Design and Fabrication of an Automatic Solar Tracking System & Comparative Analysis with Stationary Panel

Md. Raqibul Hasan,

Department of Mechanical Engineering, Chittagong University of Engineering & Technology, Chittagong, Bangladesh

raqib.cuet@gmail.com

Abstract: Solar energy is considered to be one of the most promising renewable energies. Energy generated from the sun transmitted in the form of light energy is converted into electrical energy using solar cells. This technology is widely used, the main use of solar panels is mostly in the static flat-plate scheme based on pre-determined angles. As a result, because of the variation of solar irradiation with the progress of daytime, the energy conversion is found to be decreased prominently. For serving the purpose of getting maximum power possible, this study represents a microcontroller-based energy-efficient automatic solar-tracking system. This system helps in the alignment of solar panels with the direction of the sunlight as per the changing position of the sun for maximizing power generation. The tracking system has been implemented using the necessary hardware setup and a program that controls the respective hardware. Light Dependent Resistor (LDR) sensor has been used as the input for the system to detect the brightness level of sunlight. The solar panel can rotate along with the horizontal (east-west) axis and the vertical axis depending on the intensity of the sunlight calculating input of LDR sensor. Two servo motors have been utilized for tracing the sun position. In this study, the designed tracking system has been compared to a stationary flat-plate system (30^{o} south facing horizontal) for the comparative analysis of power generation. The experimental result shows that the designed tracking system increased the power generation efficiency by 44.38% compared with the stationary panel. The result also indicates that in the mostly cloudy region the stationary panel will be more convenient than the automatic tracking system as in that case sunlight remains defused. But on regular sunny days, this proposed system over-performs existing stationary panel systems.

Keywords: Solar cell, Automatic tracker, servo motor, Arduino UNO, LDR sensor.

تصميم وتصنيع نظام التتبع الشمسي الأوتوماتيكي والتحليل المقارن باللوحة الثابتة

الملخص: تعتبر الطاقة الشمسية من أكثر الطاقات المتجددة الواعدة. يتم تحويل الطاقة المولدة من الشمس المنقولة على شكل طاقة ضوئية إلى طاقة كهربائية باستخدام الخلايا الشمسية. تُستخدم هذه التقنية على نطاق واسع، والاستخدام الرئيسي للألواح الشمسية يكون في الغالب في مخطط اللوحة المسطحة الثابتة بناءً على زوايا محددة مسبقًا. نتيجة لذلك، بسبب اختلاف الإشعاع الشمسي مع تقدم النهار، وجد أن تحويل الطاقة قد انخفض بشكل ملحوظ. لخدمة غرض الحصول على أقصى قدر ممكن من الطاقة، تمثل هذه الدراسة نظامًا آليًا لتتبع الطاقة الشمسية يعتمد على متحكم دقيق وموفر للطاقة. يساعد هذا النظام في محاذاة الألواح الشمسية مع اتجاه ضوء الشمس وفقًا لموضع الشمس المتغير لتحقيق أقصى قدر من توليد الطاقة. تم تنفيذ نظام التتبع باستخدام إعداد الأجهزة اللازمة وبرنامج يتحكم في الأجهزة المعنية. تم استخدام مستشعر المقاوم المعتمد على الضوء *(LDR)* كمدخل للنظام للكشف عن مستوى سطوع ضوء الشمس. يمكن أن تدور اللوحة الشمسية جنبًا إلى جنب مع المحور الأفقي (الشرقي الغربي) والمحور الرأسي اعتمادًا على شدة ضوء الشمس الذي يحسب مدخلات مستشعر *LDR.* تم استخدام محركين مؤازرين لتتبع موضع الشمس. في هذه الدراسة، تمت مقارنة نظام التتبع المصمم بنظام اللوحة المسطحة الثابتة (300 درجة جنوبًا أفقيًا) للتحليل المقارن لتوليد الطاقة. أظهرت النتائج التجريبية أن نظام التتبع المصمم أدى إلى زيادة كفاءة توليد الطاقة بنسبة 44.38% مقارنة باللوحة الثابتة. وتشير النتيجة أيضًا إلى أنه في المنطقة الغائمة في الغالب، ستكون اللوحة الثابتة أكثر ملاءمة من نظام التتبع التلقائي، حيث يظل ضوء الشمس في هذه الحالة معطلاً. ولكن في الأيام المشمسة العادية، يفوق هذا النظام المقترح أداء أنظمة اللوحات الثابتة الموجودة.

