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# Performance analysis of vertical axis solar tracking systems using Arduino Uno and stepper motor

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**Abstract**
The growing demand for electrical energy has made it essential to find ways to enhance power system capacity. One effective approach is to use photovoltaic (PV) systems with solar trackers to increase energy output. This research focuses on solar trackers that follow the sun's path, maximizing sunlight exposure for solar panels. Specifically, a vertical single-axis tracker was chosen for its cost-effectiveness and higher power output. The design utilizes a satellite dish base, mimicking the sun's movement along a parabolic path. A DC motor and Light Dependent Resistors (LDRs) control the panel's movement, managed by an Arduino Uno microcontroller. The system is standalone, powered by a battery charged by the PV panel. Data were collected by installing both tracking and fixed solar panels, positioned at a 32.77-degree incline and oriented southwest. The results show that the tracking solar panel consistently receives higher solar radiation and voltage, resulting in an 11.39% increase in efficiency compared to the fixed PV panel.

**Keywords:** Solar tracking system, vertical single axis, stepper moto, Arduino Uno, LDR

## Introduction
With each passing day, the world's demand for energy increases exponentially, which is not only the root cause of the continuous depletion of existing natural resources such as fossil fuels, but also the primary cause of escalating environmental pollution. Humanity must thus develop new technologies for generating electrical energy from clean, renewable, and non-polluting sources such as wind and solar power. Solar energy is a well-known non-conventional renewable energy source that has huge potential for conversion into electrical power, fulfilling a significant amount of the world's electrical energy demand [1].

The conversion of solar light into electrical energy is one of the more favorable and challenging energy techniques in improvement, as it is pure, quiet, and dependable, with meager maintenance costs and minimal environmental influence. Solar energy is free, nearly unlimited, and produces no polluting residue. Solar energy is free, nearly unlimited, and produces no polluting residue. Sunlight consists of two components: the direct beam, which carries around 90% of the solar energy, and the diffuse sunlight, which transports the remainder [2].

For the reason that the major part of the energy is concentrated in the direct beam, the sun must stay visual to the panels for as long as feasible to maximize collection. A typical solar panel converts only 30-40% of incident sun irradiation into electrical energy. To achieve a consistent output, an automated system capable of rotational the solar panel continuously is essential. The Sun Tracking System was developed as a prototype to address the aforementioned problem. It operates fully automatically and positions the panel in front of the sun until it is visual [2].

The solar tracking system is essential for getting the most power from the sun. Power generation methods were less diverse back then than they are now, with nuclear power plants hydroelectric power plants, geothermal power plants, and various non-renewable and renewable energy source power generation methods. This paper describes solar power generation as a pollution-free and zero-emission process rather than a nonrenewable energy source [3]. These trackers permit photovoltaic methods to minimize the angle of incidence among incoming sunlight and the sensor in the solar tracking device, hence lowering the quantity of power produced. All focused solar systems include trackers, which turn direct

sunlight into electricity for solar panels. These solar trackers have been discovered to use single-axis tracking technology, which combines solar modules and lowers gadget costs. Solar tracking methods are also beneficial in rural locations when electricity output is limited. One of the more significant parts is the solar panel, which transforms solar energy straight into electricity. Here, the solar panel is made of semiconductor material. Climate change leads solar panels in one direction to get less power. So, Extreme Power Point Tracking is a method for improving power generation from solar panels while keeping P-V solar panels operational [4]. Many previous studies have focused on solar energy tracking systems using the Arduino Uno controller such as Demenkovaa *et al*. [5] discussed the construction of a solar battery control system, specifically the plan of the block responsible for the accumulation of rechargeable batteries and the transfer of generated electric power. The received decisions are meant to be utilized as a knowledge base for intelligent solar panel control systems. Rajvikram *et al*. [6] increased the effectiveness of the solar cell by improving the electrical yield by raising the output power. Faiz *et al*. [7] analyzed the practical installation of a solar tracking system with two axes and four sensors for Baghdad City and found that the energy gained from the solar panel with the dual tracker exceeded 35% of the energy gained from the static solar panel. Compared to the fixed angle method, the proposed tracking system generates 10% to 40% greater power. Furthermore, Lauren Ngan *et al*. [8] reported on several PV systems evaluated in North America, which are split into two categories: Back Tracking (BT) and True Tracking. The first solar has advanced a PV system energy forecast tool that accounts for diffuse shadowing and anticipates 1% to 2% additional energy for systems in TT mode. Hend Abd El-Monem Salama *et al*. [9] designed a two -axis solar tracking system that can track the sun vertically and horizontally employing ideal light sensors connected to the controlling system, which includes the ARDUINO application. The open circuit voltage exceeds the rating of the owned panel voltages, particularly during the middle of the day. Izhar Ahmed Sohu *et al*. [10] explained a 23.93% gain in efficiency for single-axis tracking and 33.23% for two -axis tracking when compared to a stationary system. This prototype generates electricity efficiently using renewable resources. Based on the literature reviewed above, the research aims to generate electrical energy using solar panels through a vertical single-axis solar tracking system using the Arduino Uno Stepper Moto. This study aims to investigate and evaluate the efficiency and effectiveness of a solar tracking system. Specifically, it focuses on a vertical-axis solar tracking mechanism that utilizes an Arduino Uno microcontroller and stepper motors. The study focuses on comparing its energy output against fixed solar panels. It seeks to determine the effectiveness of using an Arduino Uno and stepper motor for controlling the tracking system, assessing parameters such as precision, response time, and overall system efficiency.

