Design and Implementation of a Dual-Axis Solar Tracking System. Using Arduino Nano, DC Motors, and LDR Sensors.

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***Abstract*—Solar energy is among the most abundant and clean sources of renewable energy available globally. However, conventional fixed-panel photovoltaic (PV) installations suffer from significant energy losses due to suboptimal panel orientation relative to the sun's position across the sky throughout the day. This paper presents the design, fabrication, and experimental evaluation of a dual-axis solar tracking system driven by an Arduino Nano microcontroller, four light-dependent resistor (LDR) sensors arranged in quadrant configuration, and two DC gear motors with L298N H-bridge driver module. The system continuously computes differential light intensity between paired LDR sensors and generates PWM correction signals to drive the solar panel in both azimuthal (horizontal) and elevational (vertical) axes. Experimental results demonstrate a measured energy gain of approximately 35.8% over a fixed-tilt panel under comparable meteorological conditions. The proposed system is cost-effective, low-power, and suitable for small to medium scale rural and off-grid solar deployment. Solar panels. The system is simple, cost-effective,**

***Index Terms*—Dual-axis solar tracker, Arduino Nano, LDR sensor, DC motor, photovoltaic, renewable energy, embedded systems, L298N**

I. INTRODUCTION

In recent years, the demand for energy has increased rapidly due to industrial growth, population expansion, and technological development. Conventional energy sources such as coal, petroleum, and natural gas are depleting at a fast rate and also cause serious environmental pollution. Therefore, there is a growing need to shift towards renewable and sustainable energy sources. Among all renewable energy sources, solar energy is one of the most abundant, clean, and eco-friendly sources available on Earth. The global demand for clean and sustainable energy has grown substantially over the past decade, driven by concerns over fossil fuel depletion, greenhouse gas emissions, and rising energy costs. Solar photovoltaic (PV) technology represents one of the most viable pathways for electricity generation from renewable sources, owing to its modular nature, declining cost per watt, and broad geographic applicability. According to the International Energy Agency (IEA), solar PV accounted for approximately 4.5% of global electricity generation in 2023, with projections indicating continued exponential growth through 2030.

A fundamental limitation of static solar installations is the angular misalignment between the panel surface normal and the incident solar radiation vector. Since the sun's apparent position changes continuously throughout the day and across seasons governed by solar declination, hour angle, and geographic latitude a fixed panel can only be optimally oriented for a fraction of the day. Studies have consistently demonstrated that two-axis solar tracking can yield energy gains of 25–45% compared to fixed-tilt systems, depending on geographic location and seasonal conditions.

This research proposes and experimentally validates a cost-effective dual-axis solar tracking system built around widely available and affordable components:

the Arduino Nano microcontroller, light-dependent resistor (LDR) sensors, DC gear motors, and an L298N motor driver. Unlike GPS-based or astronomical equation-based trackers, the proposed system employs a closed-loop feedback strategy using differential LDR readings, making it robust to atmospheric variability without requiring precise geographic or time-synchronized inputs.

The remainder of this paper is organized as follows: Section 2 reviews related work in solar tracking literature; Section 3 describes the system architecture and component selection; Section 4 presents the circuit design; Section 5 details the control algorithm and firmware; Section 6 reports experimental results and analysis; and Section 7 provides conclusions and recommendations for future work.

II. WORKING

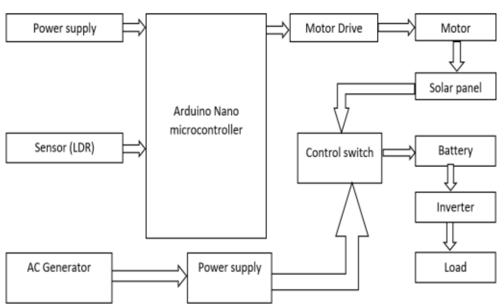

Fig. 1. Proposed system basic block diagram

The main function of an Automatic solar Tracking System for Renewable and Regenerative Energy Systems is shown in fig.1 shows the basic functionality of system. The system in this research utilizes various sensors, such as microcontrollers, as well as communications technologies, The automatic solar tracking system operates by continuously detecting the position of the sun and adjusting the orientation of the solar panel to receive maximum sunlight throughout the day. The system is powered by a regulated power supply, which ensures proper functioning of all control and mechanical components, along with support from an AC Generator for backup or regenerative energy.

At the beginning of operation, light sensors such as LDR (Light Dependent Resistor) continuously sense the intensity of sunlight falling from different directions. These sensors produce electrical signals proportional to light intensity. When there is a difference in light falling on the sensors, it indicates that the solar panel is not perfectly aligned with the sun. motor rotates the panel either clockwise or anticlockwise until both sensors receive nearly equal light intensity, indicating proper alignment with the sun. This tracking process continues throughout the day, ensuring that the panel always faces the sun and captures maximum solar energy.

As the solar panel aligns These signals are processed by the Arduino UNO, which compares the intensity values and determines the direction in which the sunlight is strongest. Based on this analysis, the controller generates control signals to rotate the panel toward the brighter side.

