SOLAR PHOTO-VOLTAIC SYSTEM EFFICIENCY IMPROVEMENT USING UNITARY-AXIS ACTIVE TRACKING SYSTEM

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Abstract — Low solar-electrical energy output conversion efficiency is a major limitation in the use of solar photovoltaic (PV) systems for power generation. This work aims at determining the degree of effectiveness of a unitary axis solar active tracker. In this work, a unitary axis solar active tracking system by which more energy from the sun can be harnessed was designed and setup. An arduino Uno (Atmega 328p) which is an Atmel microcontroller based board, was used as the main controlling unit to control the operations in the system. Two Light Dependable Resistors (LDRs) were also included in the set-up as photo sensors. The sensor and motor were properly interfaced with the arduino board and stepper motor was mechanically coupled with the PV panel to orient it towards the direction of the sun at all time. The driving program was written using the Arduino IDE. The whole tracking system was designed, implemented and experimentally tested. The test result showed that there was an increase of about 18 % and 22 % in the efficiencies of the solar panel by the tracker on both cloudy and sunny days respectively. It was therefore concluded that a photovoltaic system can perform more efficiently when it is equipped with a tracking system than when it is stationary.

Keywords: Arduino uno, Efficiency, Micro-controller Photovoltaic panel and Unitary axis solar tracker

1. INTRODUCTION

Fossil fuel exhaustion is one of the major challenges that the world is facing in the power generation and this is because the demand for electrical energy increases globally on a daily basis. This energy source will soon run out if continuously used by users because of the problems and matters related. Beside this, it is also evident that fossil fuels are mutilating the climate which is highly unsustainable [1].

Alternative measure to this problem is the harnessing of renewable energy sources like sun, wind, biomass etc for power generation but their intermittent nature is a disadvantage when considered as a solution [2]. However, with the recent developments, solar energy systems are easily and abundantly available for use serving both industrial and domestic purposes. Solar energy systems also requires minimum maintenance which is an additional benefit to the use of solar systems.

Solar PV system has two main challenges which are low energy conversion efficiency which is the most important property in PV domain [3] and the dependence of its output power on the intermittent weather. However, its efficiency can be improved by increasing the efficiency of the solar cell used, by maximizing the power output using any maximum power point tracking (MPPT) approach or by the use of a tracking system. The solar cells are made of silicon which can be monocrystalline, polycrystalline or amorphous (thin film) type. Improving the energy conversion efficiency energy conversion efficiency of a solar system using new material or new manufacturing process of solar cell seems to have approached its limit, around 15 - 19 % [4].

Solar tracking systems are mechanized to constantly track the exact position of the sun irrespective of the time of the day to increase power output of the solar panel and it was concluded from evaluation that energy extracted from solar panels can be enhanced by 20 to 30 % by using a tracking system compared to a fixed type [5]. Due to direct exposure to sunlight, the solar tracking type produces higher energy than the stationary type and the excess generation value depends on the geographical location and maximum temperature values of the solar tracking system [6]. It is a more cost effective solution to meet higher demand than purchase of more solar panels. The level of the improvement in the efficiency depends on the efficiency of the tracking system and the weather. There will be higher increase in the efficiency in places where there is sunny weather and thus consequently favorable for the tracking system [7].

[8] investigated the efficiency of PV system using maximum power point tracking (MPPT) in two different modes: on grid and off-grid and the results showed improvement in the outputs (current, voltage and power) of the PV cells. [9] in their work compared the efficiencies of unitary-axis tracking system and dual-axis tracking system with stationary solar panel and concluded that both unitary-axis and dual-axis are more efficient in terms of the electrical energy output than the stationary type. [5] developed a prototype for a dual axis tracker for a 10W panel. The tracking panel performed better the standstill type by a margin of 26% on a sunny day and 21% even on a cloudy day and this evidently showed the importance of a tracking system.

This work aims at determining the degree of effectiveness of a unitary axis solar active tracking system by designing and testing the PV tracking system experimentally.

2. MATERIALS AND METHOD

This section describes the approach to the design of the solar PV system with the incorporation of a tracker. The block diagram of the tracking system showing the various components involved is shown in Figure 1. The circuit of the designed system is of three stages:

- The input stage – This is composed of sensors;
- The control stage – Which contains a program that is embedded in a microcontroller; and
- The driving circuit stage - This has the stepper motor.

