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# DEVELOPMENT OF PROTOTYPE DUAL-AXIS SOLAR TRACKING DEVICE FOR OPTIMAL POWER GENERATION AT RESIDENTIAL AREA IN BANGLADESH

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**Abstract**

One of the main concerns in Bangladesh and other third-world developing countries is the energy crisis. There is a massive disparity between electrical energy generation and demand. A large proportion of the country's populace are completely deprived of this privilege. The sole alternative to this problem is energy derived from natural resources. Solar power ranks high among alternative sources of energy in terms of effectiveness which could play a key part in resolving the situation. This study aims to figure out the feasibility of a dual axis technique for tracking solar is superior to an immovable, single axis technique for solar tracking by putting one into practice. Three sections that make up the project execution stage are mechanical, electronic, and programming. The dual axis solar tracker drvice outperformed both the fixed and single axis tracker device (28.22% and 45.87% more efficient compared to single axis and fixed system) in terms of power generation. Consequently, it has been shown that the dual axis solar tracker device is more useful when it comes to maximizing power generation.

**Keywords**: Solar tracking device; Dual axis solar tracker; Solar energy.

## 1.0 INTRODUCTION

The National Energy Policy of Bangladesh evaluated the potential of utilizing solar heating and PV technologies favorably due to the abundance of sunlight in 2004. While worldwide exposure fluctuates from 3.8 kW/m2/day to 6.4 kW/m2/day, the amount of strong sunlight (defined as more than 200watt/m2) in Bangladesh's coastal areas varies from 3 to 11 hours per day [1]. We must largely rely on renewable energy to drive our nation's economy forward as non-renewable energy reserves are finite. Utilizing solar voltaic energy's potential also has the potential to control air emissions and prevent contamination of the environment. The effective use of solar power in our nation may be very helpful in meeting the rising demand for energy. The Bangladesh Power Development Board (BPDB) estimates that over 47% of the nation's populace lacks connection to the national power grids. According to BPDB official records, our country produces 5,300–5,500MW of power on average per day, compared to an estimated 6,500–6,000MW daily need [2]. To address this electricity shortage, the government of Bangladesh has launched many initiatives to optimize solar energy utilization. To hook up up with the country's power grids, the Bangladeshi government now mandates the installation of solar panels on household rooftops. Once more, in an attempt to fulfill the demand for power, the government is urging industrialists to put solar panels on vacant rooftops. Despite being able to fulfill the highest electricity consumption, solar power produced by this type of rigid panels only accounts for around 39% of the total energy used [3].

Expansion of rural electricity services is especially needed in Bangladesh. The country is located within 20.34 to 26.38 degree northern latitude and 88.01 to 92.41 degree eastern longitude, making it a favorable premises for harnessing energy from the sun. [4]. Thus, the possibility to expand the supply of energy supplies for remote and various families exists with the application of photovoltaic (PV) technology. It has been empirically shown that solar photovoltaic (PV) technology may function as a very effective primary energy source during emergencies [5]. Photovoltaic is a highly prevalent energy from renewable sources worldwide [6 - 7]. Photovoltaic systems are sustainable, noiseless, ecologically sound, and simple to set up and maintain [8]. Nevertheless, photovoltaic techniques are hindered by their poor efficiency and excessive cost [9 - 10]. To address this issue, certain experts have examined the ideal angle of the solar collection device to enhance the electricity generated [11]. Due to the varying location of the sun throughout the day, using a solar tracking device is a more effective approach to enhance energy generation. Currently, an increasing number of academics are doing studies on the solar tracker. Presently, there are primarily two categories of solar tracking devices distinguished by their movement capabilities: single-axis tracking device [12] and dual-axis tracking device [13]. Prior research has introduced many types of single-axis and dual-axis tracking.

Batayneh et al. [14] suggested a dual-axis sunlight tracking mechanism with altitude-azimuth mounting, controlled by a built fuzzy controller, for the purpose of designing single-axis sun tracking mechanisms. Kiyak and Gol [15] have devised a system for tracking the sun that utilizes not only fuzzy logic but also Proportional Integral Derivative (PID) controller. Through experimental analysis, they determined that the efficiency of the fuzzy logic approach significantly surpassed that of the PID controller; and Li et al. [16] have introduced a novel method for tracking sunlight using kirigami. This methodology utilizes Organic Photovoltaics (OPVs) that are manufactured on pliable materials, resembling paper. As a result, the OPVs offer both stretchability and durability.

