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EXPERIMENTAL ANALYSIS AND IMPLEMENTATION OF A SINGLE AXIS SOLAR TRACKING SYSTEM USING ARDUINO

Dr. S. Srimatha[1], A. Sandeep Kumar[2], E. Lukesh[3], V. Rajesh[4], D. Yuva Raj[5]

Asst. Prof[1], Dept of EEE, Siddhartha Institute of Technology & Sciences, Narapally, TS

UG Scholar[2,3,4,5], Dept of EEE, Siddhartha Institute of Technology & Sciences, Narapally, TS

ABSTRACT

Experimental Analysis and Implementation of a Single Axis Solar Tracking System Using Arduino shows the design, development, and performance evaluation of an automated solar tracking mechanism aimed at enhancing photovoltaic (PV) panel efficiency. Conventional fixed solar panels experience reduced energy output due to the continuous movement of the sun across the sky. To overcome this limitation, a single-axis tracking system has been implemented using an Arduino Uno microcontroller, Light Dependent Resistors (LDRs), and a servo motor. The LDR sensors detect variations in light intensity and provide real-time analog inputs to the Arduino. Based on the differential light intensity, the controller generates Pulse Width Modulation (PWM) signals to adjust the angular position of the solar panel along the east-west axis.Experimental results demonstrate that the tracking system improves solar energy capture by approximately 25–40% compared to a stationary panel under similar environmental conditions. The system is cost-effective, energy-efficient, and suitable for small-scale renewable energy applications. The proposed model validates the effectiveness of embedded systems in renewable energy optimization and provides a scalable solution for future solar power installations.

Keywords : Single-Axis Solar Tracker, Arduino Uno, Light Dependent Resistor (LDR), Servo Motor, Renewable Energy, Photovoltaic Efficiency, Embedded Systems, PWM Control, Solar Energy Optimization.

I.INTRODUCTION

The rapid growth in global energy demand, combined with environmental concerns and the depletion of fossil fuel resources, has made renewable energy sources increasingly important. Among all renewable resources, solar energy stands out as one of the most abundant, clean, and sustainable sources available. However, despite its advantages, the efficiency of conventional solar power systems remains limited due to the stationary positioning of photovoltaic (PV) panels. Fixed solar panels are typically installed at a specific tilt angle, which may be optimized for average sunlight conditions but cannot continuously adapt to the sun's movement throughout the day. As the Earth rotates, the sun's apparent position changes from east to west, causing variations in the angle at which sunlight strikes the panel surface. When sunlight does not fall perpendicular to the panel, energy absorption decreases significantly, resulting in lower power output. To overcome this limitation, solar tracking systems have been introduced. These systems dynamically adjust the orientation of the solar panel to follow the sun's path, thereby maximizing energy capture. This article on designing and experimentally evaluating an automated tracking system that improves solar energy efficiency using simple and cost-effective embedded system components.

The proposed system is based on a single-axis tracking mechanism, which rotates the solar panel along one axis—typically the east-west direction. Compared to dual-axis tracking systems, single-axis systems are simpler, more economical, and consume less power while still providing significant improvements in energy generation. The core of the system is the Arduino Uno microcontroller, which acts as the central control unit. Two Light Dependent Resistors (LDRs) are used as light sensors to detect variations in sunlight intensity. These sensors are strategically placed on either side of a small vertical divider mounted on the solar panel. When the panel is not aligned with the sun, one LDR receives more light than the other, creating a measurable difference in voltage output. The Arduino reads these analog voltage values, compares them, and determines the direction in which the panel must move. A servo motor is then controlled using Pulse Width Modulation (PWM) signals to rotate the panel accordingly. This continuous feedback mechanism ensures that the solar panel remains aligned with the maximum light source throughout the day. The embedded programming logic is carefully designed to include threshold values to avoid unnecessary oscillations caused by minor fluctuations in light intensity.

The experimental implementation of this single-axis solar tracking system aims not only to design the hardware but also to analyze its performance in practical conditions. During testing, the system's output is compared with that of a stationary solar panel under identical lighting conditions. Parameters such as voltage output, current output, and overall power generation are measured and recorded. The results demonstrate that the tracking system significantly increases energy harvesting efficiency, typically improving output by 25% to 40% depending on sunlight conditions. Additionally, the power consumed by the servo motor is minimal compared to the additional energy gained, making the system energy-efficient. The project highlights how embedded systems and automation can be effectively integrated into renewable energy solutions. By using affordable components such as Arduino, LDR sensors, and a servo motor, the system provides a practical and scalable approach for enhancing solar power installations. This research contributes to sustainable energy development and serves as a foundation for future improvements such as dual-axis tracking, IoT-based monitoring, and intelligent weather-adaptive mechanisms.

