



DESIGN AND IMPLEMENTATION OF AN OPTIMIZED AUTONOMOUS SINGLE-AXIS SOLAR TRACKING SYSTEM

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ABSTRACT

This work has produced a low cost, reliable and functional autonomous solar tracking system using locally sourced available components. This proposed autonomous solar tracking system was designed and developed based on time-triggered and event triggered methods by using Real-Time clock (RTC) and Light Dependent Resistor (LDR) respectively. If the LDR fails, the system uses the scheduled time interval from RTC module to rotate the solar panel. The aim of this research was to develop an autonomous single-axis solar tracking system with ATmega328 microcontroller as its controlling unit and linear actuator (motor) to move the solar panel into the desired angle. The algorithm provided the angle at which the panel would be positioned and automatically moved the linear actuator. Furthermore, a manual mode was provided to allow the user to adjust the panel angle at the preferred position. The tracking in this system was single axis, which allowed for an angle in which the panel needs to be shifted for optimal tracking. This developed single axis system was accurate with promising results. The output voltage obtained from the implemented autonomous solar tracking system varied from 20.12V to 20.49V between the hours of 0900 hours to 1600 hours, which showed that sunlight matters a lot and in order to make the best out of solar panel, there is need to have some kind of power tracking, which will always allow the solar panel to produce a maximum output power. Therefore, based on the results obtained from the implemented autonomous solar tracking system, more energy can be produced compared to the conventional fixed angle solar panels.

Keywords: Autonomous tracking solar system, Linear actuator, ATmega328 microcontroller, Light Dependent Resistor, Real-Time clock, Solar panels.

1. INTRODUCTION

There is increasing demand for electrical energy day by day. There are various forms of energy we are using in form of chemical, electrical, thermal, mechanical, etc. The most popular form of energy is the electrical energy as it is easy to transfer with maximum efficiency. Solar energy contributes power to various different gadgets and technologies. In theory, solar energy can be perceived as an ideal energy source, because it is free and virtually limitless and involves no polluting residues of greenhouse gases emission. However, the technological barriers with regards to its collection, distribution and storage are remarkable. Hence, with the increasing intensity of solar radiation reaching the earth, it is paramount that this invaluable resource be put into adequate and efficient use in various areas of life [1]. To harvest maximum solar energy, solar tracker is used which keeps the solar panel vertically inclined to the sun radiation during sun rise hours therefore more energy could be collected by minimizing the angle of incidence between the incoming sunlight and a photovoltaic panel, this therefore increases the amount of energy produced from a fixed amount of installed power generating capacity [2].

This research proposes the design and development of an autonomous solar tracking system that automatically adjusts the Photo-Voltaic (PV) panel (based on the given position of tilt times with respect to the natural position of the Sun at different times). Hence, this maximizes the amount of solar energy collected from the sun within a specific time frame. Thus, increasing the efficiency of the solar panel in providing enough energy to power electrical gadgets such as a laptop, television, etc.

2. BACKGROUND THEORY

The energy of the sun is the original source of most of the energy found on earth. We got solar heat energy from the sun, and sunlight can also be used to produce electricity from solar (Photovoltaic) cells. Sunlight contains a surprising large amount of energy, even after passing through hundreds of kilometers of air on a clear day. Solar energy is the most inexhaustible, renewable source of energy known to humanity. In order to increase the efficiency of solar energy systems, solar tracker is added at the expense of system's complexity and cost. The two basic categories of trackers are single axis and dual axis [3]. Single axis tracker has one axis of freedom, vertical or horizontal. Dual axis tracker has both a vertical and a horizontal axis of freedom, so it is able to track the position of the sun precisely.

Considering the present scenario, it is clear that conventional sources of energy such as coal, natural gas, oil, etc. gradually quenching. The conventional use of energies due to the burning of fossil fuels like coal, oil and natural gas is making the whole environment getting polluted. This research, therefore, by using components like LDR, linear actuator, solar panel, RTC module, etc. unlike the use of other conventional energies, would not emit any pollution and in turn act as a reservoir of energy taken from the Sun itself. As mentioned earlier, no other energy is more abundant than solar energy with respect to its availability and freeness.

The DC Motor along with the help of LDR fixed on the upper edge of the solar panel and by measuring the intensity of the sun rays will help the solar panel to revolve around proportionately with the movement of the Sun itself in order to grab and store the maximum amount of energy as it can. In order to pursue such objective, this research came into existence. The developed autonomous solar tracking system serves the purpose of utilizing the maximum amount of energy taken from the Sun and convert such energy into some other production. The system developed is economically convenient, user friendly, optimally functioning, an extension of solar energy, a renewable source of energy, and never-ending phenomena. In the world of pollution, this system is an eco-friendly alternative, hence a valuable asset.

Solar panels are a combination of photovoltaic cells. The PV cells are arranged in a solar panel or a PV array such that it serves the purpose of exciting the electron of the material consisting inside the solar cells using photons. The average amount of solar energy received by solar panels depends on the position of the sun. [4]. Solar energy is regarded to be the prominent and ever remaining source of renewable energy. A part of this source of renewable energy is received by the solar panel. Several applications have been developed to utilize this energy source as an alternative to other non-renewable sources [5].