Despite the relative ease and cost-effectiveness of building single-axis sunlight tracking mechanisms, the potential for dual-axis tracking techniques to position solar cells perpendicular to the sun and therefore achieve greater energy collection accuracy has led to a growing number of recent studies on dual-axis tracking techniques. Sungur [17] conducted a study on the development of programmable logic control in a dual-axis sunlight tracking technique. Through experimental validation, it was demonstrated that the system could generate 42.6% more power compared to the photovoltaic cells those are fixed. Kentli and Yilmaz [18] developed a mathematical formulation for a solar tracking system with two axes by analyzing its structural parts as well as photo-resistances. Their proposed system has the capability to generate 30% additional power compared to a stationary system. Syafii et al. [19] have developed a sensor less dual-axis solar tracking system that relies on databases of sun locations. This database is built using accurate measurements of solar angles, heights, geographical altitudes, and time regions, and includes information on sunrises and sunsets. Based on theoretical investigations of sun angles in Tunisia that employed spatial and temporal factors, Skouri et al. [20] developed three precise dual-axis solar tracking devices. Laseinde and Remere [21] designed the highest possible power point monitoring method used in a dual-axis servo motors feedback tracking system with an Arduino-based system, demonstrating the benefits of energy efficiency and compactness.

To provide both low cost and reliable, cost-effective performance, the solar system design needs to be modified. This work investigates the significance of dual axis solar tracking system using PV solar and also compare the proposed system with single axis and fixed sytem. The second part of this article addresses Bangladesh's solar energy scenarios. The third section describes the experimental setup of the sun tracker device. The fourth portion includes experimental results and discussion. The study is terminated in section five, which also provides ideas for future advancements.

## 2.0 SOLAR ENERGY PROFILE OF BANGLADESH

There is not enough power in Bangladesh for everyone to be lit up. In 1971, just approximately 3% populations in our nation had electrical power availability [22]. But as of right moment, the percentage is about 53% higher [2]. However, there is a lot greater demand. Load shedding is a prevalent issue in the overall growth of our nation. The national energy policy has set a 2020 deadline for supplying power to the entire nation. Bangladesh's gas supplies are running out faster than they used to. Therefore, in order to meet our demand for power, we must discover other solutions to this national issue. Natural resources, including renewable energy, can help us solve the energy crisis. Solar energy is the highest dependable natural and sustainable power resource. Solar energy is a commercially viable energy source. It offers a great deal of promise for Bangladesh. Solar energy generation in Bangladesh has a bright future, based on information from NASA Surface Meteorology and Solar Energy RET Screen. This source's data indicates that Dhaka's everyday solar irradiance is 4.65kWh/m2/day on a yearly basis [23]. At the 2008 Washington International Renewable Energy Conference, Bangladesh resolved to use five percent renewable energy for its electrical power [24]. According to a survey, our country installs more than 3,000 solar systems per month. The Grameen Shakti, a successful non-governmental organization in Bangladesh, has made solar electricity available to 7.5 million people. The organization has installed 550,000 solar panels in 40,000 cities and villages [22]. As of January 2013, almost 1,938,957 solar household systems had been built under this initiative. The Prime Minister's Office's solar system provides about 21.6kW of power [25]. To relieve the strain on the country's electrical needs, the central bank and Bangladesh bank put solar panels on their rooftops [26]. According to a new study, at the biggest refugee camps for Rohingya community in the globe, which are located in Bangladesh, solar photovoltaic cells are the only source of power and serve as an only energy medium to provide limiting availability of electrical power [5].

## 3.0 EXPERIMENTAL SETUP

Since the PV panels rotate on multiple axes, the suggested tracking system can really track a significant amount of daylight. We can follow the sun in four directions utilizing a dual axis device, which increases the energy quantity that solar panels can produce. We are able to imprison more light beams while tracking the sun. Figure 1 assists in elucidating the fundamental idea for the rear dual axis tracking system by showing movement in two dimensions. In comparison to a single-axis or fixed system, a dual-axis system can generate more power; however, because of the vertical axis, it also rotates horizontally, capturing solar energy more productively. This solar tracking system is mostly made up of a 5-watt solar panel, two servo motors, four light-dependent resistors (LDR), and an Arduino-UNO. However, the mechanical, electrical, and control units make up the three primary portions of this dual axis solar tracking device.