## Classification of Solar Trackers

### A. Single-Axis Active Solar Tracking

System The Solar Tracking system is an electromechanical device that rotates photovoltaic panels so that they face the sun, as seen in Figure 1. When the sun goes down, the tracker will either stop operating or go to sleep, depending on the software design, as required by the approach. The sun's location is monitored continuously throughout the day. This technology is widely used in solar trackers, which are designed to track the sun's angle of height (angle of tilt) along a single axis. The panel is controlled by a single linear actuator, such as a stepper motor, that moves in tandem with the sun's movement. The intensity of solar radiation is estimated by installing two light-dependent resistors, or LDRs, on opposing sides of the solar panel and measuring the voltage drop between them. This voltage drop is then compared by a driver circuit based on the controller until the voltages of the two LDRs match, causing the solar panel to cease moving. This ensures that the solar panel faces directly toward the sun at all times [11].

**Fig 1:** Active Single-Axis Solar Tracking

### B. Dual Axis Solar Tracking System

This method was created particularly for usage in non-tropical areas, specifically those more than 10 degrees north or south of the equator. In this manner, the solar tracker's azimuth and tilt angles follow the sun's motions during the year. Figure 2 depicts the two-axis solar tracking system. As a result, the solar panel is moved in the correct route by a couple of actuators, often motors. Four LDRs are placed together, with two on opposite sides of the solar panel, and these LDRs provide voltage control signals to the motors. When the voltage drops across all four LDRs are the same, the motion ceases, indicating that the panel receives the extreme quantity of solar radiation possible. This guarantees that the solar panel is always perfectly positioned to surface the sun [11].

**Fig 2:** Dual-Axis Solar Tracking System

## The System Block Diagram

### Block of Solar Tracking System

The circuit was designed for an embedded application

method. The ARDUINO-based tracking system uses LDRs and stepper motors. The work is divided into three sections: hardware design, tracking system, and ARDUINO processing unit. This solar tracking device turns the solar panel in the direction of the sun or other sources of light using an Arduino Uno board, three stepper motors, four Light Dependent Resistor, and four resistors. The advantage of solar trackers is that they increase the effectiveness of catching solar energy as the earth moves. The four LDRs function as light detectors. They are positioned on either side of the solar panel, with three stepper motors spinning it. If Light Dependent Resistor get equal amounts of light, stepper motors will not revolve. Solar panels will all times follow the sunlight and face it to get charged and produce the most power. A stationary array of solar panels can produce the maximum power at any given time.

