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Automated Solar Tracker Utilizing RTC Timing for Enhanced Photovoltaic Energy Generation

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Abstract

The problems of energy scarcity and global warming brought the interest of developing strategies for harnessing renewable energy resources. Solar energy is among the most promising sources of renewable energy. Solar trackers significantly improve a photovoltaic (PV) systems electricity production. In this research work, an automated solar tracker with data logger has been designed and constructed. This automatic tracking system consists of two parts: hardware and software. Hardware part includes voltage regulators; RTC timing device, LCD display, WIFI module, relay circuit and DC motors, while, the software part contained an Arduino programming codes used for tracking system and logging the measured solar PV data. The Atmega328 microcontroller contained in the Arduino board was used to receive the input analog signal from the RTC device which was converted to digital and gives the command to the DC motor to rotate the solar PV panel towards the sun direction. The tracker solar PV panel was tested, and it was found that the solar panel reached maximum power generated from the hour of 12:00 pm to 4:00 pm. A fixed PV panel of same size was also placed side by side and tested with the solar tracking system. The result from tracked PV panel shows an efficiency increase of about 33% over the non-tracking panel. These results indicated that the automatic solar tracker would be recommended for use in solar power generation because it increases the efficiency of the solar power generated, and it is cost-effective.

Keywords: *Microcontroller, RTC Timing Device, Solar Photovoltaic, Automatic solar tracking, data logger.*

Introduction

Background of the study

Given the serious energy deficiency in Nigeria, the electricity generated cannot meet the increasing demand of consumers. Mostly, the country uses non-renewable sources such as fossil fuels to generate electricity. These non-renewable energy resources are inadequate and environmentally unfriendly (Osueke, and Ezugwu, 2011). Nowadays, the majority of energy supply in the world depends on fossil resources such as oil, natural gas and coal which are the main cause of climate change and other environmental pollution (Gawusu *et al.*, 2022). The uncertainty and high price of fossil fuels motivate the development of new technologies for generating electricity from renewable sources. Renewable energy, as energy sources with the minimum environmental effects, is an efficient option for providing clean energy and reducing dependency on fossil fuels (Dias *et al.*, 2022).

Solar energy is one of the renewable sources of clean and sustainable energy that could overcome the scarcity challenges and reduce environmental pollution. Among all the renewable energy sources available, solar energy is the most adequate and abundant energy source capable of achieving global electricity supply, which has been significantly advancing in recent years (Ahmed *et al.*, 2022). The

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estimated amount of solar radiation falls on Earth in a minute can be enough to generate electricity that can meets the World's energy demands for the whole year. Many developing countries, including Nigeria, have underutilized solar energy despite their proximity to the equator. Nigeria, located approximately between 4^0N and 13^0N with landmass of about 9.24 x 10^5 km and with an annual average daily sun hours and radiation of 6.25 and 6.0 KW/m^2/day. Due to this availability of solar energy and high price of fossil sources in Nigeria, the switch from fossil energy sources to renewable ones becomes necessary for sustainable development.

Solar photovoltaic (PV) is one of the solar energy conversion technologies that converts solar radiation directly into electricity (Yau *et al.,* 2022). The performance of solar PV system is based on the amount of solar radiation received from the sun. Therefore, there is a need for mechanical equipment or a model that follows the sun, keeping the PV panel perpendicular to it to harness maximum solar radiation (Chandel & Chandel, 2022, Hafez *et al.,* 2018). In recent development of the solar PV technology, the solar tracking systems are considered as the paramount techniques for improving the performance of the solar PV panels.

An automatic solar tracker is an electromechanical system that orients a solar PV panel towards the sun's position. The use of solar trackers can increase electricity generated by solar PV system to almost 40% in some region compared with solar PV panels fixed at given angle (Mansouri *et al.,* 2018). Hence, the increase of the intensity of solar radiation is the most possible technique for improving the performance of whole solar PV system (Abdulrahman *et al.,* 2016).

The first solar tracking system was invented in 1962 and it was a single-axis solar tracker, also the first dual-axis PV tracking system was developed in 1984 by Zobgi and Laplaze.

