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Research Article

SOLAR TRACKING SYSTEM

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Abstract
Solar tracking is a technology designed to enhance the efficiency of photovoltaic power generation by continuously orienting solar panels toward the sun throughout the day. Unlike fixed solar panels, which receive sunlight at varying angles, solar tracking systems maintain a perpendicular alignment with solar radiation, thereby maximizing energy absorption. The working principle involves sensors, control circuits, and actuators that detect sunlight intensity and adjust the position of the panel accordingly. Fixed solar panels are limited in performance because the angle of incidence of sunlight changes throughout the day and across seasons. The principle of solar tracking often relies on Light Dependent Resistors (LDRs), control circuitry, and actuators that detect variations in solar intensity and reposition the panel to face the sun directly. Advanced designs further incorporate microcontrollers, stepper motors, real-time clocks, and GPS-based algorithms for greater accuracy and efficiency.

Keywords: Solar Tracking, Photovoltaic Efficiency, Light Dependent Resistors (LDR), Microcontrollers, Renewable Energy, Energy Absorption.

Introduction of PV

The rising global demand for energy, coupled with environmental concerns over fossil fuel use, has led to a strong focus on renewable energy sources, particularly solar energy. Photovoltaic (PV) systems are at the forefront of this revolution due to their simplicity and reliability. However, one major challenge in solar energy generation is that the intensity and angle of sunlight vary throughout the day. Fixed PV panels, while simple to install, are inefficient because they can only capture maximum energy when the sun is directly overhead.

Background of the study

Solar tracking motors help to generate solar power in a more efficient manner. It is done by enabling the solar panels to follow the path of the sun and absorbing more energy throughout the day. When solar panel is perpendicular to the sunlight, energy generation is maximized. As the sun moves east to west, the tracking system gradually rotates the panel to track sun's path. What we are planning to do is measure the intensity of light and compares those intensities. Based on the intensity of light, signal is generated by a microcontroller to cause the movement of solar panels. So, the panel moves around a single axis throughout the day to catch-up more sunlight. These systems rotate on two axes, allowing them to follow the sun's movement both daily and seasonally. It is also helpful for troubleshooting of the system. So, without any additional effort, automatically system enhances the efficiency of solar power generation.

Application and Importance's of Solar Energy

Solar energy is available in abundance and will not run out, unlike fossil fuels. As long as the sun exists, solar energy can be harvested daily, making it a sustainable long-term energy source. Solar energy is one of the most significant renewable resources because it is both abundant and inexhaustible. Unlike fossil fuels, which are finite and harmful to the environment, solar power provides a clean and sustainable alternative for electricity generation. Its importance lies in the fact that it is environmentally friendly, as it does not produce greenhouse gases, air pollutants, or toxic emissions, thereby reducing the effects of climate change and global warming. Furthermore, solar energy plays a key role in reducing dependency on conventional grid electricity, allowing households, industries, and commercial establishments to lower their electricity bills and achieve long-term cost savings. Thus, the importance of solar energy extends beyond sustainability it serves as a versatile and adaptable solution to the world's growing energy needs.

2. SOLAR TRACKING SYSTEM

2.1 Overview of Solar Tracking Systems

A dual-axis solar tracking system is an advanced mechanical device designed to maximize the energy output of solar panels by allowing them to follow the sun's position throughout the day and year. These systems rotate solar panels on two axes (horizontal and vertical), enabling them to track the sun's path from east to west and adjust for seasonal changes in its height north-south movement (fig 2.1).