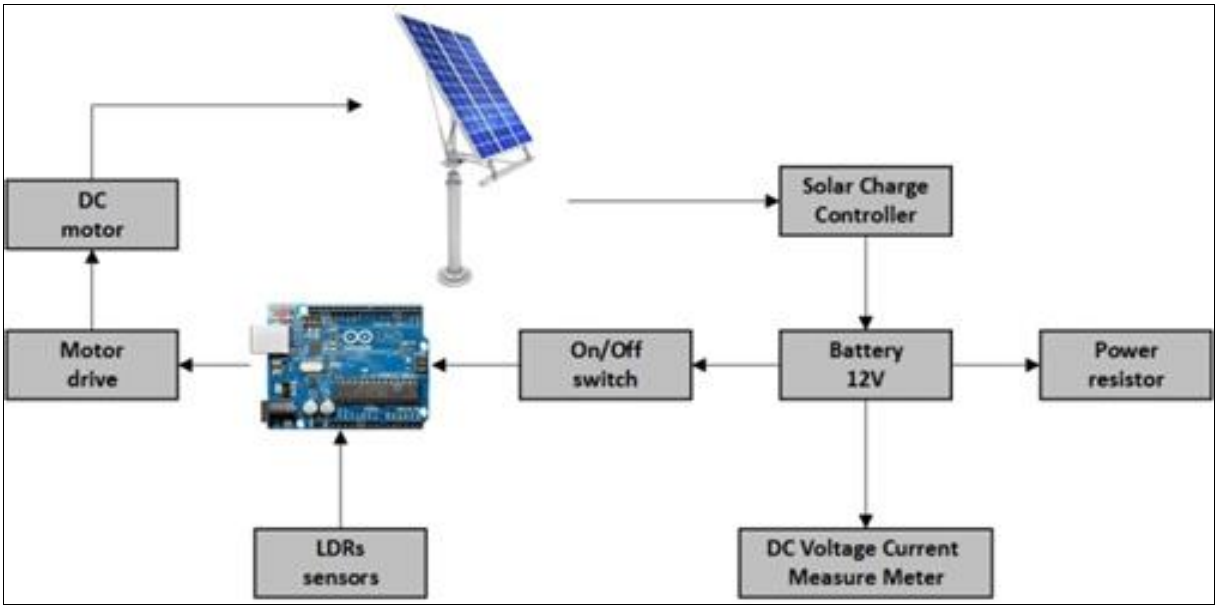


**Fig 3:** System Block Diagram

**The Arduino Uno Board**

A microcontroller board based on the ATmega328P is called the Arduino Uno. Despite having all of these elements, this is not a chip, board, company or manufacturer, programming language, or computer architecture. Fourteen digital input/output pins are present. Six analog input pins, a reset button, an ICSP header, a USB port, a power jack, and a 16 MHz quartz crystal are all included on the device. Everything required to operate the microcontroller is contained in it. The idea is that an application developer can use the board right away without having to invest anything [13].

**Light Dependent Resistor (LDR)**

The simplest kind of optical sensor is a photon resistor, sometimes referred to as a photocell. It is composed of two kinds of light-sensitive resistors: gallium arsenide and cadmium sulfide (CdS). This sun tracker device uses four Cadmium Sulfide (CdS) photocells to detect light. The photocell is a passive part whose resistance varies in direct proportion to the light intensity shining on it. The photocell in the tracker is made to endure both light and dark saturation. An LED light-dimmable resistor (LDR) exhibits a sharp decrease in resistance when exposed to light. The resistance of the LDR rises with decreasing light levels. LDRs (or photo resistors), are commonly employed in circuits to detect the presence or amount of light. They can be referred to by a variety of terms, including light-dependent resistor, photo resistor, photocell, photocell, or photoconductor. Figure 4 shows the construction of the LDRs [14].

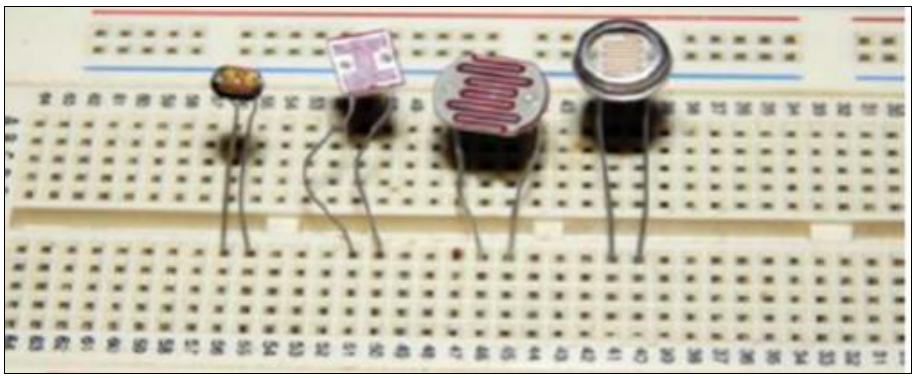

**Fig 4:** The different kinds of LDR

**Light Sensor**

When light strikes a photoconductive substance, it loses its resistance, allowing more current to flow between electrodes. The circuit is a voltage divider (or potential

divider). Here's where the resistor comes in. The circuit uses a fixed resistor (10kΩ) and a variable resistor (LDR). Interestingly, the potentiometer used in the project also functioned as a voltage divider. The voltage (Vin) is connected to both resistors. The voltage (Vout) can be measured across a resistor. If the brightness from the sum grows, the voltage at Vout lowers. As a result, the value detected by the sensor decreases, and the latency following the beep decreases, causing the beeps to occur more frequently. If the resistor and LDR were swapped, the voltage would rise as more light fell on the LDR [15].

**Stepper Motor Driver**

The ULN2003A has seven Darlington transistor drivers and is similar to having seven TIP120 transistors all in one package. The ULN2003A can handle up to 500 mA per channel and has an internal voltage drop of roughly 1V when powered on. The ULN2003 stepper motor driver PCB creates a direct drive interface between the ARDUINO and the stepper motor. The PCB has four inputs for ARDUINO, a power supply connector for the stepper motor voltage, and an ON/OFF jumper. Connect your stepper motor to this header. Step state LEDs show which channel is active. The ON/OFF jumper isolates electricity to the stepper motor. The driver board accepts a four-bit signal from ARDUINO and then applies the required power pulse to step the motor. The board may feed the motor with 5V to 12V from an independent power supply. It also contains a bank of LEDs that respond to the controller's input signals. They create a pleasing visual when stepping [16].

**Solar Panel**

A solar cell is a type of solid-state electrical device that uses the photovoltaic effect to directly convert light energy into electrical power. Solar modules, which gather energy from sunlight, are made from solar cell assemblies. The electrical energy produced by solar modules, commonly referred to as solar power, is referred to as solar energy. Technology and research in the field of solar pertain to the real-world implementation of solar cells in manufacturing. These are employed to measure light severity or detect light or other electromagnetic radiation that is close to the visible spectrum, such as infrared detectors. Figure 5 shows a solar panel or array [17].