II.LITERATURE REVIEW

1. Solar Tracking Systems for Enhanced Photovoltaic Efficiency

Several researchers have emphasized the importance of solar tracking systems in improving photovoltaic (PV) panel efficiency. Studies show that fixed solar panels lose a significant portion of potential energy because they cannot maintain perpendicular alignment with the sun throughout the day. Research conducted on single-axis and dual-axis tracking mechanisms indicates that solar tracking systems can increase energy output by 20% to 45% compared to stationary panels. Single-axis trackers follow the sun's movement from east to west, while dual-axis trackers also adjust for seasonal altitude variations. Although dual-axis systems provide higher precision, they are more complex and costly. Many researchers conclude that single-axis trackers offer an optimal balance between cost, efficiency, and mechanical simplicity, making them suitable for small and medium-scale solar installations. These findings support the implementation of a single-axis solar tracking system using Arduino for cost-effective renewable energy enhancement.

2. Arduino-Based Solar Tracking Mechanisms

Embedded systems have become widely used in renewable energy automation. Several studies have explored the use of microcontrollers such as Arduino for controlling solar tracking systems. Arduino Uno, based on the ATmega328P microcontroller, provides analog input capability, PWM output, and ease of programming, making it ideal for sensor-based automation projects. Researchers have implemented Arduino-controlled tracking systems using light sensors, stepper motors, and servo motors to dynamically adjust panel orientation. Experimental evaluations demonstrate that Arduino-based trackers provide reliable real-time response with minimal power consumption. Additionally, the open-source nature of Arduino reduces system cost and allows flexibility in programming. These studies validate the selection of Arduino Uno as the controller for implementing a single-axis solar tracking system.

3. Light Dependent Resistor (LDR) Based Tracking Systems

Light Dependent Resistors (LDRs) are commonly used in solar tracking systems due to their low cost and simple working principle. Previous research shows that LDR sensors change resistance according to light intensity, allowing the system to detect directional differences in sunlight. Many solar tracking designs use two or four LDR sensors separated by a divider to create a shadow effect, enabling accurate detection of sun position. Studies reveal that LDR-based trackers are suitable for small-scale and experimental setups because of their simplicity and affordability. However, researchers also note that LDR performance can be influenced by temperature and weather conditions. Despite these limitations, LDR-based solar trackers remain widely accepted for educational and prototype-level applications due to their ease of implementation and satisfactory performance.

4. Servo Motor Control in Solar Tracking Applications

Motor selection plays a crucial role in the efficiency and stability of solar tracking systems. Research comparing DC motors, stepper motors, and servo motors suggests that servo motors provide better positional accuracy and require simpler control mechanisms for small-scale systems. Servo motors operate using Pulse Width Modulation (PWM) signals, allowing precise angular movement between 0° and 180°. Several experimental studies confirm that servo motors consume relatively low power and provide adequate torque for lightweight solar panels. Their closed-loop feedback mechanism ensures accurate positioning without complex control circuitry.

For single-axis trackers designed for prototype models, servo motors have been identified as a cost-effective and efficient solution, which aligns with the implementation approach used in this project.

5. Comparative Analysis of Fixed and Tracking Solar Systems

Various research works have conducted comparative analyses between fixed solar panels and tracking solar systems. Experimental results consistently indicate that tracking systems outperform stationary panels in terms of energy generation, especially during early morning and late afternoon hours. Studies report that single-axis trackers can improve efficiency by 25% to 40%, depending on geographic location and environmental conditions. Although tracking systems introduce additional mechanical components and maintenance requirements, the increase in energy output often compensates for these factors. Researchers conclude that solar tracking technology is particularly beneficial in regions with high solar irradiance. These findings strongly support the experimental analysis and implementation of a single-axis solar tracking system using Arduino as an effective solution for improving renewable energy harvesting efficiency.