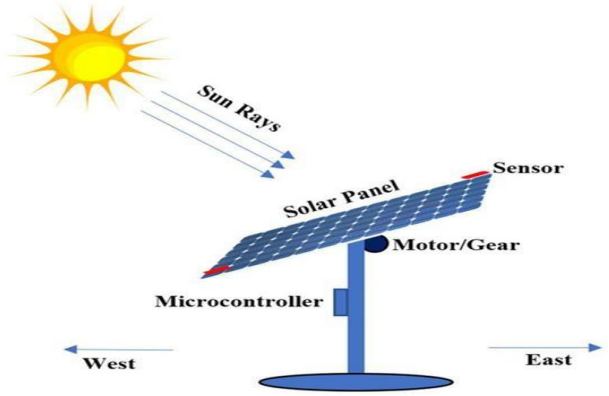


Fig: 2.1 Solar tracking system

2.2 Tracking Approaches

Solar tracking systems aim to maximize energy capture by orienting solar panels perpendicular to the sun throughout the day and year. Different tracking approaches cater to various needs and constraints. Here are the main categories:

2.2.1 Single-axis tracking

Rotates panels along one axis, typically east-to-west, following the sun's daily path. Boosts energy production by an estimated 25-30% compared to fixed tilt systems. Well suited for large-scale solar farms and commercial rooftop system and has lower maintenance requirements compared to dual-axis trackers. Examples include horizontal single-axis trackers, horizontal tilted single-axis trackers, vertical single-axis trackers, and vertical-tilted single-axis trackers.

2.2.2. Dual-axis tracking

Rotates panels along both horizontal (east-west) and vertical (north-south) axes, tracking the sun's daily and seasonal movements. Provides the highest energy yield, with potential increases of 40-60% over fixed installations. Ensures perfect perpendicular alignment of panels with the sun throughout the year. Offers optimal performance during peak demand hours and adapts to seasonal sun angle changes. More complex and expensive than single-axis trackers, requiring increased maintenance.

2.2.3. Active tracking

Uses motors, sensors, and control systems to automatically adjust panel orientation with high precision. Relies on a power source to operate mechanical components. Suitable for large and complex installations but requires regular maintenance. Operates without electricity, using natural forces like thermal expansion to move panels. Simpler and requires less maintenance but is less accurate than active trackers.

Uses automated systems such as light sensors (LDRs), microcontrollers, and motors to continuously align the solar panel with the sun throughout the day. This type of tracking ensures maximum sunlight capture and higher energy efficiency without human intervention. Although active tracking increases installation and maintenance costs due to the need for electronic and mechanical components, it significantly improves the overall performance of solar systems, especially in large-scale power plants.

Table 2.2.1 Comparison of single axis and dual-axis solar tracking device

Feature	Single-Axis Solar Tracking Device	Dual-Axis Solar Tracking Device
Energy increase	25-30% vs fixed solar panels	40-60% vs fixed solar panels*
Initial investment cost	Lower (15-20% more than fixed solar systems)	Higher (20-30% more than fixed solar systems)
Maintenance	Moderate complexity	High complexity
Moving parts	Fewer components	More mechanical components
Installation	Simpler setup	Complex installation
Best applications	Large solar farms, commercial rooftop solar systems	Commercial solar systems with space constraints
Terrain requirements	Flat, sunny areas	Any suitable solar site
Control system	Basic tracking algorithms	Advanced dual-axis control
Payback period	5-10 years typically	Under 4 years

2.2.4. Manual tracking

Requires manual adjustment of panels. Suitable for areas with lower labor costs or small, low-budget installations. Less efficient due to the need for frequent adjustments. Advanced technologies such as AI, IOT, and machine learning are being integrated into solar tracking systems for improved maintenance, monitoring, and tracking algorithms.

Manual solar tracking is a simple method where the solar panel or array is physically adjusted by hand at regular intervals to follow the sun’s position. This method does not require any sensors, motors, or control systems, making it cost-effective and easy to implement, especially in small-

scale or rural setups. However, it is labour-intensive, less precise, and may lead to energy losses if the adjustment is not done frequently

Table 2.2 Comparison of regulation techniques, advantages, limitations of solar device

Technique	Advantages	Limitations
Analog MPPT (P&O, comparator-based)	Low cost, simple, no microcontroller needed	Moderate precision; may struggle in variable light
DC–DC Converters	High efficiency; essential for MPPT systems	Requires careful design and component sizing
DC Optimizers (per module DC–DC)	Handles shading/mismatch; localized MPPT	Higher hardware complexity and per-panel cost
LDO Regulators	Very simple, low noise	High heat dissipation; inefficient for large drops
CC-CV Regulators	Cost-effective, simpler than MPPT	Less efficient than full MPPT in dynamic conditions

2.3 Regulation Techniques in Solar Systems

MPPT (Maximum Power Point Tracking) functionality can be achieved using analog circuits without microcontrollers. Simple analog designs such as perturb-and-observe algorithms implemented through logic gates, comparators, and capacitors can dynamically track the maximum power point by adjusting the duty cycle of a PWM signal based on stored values of panel voltage and power Planet Analog.