1. Introduction

Directly or indirectly the main source of renewable energy is the sun. Among all the renewable sources, solar is one of the sources which has the massive chance to replace conventional energy sources. Sunlight is converted directly into electrical energy by solar cells. A solar cell is an electrical device used to convert and produce electrical energy directly from light energy. This effect is called the photovoltaic effect. It is the phenomenon of chemical and physical. The solar panel is mainly made from the semiconductor. Mostly Si is used in the solar cell. Which have the 25% of efficiency in energy transformation. [1] Until the invention of high efficient solar cells, the mere way to increase the performance of the solar cell is tracking the sun's movement. If the tracker moves along with the sun's motion path then the PV cell converts maximum light energy to electrical energy. A solar tracker is the best and most accurate and applicable & proven system to enhance the efficiency of PV cells through alignment with the sun position. [2] The location of the sun varies with both time and season, for that reason the sun passes across the sky. So that increase of electrical energy production by using PV cell must track the location of the sun. [3] So that, the solar panel has to directly face the maximum light intensity. For that purpose, solar panels have to track the sunlight to get maximum intensity. The author [4] designed a single-axis tracker based on maximum power point tracking system (MPPT) using a DC motor and microcontroller for operation. This tracker can rotate only along horizontal axis. The author [5] designed a dual-axis solar tracker which is based on pseudo-azimuthal system for rotating the tracker. It obtains 44.89% energy efficiency compare to fixed panel.

In this paper, an automatic solar tracker is presented which is microcontroller based and easily programmable.

1.1 Types of Solar Tracker

There are two forms of the tracking system. One is manually tracking & the other is an automatic tracking system.

1.1.1 Manually Tracking

The manually tracking system is operated by a specialist operator, who aligns the PV cell to the direct location of the sun manually. It maintains with the time and movement of the sun, operator check the time and position of the sun then move the tracker by using wheel or hand. It is not an efficient system. Because the operator does not measure the appropriate angle for the tracker to track sun position. This system is costly.

1.1.2 Automatic Tracking

The automatic system is more efficient and accurate than the manual system. Automatic system controlled by computer programming. It is one of the smart tracking systems nowadays. By automatic system solar panel move along the position of the sun to get maximum light by measuring light intensity to produce maximum electrical energy. The automatic system is a cheap operating system. That is why nowadays it has become a popular using technology.

1.3 Objectives

The objectives of the reports were to:

- To design an automatic dual-axis solar tracking system.
- Fabricate and testing the design in laboratory conditions.
- Performance comparison with the stationary solar panel.

The goal of the work was to produce a locally made prototype automatic solar tracking system. Having a prototype provides clear knowledge in terms of automated dual-axis solar tracker operation.

2. Literature Review

J.V. Patil, J.K. Nayak, and V.P. Sundersingh [6] designed a computer-controlled two-axis solar tracker and testing. The designed tracker had a small error. This tracker leads to an increase in the output up to 30%. The tracker consumes the output power very small amount.

Jerin Kuriakose Tharamuttam and Andrew Keong ng [7] designed a hybrid algorithm for the automatic solar tracker. Which is not like the usual traditional active and chronological algorithm. This algorithm combine with both mathematical models and sensor for determine the very accurate sun location. To maximize collection and manage the energy of solar.

Md, Tanvir Arafat khan, S.M. Shahrear Tanzil, Rifat Rahman, and S M Shafiul Alam [2] designed an automatic solar tracking system. The designed tracker has the proper control mechanism and three-way of controlling. Their ways were daylight conditions which controlled only one direction that is east-west direction, second is a bad day condition when the sky will cloudy. And the last is bidirectional rotation. When the sun getting set then the tracker move to a certain angle till the sunset. Then the tracker moves revers to the previous direction for the next day. This tracker provides a profitable solution for the non-developed country.

Asmarashid Ponniran, Ammar Hashim, and Ariffuddin Joret [8] are constructed a single axis solar tracker where motor speed is not considerable. It was designed for residential usage and low-powered appliance. They did not consider the motor speed because, in this project, DC geared motor was used which offers a low rated speed in the output. The project was able to follow and track the sunlight intensity to collect high solar energy. The process was controlled by a microcontroller and intensity measured by an LDR sensor. They recommended that any kind of DC motor can be used because motor speed is not considerable. It was for the home appliance.