Sumathi *et al.,* (2018) in their study, different tracking methods have been investigated within the period between 1997 and 2017, where their conclusion indicates that active solar tracking is more efficient than passive tracking technique.

Active solar trackers are categorised into two main groups depending on their axis of rotation: single-axis and dual-axis solar trackers (Saymbetov *et al.,* 2018). Both trackers increase the performance of solar PV panel (Singh *et al.,* 2018). However, a dual-axis tracker will be more expensive than a single-axis solar tracker (Al-Rousan *et al.,* 2018).

Hafez *et al.,* (2018) conducted a review on different types of solar tracking systems, which involve their physical configurations and design parameters since the first solar tracker was invented. Their finding shows that; most of the solar trackers are single-axis trackers.

(Singh *et al.,* 2018) carried out a study on automatic solar tracking systems, where they found that; solar tracking system that involves microcontrollers as processor are more economical than those that uses programmable logic controllers.

Ibrahim *et al.,* (2018) construct and tested an automatic solar tracker that consist of two main parts; electrical and mechanical parts, where the electrical part classified into three subsystems; sensing, control and actuator. The sensing device was light dependent resistors, the control part was an Arduino Uno board and the actuator was a DC motor.

This paper present solar tracking system that is directly controlled by real time clock (RTC) device, which provides real time. Based on this real time clock, the tracking device will follow the sun in the atmosphere. This system has advantage over the existing methods for solar tracking; it is not dependent to the sensor. Hence, the data of current time from the RTC device that directly sends to the microcontroller device without any data loses. An I2C protocol is used between RTC device and Microcontroller device for data communication. The main advantage of this protocol is provides quick signal transmission and working in noise environment. The tracking system comprises two basic parts: the mechanical and electrical parts. The electric part consists of light sensor/timing device as input, the microcontroller as control, and DC motor as an output. The mechanical part comprises the stand and axes of rotation.

Methodology

Materials Involved

The materials involved in this research work are listed in table 1:

Table 1: *Components Involved*

S/No.	Component Name	Component Ratings	Quantity
1	ATmega328 Microcontroller	5 Volt, 50 mAmpere	1
2	Voltage Regulators	5V, 3.3V and 1.3V	4
3	Solar PV panel	24 Volt, 2.5 Ampere	2
4	DC Motor	12 Volt, 1.0 Ampere,	1
5	Power Relay Circuit	10 Ampere ,12 Volt	2
6	LCD Display	5 Volts, 0.3 Ampere	2
7	Storage battery	Lead Acid Type, 12Volts, 1.25Amperes	1
8	Data logger	5 Volts, 0.75 Ampere	1
9	WIFI module	3.3V, 50mA	1
10	RTC timing device	1.3V, 500mA	1

Design Framework

This design was aimed to provide a system that can be used to evaluate the performance of a solar PV panel. To achieve this; a solar tracking mechanism needs to be designed and constructed with PV parameters logging facility. Two different sensors are also designed to measure voltage and current and then log the result in an SD card. Every parameter logged is time stamped for historical purpose. The block diagram of the automatic solar PV tracking system is presented in Figure 1.

