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An Improved Dual Axis Controller for Photovoltaic Cells

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Abstract: *In this paper, we propose a simple and novel approach to the design of a dual axis controller for photovoltaic (PV) cells. The objective is to reduce the electronic circuitry associated with previous and existing designs while at the same time ensuring a robust principle of operation. Two pairs of Light Dependent Resistors (LDR), an ATMEGA 328P microcontroller and a servomotor form the principal components of the circuit model. The model works by performing averages of the signals generated from four (4) LDR's placed at the four corners of a photovoltaic cell. Based on the computed averages, the microcontroller relays instructions to servo motors for rotation of the PV cells towards the direction of maximum incident sun rays. All simulations were performed using the PROTEUS software. Results obtained show a 54.71% increase in the generated output power for the tracking system as opposed to the fixed solar panel. The design was successfully constructed and implemented.*

Keywords: *Photovoltaic, Proteus, Light Dependent Resistors, Controller*

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I. INTRODUCTION

Despite the unlimited availability of the solar energy, harnessing it optimally presents a challenge because of the stationary nature of photovoltaic cells. A stationary solar panel does not consistently output its maximum permissible amount of power, hence, the need for a solar panel that automatically adjusts itself to the direction of maximum irradiance. The quest to bring a solution to this problem brought about the emergence of controllers for photovoltaic cells that provides a tracking mechanism for the direction of maximum solar radiation throughout the day. The system ensures that the solar panel is properly aligned to the direction of sun light. There are two major types of solar trackers - dual axis and single axis trackers. The single axis trackers have one degree of freedom and track the sun from east to west. Dual axis trackers have two degrees of freedom which provides an additional benefit of following the elevation of the sun.

To achieve a high degree of tracking accuracy, several approaches have been widely investigated. The various approaches can be broadly classified as either open-loop tracking types based on solar movement mathematical models or closed-loop tracking types using sensor-based feedback controllers [6, 9]. In the open-loop tracking approach, the azimuth and the elevation angles of the sun is determined from the solar movement models or algorithms at the given date, time and geographical information [1, 9]. Active sensor devices, such as charge couple devices (CCDs) or light dependent resistors (LDRs) are utilized in the closed-loop tracking approach to sense the sun's position. A feedback error signal is then generated to the control system to continuously receive the maximum solar radiation on the PV panel [2, 8].

Myriads of the research conducted so far on the dual-axis solar tracking systems often involve complex electronic design circuitry. See: [3 - 5, 7, 10]. In some cases, where more than one stepper motor was used, both motors could not move at the same time [2]. In this work, we propose a cost effective means of eliminating these problems by implementing a simple, efficient and robust control scheme. The two axes of the solar tracker were designed to move independently within their respective ranges.

II. DEVELOPED CLOSED LOOP SOLAR TRACKING

The model consists of two compartments; the upper part operates on the horizontal axis while the lower part operates on the vertical axis. Since the mechanism is to operate independently on both axes, two servomotors were used for controlling the movement on both axes respectively. The design also includes four (4) light dependent resistors which serve as the solar sensors, the analogue-to-digital converter (ADC) embedded on an Arduino UNO board, the Atmega328p microcontroller chip, a small PV module and a DC battery as the power supply source. In the tracking operation, the four LDR sensor measures the sunlight intensity as a reference input signal. The output voltage of the LDRs varies in inverse proportion to the intensity of the radiation. These voltages are fed to the analog-to-digital converter (ADC). The ADC converts the analog voltages to digital signals and sends the signals to the microcontroller. The microcontroller performs the necessary arithmetic and logic operations based on the data it received and then issues control commands to the servomotors which then rotate to adjust the position of the solar module in accordance with the commands issued by the microcontroller.

