Tracking and IoT Battery Monitoring systems in residential, commercial, and industrial settings provide insights into system deployment and performance.

The survey concludes with discussions on challenges such as system complexity and scalability, as well as future research directions to further advance the field. Through this literature survey, researchers can gain a comprehensive understanding of the current state of the art and identify avenues for future research and innovation in Solar Tracking and IoT Battery Monitoring with ESP8266.

Solar energy is one of the most sustainable and clean sources of power, yet its efficiency largely depends on how effectively the solar panels are oriented toward the sun.

Conventional fixed solar panels capture limited sunlight throughout the day due to the sun's movement. Researchers have therefore developed solar tracking systems that automatically adjust the panel's position to maintain an optimal angle with the sunlight.

Parallely, IoT-based battery monitoring systems have gained importance in renewable energy projects for maintaining battery performance and ensuring reliability. These systems monitor parameters such as voltage, current, temperature, and state of charge (SOC) in real-time using sensors interfaced with microcontrollers like Node MCU ESP8266. The data collected is transmitted to cloud platforms such as Thing Speak, Blynk, or Firebase, allowing users to analyze battery health remotely. Literature highlights that real-time monitoring helps in predictive maintenance, fault diagnosis, and energy optimization, thereby extending battery life and improving system reliability.

The ESP8266 Wi-Fi module, a low-cost microcontroller with built-in internet connectivity, has been extensively utilized in IoT-based solar projects due to its ease of programming, low power consumption, and reliable data transmission capabilities. Its integration with the Thing Speak IoT platform facilitates data logging, remote visualization, and automated alerts, enabling users to make data-driven decisions. Several studies emphasize the efficiency of using ESP8266 for real-time data communication between hardware components and cloud servers, eliminating the need for wired monitoring systems.

Furthermore, hybrid systems combining solar tracking mechanisms with IoT battery monitoring have been explored in recent years to create smart solar management systems. These integrated systems not only maximize power generation but also ensure optimal energy storage and utilization. Research conducted by various scholars between 2018 and 2024 demonstrates the successful deployment of such systems in residential, industrial, and agricultural sectors. Some designs include dual-axis servo control using Arduino UNO, IoT dashboards for real-time visualization, and automated load control based on battery SOC levels.

CHAPTER 3

SYSTEM DESIGN

CHAPTER 3

SYSTEM DESIGN

3.1 Methodology

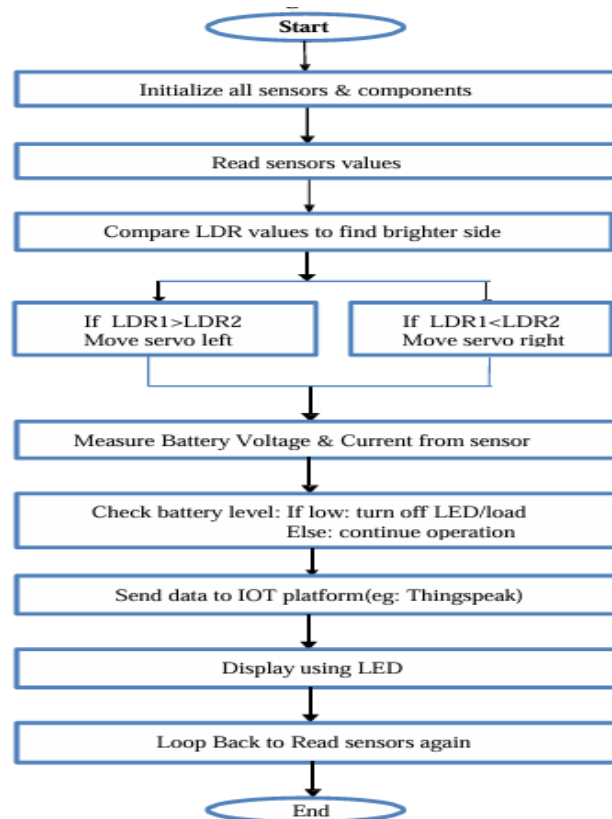


Figure 3.1 Data Flow Module

Flow of the Module

- The system begins with sensors such as LDRs, voltage sensors, current sensors, and temperature sensors collecting real-time data about sunlight intensity, power generation, and environmental conditions.
- The sensed analog signals are transmitted to the Node MCU ESP8266 microcontroller, which serves as the central control and data processing unit.

- LDR sensors detect the direction of maximum sunlight. The microcontroller compares light intensity values and determines the best angle for the solar panel.
- Based on the sensor input, the servo motor adjusts the solar panel's position (single-axis or dual-axis) to face the direction of highest sunlight intensity, ensuring maximum energy generation.
- The voltage and current sensors send data to the Node MCU to calculate the real-time power output ($P = V \times I$) and monitor the efficiency of the solar panel.
- The system continuously checks the battery's charging and discharging status to prevent overcharging or deep discharge, ensuring longer battery life and stability.
- The processed data is sent wirelessly from the Node MCU to an IoT platform (Thing Speak) using the ESP8266 Wi-Fi module, enabling remote data access.
- The IoT platform stores and visualizes data such as voltage, current, sunlight intensity, and battery status in graphical form for easy monitoring.
- Users can view system performance in real time through mobile or web dashboards. Alerts can be generated if parameters go beyond normal limits (e.g., low battery or overheating).
- Based on IoT feedback, control commands are sent back to adjust the panel's position or battery management automatically, ensuring efficient and safe operation of the solar system.

3.2 Hardware Components

3.2.1 Microcontroller (NodeMCU ESP8266)



Figure 3.2 Microcontroller (ESP8266)

The NodeMCU ESP8266 is a popular development board for IoT projects that features the ESP8266 Wi-Fi microcontroller and a USB interface for power and programming. Its key pins include power pins (3V3, VIN, GND), digital I/O pins (D1-D8, D0, and others), serial pins (TXD0, RXD0), I2C pins (SDA, SCL), and control pins (EN, RST, WAKE). You can connect external components like sensors, LEDs, and relays to these pins to create a wide range of connected devices.