These methods are particularly promising for low-power, cost-sensitive applications, incorporating MPPT directly into DC–DC controller chips for plug-and-play simplicity. Forum-based DIY projects demonstrate low-cost, effective analog MPPT controllers that use potentiometers to fix the optimal panel voltage.

Beyond simply regulating voltage, DC-DC converters are instrumental in implementing. Maximum Power Point Tracking (MPPT) algorithms. MPPT techniques dynamically adjust the operating point of the PV modules to extract the maximum possible power under varying environmental conditions. This is achieved by controlling the duty cycle of the converter, effectively changing the impedance seen by the PV module

3. SYSTEM DESIGN & METHODOLOGY

3.1 Conceptual Design & Block Diagram

A conceptual design for a solar tracking system uses sensors to detect the sun's position, a microcontroller to process this data, and motors to adjust the orientation of the solar panel, ensuring it remains perpendicular to the sun's rays for maximum energy capture. The system works by comparing light levels detected by sensors on either side of the panel, when one side is brighter, the microcontroller commands the motors to rotate the panel in that direction until the light is balanced, thus optimizing power generation throughout the day. A dual-axis solar tracking system is designed to maximize energy output from photovoltaic (PV) panels by continuously orienting them towards the sun. At its core, the system uses light-dependent resistors (LDRs) or other light sensors to detect the direction of maximum solar radiation. These sensors provide input to a microcontroller (like an Arduino Uno) which interprets the difference in light intensity to determine the sun's position.

Based on this information, the microcontroller sends signals to servo motors or stepper motors, which then rotate the solar panel on both a horizontal and vertical axis. This active positioning ensures that the panel is always perpendicular to the sun's rays, significantly increasing the amount of solar energy captured compared to a fixed panel. Multiple LDRs are placed around the solar panel to detect the direction of the highest light intensity. A microcontroller, such as an Arduino, reads the LDR values. It compares these readings to determine if the panel is facing the sun directly. If the panel is not optimally aligned, the microcontroller sends signals to geared motors to rotate the panel until maximum light intensity is detected. The solar panel generates electricity, but its voltage output fluctuates with sunlight intensity. This stable voltage is then used to power the microcontroller, sensors, and motor drivers, ensuring the system operates reliably even as the solar panel's output changes. The LDRs continuously monitor the sunlight

intensity from various directions. The microcontroller compares the readings from the LDRs to determine which direction has the highest light intensity. Based on this comparison, the microcontroller sends signals to the servo motors to rotate the solar panel to align with the brightest light source. This process repeats, ensuring the solar panel remains optimally positioned to capture the maximum amount of solar energy throughout the day are shown in (Fig.3.1).

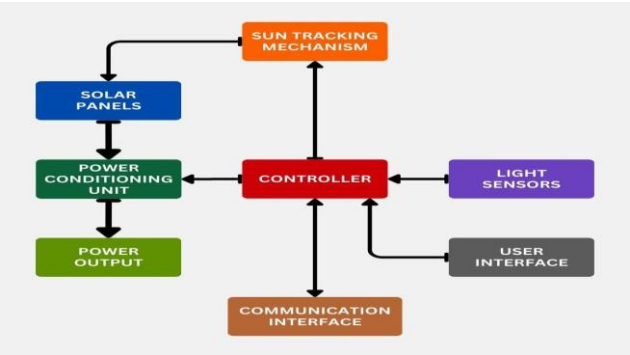


Fig.3.1 Block diagram (Block diagram of the solar tracking system, which illustrates how the system works.)

