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ENHANCING SOLAR PANEL EFFICIENCY THROUGH COST-EFFECTIVE SINGLE-AXIS SOLAR TRACKING SYSTEMS

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Abstract—Among renewable energy sources, solar power has rapidly emerged as a leading and essential form of sustainable energy. The implementation of solar tracking systems significantly enhances the production of energy by optimizing the solar panels' exposure to sunlight. The key to improving efficiency lies in maintaining the panels' perpendicular alignment with the sun's rays. Although the initial installation cost is high, more affordable alternatives are available. This project details the design and construction of a single-axis solar tracking system model. The core of the control circuit utilizes the motor controller IC L293D. Light-dependent resistor (LDR) sensors guide the DC motor to adjust the solar panel's rotation, ensuring optimal sunlight reception. Compared to other motors, the DC motor is preferred for its simplicity and higher torque, even though it inherently rotates in one direction—this limitation can be addressed through programming. Historical context shows that since 1985, when silicon solar cells achieved a 20% efficiency milestone, there has been significant progress. However, achieving optimal efficiency remains an elusive target, with most panels operating below 40% efficiency. To meet energy requirements, individuals either opt for multiple panels or a single, high-output system. Although solar cells with higher efficiencies exist, their high cost is prohibitive. One of the most effective methods to enhance solar panel efficiency, while also being cost-effective, is the utilization of tracking systems. These systems, which can be dual or single-axis, increase the panel's exposure to the sun, resulting in higher power output.

Keywords*—Solar Panel, Solar Tracker, LDR Sensors, DC Motor, Efficiency.*

I. INTRODUCTION

Over the past decade, many households worldwide have adopted solar power systems as a supplementary source of energy for their homes. This trend is driven by the recognition that solar power represents an abundant and renewable energy source, poised to play an increasingly vital role in meeting electricity and heat energy needs in the future. Solar power holds the potential to become the primary energy source in the years to come.

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A solar tracker is an automated electrical device designed to precisely follow the movement of the Sun, maximizing power generation. The Sun's position in the sky changes continuously relative to any fixed location. One common type of solar tracker is the heliostat, which employs movable mirrors to redirect sunlight to a stationary location; however, various other tracking methods are being explored. Active trackers utilize motors and gear systems controlled by a controller to adjust the tracker's orientation based on the Sun's position. Solar trackers find applications in various systems, including solar cells, solar day-lighting, and solar thermal arrays. They are particularly beneficial for devices requiring optimal sunlight exposure, such as solar cells.

Many solar panels are traditionally installed on stable surfaces like rooftops. However, as the Sun moves throughout the day, fixed panels may not capture sunlight efficiently. One solution is to implement a sun tracking system that continuously adjusts the solar panel's position to face the Sun directly. By ensuring that the panel always faces the Sun, maximum energy absorption is achieved, leading to peak efficiency.

The primary objective of this project is to maximize the efficiency of solar cells by developing a cost-effective sun tracking system suitable for residential use. While several solar trackers are available in the market, they are often prohibitively expensive, making them inaccessible to many residential users. Additionally, existing large-scale solar trackers may not be suitable for residential applications.

Previous research has utilized Light Dependent Resistors (LDR) and photodiodes as sensors, along with DC motors with gears and stepper motors. However, these approaches have drawbacks, including high development costs, difficulty in controlling motor speed, and complexity in design when incorporating microprocessors.

The key goal of this project is to create a sun tracking system model capable of accurately following the Sun's movement, regardless of motor speed. Furthermore, the aim is to enhance overall electricity generation efficiency.

II. THEORY

A. Utilizing Two Light Dependent Resistors (LDRs)

Figure 1 illustrates the concept of incorporating light dependent resistors (LDRs). A stable state is achieved when the light intensities detected by the two LDRs become equal. As the primary light source, the Sun moves from east to west, resulting in varying light intensities on the two LDRs. An algorithm is devised to compare these variations in light intensities within the microcontroller. Subsequently, the motor is activated to adjust the position of the solar panel, aligning it with the direction of the light source.