Key significant

- **Wi-Fi Connectivity (Built-in):** NodeMCU has an inbuilt ESP8266 Wi-Fi module, allowing it to connect directly to the internet or local networks ideal for IoT applications.
- **Low Cost and Compact Design:** It's inexpensive yet powerful, making it suitable for student, prototype, and research-level projects.
- **Open Source Platform:** The hardware and software are open source, enabling easy modification and wide community support.

- **Easy Programming via USB:** Can be programmed easily using Arduino IDE, Lua, or MicroPython, with simple USB connectivity.
- **GPIO Pins for Sensor/Actuator Interface:** It provides General Purpose Input/Output pins to connect sensors (e.g., LDR, current, voltage sensors) and actuators (e.g., motors, relays).

Power pins

- **3.3 V:** Provides a regulated 3.3V output.
- **VIN:** Input voltage pin, useful for powering the board from an external source.
- **GND:** Ground pin.
- **USB:** Connect via a micro-USB cable to power the board and upload code from a computer.

Digital I/O (GPIO) pins

- These are the general-purpose input/output pins. The names on the board are D1-D8, D0, and others.
- D1 (GPIO5): Connected to the SCL line for I2C communication.
- D2 (GPIO4): Connected to the SDA line for I2C communication.
- D4 (GPIO2): Typically used for the onboard LED. You can connect an external LED here (longer leg to D4, shorter leg to GND).
- Other GPIOs: D3, D5, D6, D7, D8 can be used for various inputs and outputs.
- D0 (GPIO16): Can be used for read/write, but does not support other special functions like interrupts or PWM.

Digital I/O (GPIO) pins

- **TXD0 (GPIO 1):** Transmit pin for UART0.
 - **RXD0 (GPIO 3):** Receive pin for UART0.
-

Control pins

- **EN:** Enable pin; the chip is enabled when pulled HIGH.
- **RST:** Reset pin; used to reset the chip.
- **WAKE:** Used to wake the chip from a deep-sleep state.

3.2.2 Solar Panel



Figure 3.3 Solar Panel

The working principle of a solar panel is based on the photovoltaic effect, discovered by Edmond Becquerel in 1839. A solar panel is made up of many solar cells (usually 36, 60, or 72), each constructed from semiconductor materials like silicon. These solar cells absorb sunlight in the form of photons.

When photons strike the surface of the solar cell, their energy is transferred to the electrons in the semiconductor atoms, causing the electrons to break free from their atomic bonds. This movement of electrons creates an electric current (DC), which flows through the circuit connected to the panel.

The electrical output from a solar panel is direct current (DC), which can be stored in batteries or converted into alternating current (AC) using an inverter to run household appliances and industrial machines.

The power generated depends on factors such as sunlight intensity, angle of the panel, temperature, and type of solar cells used. The solar panel plays a unique role in this project by serving as an alternative energy source. It is included to highlight the concept of sustainable and renewable energy integration with modern communication systems.

The solar panel generates electrical power from sunlight, which can be used to supply voltage to the Arduino and other components. This reduces dependency on non-renewable sources and aligns with global efforts to develop green technologies.

The presence of the solar panel also makes the project more appealing and futuristic, as it combines green energy with green communication. In future real-world applications, Li-Fi-enabled devices powered by renewable sources can drastically reduce power consumption while delivering efficient wireless communication. This also opens up possibilities for deployment in remote or off-grid areas, where electricity availability is limited.

3.2.3 Current Sensor

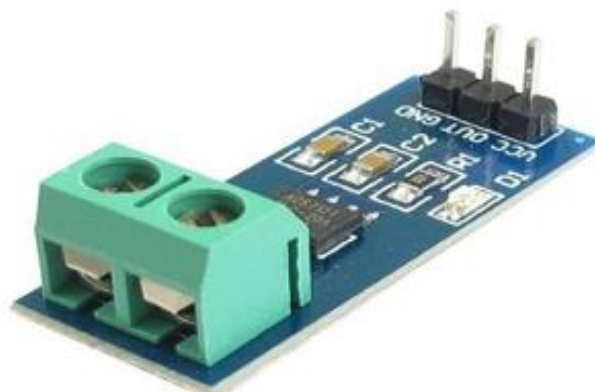


Figure 3.4 Current Sensor

A current sensor is an essential component in solar power management systems as it enables accurate measurement of the electrical current flowing from the solar panels to the load or battery. In any photovoltaic (PV) system, monitoring current is crucial to evaluate panel performance, detect faults, and calculate power generation in real time.

Current sensors operate on the principle of either direct current measurement through series resistance (shunt sensing) or indirect measurement using magnetic fields (Hall-effect sensing). In modern IoT-based solar monitoring systems, Hall-effect sensors such as ACS712 or ACS758 are widely used due to their high accuracy, electrical isolation, and safety.

The integration of current sensors plays a key role in ensuring effective power management by enabling the system to estimate power ($P = V \times I$), evaluate battery charging status, and detect abnormal conditions such as overload, short circuits, or sudden current drops due to panel malfunctions. Since solar installations operate continuously under varying environmental conditions, the stability and accuracy of the current sensor significantly impact system reliability.

In solar or IoT-based systems, the current sensor is used to:

- Measure the charging and discharging current of batteries.
- Monitor the load current to detect over current or short-circuit conditions.
- Calculate total power output when combined with a voltage sensor ($P = V \times I$).
- Send real-time current data to microcontrollers like Node MCU (ESP8266) for cloud monitoring.

3.2.4 LED (Light Emitting Diode)



Figure 3.5 LED

A Light Emitting Diode (LED) is a semiconductor device that emits light when an electric current passes through it, making it one of the most widely used indicators in electronic

and embedded systems. In solar tracking and solar power monitoring projects, LEDs play a crucial role as visual indicators to display system status, operational mode, fault alerts, and power conditions. LEDs operate on the principle of electroluminescence, where electrons recombine with holes within the semiconductor material, releasing energy in the form of photons.

Due to their low power consumption, reliability, and long lifespan, LEDs are highly preferred in modern IoT-based hardware designs. They typically operate on low forward voltages (around 2V for red, 3V for blue/white) and require current-limiting resistors to prevent damage, ensuring stable and safe operation. Different colors of LEDs are used to represent specific conditions—for example, a green LED can indicate system ON, a red LED may indicate fault or overload, and a blue LED may show internet connectivity or tracking mode activation.