At the input stage is a voltage divider circuit which consists of two Light Dependent Resistors (LDRs).

2.1 The Input Stage (The LDRs' Concept)

The two light dependent resistors used in this design are for light sensing and a static position is achieved when the intensity of light received by the light dependent resistors are equal. When the light source moves (when the sun moves from east to west), the level of the intensity of light falling on the two LDRs changes which is calibrated into voltage using voltage dividers. The changes in voltage are compared using built-in comparator of microcontroller and the solar panel is rotated by a motor in such a way that it tracks the light source always.

2.2 Micro-controller

The microcontroller selected for this work is Atmega 328p. Atmega 328p was a good choice for this work because of its wide temperature range and low power consumption. An Arduino C-program was written and loaded into the microcontroller to form the embedded software. The microcontroller requires 1.8 - 5.5 v DC power to operate. This approach, similar to stepwise refinement in modular programming, was employed as it ensures an accurate and logical approach which is direct and easy to understand. Also, this ensures that errors are considered and corrected in case there is any.

2.3 Stepper Motor

The variable reluctance type of stepper motor was used for this work because of its excellent angular resolution. An analog Light Dependable Resistor (LDR) is the photo sensor used for interfacing because it is suitable, inexpensive and simple and is the most common in electronics.

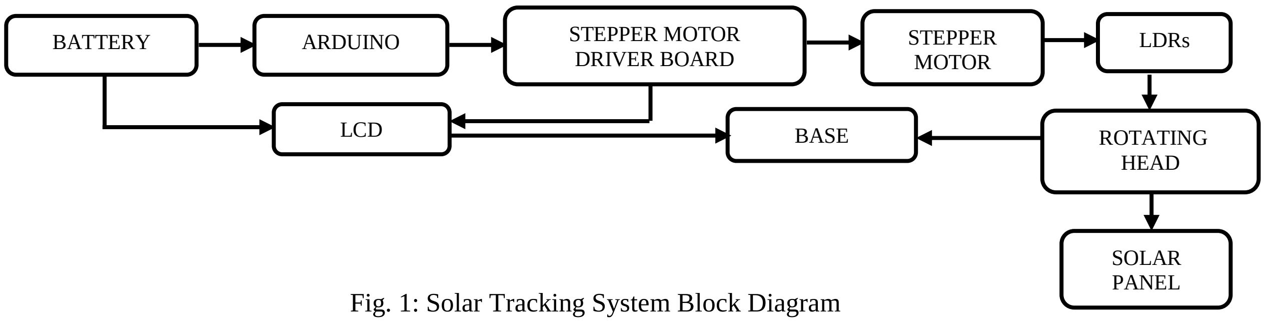

Fig. 1: Solar Tracking System Block Diagram

The solar tracking system designed in this experiment uses two photocells which are made of Cadmium Sulfide (CdS) for sensing the light. These photocells are passive components whose resistances are inversely proportional to the light intensity level directed towards it. It is connected in series with a resistor of 10 kΩ.

The photocell was used in the tracking system due to its outstanding properties of dark resistance and light saturation resistance. Light saturation implies the property of the cell at a point that further increase in the light intensity to the Cadmium Sulphide cells will not have any effect on its resistance any further. The resistance of LDR is very high but decreases drastically with illumination of light.

The output readings were taken on the Liquid Crystal Display (LCD). All the components were assembled together in a wooden frame. The three stages (input, control and output) involved were designed independently before being assembled into one system.

The complete experimental set-up of the solar tracking system is shown in Figure 2 while the flowchart showing the operation of the complete tracking system is shown in Figure 3.

