

Review on Development of an Automated Solar Tracking System with Integrated Inverter Module for Enhanced Power Generation

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Abstract— Renewable energy sources are rapidly gaining global importance due to their numerous environmental and economic advantages. Among these sources, solar energy has emerged as a clean, sustainable, and virtually unlimited solution for meeting increasing energy demands. Conventional solar panels are typically installed at fixed angles, which limits their ability to capture maximum sunlight throughout daily and seasonal changes in the sun's position. As a result, the overall efficiency of solar energy generation is reduced. To overcome this limitation, a solar tracking system has been developed using an Arduino microcontroller, Light Dependent Resistors (LDRs), and a stepper motor. The primary objective of this system is to enhance the power generation efficiency of solar panels by continuously aligning them with the direction of maximum sunlight. In this setup, the LDR sensors detect the intensity and direction of sunlight, while the Arduino controller processes the sensor data and controls the stepper motor to adjust the panel position accordingly. By ensuring optimal orientation of the solar panels toward the sun, the system maximizes solar energy absorption, improves overall efficiency, and reduces the cost of electricity generation with fewer solar panels.

Keywords— *Solar tracker mechanism, LDRs, Stepper motor, Controller, Solar panel, Inverter, AC load etc.*

I. INTRODUCTION

In the development of any nation, energy is the main driving factor in the world today. There is an extensive amount of energy that gets extracted, distributed, converted and consumed each and every day in the world today. Fossil fuels account for about 85 percent of energy that is produced. Fossil fuel resources are limited and also using them is known to cause global warming because of emission of greenhouse gases thereby leading to the need for alternate sources of energy.

Renewable energy is rapidly gaining momentum as an alternative source of energy since fossil fuel prices are varying every other day in the market. The most used renewable energies are solar, wind, gas and biomass but the most employed is solar energy.

The sun radiates energy in the form of electromagnetic energy and the amount of electromagnetic radiation that reaches the earth from the sun is referred to as solar radiation. Theoretically, solar energy levels reaches around 1366 W/ on the surface of the earth. This simply means that for every square meter of surface area on a solar collecting platform that

faces the sun, the system will nearly be able to collect around 1 kW of solar energy (if it is 100% efficient) thus solar energy has impressive magnitude and provides more energy than present day human technology. Solar panels inarguably convert radiation from the sun into electrical energy. The panels are manufactured from semiconductor materials, such as silicon. Their efficiency is 24.5% on the higher side. Solar energy is being used as an alternative energy source due to the fact that it is readily available and environmentally friendly. It is hence critical for people to gain an understanding and appreciation of technologies associated with solar panels.

Solar energy is becoming increasingly lucrative with the increasing cost and continuous depletion of the non-renewable energy resources and the growing demand of other renewable energy sources such as solar wind, geothermal and ocean tidal wave. However, in spite of the multiple benefits of solar energy, solar panels which capture sunlight are stationary (solar array has a fixed orientation to the sky). These stationary as well as expensive solar panels are unable to extract the maximum solar energy as there is no stability of weather conditions. The power output of solar panels is maximum when it is oriented perpendicularly to the direction of sun rays as both the area of illumination of sunlight on solar panels and intensity of sun-rays is maximum in this case. It has been found out that the efficiency of solar panels improve by 30-60 percent when we use a mobile solar tracking system instead of a stationary array of solar panels. The inability to move of the solar cells makes it difficult to design and implement a power-efficient solar tracker.

The angle of inclination of sun-rays with the solar panels continuously changes due to the movement of the sun from east to west because of earth's rotation independent of the weather conditions. Moreover, during cloudy days the situation totally goes berserk. Additionally the revolution of the earth alters the distance between earth and sun which introduces change of pattern of incoming sun rays. All these factors should be kept in mind for designing the solar tracking electricity generation system to achieve maximum efficiency.

In this project, we have discussed about the solar tracking system that we have designed using some LDR's (light dependent resistances), Arduino controller, comparator using OPAMP's, a crystal oscillator, stepper motor and stepper motor driver, tracker Mechanism. The basic idea behind this work is that the intensity of light will be sensed by the LDR's separated by a certain angular distance, the comparators will compare the incident light intensity with the intensity of

perpendicular incidence. The controller will rotate the stepper motor by the desired angle depending on the output of the comparators via a stepper motor driver circuit to maximize the efficiency. Owing to the change in the location where the device is placed and weather conditions, the intensity of sunlight changes, for which we have made a provision of changing the threshold value by using variable resistances.