In solar monitoring systems, LEDs also serve as quick on-site diagnostic tools. Even without a display or IoT dashboard, LEDs allow technicians to identify whether the microcontroller is functioning, whether sensors such as LDRs or current sensors are active, and whether the solar panel is generating sufficient power. This immediate visual feedback is important during installation, testing, and maintenance. LEDs are durable, resistant to shock, and operate efficiently even in outdoor conditions, making them suitable for renewable energy applications.

3.2.5 Voltage Sensor



Figure 3.6 Voltage Sensor

A voltage sensor is a critical component in solar energy monitoring and power management systems, enabling accurate measurement of the voltage produced by the solar panel, battery, and load. In any photovoltaic (PV) setup, voltage changes continuously depending on sunlight intensity, panel orientation, load variations, and battery charge level. A voltage sensor allows the microcontroller to observe these variations in real time, making it essential for maintaining efficiency and ensuring system safety.

In IoT-based solar tracking systems, commonly used voltage sensors include resistive voltage dividers and dedicated modules such as the 0–25V or 0–30V voltage sensor, which step down high voltages to microcontroller-safe levels (typically 0–3.3V or 0–5V). These sensors work by reducing the input voltage through precision resistors and outputting a proportionally smaller voltage that can be read by the ADC pin of a microcontroller such as Arduino or ESP32. This ensures that even higher solar panel voltages can be measured without damaging the controller. By continuously monitoring solar panel voltage, the system can evaluate panel performance, detect shading effects, and confirm whether the sun-tracking mechanism is improving energy output.

The voltage data is also uploaded to IoT dashboards, allowing users to track real-time system performance and daily generation patterns. Voltage sensors help in detecting abnormal conditions such as sudden voltage drops caused by faulty wiring, dust on panels, weak sunlight, or inverter issues. Their accuracy and fast response make them indispensable for intelligent decision-making within the solar power management system.

3.2.6 LCD Display



Figure 3.7 LCD Display

An LCD (Liquid Crystal Display) is an essential output device used in embedded systems to visually present real-time information, system status, and sensor readings. In solar tracking and solar power monitoring projects, the LCD display plays a crucial role by allowing users to view important parameters such as solar panel voltage, current generation, battery status, tracking direction, and overall system performance without relying solely on an external IoT dashboard. The most commonly used display in microcontroller-based projects is the 16x2 or 20x4 alphanumeric LCD, which can show multiple lines of text.

LCD displays operate using the principle of light modulation, where liquid crystal molecules align or twist when an electric field is applied, controlling the passage of light through a backlit panel. These displays are preferred because they consume very low power, making them ideal for renewable-energy systems that often run on limited energy resources. The LCD typically communicates with microcontrollers such as Arduino, ESP32, or PIC using a 4-bit or 8-bit parallel interface, although modern designs use an I2C module to reduce wiring complexity and provide more efficient communication.

In a solar monitoring system, the LCD provides immediate on-site feedback that helps technicians and users observe system behavior during installation, debugging, and regular operation. For example, the display can show whether the solar panel is correctly tracking the sun, whether the sensors are active, and how much power is being generated at any moment. Compared

to LEDs, which provide only basic indications, an LCD offers detailed numerical and textual data, making it much more informative for diagnostics and performance evaluation.

Overall, the LCD display acts as an essential human-machine interface in IoT-based solar systems, contributing significantly to monitoring accuracy, reliability, and user accessibility.

3.2.7 LDR Sensor



Figure 3.8 LDR Sensor

A Light Dependent Resistor (LDR), also known as a photoresistor, is the most fundamental and widely used sensor in sun-tracking systems because of its ability to detect the intensity of light. An LDR is a passive electronic component whose resistance changes based on the amount of light falling on its surface—its resistance decreases significantly when exposed to bright light and increases when in darkness. This optical-to-electrical property makes the LDR ideal for applications where detecting sunlight direction and intensity is essential.

In a solar tracking system, multiple LDRs are strategically positioned on the panel or a sensor module to compare light levels from different directions. When one LDR receives more sunlight than the other, the microcontroller identifies the imbalance and activates the servo or motor to rotate the solar panel toward the direction of maximum light. This ensures that the panel always aligns with the sun's position throughout the day, thereby maximizing energy generation. LDRs are simple to use, inexpensive, and highly effective, which is why they are the preferred choice for dual-axis or single-axis sun-tracking mechanisms. The use of LDRs enhances the

intelligence of the solar tracking system by ensuring that the panel never remains in a suboptimal position.

Their low power consumption and long operational lifespan make them a dependable component for outdoor renewable energy setups. Overall, the LDR sensor is a core element of the sun-tracking system, enabling efficient, automatic alignment with the sun, improving energy capture, and contributing significantly to the effectiveness and reliability of the overall solar power management system.

3.2.8 DHT11 Sensor

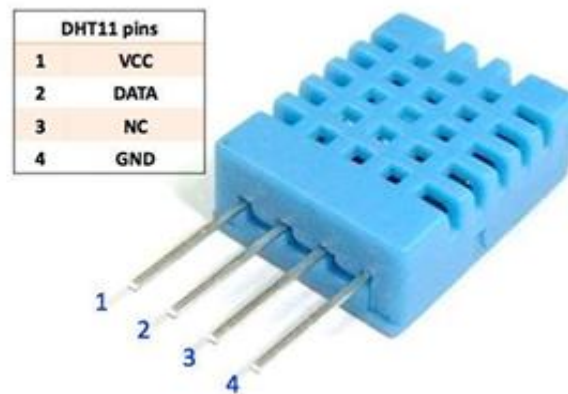


Figure 3.9 DHT11 Sensor

The DHT11 sensor is a widely used digital environmental sensor capable of measuring both temperature and humidity, making it an important component in many IoT-based monitoring and renewable-energy applications. It operates on the principle of capacitive humidity sensing and a thermistor-based temperature measurement system, providing stable and reliable readings for environmental monitoring around the solar panel installation. In solar power systems, temperature and humidity data are extremely useful for evaluating real-time weather conditions, as these factors directly influence panel performance, energy production, and overall system efficiency. For example, high temperatures can reduce the efficiency of photovoltaic cells, while high humidity levels may indicate cloudy conditions or potential moisture issues.