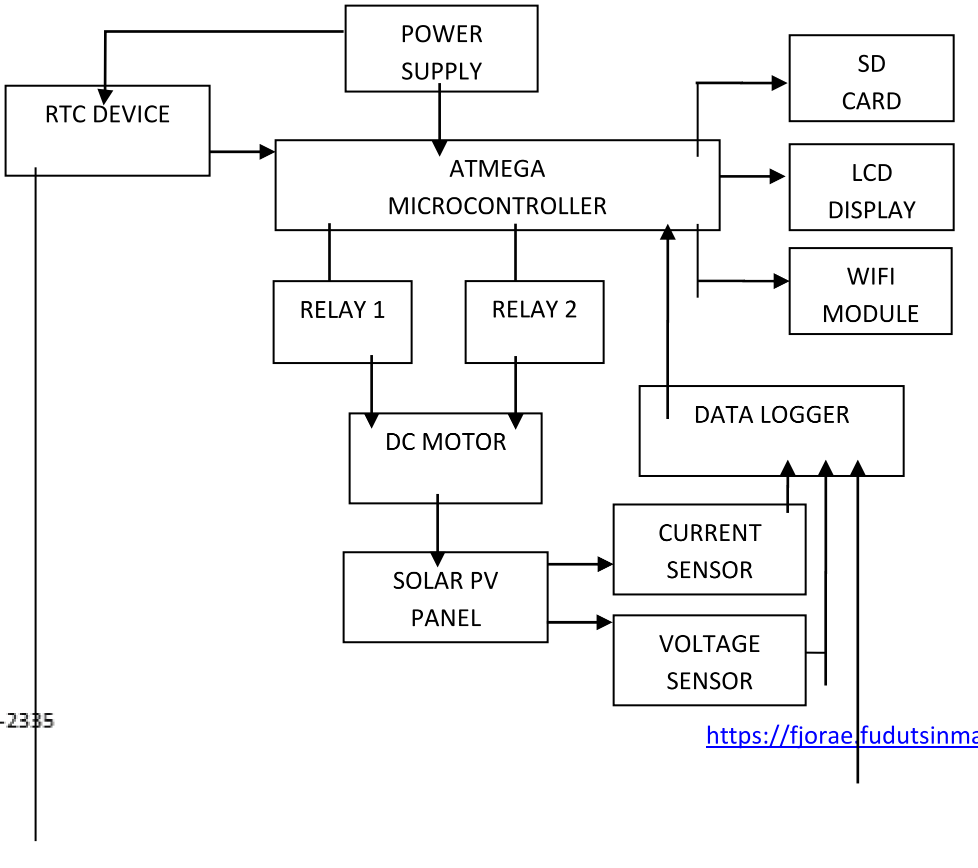

Figure 1: *Block diagram of an Automatic Solar PV tracker with Data logger*

This automatic solar PV tracker consists of two sub-parts: mechanical and electrical. The electrical part also classified as hardware and software, the hardware comprises electronic components while software referred to microcontroller programming codes. The stand, PV panel holder and axis of rotation were in mechanical sub-part. This is a structure that can support the PV panel with the degree of freedom that vary the tilt angle of the solar PV panel.

Power Supply Unit Design

The power supply needed should be able to power the Arduino, RTC device, data logger, LCD display, SD card, WIFI module and sensors, even under varying sunlight conditions. The block diagram of the power supply unit is shown in Figure 2.

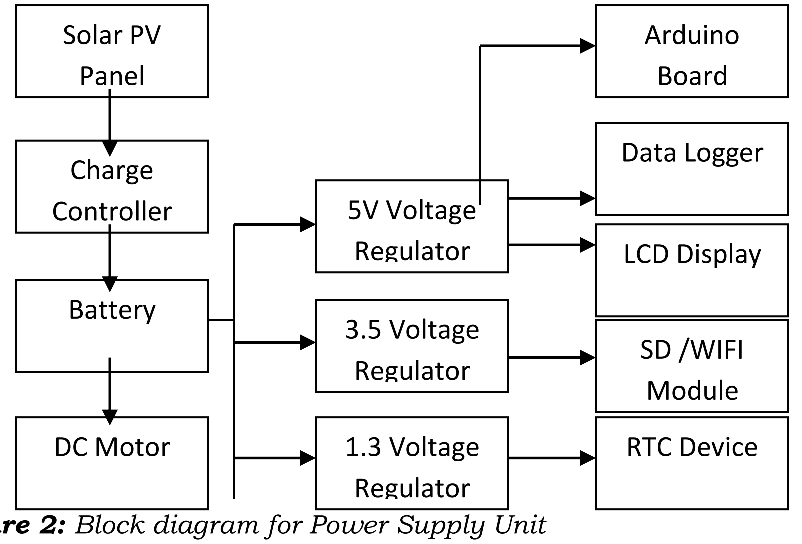

Figure 2: *Block diagram for Power Supply Unit*

Solar panel Selection

The solar panel must be able to provide 12V with current capacity of 5.8206A. This gives wattage of 69.8472 W. To be on the safer side a panel of 100W and 12V was used.