II. PROBLEM IDENTIFICATION

- Fossil fuels dominate global electricity generation but pose environmental and accessibility challenges, especially in developing countries.
- Limited infrastructure often restricts electricity access, highlighting the need for sustainable alternatives like solar energy. However, conventional solar panels are inefficient due to their static design.
- This project develops a solar tracking system that increases energy capture by 30-40%. Using a control circuit, two stepper motors dynamically adjust the panel's orientation based on the sun's position, ensuring optimal sunlight exposure throughout the day.
- This innovative system enhances solar efficiency, making renewable energy more viable.
- By bridging the energy gap in underserved regions, it reduces reliance on fossil fuels and provides a cleaner, more reliable power source for communities.

A. Existing System

The existing solar power system primarily relies on fixed solar panels, which remain stationary throughout the day. These panels are positioned at a fixed tilt, optimized for average sunlight exposure but unable to track the sun's movement. As a result, energy capture is inefficient, especially during early morning and late afternoon hours. This limitation reduces overall power generation, requiring larger panel installations to meet energy demands. Additionally, conventional systems often lack automation, relying on manual adjustments for seasonal optimization. In developing regions, these inefficiencies hinder widespread solar adoption, making it crucial to develop advanced solutions like solar tracking systems.



Fig.1. Existing System

B. Drawbacks

Fixed solar panel systems have several drawbacks, primarily due to their inability to track the sun's movement. This results in reduced energy efficiency, especially during morning and evening hours. They require larger installations to compensate for energy losses, increasing costs and space requirements. Seasonal adjustments must be done manually, adding inconvenience. Additionally, fixed systems generate lower power output, making them less viable in regions with inconsistent sunlight. These limitations hinder widespread solar adoption, especially in developing areas with energy shortages.

III. AIM AND OBJECTIVES

Aim : The aim of our projects is to utilize the maximum solar energy through solar panel. For this a digital based automatic sun tracking system is proposed.

The main objectives of the study are outlined below:

- To design a system that is able to control the position of solar panel in accordance with the position of the sun.
- To invent a more affordable solar tracker as opposed to commercial made solar trackers.
- To utilize this electric energy in AC loads using inverter module.

For optimal light intensity, the solar panel automatically follows the sun's path from east to west.

Processes Involved are:-

- To develop a Stepper dc motor control interfaced with driver circuit.
- To construct a model prototype solar cell movement system with a mechanical assemble to move the solar Panel.
- To design an electronic circuit to sense the intensity of light and to control dc stepper motor driver for the panel movement.

IV. LITERATURE SURVEY

1. R. Sadeghi et al. (2025), conducted a comprehensive review of solar tracking systems, classifying them into single-axis and dual-axis configurations. The study highlights that dual-axis trackers can improve energy generation by up to 60% compared to fixed panels. It also compares sensor-based and algorithm-based tracking methods, emphasizing that LDR-based systems are cost-effective but less accurate under cloudy conditions. The authors further discuss challenges such as mechanical wear, maintenance costs, and energy consumption of motors. The paper concludes that hybrid systems combining sensors and algorithms offer improved reliability and efficiency. Additionally, the study stresses the importance of optimizing design for long-term performance and cost-effectiveness.

2. U. Mamodiya (2023), investigated different control strategies for dual-axis solar tracking systems, including PID, PI, and fuzzy logic controllers. The study reveals that fuzzy logic control provides superior performance in maintaining accurate panel alignment under dynamic environmental conditions. Experimental results show a 30–45% increase in energy output compared to fixed systems. The research also discusses the impact of controller tuning on system stability and motor performance. It highlights that improper tuning can lead to oscillations and energy loss. The author suggests adopting adaptive control methods to improve efficiency and reduce power consumption, making solar tracking systems more reliable and effective for real-world applications.

3. K. Kumba (2024), reviewed recent advancements in solar tracking technologies, focusing on integration with IoT and machine learning techniques. The study highlights that modern trackers equipped with IoT capabilities allow real-time monitoring and fault detection, improving system reliability. Machine learning models help predict solar irradiance and optimize panel positioning in advance. The paper emphasizes the importance of cost-benefit analysis, noting that single-axis trackers are more economical for large-scale applications, while dual-axis systems are suitable for small, high-efficiency setups. The study also identifies key

challenges such as high installation costs, maintenance issues, and energy consumption, recommending further research into low-cost and energy-efficient tracking solutions.