A hybrid solar tracking system was presented in [6]. The name hybrid here points to the mixed tracking strategy used, open loop tracking which is based on solar movement model and closed loop tracking which feeds back a signal proportional to the generated output power measured by sensors. A low-profile solar tracking system with unique linkage geometry to minimize shadowing by the adjacent trackers was proposed in [7]. In order to minimize the installation costs of solar trackers, the system was secured to the ground using ground screws. The design consisted of two coplanar and perpendicular linear actuators coupled with a single linkage arm and pivots.

3. HARDWARE AND SOFTWARE IMPLEMENTATION

This project is classified into two modules; The hardware prototype and the software design. The hardware prototype was composed of different electronic devices and elementary materials used for the mechanical support. This autonomous solar tracking system was produced by using the basic materials such as Arduino Uno board which was used for programming Atmega328 microcontroller, linear actuator motor, two LDRs, LCD, solar panel which provides 12V as output, RTC module which was used to implement time-triggered task to complement the efforts of the LDRs, and a 12V, 9.2AH battery. The selected components are presented in Figure 1.



Figure 1: Component Selections for Autonomous Solar Tracker Design

The electronic circuit used in the prototype was also subdivided into two basic stages; The Solar input stage and the motor driving stage. In order to develop mechanical structure for proposed solar tracking, steel rod was used to create two pillars of support for the solar panel and the axis of rotation attached to the driving linear actuator motor. The solar input stage comprises of solar panel and two LDRs, each of which was joined to the solar panel along its length on either side of the panel. The LDRs (light sensors) were then connected to the motor driving circuit. The light sensors were used to measure light intensity. Then generate corresponding analog output value and feed to microcontroller's analog input port. The controlling circuit was designed with ATmega328 microcontroller, which was coded with some algorithm to compare and detect the direction of solar light intensities being maximum. The microcontroller takes the inputs from light sensors and then forwards the results, after computation to the linear actuator driving module. If either or both LDRs fail, the microcontroller uses the scheduled time interval from RTC module to rotate the solar panel.

The solar tracking controller shown in Figure 2, is responsible for the rotation of the solar panel, hence tracking the direction of the sun. This comprises of solar input stage, driving module (L293D) stage and a DC linear actuator motor. The driving module in this work was implemented for bi-directional movement of the rotational axis, which is attached to the solar panel. The motor driving circuit stage forces the linear actuator motor to cause solar panel rotation. The linear actuator motor will be in off mode when the difference in the intensity of both two LDRs received are small ($< 100\text{mv}$). This value was based on the experimental verification results and was intended to avoid oscillation.

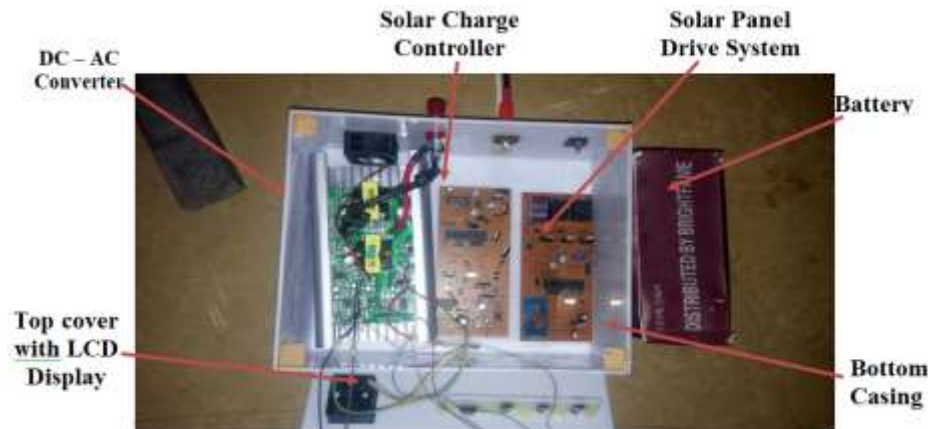


Figure 2: Implemented Autonomous Solar Tracking Controller

As shown in Figure 3, the mechanical structure employed steel rods to create two pillars of support for the solar panel. The algorithm was designed in Arduino Integrated Development Environment (IDE). The upload speed of the setup was set to 9600 and the setup was connected to COM5, Arduino Uno board with ATmega328 microcontroller onboard.