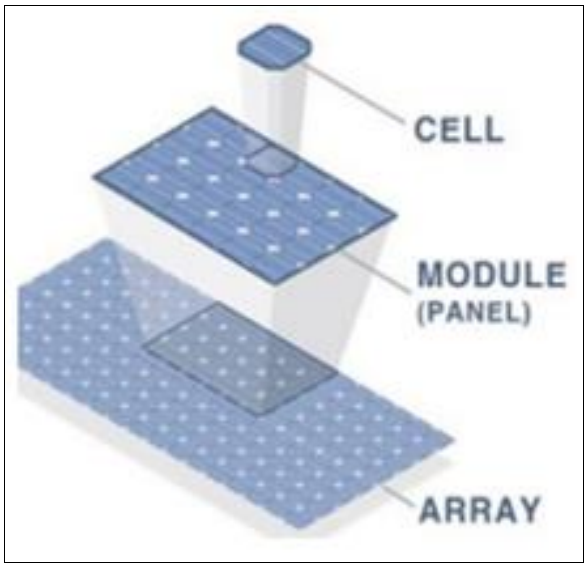


**Fig 5:** Photovoltaic panel or array

**Methodology**

This section describes the experimental setup and the mathematical method used to determine the parameters of the solar panel. To enhance the accuracy of the results, the experiment was conducted outdoors in an open area, ensuring unobstructed sunlight. The test took place from July 2 to July 4, 2024, beginning at 7:00 AM and concluding at 1:00 PM, with hourly readings to monitor the solar panels' performance at different times, in this study, a single-axis tracker due to its cost-effectiveness and higher output power, Initially, the design process involved selecting a simple, affordable, and practical structure. This led to the choice of a satellite dish base due to its similar movement principle along a parabolic path, mirroring the sun's trajectory. The panel's movement is facilitated by a DC motor and Light Dependent Resistors (LDRs), controlled by a microcontroller circuit using an Arduino Uno. This microcontroller is powered by a battery charged by the PV panel, making the system a standalone or passive PV system that operates independently the solar tracker was installed at fixed tilt angles of 32.7 degrees and 44.2898889 degrees at Q7CQ+JX6 Musayib in Babylon Governorate. Positioned to face the southwest, the motor facilitates movement along a parabolic path, mimicking the sun's trajectory. As the azimuth angle changes, the tilt (or altitude) angle remains constant where this solar tracker is operated due to the control circuit shown in Figure 6. Data was collected to compare the performance of a stationary solar panel facing southwest at a fixed tilt angle with that of the same panel controlled by a circuit and motor that adjusted its position to track the sun. During each measurement, the solar radiation severity incident on the solar panel was recorded using a Data Logging Solar Power Meter. Additionally, current and voltage were measured using a DC Voltage Current Measure Meter connected to the solar panel and a power resistor. After completing the setup, the experiment commenced to gather data for analysis. This experiment evaluates the overall system performance by measuring power output, solar irradiance, and efficiency. The solar panel properties, for example voltage and existing flow,

were measured using digital multi-meters.

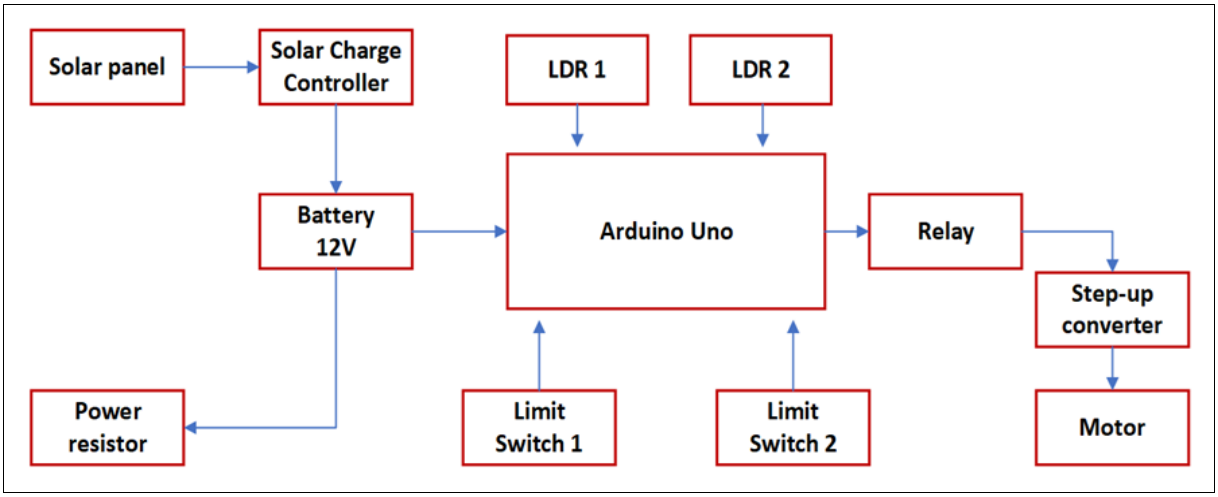


**Fig 6:** Block diagram of control electronic circuit component

Additionally, the motor movement is controlled by an electronic circuit using an Arduino Uno, operating based on the parameters outlined in Table1.This operation is facilitated by the microcontroller connection circuit, where the algorithm for the Arduino Uno, depicted in Figure 7 is programmed using the Arduino software.