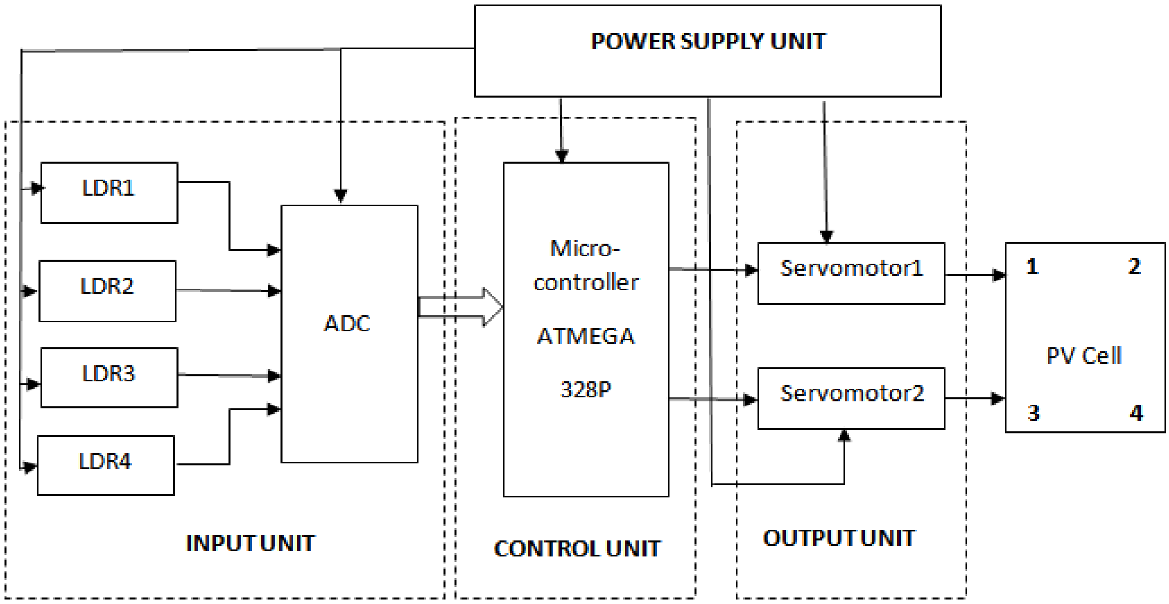

Figure 1: Block diagram of a solar tracking system

2.1 The Power Supply Unit

This unit performs the function of providing the direct current (DC) input power needed by the entire circuit. This was realized using a 9V DC battery and the LM7805 voltage regulator integrated circuit.

2.2 The Input Unit

This unit is responsible for sensing the solar radiation and converting it into a form which the microcontroller can process in order to initiate control actions. It comprises four LDRs mounted on the four corners of the solar module and the analog-to-digital converter (ADC). Each LDR is connected in series with a 100k resistor in a voltage divider fashion. The voltage that appears across each resistor is proportional to the amount of light falling on the corresponding LDR. These voltages are then fed into the ADC.

2.3 The Control Unit

This unit comprises the Atmega328P microcontroller. It does the main work of controlling the alignment of the PV module by issuing control commands to the servomotor which then rotates the module relative to the position of the sun. The microcontroller is responsible for collecting and processing the input signals from the LDRs which have been converted from analog to digital signals. As soon as the microcontroller receives the digital signals from the ADC, it then proceeds to compute the averages of the corresponding voltages of the LDR pairs as shown in equations 1- 4. After computing the averages, the microcontroller now compares the averages so as to determine what control signal to send to the servomotors. For instance, if the average of the top left & top right is greater than that of the bottom left & bottom right, the microcontroller sends a signal to the vertical servomotor to move the PV module northward and so on. The average method which the microcontroller employs is illustrated below.

$$\text{Average value of top of PV cell (Avg12)} = \frac{\text{LDR 1}+\text{LDR 2}}{2} \quad \text{-- -- -- -- --- -- -- -- -- -- -- --} \; 1$$

$$\text{Average value of bottom of PV cell (Avg34)} = \frac{\text{LDR 3}+\text{LDR 4}}{2} \quad \text{-- -- -- ---- -- -- -- -- -- -- -- -} \; 2$$

$$\text{Average value of left of PV cell (Avg13)} = \frac{\text{LDR 1}+\text{LDR 3}}{2} \quad \text{-- -- -- -- -- - -- -- -- -- -- -- -} \; 3$$

$$\text{Average value of right of PV cell (Avg24)} = \frac{\text{LDR 2}+\text{LDR 4}}{2} \quad \text{-- -- -- -- -- -- -- -- -- --- -- -} \; 4$$

2.4 The Output Unit

This unit comprise of the servomotors. The servomotors are the main components through which the microcontroller controls the photovoltaic module. Two servomotors are used in the construction of this system, with one providing movement in the vertical plane and the other providing movement in the horizontal plane. The servomotors move the PV module in accordance with control commands issued to them by the microcontroller.