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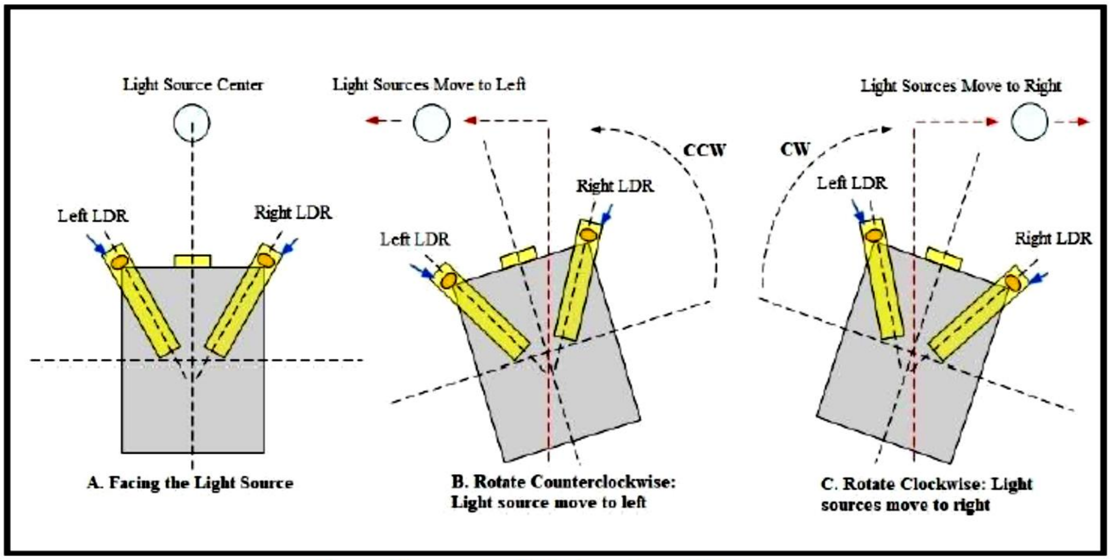

Fig. 1 Concept of Using Two LDR

B. Solar Tracker Theory

The position of the Sun undergoes continuous changes throughout the day due to the Earth's motion. The Earth's rotation on its axis and its revolution around the Sun contribute to this phenomenon. Rotation, the Earth's motion on its axis, causes the occurrence of day and night, with one complete rotation taking approximately 23 hours and 56 minutes. The Earth's rotation occurs from west to east.

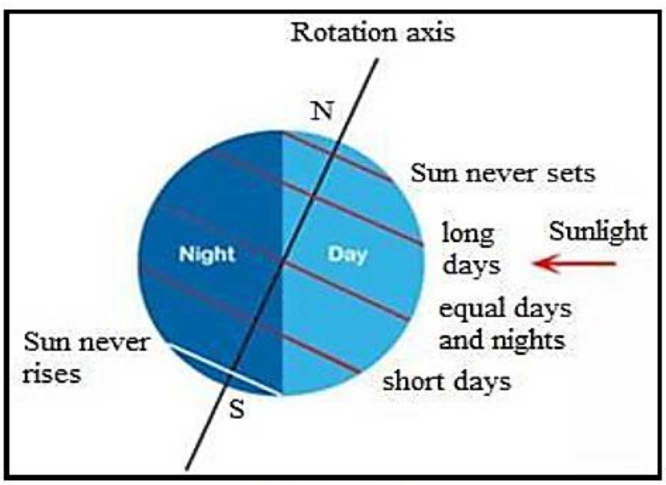

Fig. 2 Earth Rotation

Revolution, on the other hand, refers to the Earth's movement around the Sun, which is responsible for the seasonal changes experienced throughout the year. It takes the Earth one year to complete a

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revolution around the Sun in an elliptical orbit, with the plane covered by the Earth during this revolution known as the ellipse. The angle of inclination between the axis of rotation and the ellipse is approximately 66.5 degrees, leading to the occurrence of summer and winter solstices and spring and fall equinoxes.