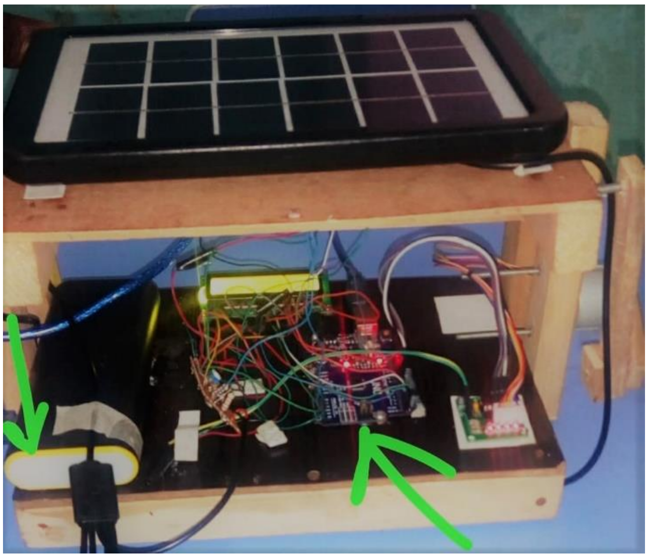

Fig. 2: The Complete Set-up of the System

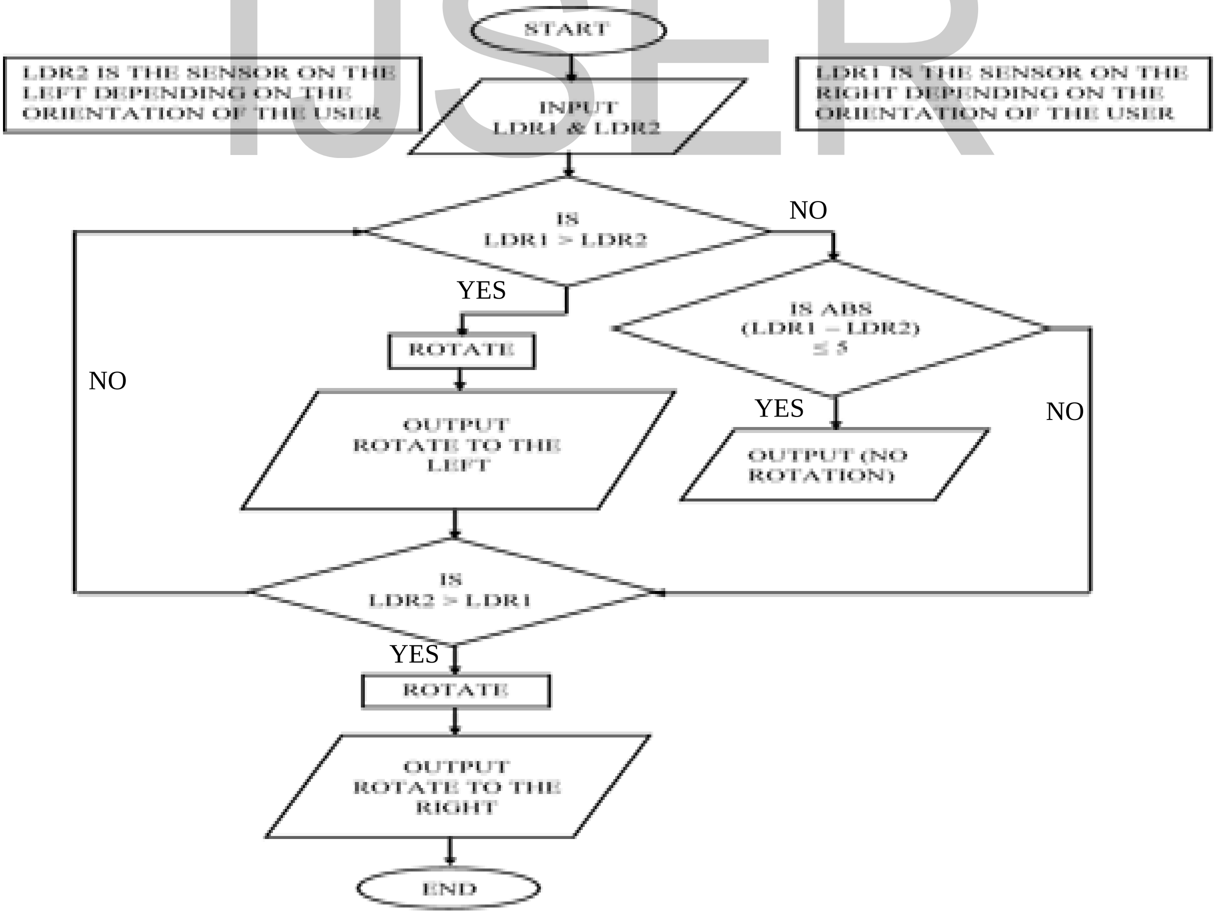

Fig. 3: The Flowchart of the Solar Tracking System

The efficiency of the solar PV system was calculated using equation 1.