**Table 1**: Control process of motor movement.

| No. | Sensor 1 | Sensor 2 | R1 | R2 | M |
|---|---|---|---|---|---|
| 1 | Sun | Shadow | OFF | ON | West |
| 2 | Shadow | Sun | ON | OFF | East |
| 3 | Sun | Sun | OFF | OFF | Stop |
| 4 | Shadow | Shadow | ON | ON | Stop |

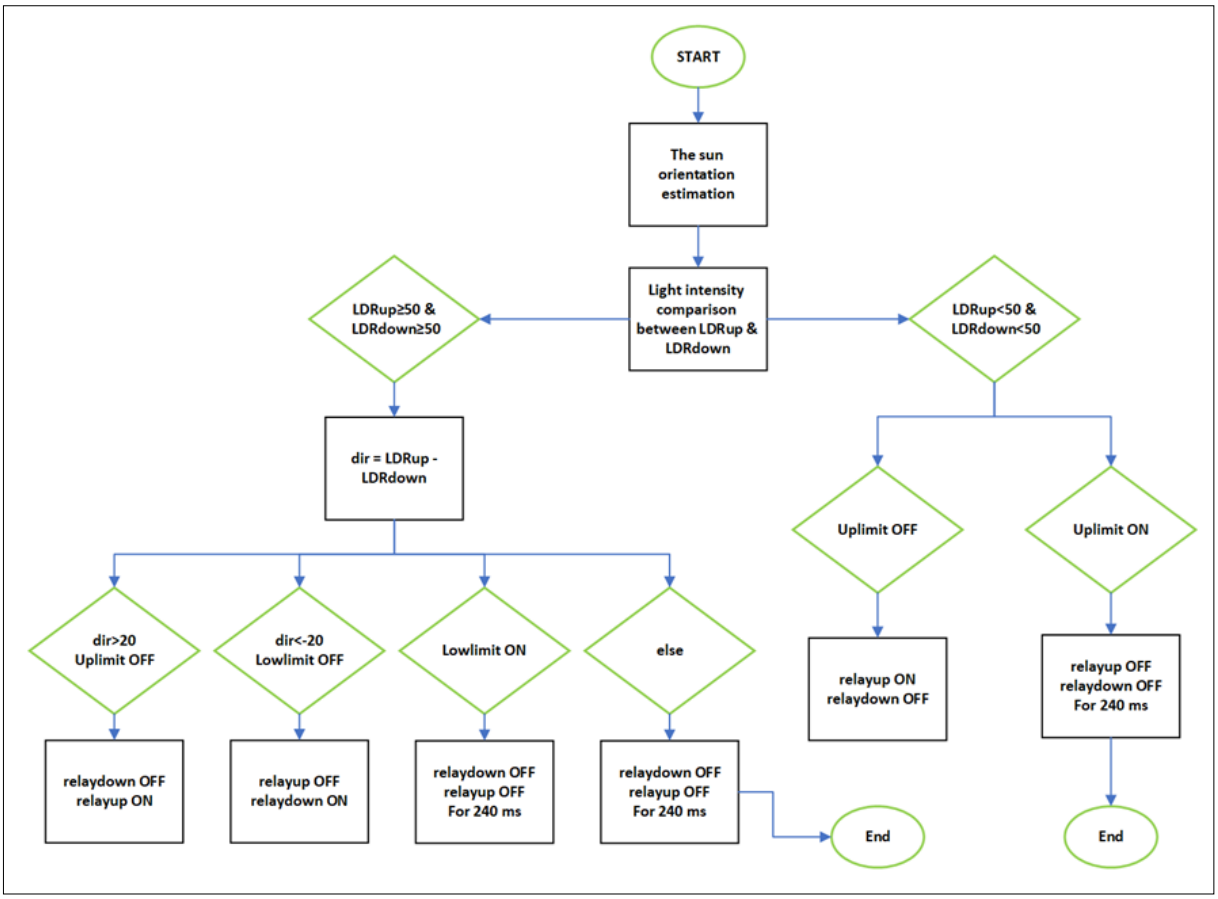


**Fig 7:** Algorithm of Arduino Uno code for vertical single axis solar tracking system

**Results and Discussion**

This section discusses the results obtained from the

conducted experiments. The experiments were done to compare the result between the Fixed solar panel and solar panel with a tracking mechanism towards the sunlight. Based on Tables 1 and 2, the data includes measurements of solar radiation, current, voltage, and power output collected in two conditions: with a fixed PV solar panel and a tracking solar panel respectively, providing insight into the system's performance during peak sunlight hours.