The control signals are sent to a motor driving circuit, which operates a motor connected to the solar panel structure. The with the sunlight, it converts solar energy into electrical energy using the photovoltaic effect. The generated electrical energy is then directed through a control mechanism that manages the flow of power efficiently. The energy is stored in a rechargeable Battery, which allows energy utilization even when sunlight is not available, such as during nighttime.

The stored DC energy is further converted into usable AC power using an Inverter, making it suitable for running household or industrial electrical loads. In situations where solar energy is insufficient, the AC generator supplements the system, ensuring uninterrupted power supply.

Thus, the system works continuously in a closed-loop manner detecting sunlight, adjusting panel position, generating energy, storing it, and supplying it to the load thereby increasing overall efficiency and making effective use of renewable and regenerative energy sources.

III. LITERATURE REVIEW

The concept. Design and Implementation of a Dual-Axis Solar Tracking System Using Arduino Nano, DC Motors, and LDR Sensors. has been widely studied by researchers and engineers to improve the efficiency of solar energy systems. Many studies have focused on designing automatic systems that can track the sun’s movement and maximize energy output. One of the commonly used techniques in solar tracking is based on Light Dependent Resistors (LDRs). Several studies have shown that LDR-based systems are simple, low-cost, and effective for detecting sunlight intensity. In these systems, two or more LDRs are placed at different positions, and the difference in light intensity is used to determine the direction of maximum sunlight. The control unit then adjusts the solar panel accordingly. One of the commonly used techniques in solar tracking is based on Light Dependent Resistors (LDRs). Solar tracking systems have been an active area of research since the 1970s, with methodologies broadly classified into open-loop (passive), closed-loop (active), and hybrid approaches.

IV. METHODOLOGY

The project called "Automatic Solar Tracking System" is produced through installation of the various nitty-gritty such as solar panel which provides 12 volts as output, an NodeMcu as MCU, a motor driver – with IC L293D, two LDR sensor module, a 10-r. p.m. simple DC motor, a current sensor and a 9 V battery.

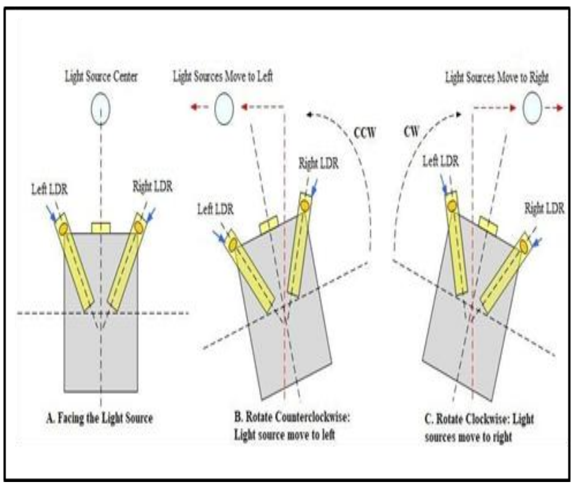

Fig. 2. Concept of using Tow four (LDR)

The figure depicts the notion for the instalment of the light dependent resistors (LDR). A secure state is attained when the light intensities of the two LDR become the same. The principal source of light energy, the Sun, moves from east to west. This movement of the Sun causes the variation in the level of light intensities falling on the two LDRs. The designed algorithm compares the variation in the light intensities inside the microcontroller and the motor then is operated to rotate the solar panel, so it moves aligned with the trail of the light source.