$$\eta = \frac{1}{n}\sum_{t=1}^{n}\frac{V_{out}(t)}{V_{rated}} \times 100\% \qquad (1)$$

And the change in the efficiency by the solar tracker was calculated using equation 2.

$$\eta_{inc} = \frac{1}{n}\sum_{t=1}^{n}\frac{V_{out,T}(t) - V_{out,F}(t)}{V_{rated}} \times 100\% \qquad (2)$$

where,

η - the solar panel efficiency

$\eta_{inc.}$ - the change in the efficiency of the solar panel due to solar tracker

$V_{out,T}(t)$ - the solar panel output voltage when tracking at time t

$V_{out,F}(t)$ - the solar panel output voltage when in fixed position at time t

V_{rated} - the solar panel rated voltage

n - the number of times the readings were taken

The solar panel output voltage at any time can be given as equation 3.

$$V_{out} = \frac{AKT}{q} In \frac{I_{pv}}{I_o}; I_{pv} \succ I_o \qquad (3)$$

where,

V_{out} is the solar panel output voltage

A is ideality factor of the diode

K is the boltzmann's constant

q is the electronic charge

I_o is the cell reverse saturation current and

I_{pv} is cell photocurrent.

The components were assembled together and constructed to function as a whole unit. This prototype construction was tested within the campus of Adeleke University Ede, Nigeria. The readings were taken for two days (cloudy and sunny days) both with and without the solar tracker and the efficiencies for the two cases were compared to ascertain the degree of effectiveness of the tracking system.

3. RESULTS

The results were gotten from the solar panel when tracking, and when it was in a stationary position. The results were tabulated and recorded for the two days. The LDRs measured the light intensity and hence, these are valid indications of the power that reach the solar panel surface. It was possible to get the difference in efficiencies between the two different positions of the panel as a result by measuring the light intensity at a given time. The readings were taken between the hours of 6am and 6pm. The results for both sunny and cloudy days are shown in Tables 1 and 2 respectively.

Table 1: Results for Day 1

(Cloudy Morning and Sunny Afternoon)

Time (hrs)	Stationary PV output (v)	Tracking PV output (v)
6:00	0.47	1.64
07:00	1.09	2.81
08:00	1.22	3.76
09:00	3.68	4.12
10:00	3.69	4.18
11:00	4.27	4.33
12:00	4.66	4.89
13:00	3.94	4.88
14:00	3.74	4.74
15:00	3.74	4.63
16:00	2.58	4.30
17:00	2.39	3.97
18:00	2.23	3.70

Table 2: Results for Day 2
(cloudy Morning and Cloudy Afternoon)

Time (hrs)	Stationary PV output (v)	Tracking PV output (v)
6:00	0.14	0.36
07:00	0.17	1.54
08:00	1.22	2.64
09:00	1.68	2.82
10:00	1.73	2.96
11:00	2.03	2.97
12:00	2.47	3.08
13:00	2.77	3.66
14:00	2.61	3.66
15:00	2.58	3.47
16:00	1.72	2.83
17:00	1.39	1.54
18:00	0.90	1.37

4. DISCUSSION

It was noted that the output of the panel was very low both in the morning and evening. This is due to low solar irradiation from the sun by that time. This could however be enhanced by using storage devices to complement the intermittent solar equipment. As expected, the output of the solar panel was high and was nearly the same at noon for both scenarios on the two days due to the high solar irradiance. This can be seen in the variations shown in Figures 4 and 5.

At 12.00 pm on sunny day, the solar panel output voltages were 4.66 v and 4.89 v for fixed and tracked positions respectively and this is the highest value for the day. But for the sunny day, the peak output of the panel occurred at 13:00 hr (i.e. 1:00 pm) which was 2.77 v and 3.66 v for fixed and tracked positions respectively. For all the hours the readings were taken on both sunny and cloudy days, the outputs of the solar panel when tracking were higher than when in fixed position and this shows that the tracker performed effectively.

During the cloudy day, the efficiency of the solar panel was increased from 32.9 % to 50.6 % which amounts to about 17.7 % increase for the cloudy day and this verifies the effectiveness of the solar tracking system. However, it is of importance to note that there were moments when the change in the power output for the tracking system in comparison with the stationary system was very minimal, especially during cloudy period. This was as expected because the intensity of sunlight was nearly the same for the two scenarios.