Salah Abdallah and Salem Nijmeh [9] evaluated two axes sun tracker which was automatically controlled by PLC. For the control, the program method was the open-loop system. This project was compared with a stationary surface tilled at a 32° angle. The experimental result was significantly higher than the fixed panel. The system showed efficient performance with an increase in the energy collection up to 41.34% than the stationary surface. Further studies can evaluate more performance in the application of a two-axis solar tracker.

Nur Mohammad and Tarequl Karim [10] designed a hybrid solar tracking system controlled automatically. This project's goal was to increase efficiency. For reaching the goal researcher implement a hybrid system combined with the dual and single-axis tracking system. And researcher made a comparison among hybrid, dual, single, and stationary tracking systems. The Dual-axis system showed 18% more gain energy than the single axis. On the other hand, the hybrid system performed and showed up to 54% efficiency than the stationary system which was situated 23.5° with horizontal.

Asmarashid Ponniran, Ammar Hashim and Handy Ali Munir [11] designed a single axis sun tracker. Which was controlled by an LDR sensor with the help of a microcontroller. It successfully tracked the sun by the measuring intensity of the sunbeam. And their goal was successfully obtained. It was applicable for the house appliance and non-critical low-powered device. It will make more efficient by further study.

P. Roth, A. Georgiev, and H. Boudinov [12] designed a sun tracker system. Which was operate automatically. For this operation, they used a pyrheliometer and guided by a closed-loop servo motor. A four-quadrant photodetector creates an image of the sun's position and the DC motor moved the system into the sun location through the sun-centered photodetector. When the sun getting invisible the system continues to move until the detector gets the sun in the center of it and making the image of the sun and stop movement. It is just a model to track the sun which will be used in the solar panel to track the sun's position accurately commercially.

Tung-Sheng Zhan, Whei-Min Lin, Ming-Huang Tsai, and Guo-Shiang Wang [13] designed a dual-axis solar tracker which was operated automatically by the programmable logic controller (PLC). This system-oriented the setup to directly perpendicular to the sunbeam. They have compared the result with a fixed solar panel. This project was cost-effective, reliable, and efficient than stationary. They got the successful result which was more than 17-25% than stationary on a sunny day. On the other hand on a cloudy day, they got 8-11% more than output than stationary. The overall output gets 8-25% more efficient than a fixed angle solar panel.

3. Methodology

The design of the framework is done by following parts:

- Program design – which is implemented in a microcontroller that controls the tracker.
- Circuit design – all electrical appliances are includes.
- Physical structure design – all mechanical parts such as the frame of the system, motor, etc.

The system of the project is constructed utilizing a decent idea which is two signs from the various sensors are compared. Light Dependent resistor (LDR) is used as a light sensor. For the solar tracker control unit, the microcontroller is used with input as LDR sensor response. A block diagram of the system is shown in Figure 1 below:

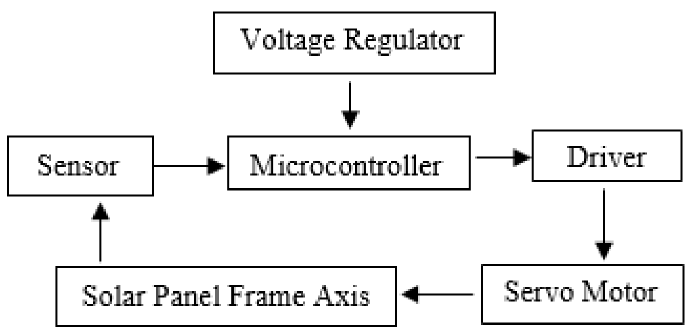

Figure 1. Block diagram of the project.