Charge controller Selection

An MPPT smart charge controller with a rating of 12 V and current carrying capacity 10 A was used for the design.

Battery selection

The system turns every 5 minutes resulting in 12 turnings in one hour and 144 times in a day (6 am to 6 pm). A battery with a capacity of 12V and 65 Ah was considered adequate for the system.

RTC Timing Device Design

This permits the microcontroller to keep track of time even if it is reprogrammed, and to put time stamp while logging. The RTC employed uses an Inter-Integrated Circuit bus (I2C) for communication with the Arduino board. The RTC module is also equipped with a battery backup device to keep the time and date going even when the Arduino is disconnected from the power supply. The DS3231 was used which, is a low cost and accurate real time clock. The RTC connection with Arduino is shown in figure 3.

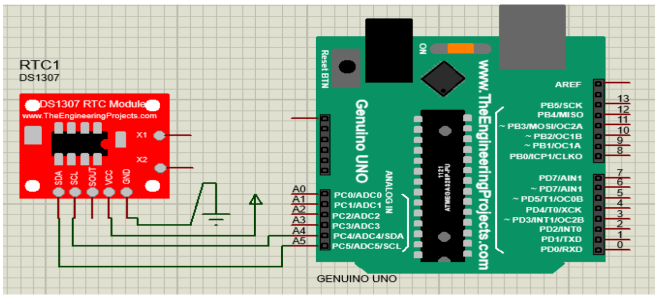

Figure 3: *Circuit diagram of RTC circuit with Arduino*

Data logger for Solar PV Design

This comprises both hardware and software programming for interfacing solar PV parameters with the Arduino board. The processor of the data logging device for solar PV applications was chosen to be ATMEGA 328 microcontroller contained in an Arduino board, where the C programming language program was written in Arduino Integrated Development Environment (IDE) for logging the power generated from the solar PV panel.

LCD Circuit Design

Liquid Crystal Display (LCD) board with an I2C module was used as display interface. It is a 20X4 display which shows information about the solar PV parameters. Since this display uses the I2C bus to communicate with the Arduino board, it requires only two digital pins connection. It is very basic and very commonly used in many devices and circuits.

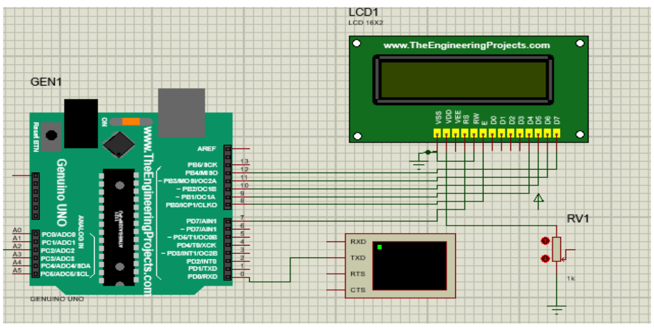

Figure 4: *Circuit diagram of LCD circuit with Arduino Board*

SD Card Circuit Design

This module saves the experimental data in a secure digital (SD) memory card to be analysed later. The SD card module utilizes the Serial Peripheral Interface (SPI) bus in order to communicate with the Arduino board. All these connections are shown in figure 5.

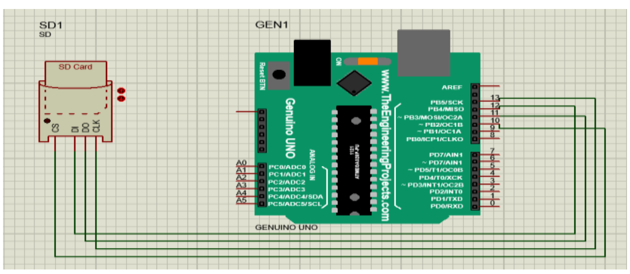

Figure 5: *Circuit Connection of SD Card with Arduino*

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WIFI Module Circuit Design

The system was designed in such a way that apart from logging data in the SD card it is also saved in a cloud server. To enable access to the saved data a Wi-Fi communication technology was employed to log and retrieve data to and from a cloud server. This allows devices to connect to the internet wirelessly using radio waves. The ESP8266 Wi-Fi module was used to communicate with cloud service. Its operation is based on the IEEE 802.11 standards.