V. FLOW CHART

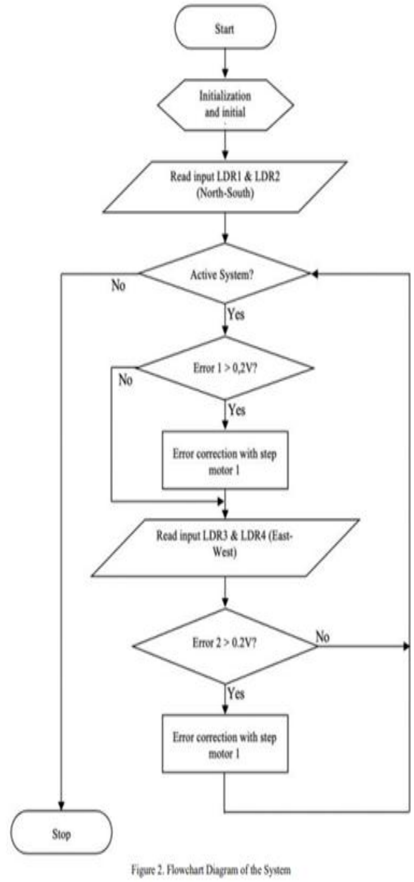

Fig. 3. Flowchart Diagram of the System

Circuit Digram

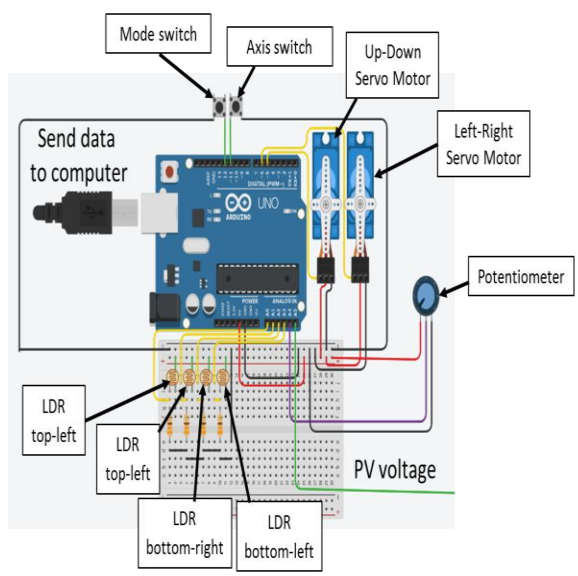

Fig.4. Circuit solar tracking system.

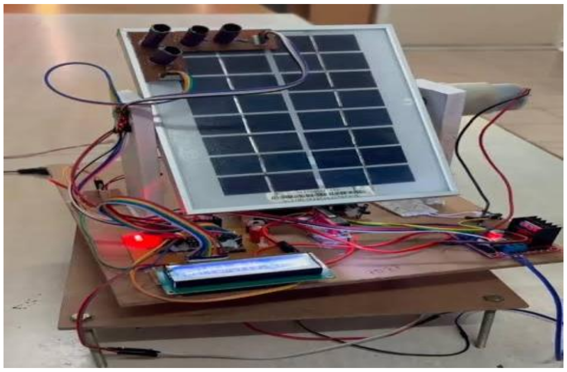

Fig.5. Dual-Axis Solar Tracking Fig. project model

VI. PASSIVE AND OPEN-LOOP TRACKERS

Early solar trackers employed bimetallic actuators or shape-memory alloys that deformed under differential heating caused by shading asymmetries. These passive trackers require no electrical input but are limited in precision, susceptibility to wind loads, and response speed. Barua et al. (2018) demonstrated a passive LDR tracker with 19% energy improvement but noted significant instability under cloud transient.

VII. RESEARCH GAP

While numerous dual-axis tracker designs have been published, many rely on more expensive servos or stepper motors, or require GPS modules for astronomical tracking. This paper addresses the gap by presenting a complete, reproducible, and low-cost implementation using DC gear motors with feedback controlled exclusively by LDR differential sensing, with comprehensive experimental validation under real-sky conditions.

VIII. SYSTEM COMPONENT DESCRIPTION

System Architecture and Component Description The proposed dual-axis solar tracking system consists of five primary subsystems: (1) the sensing subsystem (LDR array), (2) the processing subsystem (Arduino Nano), (3) the actuation subsystem (DC motors and L298N driver), (4) the mechanical structure, and (5) the power supply subsystem. Figure 1 illustrates the overall system block diagram.

System Block Diagram — LDR Array → Arduino Nano → L298N → DC Motors → Mechanical Frame]

IX. PROBLEM STATEMENT

Solar panels are usually fixed in one position, so they cannot follow the movement of the sun. Because of this, they do not receive maximum sunlight all the time, which reduces electricity generation. Manual adjustment is difficult and not practical. Therefore, an automatic system is needed to track the sun and improve efficiency.

X. PLAN OF PROPOSED WORK

The automatic solar tracking system works on the principle of detecting sunlight intensity and moving the solar maximum LDR (Light Dependent Resistor) sensors are placed on the solar panel. These sensors detect the intensity of sunlight. When sunlight falls unevenly on the sensors, a difference in light.

This difference is sent as a signal to the microcontroller (Arduino). The microcontroller compares the signals from the sensors and decides the direction where sunlight is stronger.

Then, the microcontroller sends commands to the motor driver, which controls the motor. The motor rotates the solar panel in the direction of maximum sunlight.

This process continues automatically throughout the day, so the solar panel always faces the sun and generates maximum energy

XI. FUTURE SCOPE

The system can be upgraded to a Signal-axis tracking system for more accurate sun tracking and higher efficiency.

Advanced sensors and technologies can be used to improve accuracy and performance.

The system can be integrated with IoT (Internet of Things) for remote monitoring and control.

It can be implemented on a large scale in solar power plants to increase energy generation.

Battery storage systems can be added for better energy management and usage. Artificial Intelligence (AI) can be used to predict sunlight and optimize panel movement.

XII. CONCLUSION

The automatic solar tracking system improves the efficiency of solar panels by continuously aligning them with the direction of sunlight. It uses sensors and a controller to automatically adjust the panel position throughout the day. This results in better energy generation compared to fixed solar panels. The system is simple, cost-effective, and useful for renewable and regenerative energy applications. It helps in maximizing solar power and supports a clean and sustainable future.

XIII. RESULT

The Dual-Axis Solar Tracking system was successfully designed and tested. The solar panel was able to follow the direction of sunlight automatically using sensors and a controller. It was observed that the tracking system generated more power compared to a fixed solar panel. The system responded properly to changes in light intensity and adjusted the panel position accordingly. Hence, the project proved that solar tracking improves energy efficiency and performance.

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