The methodology of the whole system is contracted as below in Figure 2:

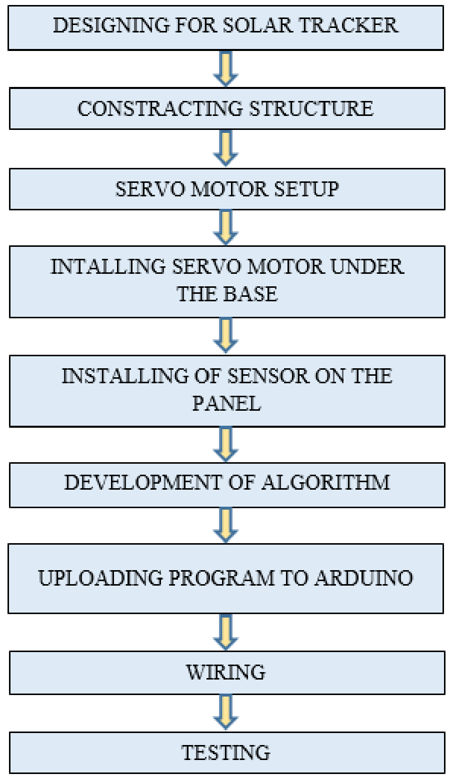

Figure 2. Flow chart of the project methodology

LDR changes resistance with a change in light intensity. Two servo motor was used for rotation of the panel. One servo motor rotates along the horizontal axis and the other rotate along with the vertical axis. Four LDR sensors are used in controlling servo rotation. Two sensors detect the sun's vertical position, while the other two detect the sun's horizontal position.

3.1 Microcontroller

Both the Arduino UNO and Nano have been used. The Arduino Nano board is identical to the Arduino UNO board in that it uses the same Atmega328p microprocessor. As a result, they can use the same program. The size difference is the most significant distinction between these two. Because the Arduino Uno board is double the size of the

Arduino Nano board. As a result, Uno boards take up more room on the system. UNO can be programmed using a USB cable, whereas Nano requires a small USB cable. Arduino Nano has 8 analog inputs and 14 digital outputs, while Arduino UNO has 14 digital outputs and 6 analog inputs. [14]

3.2 Servo motor

The servo motor is a type of rotary actuator that is widely used in a variety of applications. It's a self-contained electrical device that rotates machine parts with high efficiency and precision. The servo motor's output shaft can be rotated to a specific angle. Can perform well at low speeds and with the proper gear ratio, resulting in low heat production.[15]

3.3 Light Dependent Resistor

The light-dependent resistor (LDR) is made from the exposed semiconductor. Its resistor value changes exponentially with the change of intensity of light. It sensed the light intensity which is used as the analog input voltage to the microcontroller. [16]

3.4 Circuit Diagram

Figure 3 & Figure 4 showing the control circuit of the dual-axis solar tracker. Which is based on Arduino UNO & NANO.

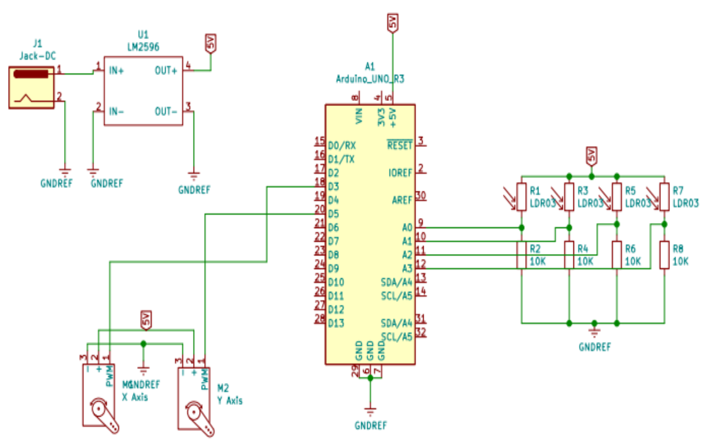

Figure 3. Circuit diagram for the dual-axis solar tracker

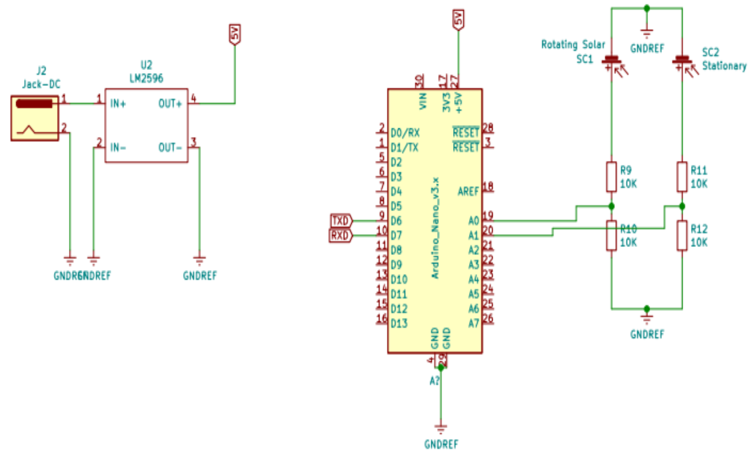

Figure 4. Circuit diagram for power logger.