The DHT11 helps analyze such conditions and assists in correlating environmental factors with solar output. The sensor outputs calibrated digital values, which means it requires minimal external components and can be easily interfaced with microcontrollers such as Arduino, Raspberry Pi, ESP8266, or ESP32 using a single data pin, making the integration simple and reliable. The sensor's compact size and digital interface make it ideal for long-term deployment in outdoor environments when properly enclosed. Overall, the DHT11 sensor adds significant value to an IoT-based solar monitoring system by offering essential environmental data that improves analysis, enhances efficiency, and supports intelligent decision-making in renewable power applications.

3.2.9 Servo Motor



Figure 3.10 Servo Motor

A servo motor is an essential electromechanical device used in automated control systems where precise angular positioning is required. In sun-tracking solar panel systems, servo motors play a crucial role in adjusting the orientation of the solar panel to continuously face the sun throughout the day. This precise alignment significantly increases the efficiency of solar energy capture compared to fixed panels. A typical servo motor used in embedded projects consists of a small DC motor, a gear system, a position-sensing potentiometer, and an internal control circuit.

It receives control signals in the form of PWM (Pulse Width Modulation), where the width of the pulse determines the angular position of the motor shaft. Microcontrollers such as Arduino or ESP32 send these PWM signals to rotate the servo to a specific angle, enabling smooth and accurate panel movement. In a single-axis tracker, one servo motor is used to rotate the panel horizontally, while in dual-axis tracking, two servos manage both horizontal and vertical alignment. The high torque and stability of servo motors make them suitable for handling lightweight to medium-weight solar panel structures commonly used in academic and prototype models.

In an IoT-based solar monitoring setup, the servo's performance can be monitored remotely, and control algorithms can adjust tracking speed and angle based on sunlight intensity or weather conditions. Overall, the servo motor is a critical mechanical component that enhances the system's efficiency by ensuring accurate sun alignment, leading to higher power generation and improved overall performance of the solar power management system.

3.2.10 Lithium Ion Battery

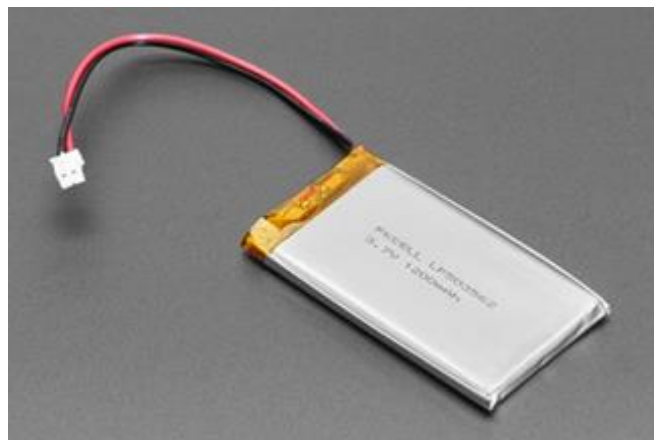


Figure 3.11 Lithium Ion Battery

A lithium-ion battery is a highly efficient rechargeable energy storage device widely used in modern portable electronics, electric vehicles, and renewable energy systems due to its high energy density, long cycle life, lightweight design, and stable performance. In solar power

management and sun-tracking systems, lithium-ion batteries serve as the primary energy storage unit, storing electrical energy generated by the solar panel during daylight hours and supplying power to the load and control electronics when sunlight is insufficient. They operate based on the movement of lithium ions between the anode and cathode through an electrolyte during charging and discharging.

This reversible ion flow allows the battery to store and release energy efficiently over many cycles. Lithium-ion batteries are preferred over traditional lead-acid batteries because they offer faster charging, lower self-discharge rates, greater efficiency, and superior lifespan, making them ideal for IoT-based solar systems that require reliability and uninterrupted operation. Their compact size and light weight also allow easy integration into portable or small-scale solar tracking prototypes.

In solar-based IoT applications, lithium-ion batteries ensure continuous system functionality, powering microcontrollers, sensors (like LDR, DHT11, voltage and current sensors), and communication modules even when the sun is not available. Their stable voltage output provides consistent energy to critical components such as servo motors, which require smooth and reliable power for accurate sun tracking. The battery's performance is typically monitored using voltage sensors to prevent overcharging, deep discharge, and overheating—conditions that can reduce battery life or cause safety hazards. Charge controllers or battery management systems (BMS) are often used to protect the battery by regulating charging cycles and ensuring safe operation. Lithium-ion batteries are also highly suitable for IoT applications because they support efficient energy storage and quick discharge cycles, enabling the system to respond rapidly to changing power demands.

3.2.11 Jumper Wire



Figure 3.12 Jumper Wire

Jumper wires are essential electrical conductors used in electronics and embedded systems to establish temporary or permanent connections between different components on a breadboard, PCB, or microcontroller. They play a fundamental role in prototyping, especially in academic and IoT-based projects such as sun-tracking solar panel systems, where multiple sensors, modules, and actuators must be interconnected for proper functioning. Jumper wires are available in three main types—male-to-male, female-to-female, and male-to-female—each designed for specific interfacing needs.

Male ends are typically used to plug into breadboards or female headers on microcontrollers, while female ends connect to pins on sensors or modules. These wires consist of a flexible insulated conductor that ensures secure signal transmission while preventing short circuits. In a solar tracking system, jumper wires are used to connect key components such as LDR sensors, voltage and current sensors, servo motors, LCD displays, IoT modules, and the microcontroller, enabling the smooth flow of power and data throughout the circuit.

They support low-voltage DC signals commonly used in microcontroller-based environments, ensuring safe and efficient operation. In renewable energy projects, the quality of wiring is particularly important since loose or poorly connected wires can lead to incorrect sensor data, unstable servo movement, or intermittent power supply to critical components. Jumper wires

simplify the process of organizing connections and allow for quick adjustments when optimizing the tracking mechanism or adding new IoT features. Overall, jumper wires are indispensable in any solar tracking or embedded system prototype, enabling dependable electrical connectivity, flexibility in circuit design, and smooth integration of all components required for efficient operation.