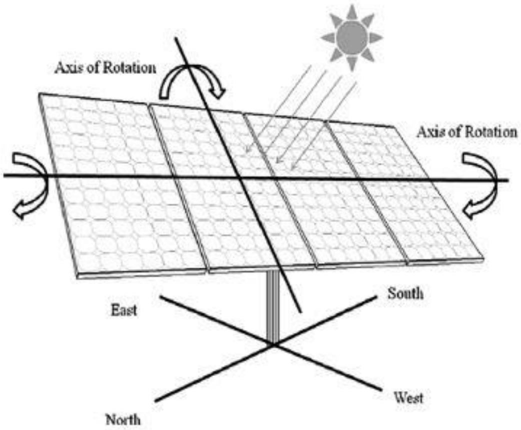


**Figure 1**. Two axes movement in dual-axis solar tracking system, adapted from [27].

### 3.1 Mechanical Part

In order to monitor the movement of sun during the day, year-round, mechanical construction of the solar tracking device is composed of both permanent and mobile fragments. Since the system will remain outside, the construction must be able to withstand outside conditions like wind and heat while also being able to be easily relocated. The initial component of the structure's design is a strong foundation that can support a solar panel equipped with electric motors for mobility to reposition the device. A column is positioned in the center of the base. The opposite ending section has a shaft at a sixty-degree angle with a ball joint at the end that is attached to the solar panel. This allows the system to move in tandem with the sun's movement. Two arms of the motors are attached to the column that supported them, and a ball joint connects the opposite part of the motor to the solar board. The first motor, that is placed in the center of the solar board's wide edge, is in charge of the vertically elevating angle from north toward south.

The second motor is in charge of the system's horizontally movable angle of azimuth from east toward west. It is attached to the PV panel distancing from its tiny border in order to secure the system's maximum angle of movement when it follows the sun from east toward west. The tracking system's mechanical specifications are illustrated in Table 1.

**Table 1**. Mechanical specification of the implemented tracking system.

| Sl. No | Design Aspect | Specification |
|---|---|---|
| 1 | Weight | 1.736 Kg |
| 2 | Height | 20 Inches |
| 3 | Material | Wood |

### 3.2 Electrical Part

When solar cells placed at proper angles to the sun, which results in sun rays descending straight down onto the cell, they produce more energy and operate more efficiently. This is accomplished by utilizing a sun tracking device with sensing components to detect sunlight. The sensing components are linked to an electrical network which tracks the positioning of the sun and maintains the PV board in direct sunlight by receiving and interpreting the intended action and then directing the motor to rotate either clockwise or counterclockwise. If the solar energy striking the sensing component is uniform at all light levels, the electrical circuit functions as a comparator to maintain the matter at the optimal position. Nevertheless, as the sun's position changes, so does the light quantity falling on the sensors, causing one of them to cast a shadow. This information is then relayed to the motor, which goes back into dormancy when the quantity of light falling on the sensing components is equal. Motors stay in a relaxed condition when all the sensors are shaded. In Figure 2, the system's circuit diagram is represented.