3.5 Research Design

The structure of the automatic solar tracker consists of a solar panel, two servo motor, a wooden panel holding arm, and a wooden base. One servo motor is placed in the panel holding arm to rotate the panel at the horizontal axis about 65^o horizontally in both side. Another servo motor is mounted on the wooden base so that the panel holding arm can rotate at the vertical axis about 165^o vertically. Arduino UNO is used for this tracker which gets input from the LDR sensor and leads to rotate servo motors. Arduino Nano is used for logging the power output of the panel and send to the Bluetooth module. Panel holding arm mounted on servo motor which leads to rotate the arm in the vertical axis. Another servo motor mounting on the panel holding arm which leads to rotate the panel in the horizontal axis.

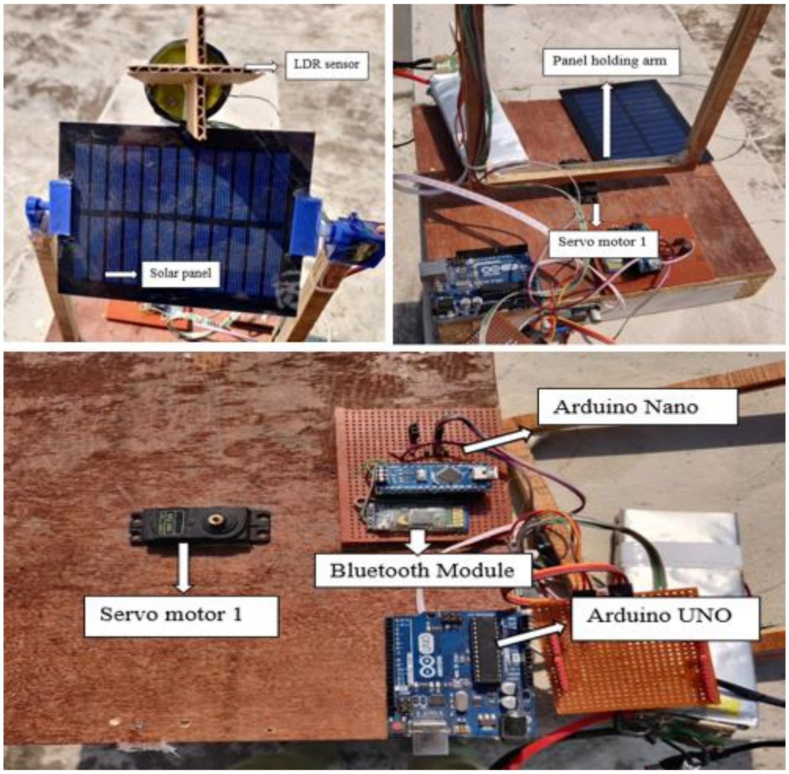

Figure 5. Construction of the system

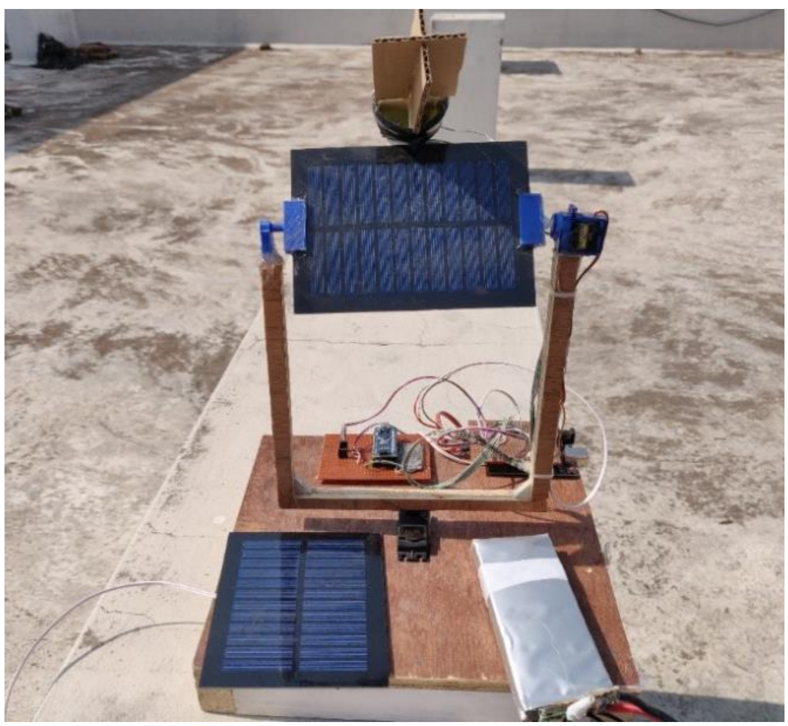

Figure 6. Overall view of the tracker

The complete mechanical structure of the design of the automatic dual-axis solar tracker is shown in Figure 5 & Figure 6. Solar panels, Arduino UNO, Arduino Nano, LDR sensor, servo motor, motor driver, Bluetooth module, and power resistor are used to execute this project.

4. Result, Data Collection & Analysis