3.2.12 ThingSpeak Platform



Figure 3.13 ThingSpeak Platform

ThingSpeak is a widely used IoT (Internet of Things) analytics and cloud platform that enables users to collect, visualize, and analyze real-time data from connected devices over the internet. It provides a simple yet powerful interface for storing sensor data, performing statistical analyses, and creating visualizations in the form of charts, graphs, and dashboards. In IoT-based solar tracking and solar power management systems, ThingSpeak plays a crucial role in monitoring parameters such as solar panel voltage, current, battery status, environmental conditions, and the position of the solar panel. Sensors like LDRs, voltage and current sensors, DHT11, and microcontrollers such as Arduino or ESP32 continuously send data to the ThingSpeak cloud through the internet using Wi-Fi or GSM modules. Once the data reaches the platform, it can be processed, logged, and displayed in real time, allowing users to remotely monitor system performance from anywhere in the world.

The platform supports API integration, MATLAB analytics, and custom alerts, making it highly flexible for research, educational, and commercial applications. ThingSpeak also supports automated notifications and alerts, allowing the system to warn users when battery voltage drops below safe levels or when environmental conditions are unfavorable. Furthermore, the platform allows historical data storage and analysis, helping evaluate long-term solar energy trends, panel performance, and overall system efficiency. Its compatibility with MATLAB enables advanced data processing, prediction models, and visualization, which is especially useful in academic and research projects. Overall, the ThingSpeak platform serves as a vital cloud-based tool in IoT-based solar monitoring systems, enhancing remote accessibility, performance analysis, energy management, and data-driven decision-making for efficient renewable power applications.

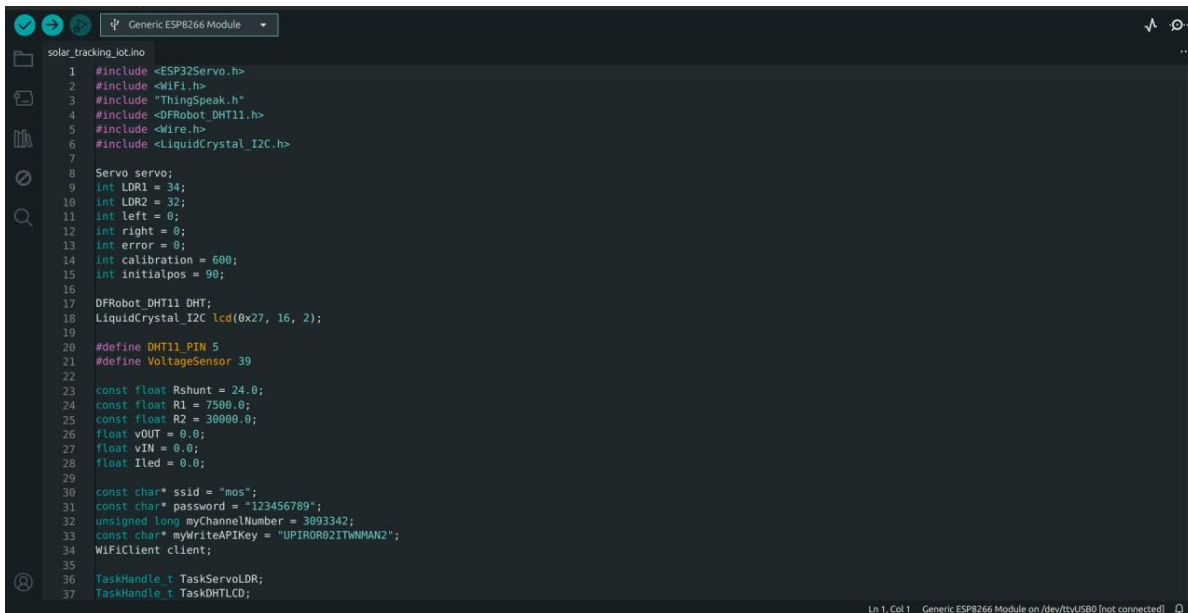
3.2 Software Implementation

3.3.1 Generic ESP8266 Module

The ESP8266 Wi-Fi module is a highly versatile and cost-effective microchip developed by Express if Systems, designed to provide reliable wireless networking capabilities for Internet of Things (IoT) applications.

In the context of the IoT-Based Sun Tracking Solar Panel Monitoring and Solar Power Management System, the ESP8266 serves as the backbone of wireless communication, enabling real-time monitoring, data transmission, and remote control of the solar tracking system through an internet connection.

The advantages of using the ESP8266 include low cost, compact size, easy programming via the Arduino IDE, and reliable Wi-Fi performance, all of which contribute to the development of a smart, energy-efficient, and connected solar tracking system.



```
solar_tracking_iot.ino
1 #include <ESP32Servo.h>
2 #include <WiFi.h>
3 #include "ThingSpeak.h"
4 #include <DFRobot DHT11.h>
5 #include <Wire.h>
6 #include <LiquidCrystal_I2C.h>
7
8 Servo servo;
9 int LDR1 = 34;
10 int LDR2 = 32;
11 int left = 0;
12 int right = 0;
13 int error = 0;
14 int calibration = 600;
15 int initialpos = 90;
16
17 DFRobot DHT11 DHT;
18 LiquidCrystal_I2C lcd(0x27, 16, 2);
19
20 #define DHT11_PIN 5
21 #define VoltageSensor 39
22
23 const float Rshunt = 24.0;
24 const float R1 = 7500.0;
25 const float R2 = 30000.0;
26 float vOUT = 0.0;
27 float vIN = 0.0;
28 float Iled = 0.0;
29
30 const char* ssid = "mos";
31 const char* password = "123456789";
32 unsigned long myChannelNumber = 3093342;
33 const char* myWriteAPIKey = "UPIR0R02ITWWMAN2";
34 WiFiClient client;
35
36 TaskHandle_t TaskServoLDR;
37 TaskHandle_t TaskDHTLCD;
```

Figure 3.14 Generic ESP8266 Module

The module allows the system to connect seamlessly to a Wi-Fi network, thereby transmitting data such as solar panel voltage, current, temperature, light intensity, and battery level to a cloud platform or web-based dashboard for continuous observation and analysis.