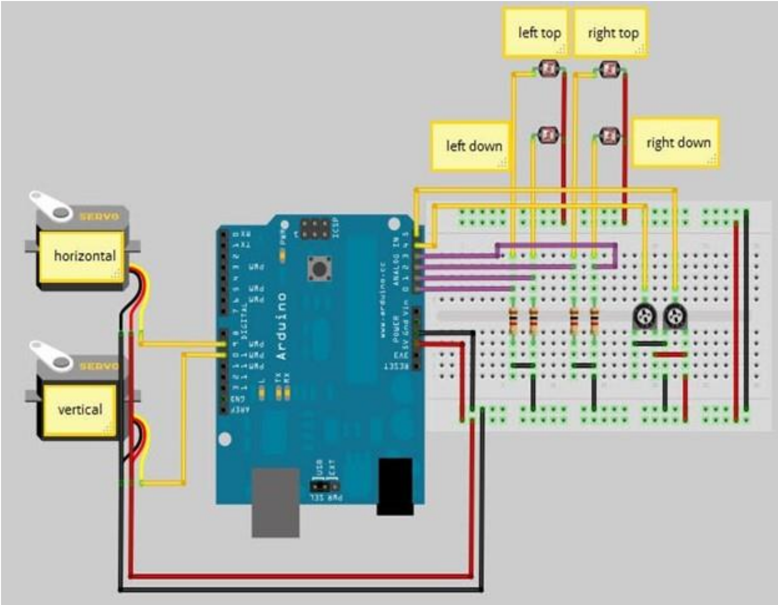


**Figure 2**. Circuit diagram of dual-axis solar tracking device.

### 3.3 Controlling Part

Typically, the hardware component consist of an electronic circuit, servo motor, solar panels, LDR sensor, and microcontroller. The programming portion depicts the system's thought process and how it behaves in various atmospheric conditions. The developed dual axis solar tracking device's block diagram and flowchart are shown in Figures 3 and 4.

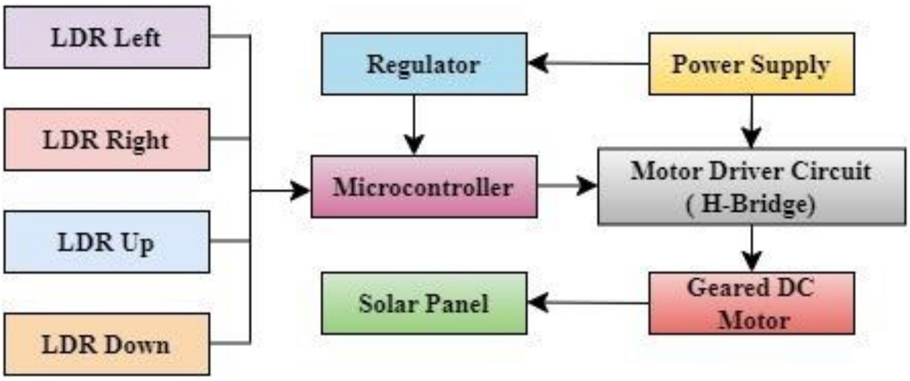


**Figure 3**. Block diagram of dual axis solar tracking device.

Figure 3 represents the system that uses LDRs to detect the direction of maximum sunlight intensity. A microcontroller processes the sensor data and commands a motor driver circuit to rotate a solar panel via a geared DC motor, keeping the panel optimally positioned towards the sun. The system is powered by a regulated supply, which can be supplemented or driven directly by the solar panel itself, enabling efficient solar energy generation through continuous tracking and alignment with the sun's rays.