The system relies on a combination of Light Sensors, Controller, Sun Tracking Mechanism, Solar Panels, Power Conditioning Unit, Power Output, User Interface, and Communication Interface. Converts sunlight into electrical energy (DC power). Measures the amount of light and sends this information to the control unit. Receives sensor data, processes it, and sends commands to the movement adjustment unit.

3.2 Sensing Mechanism: LDR Configuration and Differential Signal Approach

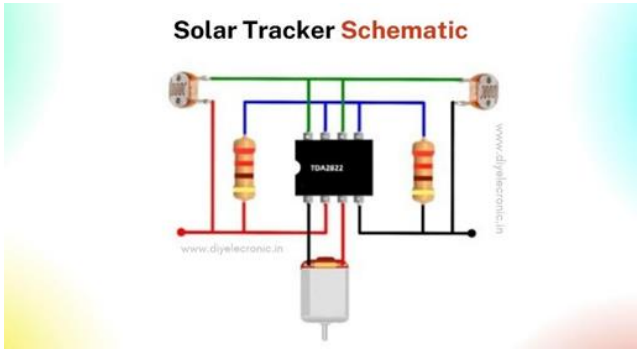
The dual problems of energy shortage and global warming brought at the forefront of public interest the development of strategies for harnessing renewable energy resources. Solar power is among the most promising sources of renewable energy. Sun trackers can significantly improve a photovoltaic (PV) system's electricity production. This paper presents a novel approach to design of an automatic dual-axis solar tracking system is designed and developed on a mechanical structure with gear arrangement using Light Dependent Resistor (LDR) and DC motors.

Light Dependent Resistors (LDRs) are typically used in pairs, positioned to detect the direction of the sun's rays by measuring varying light intensities that fall on them, causing changes in their electrical resistance. A differential paragraph describes how a controller, such as a microcontroller compares the electrical signals from these pairs of LDRs, calculates the difference in light intensity, and then sends instructions to motors to move the solar panel towards the LDR receiving the lightest, thereby aligning the panel to face the sun directly and maximizing energy capture.

3.3 Analog Control Circuit Design

An analog-based solar tracking system uses Light Dependent Resistors (LDRs) and a voltage divider circuit to convert light intensity into proportional analog voltages, which are then fed into an operational amplifier (OP-AMP) circuit to generate signals for driving a DC motor or servo motor that adjusts the solar panel's position, thereby maximizing solar energy capture by continuously orienting the panel towards the brightest light source without relying on a microcontroller.

Components of an Analog Solar Tracker Light Dependent Resistors (LDRs) are the primary light-sensitive



components. In a typical dual-axis system, four LDRs are placed at the corners of the solar panel. In Voltage Dividers each LDR is paired with a fixed resistor to form a voltage divider circuit are shown in (fig 3.2)

Fig.3.2 Analog Control Circuit

3.4 Actuation: Motor Driver Interface and Actuator Selection

For a solar tracker, a linear actuator or a DC stepper motor is selected as the actuator, driven by a microcontroller and a motor driver IC which provides high current for the motor from a stable, regulated power supply. The system requires voltage regulation to ensure consistent power for the control circuitry, while the chosen actuator provides the precise movement for the solar panel to track the sun.

Actuators have become increasingly popular in solar tracking applications. The technology enables the precise positioning of solar panels for maximum energy efficiency. The actuators are critical components in solar tracking systems that adjust the angle of the panels to track the sun as it moves throughout the day. The actuator is a mechanical device that converts rotational motion into linear motion.

The angle of the solar panels affects the amount of solar radiation that is absorbed, which directly impacts the amount of energy generated. The actuators are used to adjust the angle of the panels in two axes and elevation. The azimuth axis determines the east-to-west movement of the sun, while the elevation axis determines the north-to-south movement of the sun. In a solar tracking system, the linear actuators are controlled by a controller that receives input from a sensor that tracks the sun's position.

In Solar Tracking is a renewable energy is an increasingly popular and necessary alternative to traditional power sources. Solar energy is one of the most abundant sources of renewable energy available. To increase the efficiency of solar panels, solar tracking systems
are used. Solar tracking systems move solar panels to follow the sun's path throughout the day to ensure maximum exposure to actuators are crucial components of solar tracking systems, and their use provides numerous benefits.