Automatic Solar Tracker Circuit Construction

After the circuit design it was constructed on a Vero board. Care was taken to ensure that the semiconductor components were not subjected to excessive heat during soldering. The circuit was cased in a white plastic. It was then screwed to the frame holding the tracker. The hardware construction involves the coupling of physical part of the system which was made up of circuit units, mounting/soldering of the electronics components on the PCB/Vero board and interface between sub-units of the system. Inner view and coupled assembled components was shown in results.

Automatic Solar PV Tracker Software Development

The Arduino Integrated Development Environment (IDE) was used for the programming of the microcontroller with other devices. It was used to write and upload program to Arduino board using C programming language.

Automatic Solar PV Tracker Working Principles

ATMEGA 328 microcontroller contained in Arduino board as the controller of the tracking system receives and sends commands through input and output pins from RTC timing device to the DC motor. RTC device sends signal every 5 minutes which produces an analog output voltage, which was converted by microcontroller into digital bits. Firstly, the solar tracker takes a calibration sweep after receiving signal from RTC timing device. Then it goes back to its initial position (East direction). The main logic in the solar tracking technique is to move towards west direction in every 5 minutes towards maximum sunlight, else it would remain stationary.

Testing, Results and Discussion

Power Supply Tests

After the construction of the power section, it was tested by connecting to a solar panel and the voltages at the various points measured using a digital voltmeter. The result obtained is tabulated in the results section.

Automatic Solar PV Tracker Experimental Testing

Experimental measurements were demonstrated to verify the validity of the performance of constructed automatic solar PV tracker.

The constructed solar tracker was tested and all the developed circuits were found to be working perfectly. The testing was conducted on the 26th, 27th and 28th of March, 2024 at College of Engineering and Technology, Umaru Ali Shinkafi Polytechnic, Sokoto. The readings were taken from 8:00am to 6:00pm daily for each of the testing days.

Power Supply Test Results

Table 2: *Measured Power of the Components*

S/N	Electronic Components	Voltage Measured	Expected Voltage
1	Arduino	5.12V	4.5-5.5V
2	RTC	1.28 V	1.3V
3	Wi-Fi module	3.28V	3.3V
4	LCD	5.13 V	5V
5	SD card	3.28V	3.3
6	Mechanical	12.34V	12V