Table 1 shown a performance comparison of the Automatic dual axis solar tracker and stationary solar panel for day 1 (17/04/2021) which was a fully sunny and sun rises at 5.31 AM and sets at 6:14 PM on April 2021 in Raozan, Chittagong, Bangladesh.

Table 1. Performance of Automatic tracker & stationary solar panel (Day1)

Time Of the day(h)	**Dual Axis Tracker**			**Stationary Panel(30°)**			**Condition**
	Power (mW)	Current (mA)	Voltage (V)	Power (mW)	Current (mA)	Voltage (V)	
9.00	67.30	9.93	6.78	30.00	9.90	3.03	Sunny
9.20	65.20	9.97	6.54	33.10	9.97	3.32	Sunny
9.40	64.00	9.98	6.41	29.00	9.83	2.95	Sunny
10.00	66.90	9.99	6.70	33.30	9.97	3.34	Sunny
10.20	66.70	10.05	6.64	34.00	9.86	3.45	Sunny
10.40	66.30	10.03	6.61	34.80	9.94	3.50	Sunny
11.00	67.30	10.01	6.72	37.80	9.95	3.80	Sunny
11.20	67.40	10.00	6.74	34.40	9.94	3.46	Sunny
11.40	68.60	10.04	6.83	32.70	9.94	3.29	Sunny
12.00	71.20	10.06	7.08	46.40	9.87	4.70	Sunny
12.20	69.40	10.06	6.90	34.00	9.94	3.42	Sunny
12.40	68.50	10.07	6.80	34.70	9.89	3.51	Sunny
13.00	68.80	10.01	6.87	31.50	9.94	3.17	Sunny
13.20	67.40	10.00	6.74	30.70	9.90	3.10	Sunny
13.40	67.20	9.97	6.74	31.70	9.88	3.21	Sunny
14.00	66.70	10.06	6.63	33.00	9.88	3.34	Sunny
14.20	66.50	10.00	6.65	32.40	9.97	3.25	Sunny
14.40	66.30	10.02	6.62	32.00	9.88	3.24	Sunny
15.00	65.90	10.00	6.59	31.80	9.94	3.20	Sunny
Average	67.24	10.01	6.72	33.54	9.91	3.38	

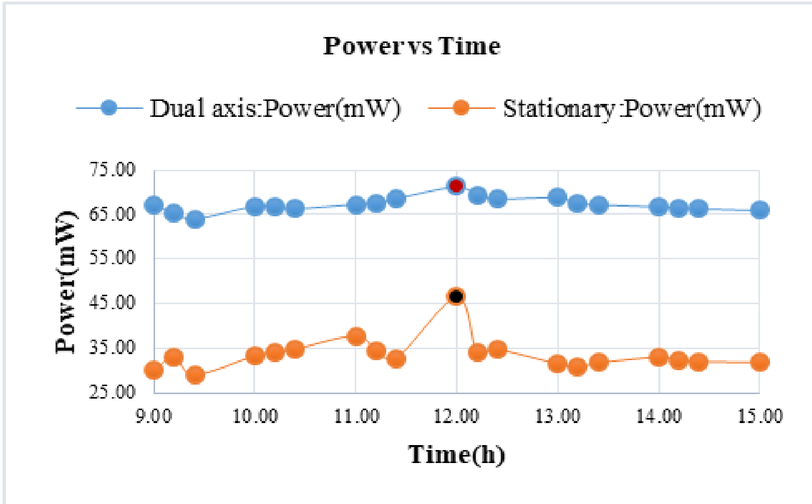

Figure 7. Power vs Time of automatic and stationary solar panels (Day1)