The ESP8266 module integrates a powerful 32-bit Tensilica L106 microprocessor, operating at clock speeds up to 160 MHz, which makes it capable of handling both communication and control tasks efficiently.

It comes with built-in TCP/IP protocol stack support, which simplifies network programming and ensures smooth data transfer between the device and the server. Operating at a voltage of 3.0V to 3.6V, the module consumes minimal power, making it an excellent choice for solar-powered applications where energy efficiency is crucial.

Furthermore, it offers a set of GPIO (General Purpose Input/Output) pins, along with UART, SPI, and I²C interfaces, allowing easy integration with microcontrollers such as Arduino Uno, Node MCU, or ESP32, and sensors like LDRs and current sensors used in the solar tracking system.

In the system's operation, the ESP8266 plays a pivotal role in collecting sensor readings, sending them to cloud-based platforms such as Thing Speak, Blynk, or Firebase, and receiving commands for control actions. This enables the solar panel to automatically align with the direction of maximum sunlight using servo motors, ensuring optimal energy capture throughout the day.

Additionally, users can remotely monitor performance data and manage system parameters via a smart phone or web interface, providing convenience, scalability, and intelligent management of the solar power system.

The advantages of using the ESP8266 include low cost, compact size, easy programming via the Arduino IDE, and reliable Wi-Fi performance, all of which contribute to the development of a smart, energy-efficient, and connected solar tracking system.

Its ability to support Over-The-Air (OTA) firmware updates further enhances system flexibility by allowing updates or modifications without the need for physical access.

Overall, the ESP8266 module is a crucial element that bridges the gap between the physical solar tracking hardware and the digital IoT ecosystem, ensuring efficient communication, real-time monitoring, and improved control over the solar energy management process.

CHAPTER 4

IMPLEMENTATION

& RESULT

CHAPTER 4

IMPLEMENTATION & RESULT

4.1 Block Diagram

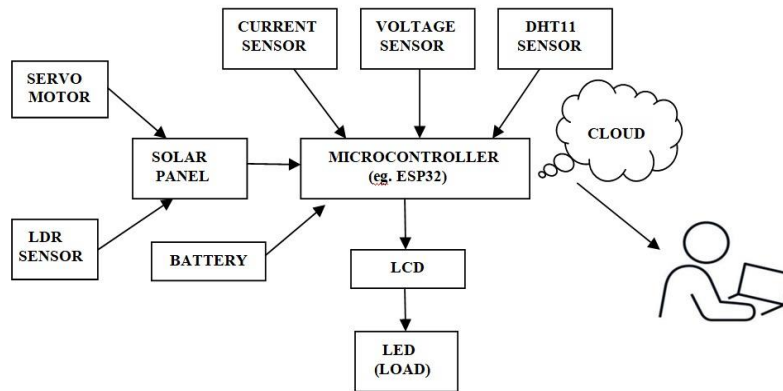


Figure 4.1 Block Diagram of IoT Based Sun Tracking, Solar Panel Monitoring & Solar Power Management System

The IoT-Based Sun Tracking Solar Panel Monitoring and Solar Power Management System consists of several key components integrated to optimize solar energy generation and enable remote monitoring. The system uses Light Dependent Resistors (LDRs) to detect the direction of maximum sunlight, allowing the microcontroller to control servo or stepper motors through a motor driver circuit to automatically adjust the solar panel's position for maximum exposure.

The solar panel converts sunlight into electrical energy, which is regulated by a solar charge controller to safely charge a battery and supply power to the connected load. Various sensors such as voltage, current, and temperature sensors continuously monitor the system's performance.

The collected data is processed by the microcontroller and transmitted through an IoT module (like Wi-Fi or GSM) to a cloud server or online dashboard, enabling users to monitor real-time parameters such as power output, panel position, and battery status remotely. This intelligent system enhances power efficiency, ensures effective energy management, and supports preventive maintenance through IoT-based monitoring.

4.2 Circuit Diagram

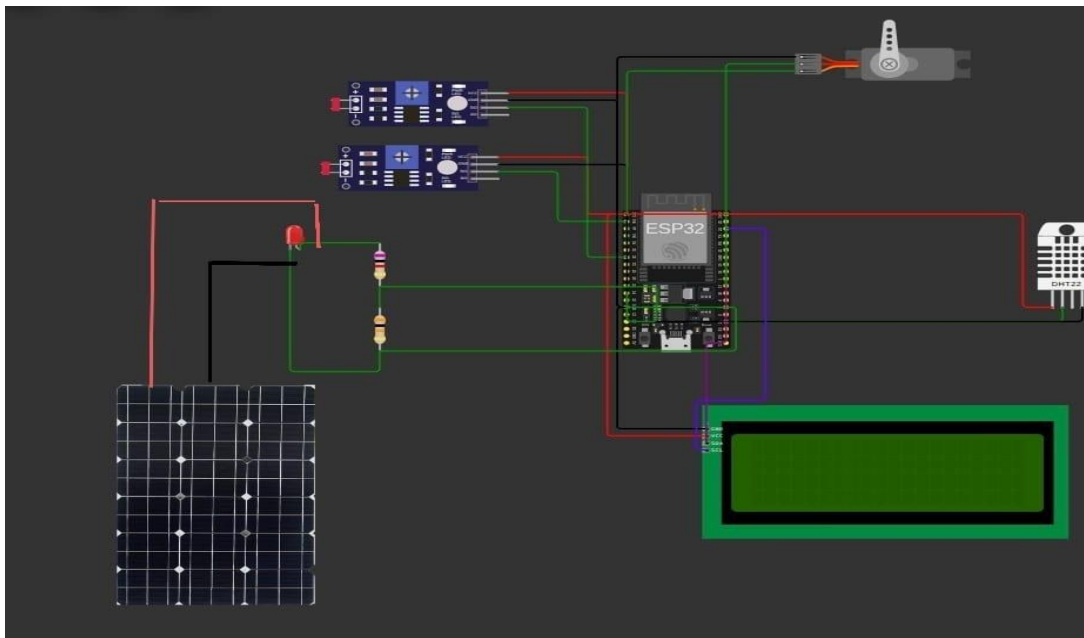


Figure 4.2 Circuit Diagram of Transmission & Receiver Side

The circuit diagram of the IoT-Based Sun Tracking Solar Panel Monitoring and Solar Power Management System shows how all the components are connected to work together efficiently. The solar panel is linked to a charge controller, which manages the power flow to the battery for safe charging and storage.

