



## Automatic Solar Tracking System with Real-Time Energy Monitoring and Control

Bharath.R<sup>1</sup>, Balamurugan.R<sup>2</sup>, Dhivakar.S<sup>3</sup>, Balaji.B<sup>4</sup>, Jayapradeep.M<sup>5</sup>

<sup>1,2,3,4,5</sup>UG Scholar, Dept. of Mechatronics, Hindusthan college of Engg. & Tech., Coimbatore, Tamil Nadu, India.

**Emails:** bharath2007r@gmail.com<sup>1</sup>, balaexpens@gmail.com<sup>2</sup>, dhivakar718@gmail.com<sup>3</sup>, balajibalu2021@gmail.com<sup>4</sup>, jayapradeep617@gmail.com<sup>5</sup>

### Abstract

The demand for renewable energy is increasing rapidly due to the rising global need for clean and sustainable power sources. Solar energy is one of the most widely accessible renewable resources; however, the efficiency of conventional fixed solar panels is limited because they receive maximum sunlight only for a short period each day. To overcome this limitation, an automatic solar tracking system is designed to continuously adjust the orientation of a panel so that it remains perpendicular to the sun's rays throughout the day. The aim of this project is to enhance the power output of solar panels by implementing an intelligent tracking mechanism using a(LDR) light-dependent resistor based a microcontroller to drive the tracking motors. The system compares light intensity values from multiple sensors and positions the panel using a dual-axis rotation mechanism that follows the sun's movement from sunrise to sunset. Performance evaluation was carried out by comparing the energy produced by the tracking system with a fixed solar panel under the same environmental conditions.

**Keywords:** Light Dependent Resistors (LDR Sensors); Microcontroller (ArduinoUNO); Motor Driver Module (L298N); Servo Motor; LCD Display.

### 1. Introduction

- The global demand for sustainable and renewable energy sources has grown rapidly due to rising environmental concerns, depletion of fossil fuels, and the increasing need for reliable power solutions.
- Solar energy has emerged as one of the most promising and accessible renewable resources, but its efficiency is often limited when panels remain fixed and fail to capture maximum sunlight throughout the day.
- Automatic solar tracking systems provide a significant improvement in energy generation, as they continuously adjust the panel's orientation toward the sun, increasing power output compared to traditional fixed installations.
- Conventional tracking systems often face limitations such as high cost, mechanical complexity, or lack of integrated monitoring features, making them unsuitable for small-scale or low-budget applications.
- Recent advancements in microcontrollers, sensors, and IoT technologies have created new opportunities for designing efficient, low-cost solar tracking systems with enhanced real-time monitoring capabilities.
- This work presents an intelligent, single-axis automatic solar tracking system built using Arduino and ESP32 microcontrollers, LDR-based sunlight detection, and a high-torque gear motor for precise panel [1].

#### 1.1 Scope of the Work

This work focuses on developing a low-cost, single-axis automatic solar tracking system that increases energy capture by continuously aligning the panel toward maximum sunlight. The project integrates

Arduino and ESP32 controllers for motor control, sensor monitoring, and real-time data display. It includes voltage and current sensing modules, a solar charge controller, battery storage, an inverter, and protective components to ensure safe and reliable operation. The system aims to provide an efficient, practical, and easily replicable solution suitable for homes, small farms, and educational applications.

### 1.2 Objective of the Project

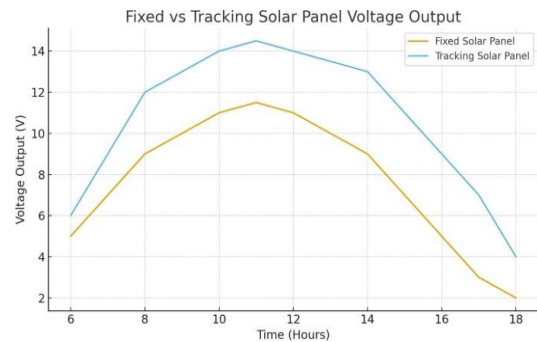
- To develop an automatic single-axis solar tracking system that accurately aligns the panel with the sun using LDR sensors to improve overall energy capture.
- To implement an integrated monitoring setup using Arduino and ESP32 for real-time measurement of voltage, current, and system performance.
- To design an efficient power management system that includes battery storage, a solar charge controller, and an inverter for stable DC and AC power output.
- To create a low-cost and reliable prototype that is simple to build, energy-efficient, and suitable for practical use in homes, laboratories, or remote areas [2-4].

## 2. Method

### 2.1 System Architecture

The system architecture integrates solar tracking, power management, and real-time monitoring into one unified setup. The Arduino Uno controls the LDR-based tracking mechanism and drives the high-torque motor through the L298N driver. The ESP32 manages voltage and current sensing using DC sensors, the ZMPT101B AC sensor, and an AC current sensor, with all data shown on a 16×2 I<sup>2</sup>C LCD. A 12 V solar panel charges either a lead-acid or lithium-ion battery through a solar charge controller, while an inverter provides 230 V AC output. Safety components like relays and an MCB ensure stable and protected system operation, shown in Figure 1 & 2.

### 2.2 Difference Between Fixed and Tracking



**Figure 1 Fixed vs Tracking Solar Panel Voltage Output**

### 2.3 Hardware Working

Component	Function in Project
Arduino UNO	Acts as the primary microcontroller for reading sensors and controlling relays
ESP32	Handles wireless communication and data logging
ZMPT101B AC Voltage Sensor	Measures the AC output voltage from the inverter
Relay Module	Switches loads automatically based on sensor readings and battery level
DC Voltage Sensor	Reads the battery voltage and solar panel voltage for charging control

**Figure 2 Function of the Components**

## 3. Results and Discussion

### 3.1 Results

This project successfully culminated in the development of an Automated Solar Tracking and Power Management System, which demonstrably enhances solar energy capture compared to fixed-panel setups. Utilizing an ESP32 microcontroller to analyze directional sunlight via LDR sensors, the system dynamically repositions the solar panel using a high-torque gear motor, achieving peak efficiency throughout the day. Crucially, the system integrates comprehensive power storage and conversion—



managing battery charging via a solar controller and providing regulated 230V AC output via an inverter. Real-time performance metrics, including voltage and current measurements from dedicated sensors, are displayed on an I2C screen, confirming the tracker's ability to create a safe, self-contained, and optimized renewable energy solution.

### **3.2 Discussion (12 pt)**

The experimental results show that the automatic solar tracking system significantly improves solar energy capture compared to a fixed panel. By continuously adjusting the panel toward the direction of maximum sunlight using LDR sensors and a gear motor, the system ensures optimal alignment throughout the day. This leads to a measurable increase in voltage and power output, confirming the effectiveness of the tracking approach. The overall design remains cost-efficient, making it suitable for small- and large-scale renewable energy applications.

### **Conclusion (12 Pt)**

The automatic solar tracking system effectively improves the efficiency and output of solar panels by maintaining continuous alignment with the sun. By using LDR sensors, Arduino control, and a geared motor mechanism, the system ensures maximum energy absorption throughout the day. Experimental results show a significant improvement in power generation compared to a fixed panel setup. Overall, the proposed tracking system is reliable, cost-effective, and suitable for enhancing renewable energy performance in real-time applications

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