For day 1 the overall power for the automatic solar tracker is 67.24 mW, on the other hand for the stationary panel (30° south facing horizontally) the overall power is 33.34 mW. In Fig 7 (day1), the day was completely sunny all day. So that the power output for both panels has a huge difference. In the automatic tracker, overall performance was high all day than the stationary panel. From 9.00 AM to 12.00 PM output is increasing and after 12.00 PM output is decreasing for both panels. The peak value of power is obtained at sharp 12.00 PM for both panels is 71.20 mW for automatic tracker and 46.40 mW for the static panel.

Table 2 shown a performance comparison between the Automatic dual axis solar tracker and stationary solar panel for day 2 (18/04/2021) which was a partly cloudy.

Table 2. Performance of Automatic tracker & stationary solar panel (Day2)

Time Of the day(h)	Dual Axis Tracker			Stationary Panel(30°)			Condition
	Power (mW)	Current (mA)	Voltage (V)	Power (mW)	Current (mA)	Voltage (V)	
9.00	66.90	9.99	6.70	29.30	9.83	2.98	Sunny
9.20	66.60	10.05	6.63	33.80	10.03	3.37	Sunny
9.40	65.60	9.45	6.94	32.30	9.91	3.26	Sunny
10.00	68.90	10.06	6.85	36.70	10.11	3.63	Sunny
10.20	65.70	10.03	6.55	67.40	9.99	6.75	Cloudy
10.40	67.30	9.97	6.75	66.80	10.00	6.68	Cloudy

11.00	66.20	10.02	6.61	67.80	10.03	6.76	Cloudy
11.20	66.40	10.06	6.60	67.70	9.99	6.78	Cloudy
11.40	67.20	10.07	6.67	71.20	10.06	7.08	Cloudy
12.00	69.80	10.17	6.86	54.80	10.06	5.45	Cloudy
12.20	66.50	9.98	6.66	67.90	9.96	6.82	Cloudy
12.40	66.60	10.00	6.66	67.80	10.04	6.75	Cloudy
13.00	66.10	9.98	6.62	65.90	10.00	6.59	Cloudy
13.20	66.10	10.06	6.57	57.50	9.91	5.80	Sunny
13.40	66.50	9.97	6.67	54.30	9.96	5.45	Sunny
14.00	65.80	10.03	6.56	46.10	10.20	4.52	Sunny
14.20	65.30	10.02	6.52	43.20	9.69	4.46	Sunny
14.40	66.10	9.97	6.63	42.60	9.95	4.28	Sunny
15.00	66.30	10.03	6.61	45.10	10.07	4.48	Sunny
Average	66.63	10.00	6.67	53.59	9.99	5.36	

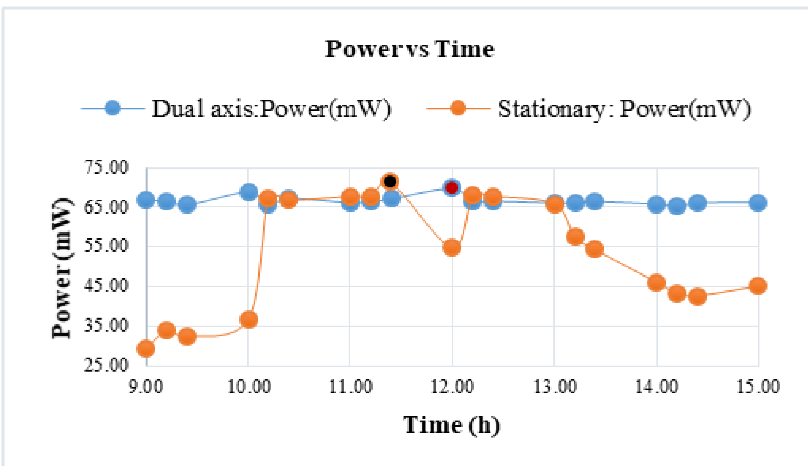

Figure 8. Power vs Time of automatic and stationary solar panels (Day2)

For day 2 the overall power for the automatic solar tracker is 66.63 mW on the other hand for the stationary panel (30° south facing horizontally) the overall power is 53.59 mW. In Fig 8 (day2), the day was cloudy from 10.20 AM to 1.00 PM. So that in this range the power output for both panels was near to same. 9.00 AM to 10.20 AM and 1.00 PM to rest of the day sky was sunny, in this range the output for dual-axis tracker is compared to high than the stationary panel. The peak value was achieved for the automatic tracker is 69.80 mW at 12.00 PM and the stationary panel is 71.20 mW at 11.40 AM.