Results from the Construction

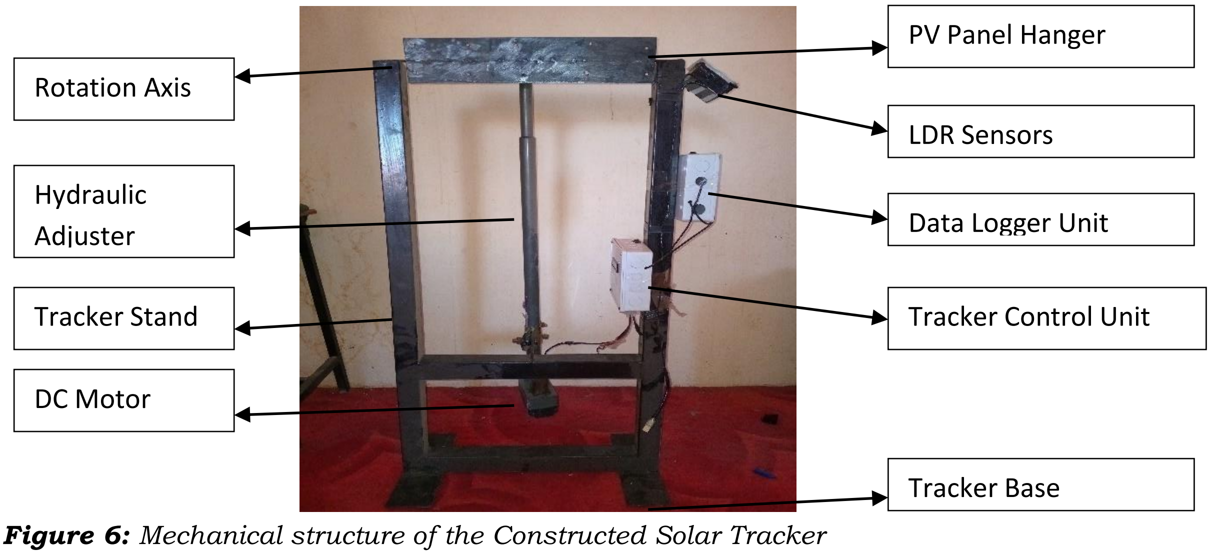

Figure 6: *Mechanical structure of the Constructed Solar Tracker*

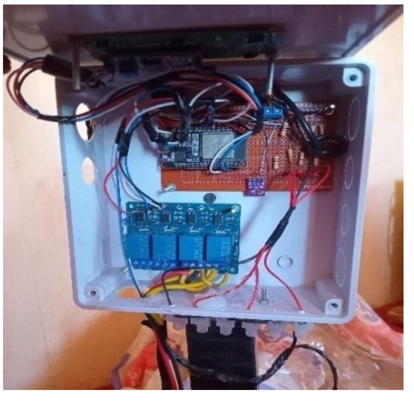

Figure 7: *Inner View of the Solar Tracker Control Unit*

Figure 8: *Coupled View of the Control/ Data Logging Unit*

Solar PV Tracking Results

Experimental measurements were demonstrated to verify the validity of analysis as well as the performance of the constructed automatic solar PV tracker. A continuous test was carried out for 3 days, from 26th to 29th of March, 2024. The three days results were shown in figure 9.

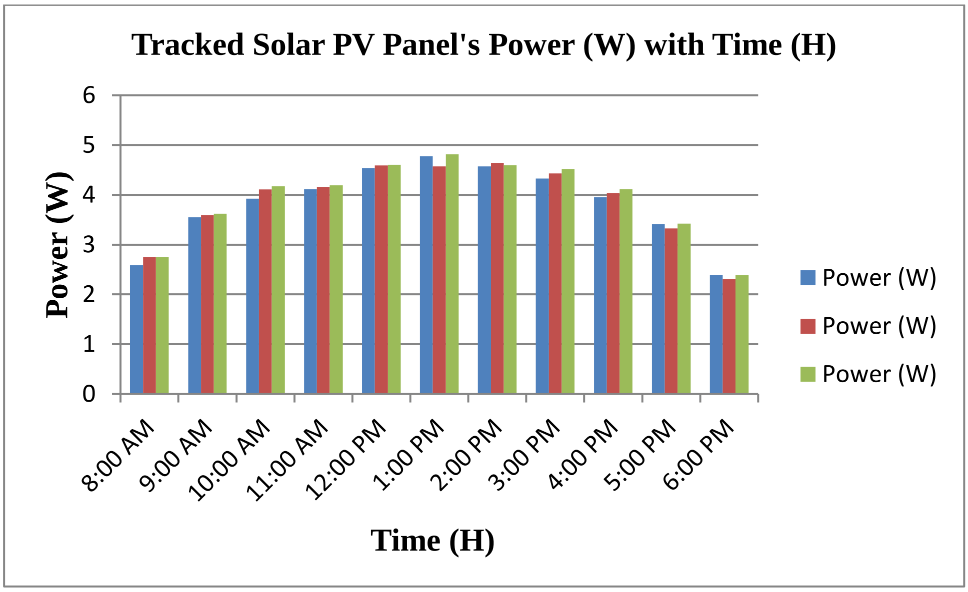

Figure 9: *Graph of solar PV Power and Time of the Sun days.*

Discussion of Results

Table 2 shows the measured and expected voltages for various sections of a power supply system designed to provide 12V, 5V, 3.3V, and 1.3V outputs. The measured voltages closely match the expected values, indicating that the power supply design is operating effectively. However, some minor discrepancies between the measured and expected voltages are observed across the different sub systems. The measured voltage for the Arduino section is 5.12V, which is within the recommended range of 4.5 to 5.5V (Arduino datasheet, 2023). This minor deviation, which is about 2.4% above the expected value, can be attributed to factors like the tolerance of the voltage regulators and slight variations in the input supply. This difference is within an acceptable range and should not affect the performance of the system. The power for the Real-Time Clock (RTC) section shows a measured voltage of 1.28V compared to the expected 1.3V, a difference of approximately

1.5%.