The primary benefit of using linear actuators in solar tracking applications is increased efficiency. Solar panels that are static throughout the day only receive a limited amount of sunlight. By increasing the efficiency of solar panels, linear actuators can help reduce the environmental impact of solar energy systems. The technology enables the precise positioning of solar panels for maximum energy efficiency. The actuators are critical components in solar tracking systems that adjust the angle of the panels to track the sun as it moves throughout the day.

3.5 System Testing and Analysis

Solar tracking system testing and analysis involve rigorous testing of both hardware and software components to ensure accurate sun-following capabilities and optimal energy capture. Testing methods range from experimental setups comparing the tracker's output against static systems to utilizing data and complex algorithms for precise solar position calculations to validate the system's ability to maintain perpendicular with direct sunlight across different times and seasons. Testing the physical components, such as motors and sensors, to ensure they operate correctly and respond to commands. This includes verifying the precision of light-dependent resistors (LDRs) and servo motors in detecting and adjusting panel orientation.

3.6 Hardware Specifications

A solar tracking system with voltage regulation requires Light Dependent Resistors
(LDRs) for sun detection, a microcontroller for control, and motors for panel movement, a mechanical structure, a solar panel, and a voltage regulator like an integrated module to provide stable power to the system. Key hardware specifications include selecting motors suitable for the panel's weight and torque, choosing an LDR with appropriate sensitivity, and matching the voltage regulator's output to the control circuit are shown (fig 3.3).

3.6.1 Mechanical Structure & Frame:

Materials: Constructed from durable, corrosion-resistant materials like stainless steel, aluminium, or other metal alloys.

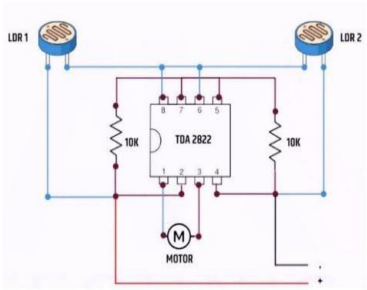
Design: A sturdy frame is crucial to support the solar panels and allow for rotation on one or two axes.

Solar Panel: The primary power source, with its output potentially managed by the tracking system to power itself.

Battery: Stores energy, often a 3.7V DC battery for DIY projects.

Resistors & Diodes: Used in sensor circuits, like the 220R and 1N4007 diode in some designs.

Wiring: High-quality wires and connectors are needed to ensure reliable power and data transfer.



Solar Tracker Circuit

Fig 3.3 Circuit connections

4. COMPONENTS & IMPLEMENTATION

4.1 Mechanical setup

A mechanical setup and mounting structure refer to the physical support system designed to hold and stabilize equipment, such as solar panels, ensuring they are securely fixed in place and optimally positioned to capture sunlight. Key aspects include the type of material (like galvanized steel or aluminium), the foundation or anchoring method (e.g., ballast, helical piles, or concrete anchors), and the structure's design to withstand environmental factors like wind and snow, all while providing the correct angle for maximum energy absorption.

4.2 LDR Sensor (Light Dependent Resistor)

A Light Dependent Resistor (LDR) is a semiconductor device whose resistance varies according to the intensity of light falling on its surface. When exposed to bright light, the resistance of an LDR decreases significantly, allowing more current to pass through the circuit. Conversely, in low-light or dark conditions, its resistance increases, thereby restricting the current flow. This property makes LDRs highly useful in solar tracking systems, where they act as light sensors to detect the position of the sun.



Fig 4.1 LDR Sensor

4.3 D2822N Integrated Circuit (IC)

The component shown in the (Fig 4.2) is a D2822N Integrated Circuit (IC). This IC is a horizontal processor deflector signal processor specifically designed for CRT display applications. It is typically found in a 12-pin SIL plastic package and is now discontinued by the manufacturer. The IC D2822N is a dual low-voltage audio power amplifier integrated circuit primarily used in portable cassette players and radios, featuring low crossover distortion, low quiescent current, and the ability to be configured in bridge modes. It is a compact, 8-pin package



designed for battery-powered applications, operating from a low supplyvoltageaslowas1.8V.