The results highlight the relationship between solar radiation and the electrical output of the system, offering a basis for analyzing its efficiency and consistency. Also, the power generated per hour from tracking solar panels and the fixed panel in the day can be estimated from the equation following and as shown in table 3:

**Table 2**. Show the results of Fixed PV

| Day | Time(hour) | Average Solar Radiation (W/m$^2$) | Current (A) | Voltage (V) | Power(W) |
|---|---|---|---|---|---|
| 2-Jul | 7:00 | 92 | 2.95 | 11 | 32.45 |
| | 8:00 | 240.3333333 | 3.6 | 12 | 43.2 |
| | 9:00 | 425.2666667 | 3.26 | 13.4 | 43.684 |
| | 10:00 | 610.9666667 | 3.09 | 12 | 37.08 |
| | 11:00 | 724.6666667 | 3.4 | 14.1 | 47.94 |
| | 12:00 | 819.0333333 | 3.33 | 14.1 | 46.953 |
| | 13:00 | 863.3 | 3.3 | 14 | 46.2 |
| | | | | | ∑=297.507 |
| 3-Jul | 7:00 | 121.7 | 2.93 | 10.9 | 31.937 |
| | 8:00 | 296.4666667 | 3.19 | 12.1 | 38.599 |
| | 9:00 | 447.5666667 | 3.33 | 13.7 | 45.621 |
| | 10:00 | 625.4666667 | 3.33 | 14 | 46.62 |
| | 11:00 | 740.2666667 | 3.35 | 14 | 46.9 |
| | 12:00 | 855.7 | 3.33 | 14.1 | 46.953 |
| | 13:00 | 864.5 | 3.25 | 14.2 | 46.15 |
| | | | | | ∑=302.78 |
| 4-Jul | 7:00 | 97.26666667 | 3.04 | 12.1 | 36.784 |
| | 8:00 | 259.4333333 | 3.09 | 11.9 | 36.771 |
| | 9:00 | 471.2333333 | 3.28 | 13.3 | 43.624 |
| | 10:00 | 669.5666667 | 3.33 | 13.8 | 45.954 |
| | 11:00 | 750.8333333 | 3.33 | 13.8 | 45.954 |
| | 12:00 | 810.9 | 3.35 | 13.8 | 46.23 |
| | 13:00 | 819 | 3.30 | 14.0 | 46.14 |
| | | | | | ∑=301.457 |

**Table 3:** Show the results of Tracking Solar Panel

| Day | Time(hour) | Average Solar Radiation (W/m$^2$) | Current (A) | Voltage (V) | Power(W) |
|---|---|---|---|---|---|
| 2-Jul | 7:00 | 614.9666667 | 3.4 | 14.6 | 49.64 |
| | 8:00 | 672.8666667 | 3.4 | 14.4 | 48.96 |
| | 9:00 | 728.7333333 | 3.4 | 14.4 | 48.96 |
| | 10:00 | 768.7666667 | 3.36 | 14.2 | 47.712 |
| | 11:00 | 800.7 | 3.36 | 14.2 | 47.712 |
| | 12:00 | 830.6333333 | 3.33 | 14.1 | 46.953 |
| | 13:00 | 865.1333333 | 3.3 | 14 | 46.2 |
| | | | | | ∑=336.137 |
| 3-Jul | 7:00 | 642.9333333 | 3.4 | 14.5 | 49.3 |
| | 8:00 | 716.3333333 | 3.4 | 14.4 | 48.96 |
| | 9:00 | 755.67 | 3.4 | 14.4 | 48.96 |
| | 10:00 | 761.5 | 3.37 | 14.1 | 47.517 |
| | 11:00 | 790.1666667 | 3.35 | 14.1 | 47.235 |
| | 12:00 | 835.1666667 | 3.32 | 14.1 | 46.812 |
| | 13:00 | 864.5 | 3.25 | 14.2 | 46.15 |
| | | | | | ∑=334.934 |
| 4-Jul | 7:00 | 640.2 | 3.44 | 14.5 | 49.88 |
| | 8:00 | 695.9666667 | 3.37 | 14.1 | 47.517 |
| | 9:00 | 754.9333333 | 3.38 | 14.2 | 47.996 |
| | 10:00 | 781.6666667 | 3.36 | 13.9 | 46.704 |
| | 11:00 | 812.7333333 | 3.35 | 14 | 46.9 |
| | 12:00 | 831.5 | 3.37 | 14 | 47.18 |
| | 13:00 | 845 | 3.37 | 14.2 | 47.20 |
| | | | | | ∑=333.377 |

Based on the results in Tables 1, 2 the tracking solar panel consistently receives higher average solar radiation compared to the fixed PV panel. This is due to the tracking panel's ability to follow the sun, maintaining optimal exposure throughout the day where both panels exhibit similar current values, but the tracking solar panel tends to maintain slightly higher current values, especially during the early hours. Furthermore, the voltage output of the tracking

solar panel is always higher than that of the static PV panel, this contributes to the overall higher power output from the tracking panel as shown in figures (8, 9, and 10) for three days respectively.