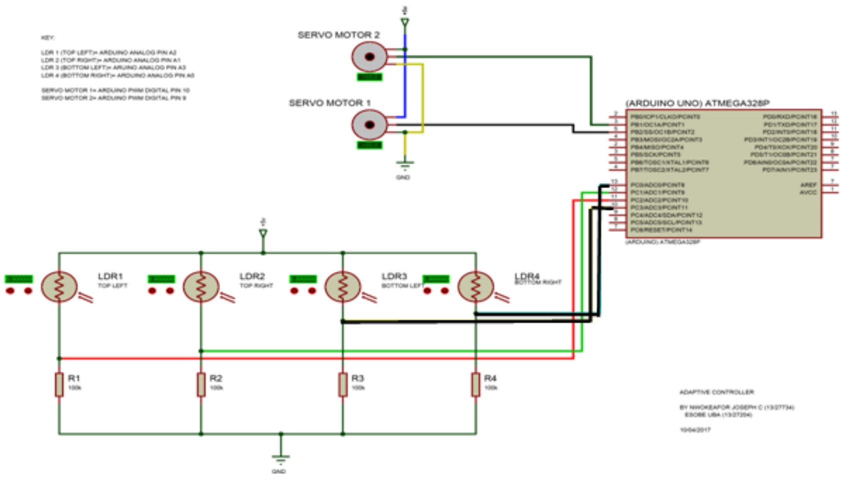

Figure 2: Circuit diagram of a dual axis solar tracker

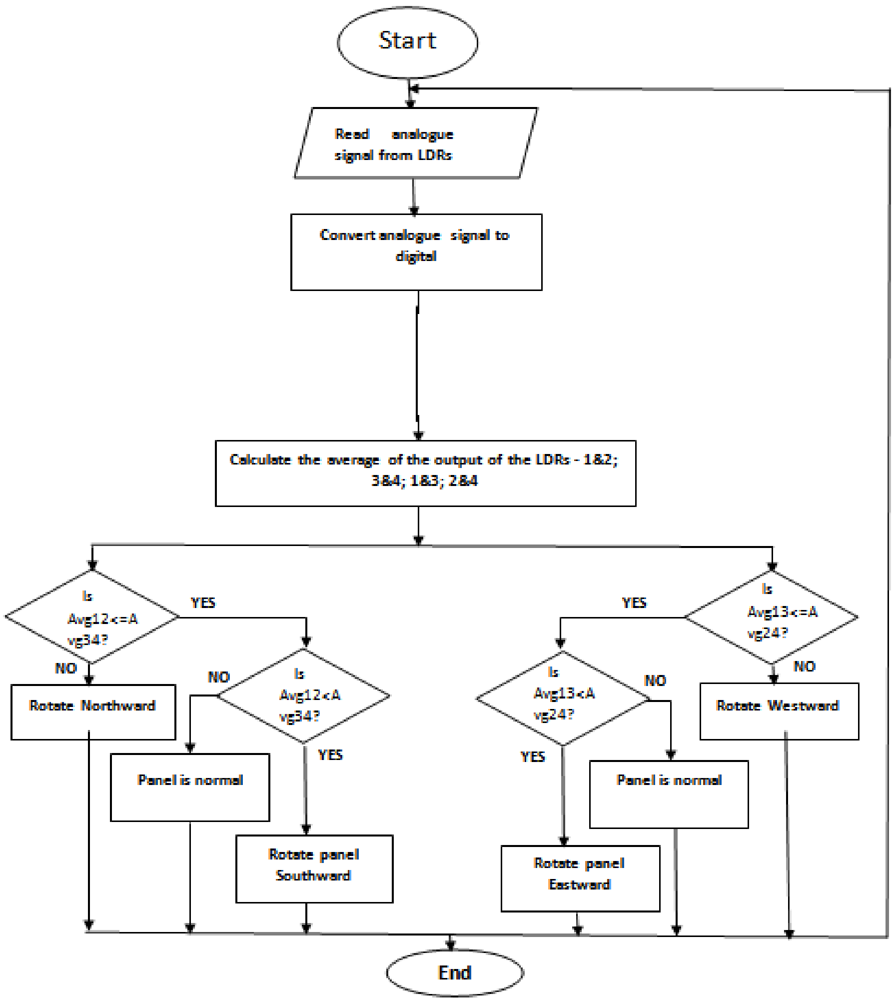

Figure 3: Flow chart of a dual axis solar tracker

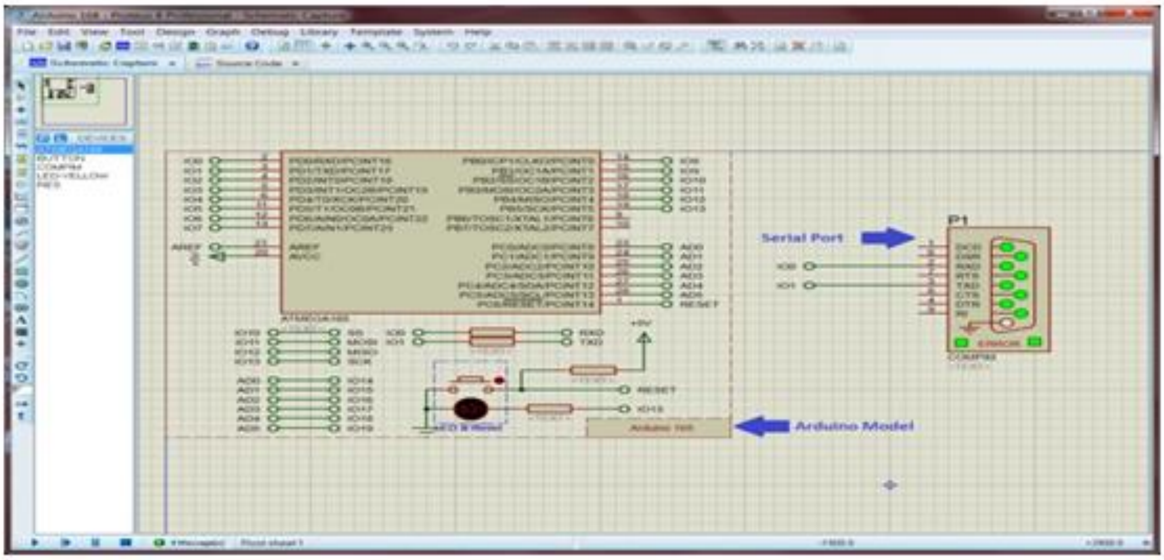

Plate 1: Dual axis controller design in proteus environment

III. EXPERIMENT VALIDATION

Plate 2 shows the experiment tests on the polycrystalline PV panel with the Sun tracker and with a fixed angle. The physical dimensions of the PV panel 19.6 x 10.5cm giving an area of 0.02058m^2. Two servo motors were used to provide two degrees of freedom to move the panel in the azimuth angle and the altitude angle simultaneously.

Plate 2: Constructed dual axis solar tracker

IV. RESULTS

The mean value for the four LDR outputs were obtained and recorded in 1-hour intervals from 06:30 a.m to 18:30 p.m for four days using a digital multimeter. The average values for the four days were recorded and tabulated as shown below:

The solar irradiation is estimated using a 3W solar panel by measuring the output voltages and currents for the fixed-panel system as well as the tracking system. The dimensions of the panel are: 19.6 x 10.5cm giving an area of 0.02058m^2 and the irradiation is obtained using the relation:

$$P = \frac{VI}{0.02058}\ (w/m^2) \text{ -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- } 5$$

Table 1: LDR outputs for the tracking system and the fixed-panel system

Time(hrs)	Fixed panel (volts)	Tracking panel (volts)
06:30	0.484	1.482
07:30	0.627	2.822
08:30	1.826	3.021
09:30	2.183	3.990
10:30	2.824	4.130
11:30	3.006	4.545
12:30	4.985	4.990
13:30	4.904	4.988
14:30	4.015	4.981
15:30	3.946	4.917
16:30	3.080	4.832
17:30	2.039	3.952
18:30	1.300	2.762

Table 2: Irradiation values for the fixed-panel and tracking systems

Time(hrs)	Irradiation for fixed panel (w/m^2)	Irradiation for the tracking system (w/m^2)
06:30	11.005	38.011
07:30	25.565	68.031
08:30	43.561	116.637
09:30	61.009	137.098
10:30	89.936	139.496
11:30	112.587	140.625
12:30	142.526	145.025
13:30	140.002	145.022
14:30	131.236	142.257
15:30	90.113	140.639
16:30	55.205	130.931
17:30	24.005	68.053
18:30	12.982	42.026