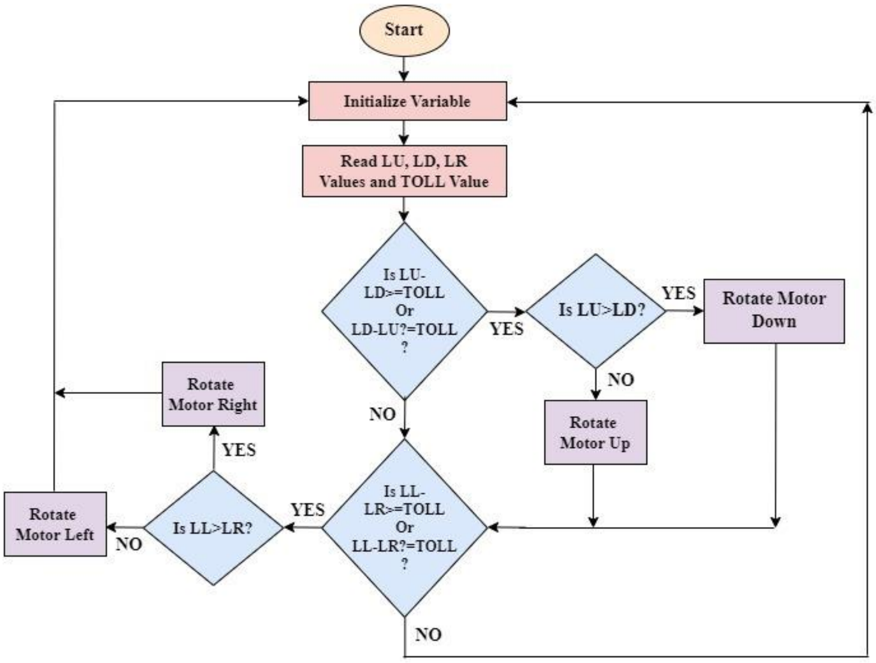


**Figure 4**. Flow chart of dual axis solar tracking device.

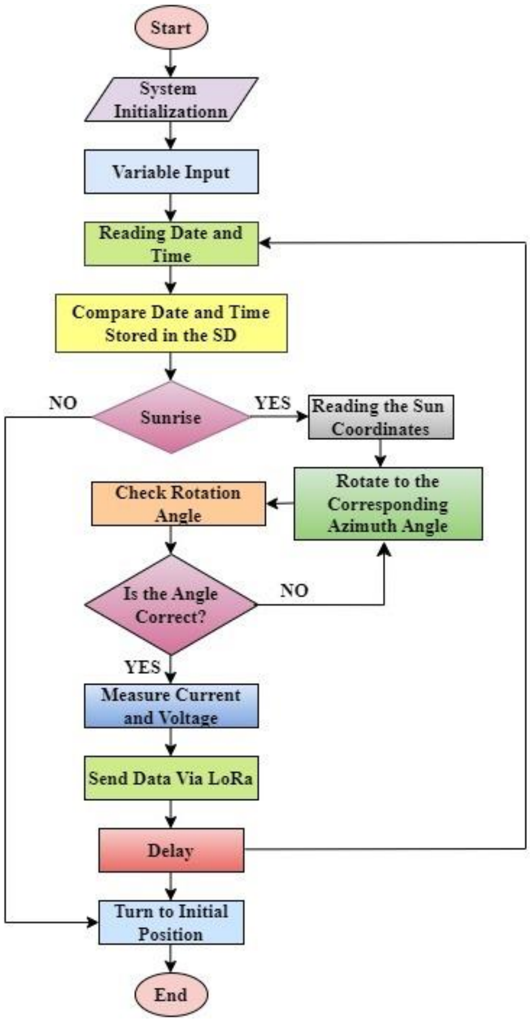


**Figure 5**. Flow chart of single axis solar tracking device.

Figure 4 illustrates an algorithm for controlling the rotation of a motor based on input values from multiple sensors (LU = resistance value of upper LDR, LD = resistance value of down LDR, and LR = resistance value of right LDR) and a specified tolerance (TOLL) value. The process begins by initializing variables and reading the sensor values LU, LD, LR, and the TOLL value. It then checks if the difference between LU and LD is greater than or equal to TOLL, or if LD is greater than or equal to LU plus TOLL. If either of these conditions is true, it rotates the motor down. If neither of those conditions is met, it checks if the difference between LL (resistance value of left LDR) and LR is greater than or equal to TOLL. If so, it rotates the motor left. If not, it checks if LL is less than or equal to LR minus TOLL. If this condition is true, it rotates the motor right. If none of the conditions involving LU, LD, LR, and LL are met, it rotates the motor up. This framework appears to be designed for positioning or alignment purposes, where the motor rotation is adjusted based on the relative values of multiple sensors and a specified tolerance threshold.

However, for experimental comparison, we also developed and checked single axis tracking system. Figure 5 illustrates the framework for controlling a single axis solar tracking, with the aim of optimizing energy capture based on the position of the sun throughout the day. The process initiates with system initialization, ensuring all components are prepared for operation. Following this, the algorithm awaits variable inputs, which might include calibration data or user-defined parameters necessary for proper functioning. Subsequently, it reads the current date and time from the system clock and compares these values with those stored in a memory device, likely an SD card. This comparison serves as a determinant for sunrise time, a pivotal moment for solar tracking operations.

Upon confirming sunrise, the algorithm proceeds to read the coordinates of the sun's current position, crucial information for determining the optimal orientation of the solar panel or tracking mechanism. It then checks the rotation angle of the system, presumably a solar panel or tracking mechanism, to assess its alignment with the sun. If the rotation angle is deemed incorrect, the algorithm initiates adjustments to align the system with the sun's position, typically by rotating it to the corresponding azimuth angle.