**Table 3:** Shows the energy in hour for fixed PV and tracking solar panel

| Day | Power in hour for Fixed PV | Power in hour for Tracking Solar Panel |
|---|---|---|
| 2-Jul | 42.501 | 48.02 |
| 3-Jul | 43.25 | 47.85 |
| 4-Jul | 43.06 | 47.63 |

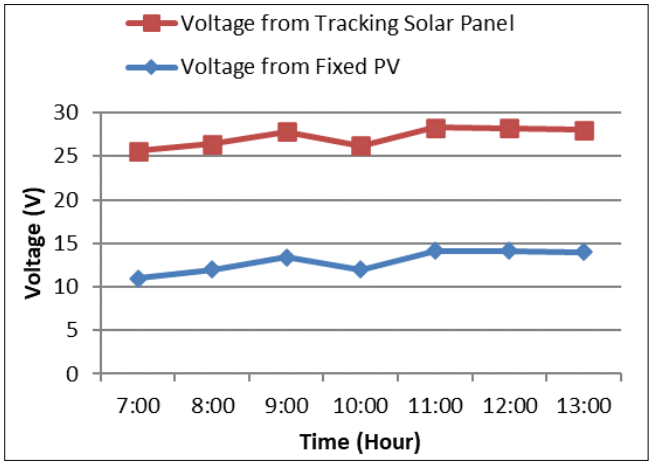


**Fig 8:** Illustrates the relationship between voltage and time for Fixed PV and tracking solar panels on the first day

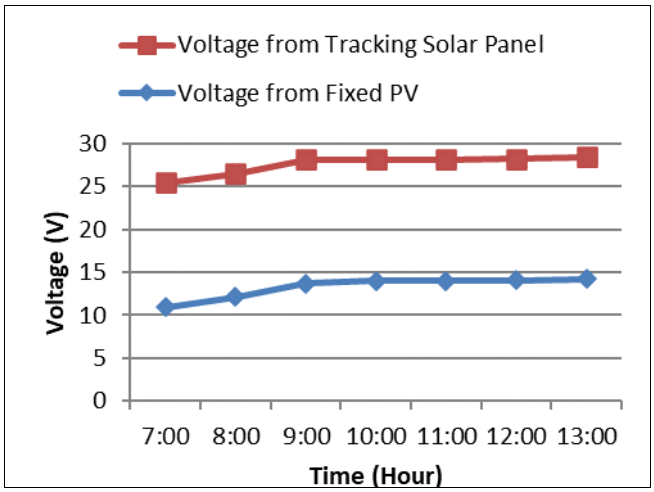


**Fig 9:** Illustrates the relationship between voltage and time for fixed PV and tracking Solar Panels on the second Day

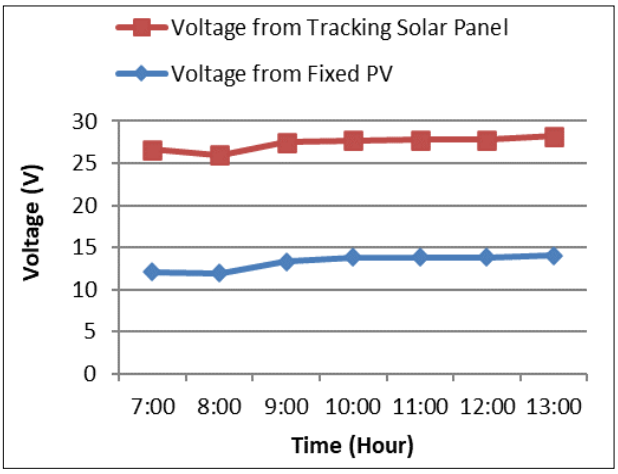


**Fig 10:** Illustrates the relationship between voltage and time for fixed pv and tracking solar panels on the third day