Light Dependent Resistors (LDRs) detect the sunlight's direction and send signals to the microcontroller (Node MCU/ESP8266), which controls the servo motor to adjust the solar panel's position toward the sun for maximum energy generation.

Voltage and current sensors monitor the output from the panel and the battery, while a DHT11 sensor measures temperature and humidity. The LCD display shows real-time data, and through Wi-Fi connectivity, the system uploads information to the IoT platform (like Thing Speak) for remote monitoring. The circuit ensures continuous tracking of the sun, efficient energy storage, and monitoring of system performance.

4.3 Working Principle

The IoT-Based Sun Tracking Solar Panel Monitoring and Solar Power Management System operates on the principle of automatic solar tracking, smart power control, and real-time IoT-based monitoring to ensure maximum energy generation and efficient utilization.

The system uses Light Dependent Resistors (LDRs) to sense the intensity of sunlight from different directions. These LDRs act as inputs to the microcontroller (Node MCU/ESP8266), which processes the signals and determines the direction of maximum sunlight. Based on this information, the microcontroller controls the servo motor to rotate the solar panel toward the sun's position.

This continuous adjustment allows the panel to face the sun directly throughout the day, maximizing the amount of solar energy captured. The voltage and current sensors measure the solar panel's output and the battery's charging level, while the DHT11 sensor monitors environmental factors like temperature and humidity. The charge controller manages the flow of electricity between the solar panel, battery, and load, ensuring that the battery is safely charged and preventing overcharging or deep discharge.

All the collected data including panel voltage, current, power output, battery level, and temperature is displayed locally on an LCD display and transmitted via Wi-Fi to an IoT platform (like Thing Speak) for remote monitoring. Users can view this information in real time from anywhere using a computer or smart phone.

Thus, the overall working of the system involves detecting sunlight, tracking the sun automatically, generating and storing solar power safely, and monitoring system performance through IoT connectivity. This integration of solar tracking and IoT technology ensures maximum efficiency, better energy management, and smart monitoring of the solar power system.

4.4 Implementation

The implementation of the IoT-Based Sun Tracking Solar Panel Monitoring and Solar Power Management System involves integrating hardware components with IoT technology to enhance solar energy efficiency and enable real-time monitoring.

The system uses a NodeMCU ESP8266 microcontroller as the central control unit, connected to LDR sensors that detect sunlight intensity from various directions. Based on the sensor readings, servo motors adjust the solar panel's position to ensure it always faces the direction of maximum sunlight, thus improving energy generation.

Voltage and current sensors continuously measure the power output, while a DHT11 sensor monitors environmental factors such as temperature and humidity. The collected data are processed by the NodeMCU and transmitted via Wi-Fi to an IoT cloud platform like ThingSpeak, where users can view and analyse real-time data through graphical dashboards.

Voltage and current sensors monitor the output from the panel and the battery, while a DHT11 sensor measures temperature and humidity. The LCD display shows real-time data, and through Wi-Fi connectivity, the system uploads information to the IoT platform (like Thing Speak) for remote monitoring. The circuit ensures continuous tracking of the sun, efficient energy storage, and monitoring of system performance.

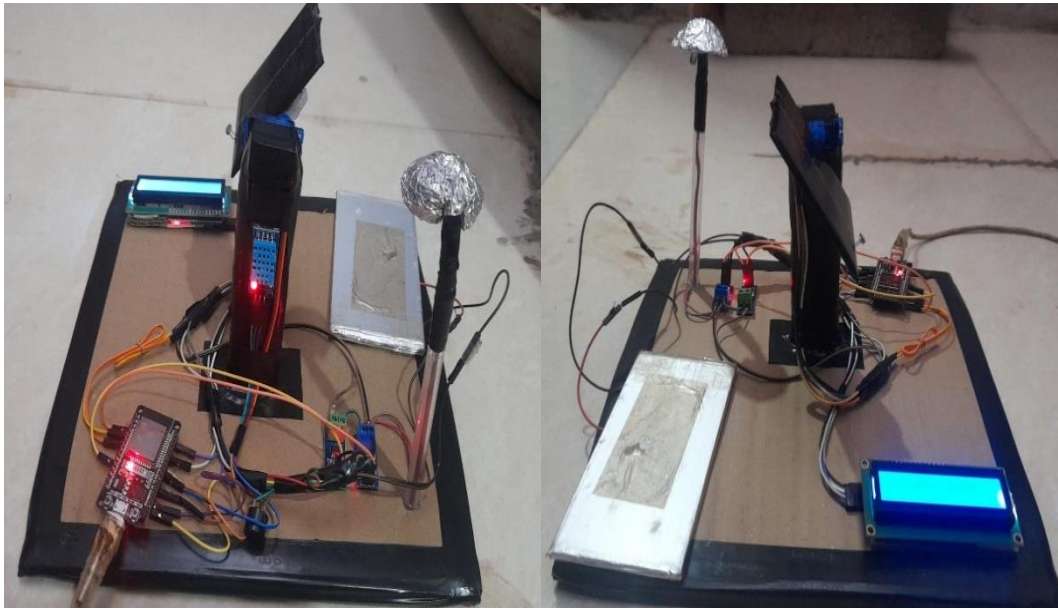


Figure 4.3 System Connection

4.5 Results

The IoT-Based Sun Tracking Solar Panel Monitoring and Solar Power Management System was successfully designed, implemented, and tested using the ESP32 microcontroller. The system automatically tracked the movement of the sun using dual LDR sensors and a servo motor, ensuring that the solar panel continuously faced the direction of maximum sunlight. This increased the panel's power output compared to a fixed solar panel. Real-time measurements of temperature, humidity, voltage, and current were successfully obtained using DHT11 and voltage/current sensors. These parameters were displayed on the 16×2 I2C LCD display and periodically uploaded to the Thing Speak IoT cloud platform, where data graphs were generated for performance analysis and remote monitoring.