Once the orientation is optimized, the algorithm proceeds to measure the current and voltage output, likely from the solar panel or associated components. These measurements provide valuable insights into the system's performance. The collected data, including current, voltage, and potentially other parameters, is then transmitted, known for its long-range data transmission capabilities. Following data transmission, the process introduces a delay, allowing the system to continue tracking the sun's movement throughout the day before returning to its initial position. The process concludes at this point with the next iteration, which would commence with system initialization and the comparison of date and time against the stored values. In summary, this process streamlines the automated control of solar tracking systems, facilitating optimal energy capture and monitoring system performance for efficient and sustainable energy utilization.

## 4.0 EXPERIMENTAL RESULTS AND DISCUSSION

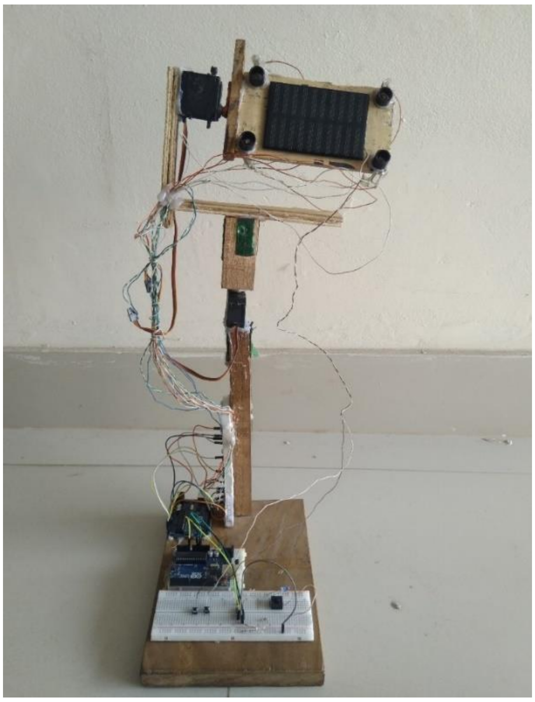

**Figure 6**. Final outlook of prototype dual axis solar tracking device.

The suggested system was installed on a rooftop at Jurain-City, Dhaka, Bangladesh, in order to conduct experiments and measure the results. It was also taken into consideration to set up the dual-axis solar tracking system for testing (latitude: 23.693068 and longitude: 90.445731). Three different configurations for the test were used: fixed, single axis tracker, and dual axis tracker. These annotations were completed for three cases on April 18, 19, and 22, 2023. The time frame for gathering the output power data is 8:00 AM to 6:00 PM. Figure 6 displays the final prognosis for the prototype project.
As is well known, a single axis solar tracker device cannot capture all the sun's strength. Consequently, a single axis solar tracker device performs better than a stationary module. The single axis solar tracker isn't able to gather solar energy from sunlight in predicted amount. For a single axis solar monitoring system only monitors the sun's single path, not its dual axis. For this reason, we suggest installing dual axis solar tracker device for the roofs of all Bangladeshi residential buildings. Table 2 represents the experimental value for all three systems and Equation 1 is used to evaluate the performance efficiency of three systems.

**Table 2**. Recorded power for three different scenarios.

| Time (Bangladesh Time) | Fixed system (Watt) | Single axis system (Watt) | Dual axis system (Watt) |
|---|---|---|---|
| 8.15 | 0.04 | 0.06 | 0.06 |
| 9.00 | 1.46 | 1.70 | 2.13 |
| 10.00 | 2.47 | 2.89 | 3.44 |
| 11.00 | 2.86 | 3.03 | 3.77 |
| 12.00 | 3.21 | 3.46 | 4.31 |
| 13.00 | 3.88 | 4.02 | 4.66 |
| 14.00 | 2.76 | 3.14 | 4.17 |
| 15.00 | 2.35 | 3.02 | 4.00 |
| 16.00 | 1.77 | 2.28 | 3.29 |
| 17.00 | 1.05 | 1.24 | 2.06 |
| *Total* | *21.85* | *24.84* | *31.89* |
| *Average (P)* | *2.18* | *2.48* | *3.18* |

$$\eta = \frac{P_2 - P_1}{P_1} \text{ x } 100\% \tag{1}$$

With the assistance of Equation 1 and data in Table 2, dual axis solar tracking system produces 28.22% more power compared to the single axis system and 45.87% more power compared to fixed system. The output power for each of the three scenarios is graphically evaluated in Figure 7, and the data used to depict those circumstances was experimental data. The graphic evaluation also illustrates the enhanced solar energy conversion for the dual axis tracking circumstance. Although the curve of the single-axis solar tracker is more significant than that of the traditional system. In contrast to the single axis tracker, the dual axis tracker system is demonstrating more effect.