It is observed that the dual-axis tracking system provides more power and voltage than the stationary panel. About 44.38% more power is produced by the automatic tracker than the stationary panel (30^{0} south facing horizontally). And also shows that when the sky was sunny automatic tracker performed well than static. And when the sky was cloudy both panels performed too closed. So that for a sunny region, it is more efficient to use an automatic solar tracker for maximum output. For a partly cloudy or cloudy region, it will be efficient to use a usual or stationary solar panel.

4. Discussion on Result

The overall outcome for the dual-axis tracker is better than the stationary panel. The optimal power output for both of the panels is achieved from 11.40 AM to 12.20 PM. For day1 which was a sunny day, the average power output is 101.68% more for the automatic tracker than the stationary. For day2 which was cloudy, the average power output is 24.33% more for the automatic tracker than the stationary. Compared to the stationary panel, Overall performance increased by 44.38% for the dual-axis solar tracker than. The result demonstrate that for cloudy regions stationary solar panel would be more practical than an automatic tracker.

Table 3. Average performance comparison for both solar panels.

No. of day	**Average Power (mW)**		**Average Voltage (V)**	
	Automatic	Stationary	Automatic	Stationary
Day 1	67.24	33.34	6.72	3.38
Day 2	66.63	53.59	6.67	5.36

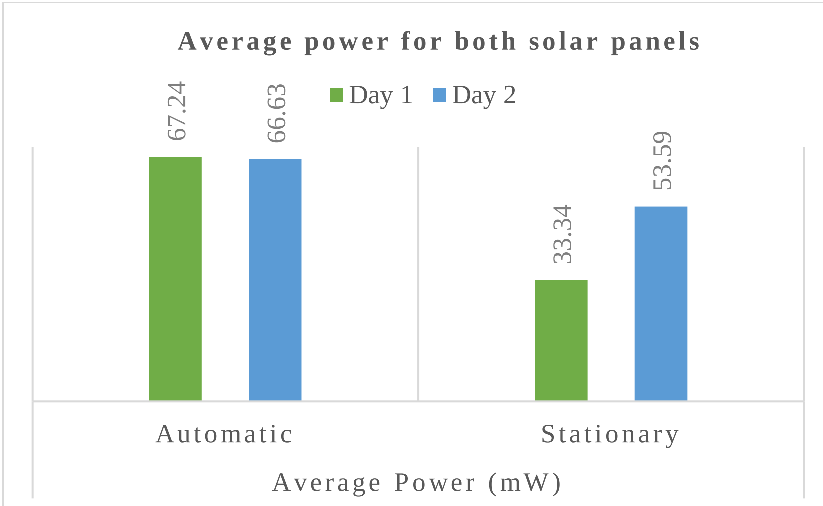

Figure 9: Average Power of the dual-axis solar tracker and stationary panel

For a sunny day, the result shows that the automatic tracker performed to compare to higher than the static solar panel. And for cloudy day stationary solar panel performed close to the automatic solar tracker. So it can be more effective to use a stationary panel instead of an automatic tracker in the cloudy region, which results in reducing maintenance costs. The structure and electrical circuit of the automatic solar tracker is a bit sensitive to strong wind conditions. It is the main disadvantage of this type of tracking system.

5. Conclusion

This paper describes a method of tracking sun position by using microcontroller. The designed tracker system is easy to operate under all circumstances. The automatic tracker is performed better overall. Recorded data and analysis represent that an automatic tracker is more convenient than stationary in the field of producing power in the sunny region. And in the cloudy condition since both are performed near to same so that, it will be wise to use stationary panel rather than automatic one. Which has an economic impact on operations. The solar tracker also provides a beneficial clue for third-world countries to accomplish it into their solar system. For a developing country, where the energy crisis is a big issue, these tracking systems may have an important aspect to make more power and reduce power crises. Though the prototype has some limitations, still it provides a scope for the betterment of the design method in the future.

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