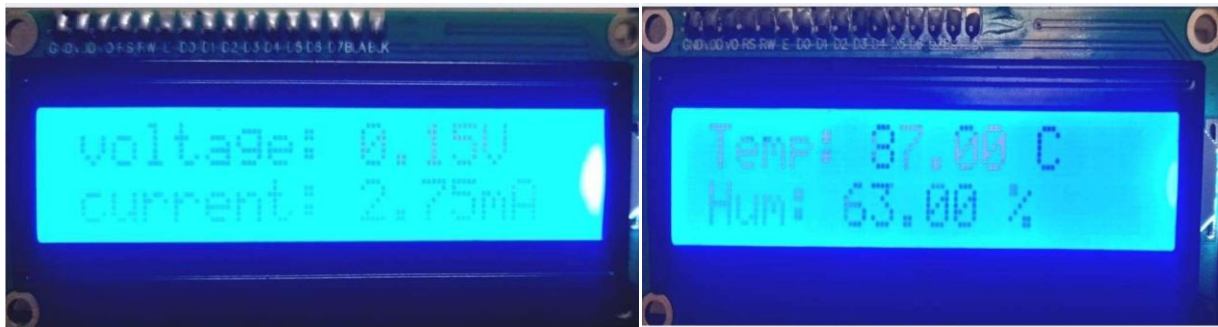


Figure 4.4 LCD Output

Thus, the project effectively achieved its objective of maximizing solar energy utilization and providing an IoT-enabled smart monitoring solution for solar power systems.

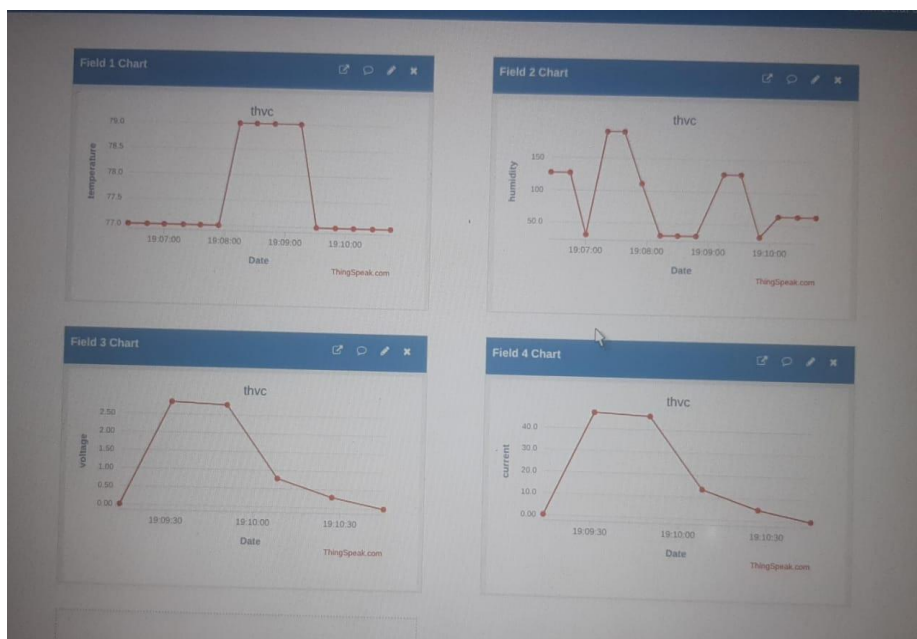


Figure 4.5 ThingSpeak Output

CHAPTER 5

CONCLUSION & FUTURE SCOPE

CHAPTER 5

CONCLUSION & FUTURE SCOPE

5.1 Conclusion

The IoT-Based Sun Tracking Solar Panel Monitoring and Power Management System plays a vital role in improving the performance and efficiency of solar energy utilization. By incorporating advanced components such as the ESP32/ESP8266 microcontroller, LDR sensors, DHT11 sensor, voltage and current sensors, and a servo motor, the system is capable of automatically tracking the sun's position throughout the day to ensure that the solar panel always faces the direction of maximum sunlight.

Through IoT connectivity, the system is capable of collecting real-time data such as voltage, current, light intensity, temperature, and humidity, and uploading this information to the Thing Speak cloud platform. This enables users to remotely monitor performance trends, energy generation statistics, and environmental parameters from anywhere. The inclusion of cloud-based analytics not only enhances usability but also supports predictive maintenance and troubleshooting.

Furthermore, the automation embedded in the system makes it highly reliable, user-friendly, and energy efficient. It includes efficient battery charging and discharging management, ensuring a stable and uninterrupted power supply even during periods of low sunlight or cloudy weather. The combination of real-time monitoring, automated tracking, and intelligent power management demonstrates a modern, eco-friendly, and cost-effective approach to renewable energy systems. Overall, by integrating IoT with solar tracking technology, this project showcases a scalable solution suitable for households, institutions, remote areas, and smart energy management applications.

5.2 Future Scope

5.2.1 Integration with smart grid systems

The system can be connected to smart grids for real-time energy distribution and load balancing. This allows efficient use of solar energy across multiple households or industries.

5.2.2 AI-Based solar tracking optimization

Artificial intelligence can predict sun positions and environmental conditions for more precise tracking. This reduces energy losses and enhances panel efficiency over conventional tracking methods.

5.2.3 Weather-adapted energy management

Integration with weather forecast APIs can help the system adjust panel angles and battery usage accordingly. This ensures maximum energy harvesting even on cloudy or rainy days.

5.2.4 Integration with energy systems

Advanced battery management systems can be integrated to optimize charging and discharging cycles. This ensures longer battery life and more efficient energy utilization.

5.2.5 Mobile app & cloud-based monitoring

Users can monitor real-time performance, energy production, and system health through mobile apps. Alerts and analytics can help in predictive maintenance and improved decision-making.

5.2.6 Scalability for large solar farms

The IoT monitoring system can be scaled to control multiple panels in large solar farms. Remote monitoring and automated adjustments can significantly reduce maintenance costs.

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