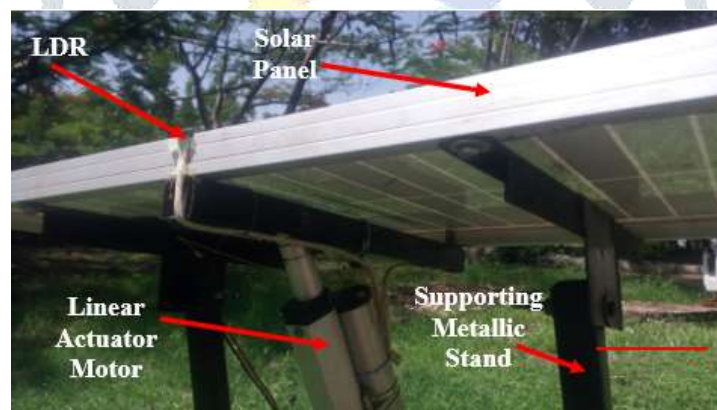


Figure 3: Solar Panel with Mechanical Support

4. RESULTS AND ANALYSIS

The complete setup of the implemented autonomous single-axis solar tracking system is shown in Figure 4. The system comprises of one Polycrystalline solar panel, two Light dependent resistors (LDR), Real time clock (RTC) module, Atmega328 microcontroller, L293D motor driver, linear actuator motor and a 12 V Battery. Depending on the solar panel employed with the tracking system, the values of the LDRs are expected to be closed because whenever they are in different positions, there is always an error generated that enables the solar panel movement. The motion of the solar panel is stopped when the values are the same, which implies that the LDRs receive the same intensity of sunlight.



Figure 4: Complete setup of Automatic Solar Tracker System

In this system, by considering 12 hours solar tracking per day, 12 positions were programmed for the solar panel to enable effective tracking of sun's coordinates. When the microcontroller reads the time from the Real Time Clock (RTC) and also compares the solar intensities from the two LDRs, signal is sent to the linear actuator driver so that the panel can be aligned properly facing the sun with certain changes of angular position after predetermined regular time interval. The positions of the solar panel are presented in Table 1.

Table 1: Angular Displacement of the Solar Panel

Position	Time (Hrs)	Angular position	Angular displacement
1	0800	+7.5°	15°
2	0900	+22.5°	15°
3	1000	+37.5°	15°
4	1100	+52.5°	15°
5	1200	+67.5°	15°
6	1300	+82.5°	15°
7	1400	+180.0°	15°
8	1500	+112.5°	15°
9	1600	+127.5°	15°
10	1700	+142.5°	15°
11	1800	+157.5°	15°
12	1900	+172.5°	15°

As illustrated in Table 1 above, by 0800 hours in the morning, the solar panel was at an angular position of +7.5° without linear displacement of the actuator shaft while the solar panel remained tilted towards the east direction. The solar panel movement started by 0900 hours with an angular position and displacement of +22.5° and 15° respectively. The solar tracking continued with an incremental position of 15° per hour till 1900 hours in the evening when the angular position of the solar panel became 172.5°. Data collected on May 3rd 2021 were used for analyzing the efficiency of the constructed autonomous solar tracking system in this research. The 13 hours' data of 3rd May 2021 is presented in Table 2 when the daily temperature was 35°C.

Table 2: Efficiency Measurements for the Solar Tracking System

Time (Hrs)	Current (A)	Voltage (V)	Power (W)	Efficiency (%)
0600	0.22	16.50	3.63	12.10
0700	0.32	17.05	5.46	18.20
0800	0.46	19.01	8.74	29.13
0900	0.91	20.12	18.31	64.37
1000	1.22	20.25	24.71	82.37
1100	1.35	20.36	27.48	91.60
1200	1.45	20.48	29.70	99.00
1300	1.46	20.49	29.92	99.72
1400	1.36	20.27	27.56	91.87
1500	1.31	20.25	26.52	88.40
1600	1.24	20.36	25.25	84.17
1700	0.88	18.32	12.60	42.00
1800	0.44	16.68	6.37	21.33

From the Table 2 above, it can be seen that the maximum sunlight was tracked nearly throughout the day with maximum values obtained between 0900 hours and 1600 hours. In the morning and late evening, intensity of sunlight diminishes and the values obtained are less than those obtained during these periods (0900 hours and 1600 hours). After sunset, the tracking system moved back to the East direction to prepare for the next day. The tracking later starts in the morning. It can be concluded that solar panels are greatly dependent on the intensity of light falling on them to produce output voltage. This showed that sunlight matters a lot and in order to make the best out of solar panel, there is need to have some kind of power tracking which will always allow the panel to produce a maximum power. Therefore, based on the results obtained from the implementation of the proposed autonomous single-axis solar tracking system, more energy can be produced compared to the conventional fixed angle solar panels. In addition to this, based on the analysis of the data presented in Table 2, it can be stated that if the RTC based (time triggered) solar tracking system is implemented and maintained properly, it could work efficiently in a country like Nigeria.

5. CONCLUSION

An autonomous single-axis solar tracking system has been proposed, designed and implemented using ATmega328 microcontroller, which combined time-triggered and event triggered tasks using Real-Time Clock (RTC) module and LDRs respectively. The tracker uses RTC to change the solar panel position based on the scheduled time interval while LDRs measure the intensity of the sun and a DC motor adjusts the position of the solar panel. The developed tracker was able to track the sun with a high degree of accuracy and increased efficiency. Autonomous solar trackers are an effective way to increase the efficiency of solar panels and make them more practical for use in a wide range of applications. Automatic solar trackers offer several advantages over traditional fixed solar panel.

By using this autonomous solar tracker, we can produce an abundant amount of energy which makes the solar panel's workability much more efficient than the conventional fixed solar trackers. The proposed method is scalable to full size system.

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