Due to these motions of the Earth, the amount of sunlight received varies throughout the year. Sunlight, as the radiation emitted by the Sun, is absorbed by the Earth's surface. The total energy emitted by the Sun into space far exceeds that intercepted by the Earth. Over a given period, the emission of radiation remains relatively constant, and the intensity of this radiation striking a unit area of the Earth's surface is known as the solar constant.

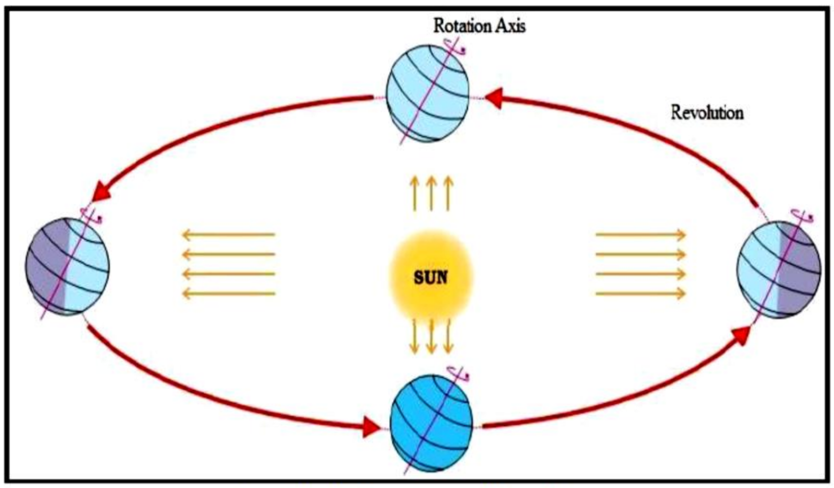

Fig. 3 Earth Rotation and Revolution

Various factors affect the absorption of radiation on the Earth's surface, including latitude and longitude. Latitude refers to the horizontal imaginary lines parallel to the equator, while longitude refers to the vertical imaginary lines passing through a given location and intersecting the prime meridian. These lines determine north-south and east-west directions on the Earth's surface, respectively.

Sunlight angles vary depending on the location on Earth and the position of the sun. These angles can be categorized as follows:

1. Elevation Angle: This angle represents the angle formed by the sun with the horizon. It is zero degrees at sunrise and reaches ninety degrees around noon at the equator. The elevation angle varies throughout the day and differs for different latitudes. The following formula can be used to calculate the elevation angle.

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2. Zenith Angle: The zenith angle is similar to the elevation angle but measured vertically. It is the angle between the sun and the vertical line, calculated as 90 degrees minus the elevation angle.

3. Azimuthal Angle: This angle indicates the compass direction from which sunlight is coming. At solar noon, the sun is directly south in the northern hemisphere and directly north in the southern hemisphere. The azimuthal angle changes throughout the day and varies depending on the latitude. During the equinoxes, the sun rises directly east and sets directly west, resulting in azimuth angles of ninety degrees at sunrise and 270 degrees at sunset.

Fixed collectors are positioned in areas where the overall solar power received is relatively high compared to most other locations, and the inclination is maintained according to predefined parameters. The goal is to install collectors in locations that receive the maximum amount of sunlight and can collect solar energy efficiently over an extended period, thus minimizing the need for tracking devices. This approach significantly reduces costs and preserves the collectors. Understanding the movement of the sun throughout different seasons and times of the year is essential for maximizing solar energy absorption.