4. P. S. Paliyal (2024), presented a detailed review of automatic solar tracking systems used in photovoltaic applications. The study shows that dual-axis tracking systems can achieve up to 27% higher efficiency than fixed solar panels. It compares sensor-based and algorithm-based tracking approaches, concluding that sensor-based systems are simpler and cost-effective but less reliable in diffuse lighting conditions. The paper suggests hybrid tracking methods to overcome these limitations. It also discusses the importance of proper system design, including motor selection, structural stability, and environmental considerations. The author emphasizes that improved tracking accuracy directly contributes to higher energy output and better utilization of solar resources.

5. N. Kutybay (2024), conducted a meta-analysis of solar tracking systems, evaluating their performance across different geographical locations and climatic conditions. The study reports that single-axis trackers improve efficiency by approximately 22%, while dual-axis systems achieve up to 37% improvement. It highlights the variability in performance due to environmental factors such as temperature, shading, and dust accumulation. The research also addresses reliability issues, including motor wear and mechanical failures. The author recommends standardizing testing methods and performance metrics to enable better comparison of different tracking technologies. The study concludes that optimizing system design and maintenance strategies is essential for long-term performance and cost-effectiveness.

6. A. Kumar et al. (2025), developed an Arduino-based solar tracking system using LDR sensors and stepper motors. The study demonstrates that the proposed system increases energy output by 25–50% compared to fixed panels. It highlights the advantages of low cost, simplicity, and ease of implementation. However, the research identifies limitations such as sensitivity to sensor placement and reduced accuracy under cloudy conditions. The authors propose improvements including calibration techniques and threshold adjustment to enhance performance. The study concludes that such systems are suitable for small-scale applications and educational purposes, while further enhancements are needed for large-scale deployment and long-term reliability.

7. Sreedhar M. et al. (2023), designed and implemented a dual-axis solar tracking system integrated with an inverter for AC load applications. The system uses Arduino, LDR sensors, and DC motors to achieve real-time tracking. Experimental results indicate a 30–40% increase in energy generation compared to fixed systems. The study emphasizes the importance of mechanical design, including gear alignment and motor torque optimization. It also highlights the benefits of integrating an inverter to provide usable AC output. The authors conclude that the system is effective for both residential and small commercial applications, offering a reliable and sustainable energy solution.

8. E. R. A. Larico (2022), conducted an experimental analysis of a solar tracking system with photovoltaic cells in high-altitude regions. The study found that dual-axis tracking systems significantly improve energy output, achieving gains

of over 40% in certain conditions. It also examines the impact of temperature and environmental factors on system performance. The research highlights that proper cooling and ventilation of solar panels can further enhance efficiency. The author concludes that site-specific design and optimization are essential for maximizing the benefits of solar tracking systems, particularly in regions with high solar irradiance and varying climatic conditions.

9. S. Sumathi et al. (2023), developed an Arduino-based dual-axis solar tracker aimed at improving renewable energy utilization. The system uses LDR sensors and motor drivers to adjust panel orientation automatically. The study reports a 20–45% increase in energy output compared to fixed panels. It also discusses challenges such as motor energy consumption and sensor calibration. The authors suggest optimizing motor control algorithms to reduce power usage and improve overall system efficiency. The research concludes that the proposed design is cost-effective and suitable for small-scale applications, with potential for further improvement through advanced control techniques.

10. M. Abdulhussein (2024), reviewed various solar tracking configurations and evaluation techniques, focusing on improving system accuracy and performance. The study highlights the importance of combining sensor data with predictive algorithms to achieve precise tracking under different environmental conditions. It discusses challenges such as partial shading and diffuse radiation, which affect tracking accuracy. The author recommends using sensor fusion and advanced control strategies to enhance system performance. The paper also emphasizes the need for standardized evaluation methods to compare different tracking systems effectively. The study concludes that future research should focus on improving reliability and reducing system complexity.