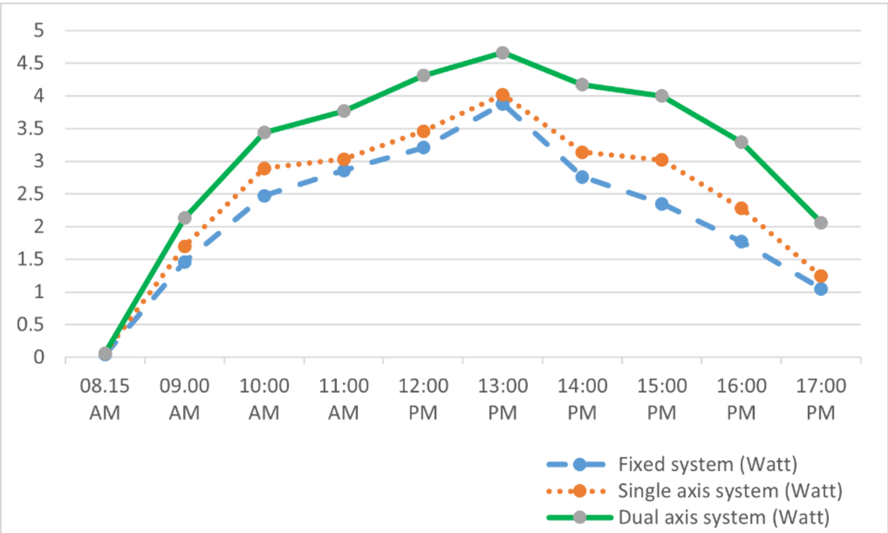


**Figure 7**. Graphical comparison of three different cases

Other methods of tracking solar power exist besides the dual axis system, including power towers, parabolic trough concentrators, central receiver concentrators, parabolic dish concentrators, etc. This whole setup generates more power and is highly efficient [28]. However, setting up each one is highly costly. When compared to other solar tracking systems currently on the market, our suggested dual-axis solution is more economical, easier to install, and more efficient.

## 5.0 CONCLUSION AND FUTURE WORK

A dual axis solar tracking system demonstrates remarkable performance enhancements, precisely aligning with the sun's path and dynamically tracking its movement at a cost-effective scale. Our experiment unequivocally showcases the superiority of dual-axis tracking over fixed and single-axis systems. The data reveals a substantial increase in efficiency with the dual-axis system outperforming the single-axis counterpart by 28.22% and exceeding the fixed system's efficiency by 45.87%. This significant efficiency gain underscores the cost-effectiveness of the dual-axis approach, attributed to its ability to harness more solar energy through precise tracking. Despite the potential advantages, commercial dual-axis solar tracker systems are still relatively uncommon, even in countries heavily reliant on solar power for electricity generation. The prevailing tendency to employ single-axis tracking suggests a gap in understanding the benefits offered by dual-axis systems.

Our research, conducted using photovoltaic cells with sporadic power output, highlights the potential for further enhancements in efficiency and cost-effectiveness with dual-axis tracking. While we utilized monocrystalline PV panels in our study, the suggested architecture is adaptable to panels made of polycrystalline material. Additionally, we acknowledge the limitations of using Light Dependent Resistors (LDRs) as sensors due to their sensitivity to dust, indicating the need for more robust sensor technologies in future iterations.

Furthermore, exploring the feasibility and economic viability of integrating additional panels into the system warrants consideration. This approach may prove more cost-effective than investing in complex tracking frameworks, as reliable tracking mechanisms can incur significant expenses compared to solar panels themselves. Therefore, a more thorough examination of technical performance aspects and cost-benefit analyses is imperative for optimizing solar tracking systems for widespread adoption and maximum efficiency.

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