III.WORKING METHODOLOGY

The working methodology of the project titled Experimental Analysis and Implementation of a Single Axis Solar Tracking System Using Arduino is based on real-time light intensity comparison and automated panel positioning using an embedded control system. The system operates through three major stages: sensing, processing, and actuation. In the sensing stage, two Light Dependent Resistors (LDRs) are mounted on opposite sides of the solar panel with a small vertical divider placed between them. This divider creates a shadow effect when the panel is not aligned with the sun. Each LDR is connected in a voltage divider configuration, converting variations in light intensity into corresponding voltage levels. These analog voltage signals are fed into the analog input pins (A0 and A1) of the Arduino Uno microcontroller. The Arduino continuously reads the sensor values using its built-in Analog-to-Digital Converter (ADC), which converts the analog signals into digital data for processing.

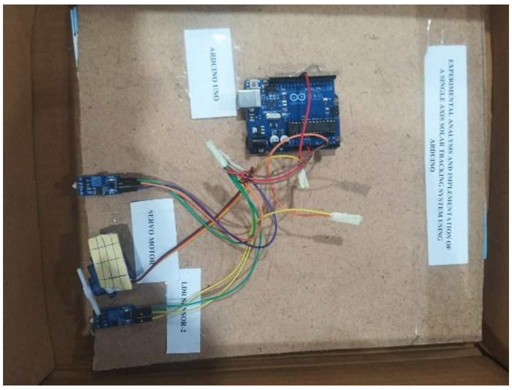

fig 1: Hardware implementation

In the processing stage, the Arduino compares the voltage values obtained from both LDRs. The controller calculates the difference between the left and right sensor readings to determine the direction of maximum light intensity as fig 1. A predefined threshold value is programmed to avoid unnecessary small movements caused by minor fluctuations in sunlight. If the difference exceeds the threshold, the Arduino generates a Pulse Width Modulation (PWM) signal to control the servo motor. The logic implemented in the program ensures that the servo rotates either clockwise or counterclockwise depending on which LDR receives more light. This continuous feedback mechanism enables automatic adjustment of the panel's position throughout the day.

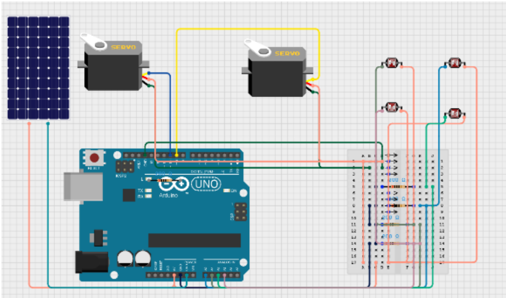

Fig 2: interfacing diagram

In the actuation stage, the servo motor physically rotates the solar panel along a single axis (east-west direction) within a 0° to 180° range as fig 2. The servo motor operates based on PWM signals provided by the Arduino through a designated digital pin. As the servo rotates, the panel orientation changes until both LDR sensors receive nearly equal light intensity, indicating proper alignment with the sun. Once balanced, the motor stops moving, conserving power. The system continuously monitors light intensity and repeats this cycle to maintain optimal positioning. Experimental analysis involves comparing the voltage and current output of the tracking panel with a stationary panel under identical conditions. The results confirm improved efficiency and enhanced energy harvesting using the single-axis solar tracking mechanism.

IV.CONCLUSION

Experimental Analysis and Implementation of a Single Axis Solar Tracking System Using Arduino" successfully demonstrates the design, development, and performance evaluation of an automated solar tracking mechanism aimed at enhancing photovoltaic (PV) panel efficiency. The study addressed the primary limitation of conventional fixed solar panels, which experience reduced energy output due to the changing position of the sun throughout the day. By implementing a single-axis tracking system, the solar panel was dynamically aligned with the direction of maximum sunlight, thereby improving energy absorption and overall system performance.The developed system utilized an Arduino Uno microcontroller as the central control unit, along with Light Dependent Resistors (LDRs) for real-time light intensity sensing and a servo motor for precise panel positioning. The embedded control algorithm compared sensor values and generated Pulse Width Modulation (PWM) signals to adjust the panel orientation along the east-west axis. A threshold-based logic was incorporated to prevent unnecessary oscillations caused by minor variations in light intensity, ensuring stable and energy-efficient operation. The experimental results confirmed that the tracking system significantly increased power output compared to a stationary panel under similar environmental conditions.Performance analysis revealed that the single-axis tracking mechanism improved solar energy capture by approximately **25% to 40%**, depending on sunlight intensity and time of day. The additional energy gained outweighed the minimal power consumption of the servo motor, making the system energy-efficient and practically viable. Moreover, the use of affordable and easily available components such as Arduino, LDR sensors, and a servo motor makes the system cost-effective and suitable for small-scale and educational renewable energy applications.

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