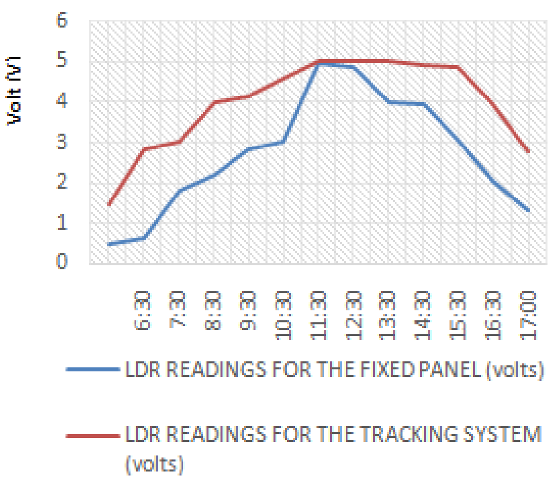

Figure 4: Plot of output voltages against time

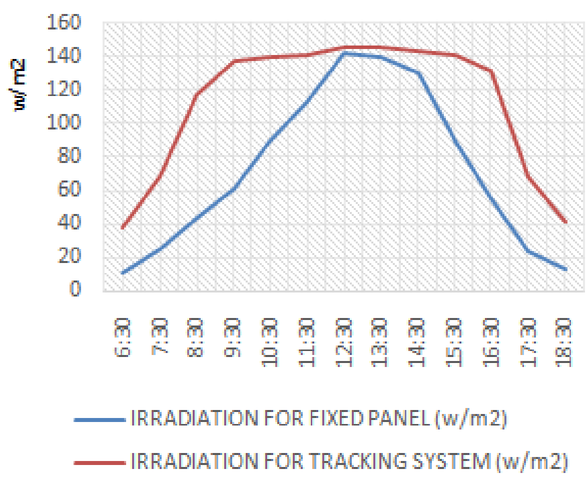

Figure 5: Plot of solar irradiation against time.

The combined plot of the solar irradiation and the LDR output voltages against time for the fixed-panel system as well as the tracking system can be obtained by referring the values of the LDR output voltages to a base of 145.7725948w/m^2, which is the maximum obtainable value for solar irradiation. The referred values are obtained using the relation:

$$Referred\ LDR\ reading = \frac{LDR\ reading}{5} * 145.7725948\ \text{w/m}^2 \quad \text{-- -- -- -- -- -- -- --}\ 6$$

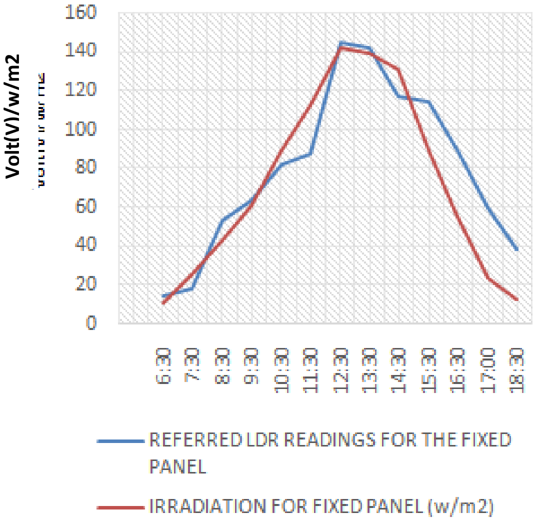

Figure 6: Plot of irradiation and LDR output voltage against time for the fixed-panel system

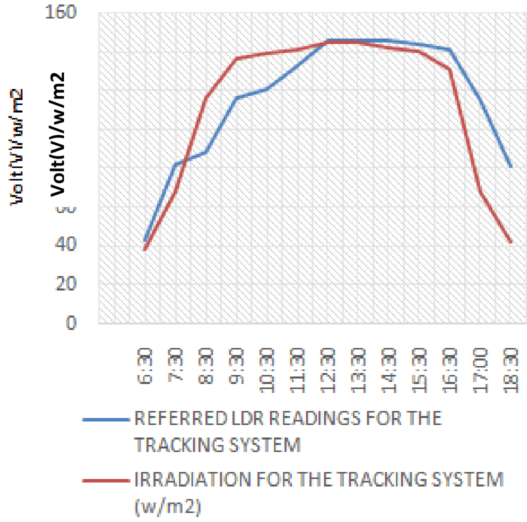

Figure 7: Plot of irradiation and LDR output voltage against time for the tracking system

V. DISCUSSION

Figures 4 and 5 show that there was no significant difference between the output of the fixed and tracking system panels between 11:30 am to 12:30 pm. It can be deduced that between 11:30 am to 12:30 pm, both of the PV panels were aligned in the same direction but with a slight difference of angle. Figures 4 and 5 also show that there was a significant difference in the generated output power in both systems (fixed and tracking panels) at other times in the day. From table 2, the total irradiance of the fixed panel was 939.732 w/m^2. This gives a total output power of 939.732 x 0.02058 = 19.3394 watts. Similarly, for the tracking system, the total output power was 1453.851 x 0.02058 = 29.9203 watts. This implies that the tracking system produces an extra 10.5809 watts over an averaged four day period.

VI. CONCLUSION

In conclusion, we have presented a simple, cost effective and robust design of a dual axis controller for photovoltaic cells. The solar tracking problem of how to cause the PV panel to follow the sunlight location as closely as possible was successfully tested and implemented.

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