The Wi-Fi module's voltage was measured at 3.28V, slightly below the expected 3.3V. These minor discrepancies of about 0.6% can be caused by the regulator's tolerance, load variations. Most Wi-Fi modules are designed to operate within a tolerance range, and this variation is generally acceptable (Duffie and Beckman, 2013). The LCD section has a measured voltage of 5.13V compared to the expected 4.5 to 5.5V. This value falls within the accepted range as specified by the datasheet of the board. The SD card section shows a measured voltage of 3.28V, with a deviation of about 0.6%. This is also within acceptable range for most SD cards, which can not affect data integrity or performance. The mechanical section, which involves the motor, showed a measured voltage of 12.34V. This level of deviation (2.8%) should be acceptable for DC motor that are less sensitive to slight voltage increases. However, the battery charger showed 13.5V which should be ok to charge a 12V battery. The charging voltage is normally expected to be a little bit higher than the rated voltage of the battery to make room for its internal resistance.

The solar PV power experiment was conducted for a period ranging from 8:00AM to 6:00PM for three consecutive days from 26th to 28th of March, 2024 when the weather condition was on clear sunny conditions. The current and voltage values from solar PV panel were measured and the corresponding power was computed as shown in figure 9. Solar PV tracking panel was observed to be more effective in collecting solar energy from 12:00 PM to 3:00 PM daily. The measured power P_1, P_2, P_3, indicates very close relationship because the data was taken in three consecutive days in the same season of the year. This also demonstrates the accuracy of the tracking system. The graph of tracked solar PV panel shows that; there is a positive correlation for all of the power generated for three days with solar radiations. But, there are some variations, particularly at the 11th hour (6:00PM). These small differences are typical in practical measurement systems and can be attributed to motor delay or environmental factors. Additionally, the test results for the solar tracker system demonstrate high precision and effectiveness. The system maintains near-optimal alignment with the sun throughout the day, reflecting consistent adjustments.

Conclusion and Recommendations

Conclusion

An automated microcontroller-based solar tracking system with data logging facility and a WIFI module was designed and constructed using Arduino board programmed using the Arduino IDE by considering the given specifications. The system was able to track and follow the sun trajectory in order to harness maximum solar energy and is also suitable for investigating the performance of a typical solar PV panel. The measured and expected voltages across the various sections of the power supply unit showed that the power supply is functioning effectively. The minor discrepancies between the measured and expected values, such as in the Arduino (5.12V), Wi-Fi module (3.28V), RTC (1.28V), and SD card section (3.28V), are within acceptable tolerances and should not significantly impact system performance. This shows that the tracking PV system increased energy generation by almost 33% compared to the fixed PV system, which demonstrate high precision and effectiveness. The system maintains near-optimal alignment with the sun throughout the day.

Recommendations

- In future, there is need to provide an interfacing of internet of things, wireless sensors and wireless relays in designing data logger, to operate remotely in monitoring, logging and storing of electrical parameters of PV solar panel.
- The programming codes of the data logger can also be modified to measure the other physical quantities like temperature, wind speed, atmospheric pressure and humidity could be analyzed in further research work instead of measuring current, voltage and light intensity only.
- Protection circuit operations with wireless relays could be examined in future work and different and automatic process control through wireless control could be examined in future research work.
- Comparative analysis, between tracking solar PV panel and fixed-mount solar PV panel at optimum tilt angle need to be carried out in further research.