Similarly on the sunny day, at midday, both systems had almost the same output because the sun was perpendicularly above. As such, both systems received almost the same amount of irradiation. The efficiency of the solar panel was increased from 58 % to 79.9 % which amounts to about 21.9 % increase which characterizes the degree of the effectiveness of the solar tracking system. The difference in the efficiencies increase of the sunny day and the cloudy day justifies that the weather has significant effect on the characteristics of a solar system. Figures 4 and 5 show the graphs of the output variations for both the fixed and the tracking positions of the panel, for two days in different weather condition.

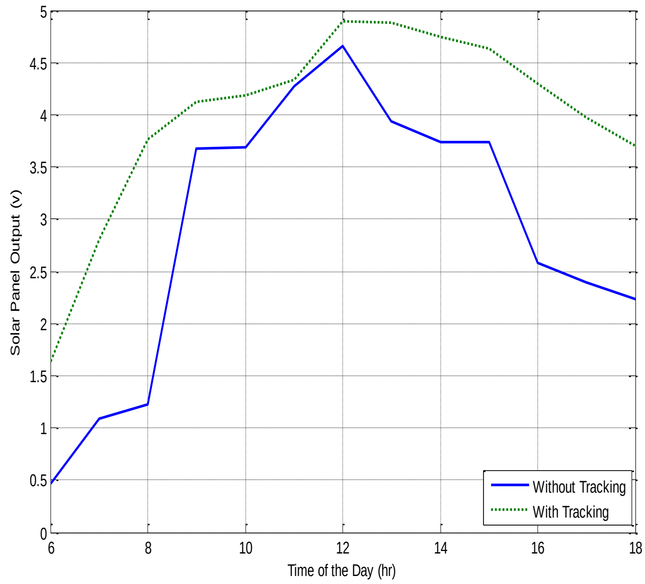

Fig. 4: Variations of Solar Panel Output with Time for Day 1

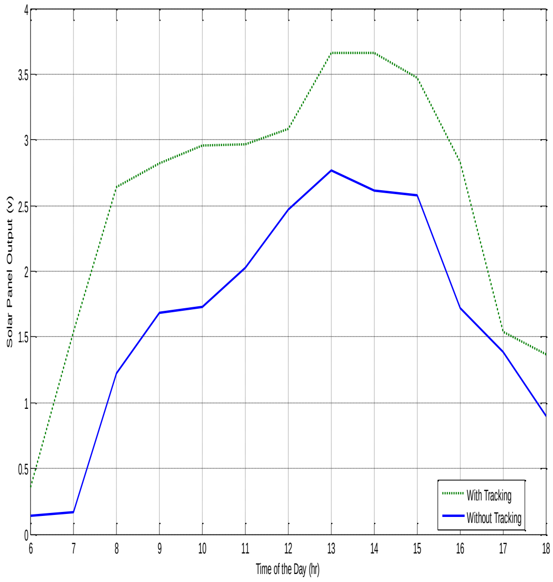

Fig. 5: Variations of Solar Panel Output with Time for Day 2

As it is evident in the two graphs, the output voltage of the solar panel during the sunny day is more stable than the cloudy day, this was because there was much sun on the sunny day which allowed maximum illumination to be obtained from the sun almost all the time. But for cloudy day, it was quite cloudy at some times. The sun was blocked by the cloud and obstructed the panel from receiving maximum radiation from the sun.

4. CONCLUSION

A payload system that tracked the sun throughout the day was designed and set-up. The required program to specify the various actions needed for the set-up to perform its function was written and encoded into the micro controller. By this, the goal of solar tracking was achieved. A unitary axis solar active tracking system was designed and successfully set-up. Though, dual axis trackers would be expected to be more efficient than other types (unitary-axis and stationary) in tracking the sun but the additional circuitry and complexity was a limitation. The reason unitary-axis tracking system was used is that Nigeria lies along the equator and hence there are no significant changes in the apparent position of the sun in the various seasons. Hence, using dual-axis tracker will jeopardize the economic value of the work. Dual trackers are most suitable in regions where there is a change in the position of the sun. This work was implemented with minimum resources possible and available. The circuitry was kept simple, and the efficiency of the solar panel was increased by almost 18 % and 22 % for both cloudy and sunny days respectively by the solar tracker. Hence, a photovoltaic panel can perform better and more efficiently with a unitary axis active solar tracker than when it is stationary.

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