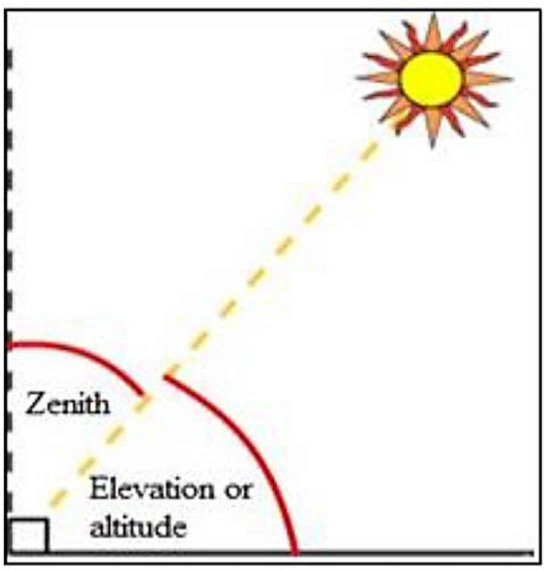

Fig. 4 Angle of Elevation and Zenith Angle

III. METHODOLOGY

A. Hardware The hardware setup comprises various electronic components and basic materials for mechanical support. The electronic components utilized in the setup can be categorized into three main sections:

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1. Solar Input The solar input consists of the solar panel and two sets of photo sensors, each attached to the solar panel along its length on both sides. The solar panel is mounted on a wooden base using a mechanical structure. The photo sensors are then connected to the control circuit. In this setup, light-dependent resistors are employed as the photo sensors.

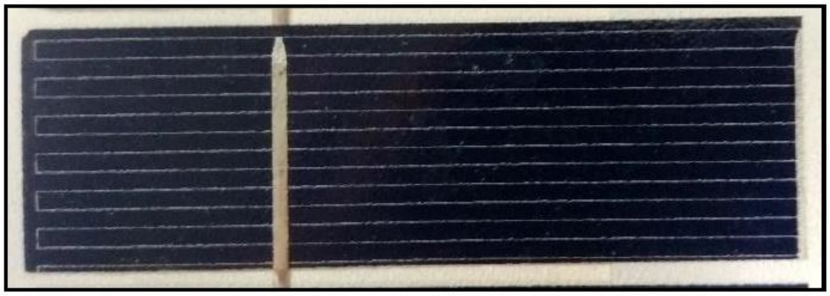

Fig. 5 Solar Cell

2. Light Dependent Resistor The light dependent resistor (LDR), also known as a photoresistor, operates in both a supplementary and complementary manner within a given area. As a photosensitive device, it exhibits a change in electrical resistance in response to incident radiation. It is also referred to as a photoconductor, photoconductive cell, or photocell. These devices are typically made of semiconductor materials and have high resistance. A commonly used symbol to represent an LDR is depicted in the figure below, with an arrow indicating incident light.

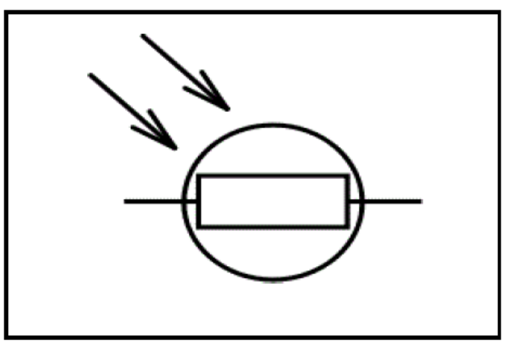

Fig. 6 Symbol of LDR

3. The Drive Motors (DC motor) This component of the prototype is responsible for the rotation of the solar panel to track the movement of the sun. It consists of a driving module (L293D) and a DC motor. The driving module facilitates the bidirectional movement of the rotation

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axis connected to the solar panel. It controls the rotation of the DC motor. Additionally, the driving module is linked to a nine-volt DC power supply. Equipped with components such as a shaft, rotor (armature), stator, commutator, field magnet(s), and brushes, the DC motor finds applications in various systems. This section provides an in-depth understanding of the operation and structure of DC motors. DC motors possess characteristics such as low power consumption, high torque, low noise, compact size, light weight, and ease of use. The DC motor employed in the system has a maximum angular speed of ten revolutions per minute and operates with a voltage supply of twelve volts. It can rotate smoothly, as illustrated in Fig. 7. The direction and speed of the DC motor serve as outputs for the system. In this scenario, the direction of the DC motor is controlled using the motor driver module, specifically the L293D. As mentioned earlier, the DC motor remains in an off-mode when the voltage difference between the two LDRs is small (< 0.1V). This value is determined based on experimental results and is designed to prevent oscillation.