References

Abdulrahman, A., Al-Nehari, H. A., Abdulsalam N.,Almakhlafy, A. N. and Baggash, M. (2016). Design and Implementation of Solar Tracking System. *International Journal of Engineering and Technical Research,* ***4***(1), 71-75. ISSN: 2321-0869.

Ahmed, S., Mekhilef, S., Mubin, M. B. andTey, K. S. (2022) Performances of the adaptive conventional maximum power point tracking algorithms for solar photovoltaic system. *Sustainable Energy Technologies and Assessments*, *53,* 102390. doi.org/ 10.1016/j.seta.2022.102390.

AL-Rousan, N., Isa, N.A. M. andDesa, M.K.M. (2018). Advances in solar photovoltaic tracking systems: A review. *Renewable and Sustainable Energy Reviews, 82,* 2548-2569.

Chandel, R. And Chandel, S. S. (2022). Performance analysis outcome of a 19-MWp commercial solar photovoltaic plant with fixed-tilt, adjustable-tilt, and solar tracking configurations. *Programme Photovoltaics Residential Application*, *30,* 1–22. doi.org/ 10.1002/pip.3458.

Dias, R.R., Depr´a, M.C., Severo, I.A., Zepka, L.Q. and Jacob-Lopes, E. (2022). Smart override of the energy matrix in commercial microalgae facilities: A transition path to a low carbon bioeconomy. *Sustainable Energy Technologies and Assessments*, *52,*102-109. doi.org/10.1016/j.seta.2022.102073.

Duffie, J. A., and Beckman, W. A. (2013). *Solar Engineering of Thermal Processes.* John Wiley & Sons. This reference discusses the expected solar positions throughout the day, providing a foundation for analyzing tracker movement.

Gawusu, S., Zhang, X., Ahmed, A., Jamatutu, S. A., Miensah, E. D. Amadu, A. A. and Osei, F. A. (2022). Renewable energy sources from the perspective of block chain integration: From theory toapplication. *Sustainable Energy Technologies and Assessments, 52,*102-108.doi.org/10.1016/j.seta.2022.102108.

Hafez, A. Z., Yousef, A. M. and Harag, N. M. (2018). Solar tracking systems: Technologies and trackers drive types – A review. *Renewable and Sustainable Energy Reviews*, *91,* 754-782. doi.org/10.1016/j.rser.2018.03.094.

Ibrahim, A., Abdurrahman, S. H. and Lombe, I. (2018). Design and implementation of an automatic sun tracking solar panel without light sensors. *International journal of electrical and electronic science, 5(3),* 77-83.

Mansouri, A., Krim, F. and Khouni, Z. (2018). Design of a prototypical dual-axis tracker solar panelcontrolled by geared dc servomotors. *ScientiaIranica, 25*(6), 3542-3558.

Osueke, C.O, and Ezugwu, C.A.K. (2011). Study of Nigeria Energy Resources and its Consumption. *International Journal of Scientific and Engineering Research, 2, (12),*121-130.

Saymbetov, A. K., Nurgaliyev, M. K., Tulkibaiuly, Y.,Toshmurodov, Y. K., Nalibayev, Y. D.,Dosymbetova, G. B.,Kuttybay, N. B.,Gylymzhanova, M. M. andSvanbayev, Y. A. (2018). Method for Increasing the Efficiency of a Biaxial Solar Tracker with Exact Solar Orientation. *Applied Solar Energy,54,* 126-130.

Singh, R., Kumar, S.,Gehlot, A. and Pachauri, R. (2018). An imperative role of sun trackers in photovoltaic technology: A review. *Renewable and Sustainable Energy Reviews, 82,* 3263-3278.

Sumathi, S., Gayathri, G., Jancy Rani, A., Deepalakshmi, S. and Karthikeyan, K. (2018). Design and implementation of solar tracking system using LDR sensor. *International Journal of Advanced Science and Engineering, 3,* 1456-1461.

Yau, Y. H., Poh, K. S. andBadarudin, A. A. (2022). Techno-economical study of a solar assisted under floor air distribution system for buildings in the tropics. *Sustainable Energy Technologies and Assessments, 51,* 101915. doi.org/10.1016/j.seta.2021.101915.