Fig 4.2 Integrated Circuit

4.4 Resistances

One ohm (1 Ω) of resistance is defined as the opposition to electrical current in a conductor, where a potential difference of 1 volt (1 V) causes a steady current of 1 ampere (1 A) to flow through it.

4.5 Solar Panel

A solar panel, also known as a photovoltaic (PV) module, is a device that converts sunlight directly into electrical energy using the photovoltaic effect. It is made up of multiple solar cells, usually constructed from semiconductor materials such as silicon, which absorb photons from sunlight and release electrons to generate a flow of electric current.

The amount of electricity produced depends on factors such as the intensity of sunlight, the surface area of the panel, the angle of incidence, and the efficiency of the solar cells. Solar panels typically produce direct current (DC) electricity, which either can be stored in batteries or converted into alternating current (AC) using an inverter for household and industrial applications.

4.6 Battery

A battery in a solar power system serves as an energy storage device that stores the electricity generated by the solar panel during daylight hours. Since solar panels produce direct current (DC) power, the battery stores this energy in chemical form and makes it available for use when sunlight is insufficient, such as during cloudy weather or at night. In a solar tracking system, the battery not only supplies power to external loads but can also provide a stable energy source for operating the tracker’s electronic control circuits, sensors, and motors. This makes the system

self-sufficient and reliable, as it can maintain its tracking function even under fluctuating sunlight conditions. Thus, the integration of a battery enhances both the efficiency and practicality of solar tracking systems by ensuring continuous and uninterrupted power availability.

5.TESTING & PERFORMANCE ANALYSIS

5.1 Testing Procedure

The testing procedure of the solar tracking system was designed to evaluate its functionality, efficiency, and reliability under real-world conditions. The system was tested throughout the day to monitor how accurately it followed the sun's movement. Different scenarios were considered, including varying sunlight intensity, partial shading, and changes in temperature. This systematic approach ensured that both the mechanical and electrical components were functioning optimally and provided consistent results under different environmental conditions.

The response of the LDR to varying light intensity was measured by recording its resistance values in bright light, shade, and darkness. The comparator and motor driver circuit were tested to ensure proper movement of the solar panel in response to differential LDR signals. The solar panel was mounted on the mechanical frame and exposed to sunlight. The accuracy of alignment with the sun was compared against a fixed panel.

5.2 Performance Analysis

The performance analysis involved comparing the energy output of the solar tracker with that of a fixed solar panel of the same capacity. The data showed that the dual-axis tracker increased energy generation by a measurable percentage, highlighting its advantage in maximizing solar exposure. Tracking accuracy was quantified using angular error measurements, which remained within acceptable limits throughout the day. The system's efficiency, stability, and mechanical durability were also assessed, confirming that the implemented design met the intended objectives. Overall, the analysis demonstrated the practical benefits of solar tracking in improving energy yield and optimizing the utilization of solar resources. The tracking system improved the panel's efficiency by ensuring maximum sunlight capture throughout the day. The analog control design (without microcontroller) proved to be cost-effective, simple, and reliable. The battery and voltage regulation system provided consistent power storage and supply, demonstrating system reliability for small scale applications. Limitations included, slower response during cloudy conditions, small motor torque for heavy panels, and minor energy consumption by the motor.

Conclusion

The design and implementation of the solar tracking system using LDR sensors, analog circuitry, solar panel, and battery storage have been successfully carried out. Based on testing and performance evaluation, the following conclusions are drawn. The LDR-based sensing mechanism accurately detected the direction of maximum sunlight and guided the solar panel orientation. The tracking system demonstrated a noticeable improvement in energy output compared to a fixed solar panel, with an average increase of approximately. The analog control circuit proved to be a reliable alternative to microcontroller-based systems. The voltage regulation and battery charging system ensured stable power supply, making the system suitable for small-scale renewable energy applications.

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