Fig. 7 DC Motor

B. Implementation

The solar tracker comprises a comparator circuit consisting of two PNP transistors, an H-bridge motor driver IC (Integrated Circuit), and several discrete components. Light Dependent Resistors (LDR1 and LDR2) serve as sensors to determine the position of the panel relative to the sun. These sensors transmit signals to the motor driver IC, instructing it to adjust the solar panel's position according to the sun's movement. LDR1 and LDR2 are mounted at the edges of the solar panel along the X-axis and are connected to transistors T1 and T2, respectively. Preset resistors VR1 and VR2 are adjusted to produce a low comparator output through T1 and T2, respectively. This configuration halts motor M when the sun's rays are perpendicular to the solar panel.

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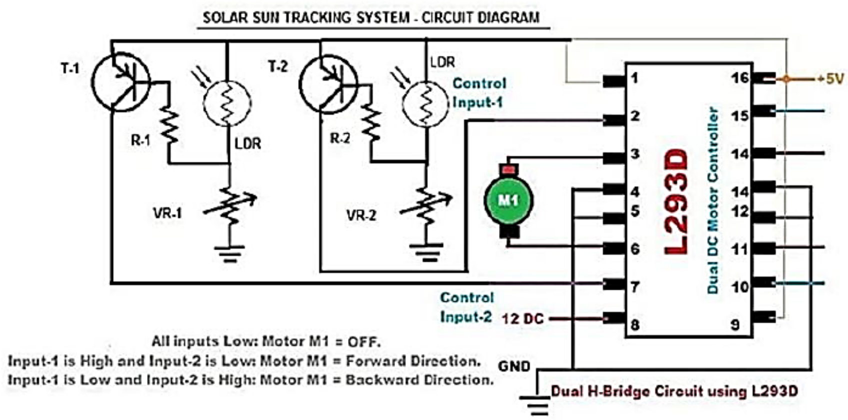

Fig. 8 Circuit Diagram

When LDR1 receives additional light than LDR1, it offers lower resistance than LDR1, providing a high input to transistors t1 and transistors t2 severally. As a result, motor controller rotate motor M in one direction (Anti-clockwise) and switch the solar panel. When LDR2 receives additional light than LDR2, it offers lower resistance than LDR2, giving an occasional input to transistors t1 and t2 severally. As a result, motor M rotates within the other way (Clock-wise) and therefore the solar panel turns.

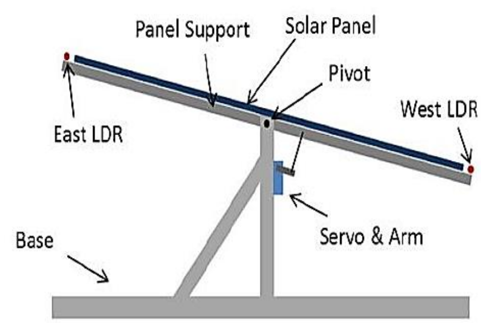

Fig. 9 Single Axis Tracker

IV. FUTURE PROSPECTS

The innovative solution presented by the project known as "Single Axis Sun Tracking Solar System" holds great promise for addressing contemporary challenges. It operates with exceptional efficiency, both in terms of its cost-effectiveness and accessibility. In an era overshadowed by environmental pollution, this system stands out as a beacon of progress, actively working to mitigate pollution on a large scale.

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V. CONCLUSION

In today's world, energy serves as the cornerstone of civilization, indispensable for all aspects of life. Recognizing the finite nature of earthly energy sources, it becomes imperative to explore sustainable alternatives. The project discussed herein aims to unlock the potential of solar energy, the most abundant and fundamental source of energy in our universe. By harnessing the power of the sun, we can reduce our reliance on polluting energy sources, thereby preserving our environment and ensuring a sustainable future. In a world driven by commercial interests, it is essential to prioritize environmental healing and sustainable development. This project exemplifies a step towards achieving these goals by promoting clean energy and fostering technological advancement.

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