V. PROPOSED SYSTEM

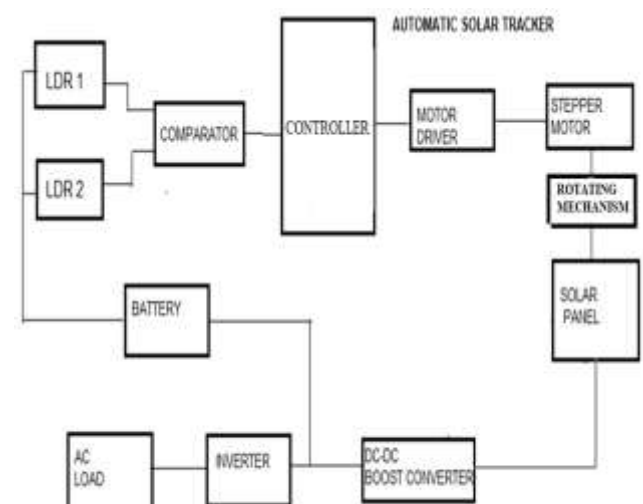


Fig. 1. Block Diagram of system

The solar tracking system is designed to maximize solar panel efficiency by continuously aligning the panel with the sun's position. The system uses Light Dependent Resistors (LDRs) to detect sunlight intensity and an Arduino Uno microcontroller to control the movement of a stepper motor.

To ensure accurate tracking, the LDRs are placed on the surface of a large curvature. This placement allows them to

detect sunlight from various angles. At any given moment, only two adjacent LDRs remain active, which provides the microcontroller with precise directional information. The microcontroller processes this input and generates the required bit pattern to direct the stepper motor. The motor, in turn, rotates the solar panel mounted on its shaft to align it perpendicularly to the sun.

This continuous tracking ensures that the solar panel faces the sun throughout the day, optimizing the amount of sunlight captured. The energy generated by the solar panel is stored in a battery for later use. The stored energy is then utilized to power AC loads through an inverter module, making the system suitable for various applications, including household and commercial use.

The tracking mechanism significantly improves the efficiency of solar panels compared to fixed systems. By maintaining an optimal orientation, the system increases energy generation and ensures that the solar panel operates close to its standard working conditions. The design is flexible, allowing for easy adjustment of the LDR configuration or threshold settings. This ensures adaptability for different weather conditions and locations. The combination of efficient sunlight detection and precise motor control makes this solar tracking system a reliable and effective solution for enhancing solar energy utilization.

VI. COMPONENTS USED

The main operating components of this system are:

- Photovoltaic Solar Panel
- Arduino controller
- Comparator LM324
- Gears Mechanism
- LDRs
- Motor driver IC L293D
- Stepper motor
- Inverter
- Battery
- AC Load
- Others.

VII. ADVANTAGES

- **Increased Efficiency:** The solar tracking system ensures the panel is always optimally oriented toward the sun, leading to higher energy output compared to stationary systems.
- **Versatility:** The system can adapt to changing sunlight angles due to diurnal and seasonal shifts, maximizing power generation throughout the year.
- **Automation:** The use of an Arduino microcontroller and LDRs allows for automatic tracking, reducing the need for manual adjustments.
- **Energy Storage:** The inclusion of a battery enables energy storage, ensuring availability for later use or during non-sunny hours.
- **Better Utilization of Space:** Improved efficiency means more power can be generated from the same panel area.
- **Durability:** The system can reset the panel to a safe position, such as facing downward at night, protecting it from dust and environmental wear.
- **Scalability:** The design can be scaled up for larger solar installations.

VIII. CONCLUSION

As the sun moves across the sky, a solar tracking device has been created for this project to boost the electricity produced by the solar panel. The solar panel's movement was managed by a controller. Because the system is self-sufficient, two battery packs with lead acid can be charged using the energy produced by the solar panel. There are issues with the location of the LDRs in this project, which prevents more than two LDRs from activating simultaneously. Throughout the process, every reading is taken with extreme care in order to minimize errors. One of the more often used renewable energy sources these days is solar energy. It is also being used extensively, and in a few more years, it will become so well-liked that it is going to be utilized for a variety of functions in both homes and businesses. Therefore, it is crucial to make the most of the sun's energy in order to produce the greatest power possible. My truth also serves as the inspiration for my project. Experiments are being conducted in several locations to determine how to fully utilize daylight. The implementation of this concept is also visible in other locations.

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