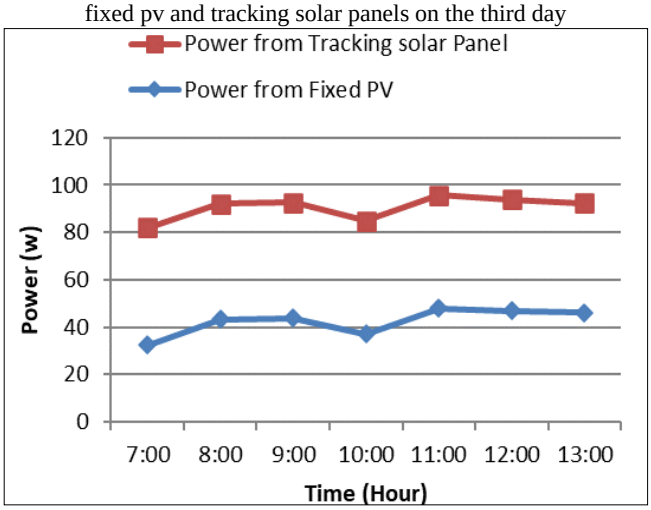


**Fig 11:** Illustrates the relationship between power and time for fixed PV and tracking solar panels on the first day

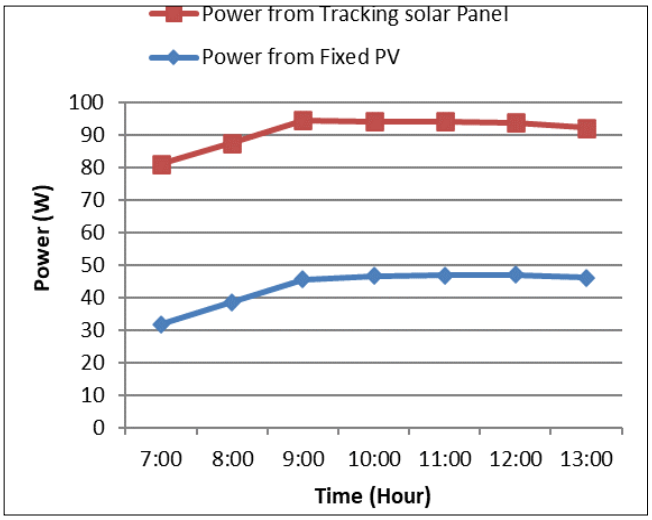


**Fig 12:** Illustrates the relationship between power and time for Fixed PV and tracking solar panels on the second day

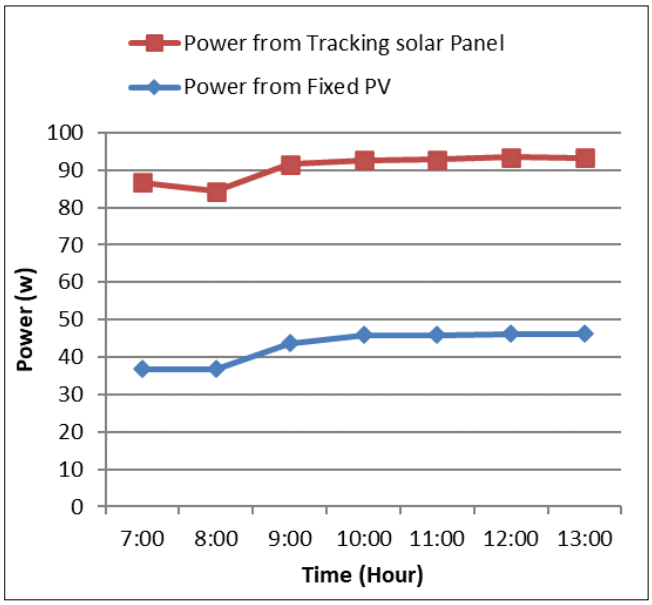


**Fig 13:** Illustrates the relationship between power and time for fixed PV and tracking solar panels on the third day

But regarding Power, the power output (W) is consistently higher for the tracking solar panel across all measured times. The total power output for each day shows that the tracking solar panel outperforms the fixed PV panel significantly as shown in Figures (11, 12 and 13) respectively.

Based on the figures above, the superiority of tracking solar panels over fixed PV panels in terms of voltage output and stability is evident. The tracking solar panel consistently maintains a higher and more stable voltage throughout the day, underscoring its efficiency in converting solar energy into electrical energy. This makes tracking solar panels a better choice for applications that require a reliable and continuous power supply.

Also, the solar tracking power gain can be calculated in both cases using the following equation:

$$\text{Gain} = \frac{\sum tracking\ power - \sum fixed\ power}{\sum fixed\ power} \quad \text{equ.1}$$

Gain = **(**1004.448-901.744/901.744) * 100 = 11.39%

## Conclusion

This study presents an interesting and easy try to evaluate a vertical single Axis Solar Tracker using LDR with Arduino Uno. To achieve this goal, an outside experiment is carried out to evaluate the parameters of solar panels and compare their performance with a tracking mechanism and a fixed solar panel. According to the results, the tracking solar panel consistently receives higher average solar radiation compared to the fixed PV panel. This is due to the tracking panel's ability to follow the sun, maintaining optimal exposure throughout the day where Both panels exhibit similar current values, but the tracking solar panel tends to maintain slightly higher current values, especially during the early hours. Furthermore, the voltage output of the tracking solar panel is consistently higher than that of the static PV panel, which contributes to the overall higher power output from the tracking panel, also using a solar tracking device boosted the efficiency of solar panels by 11.39%. A solar tracking device has been shown to have a day-long advantage over static solar panels by following the Sun's location. This permits the solar panel to absorb more solar irradiance to generate electricity, resulting in a lower cost of electricity. To enhance the performance and efficiency of Vertical Axis Solar Tracking Systems using Arduino Uno and Stepper Motor, the following future recommendations could be considered:

### Optimization of Power Consumption

- Low-Power Components: Consideration using low-power ARDUINO models or microcontrollers to reduce overall energy consumption.
- Power Management Algorithms: Implement smart algorithms that put the system into sleep mode when sunlight is insufficient or during nighttime.

### Enhanced tracking accuracy

- To improve tracking precision, consider using advanced sensors for example LDRs, photodiodes, or camera-based systems.
- Develop adaptive algorithms to modify tracking strategies based on weather conditions.

### Energy Storage and Management

- Integrate batteries to store excess energy generated during peak solar hours.
- Create an Energy Management System (EMS) to maximize the usage of stored energy while balancing consumption and grid interactions.

### Environmental Adaptation

- Design adaptive mounting systems that modify panel tilt angle based on seasonal changes in the sun's position.
- Consideration of local microclimate differences when creating tracking algorithms for optimal performance.

## References

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