https://doi.org/10.24191/jeesr.v27i1.006

Development and Performance Analysis of a Solar Panel with Solar Tracking System

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***Abstract*—In response to the growing demand for renewable energy, there has been significant research in the field of solar power generation. One promising solution to maximize energy production is the integration of solar tracking systems into solar panels. These systems aim to optimize the capture of solar radiation by continuously adjusting the panel's position to align with the sun's rays throughout the day. This report focuses on the development and performance analysis of a solar panel integrated with a solar tracking system. By detailing the design process and conducting a thorough performance evaluation, this study aims to contribute to the advancement of solar tracking technology and its role in enhancing solar energy generation. The system utilizes sensors, actuators, and a microcontroller to continuously align the panel with the sun's direct rays. The report outlines the design process, including the selection of materials and tracking mechanisms, and evaluates the performance of the solar panel with tracking compared to a fixed panel under varying solar conditions. Results indicate that the solar panel with tracking consistently outperforms the fixed panel, capturing more solar energy. The findings contribute to the understanding of solar tracking technology and its potential to enhance solar power generation.**

***Index Terms*—Solar tracking, Solar panel, Fixed angle, Dual axis tracker, Solar power generation**

I. INTRODUCTION

When moving forward into the future, the exponential growth of technology becomes apparent, leading to increased demand for power systems. Conventional energy production, reliant on coal and fossil fuels, is recognized as limited and environmentally harmful due to carbon emissions.

To address these challenges, the utilization of renewable energy sources is crucial. Renewable energy offers a sustainable and environmentally friendly alternative, minimizing depletion of resources and reducing greenhouse gas emissions. By transitioning to renewable energy, it can reduce reliance on fossil fuels, mitigate air pollution and combat climate change, ensuring a cleaner and more sustainable future for generations to come. However, current methods of harvesting energy from renewable sources, such as fixed solar panels, are often inefficient due to their inability to maximize energy production by constantly aligning with the sun. To address this issue, the development of a solar tracking system project was undertaken. This device follows the sun's movement across the sky, increasing the amount of sunlight that falls on the solar panels. By continuously tracking the sun's position using Light Dependent Resistor (LDR) as a sensor, motors, and a microcontroller, the system enhances overall power output and efficiency. Implementing a solar tracking system offers an affordable and effective solution to optimize solar power generation.

The current focus on harnessing solar energy effectively has made the study of solar tracking systems crucial [1]. Understanding the potential benefits and limitations of this technology is essential. A dual-axis solar tracking system is a specific type of solar panel installation that utilizes motors to adjust the panel angles for optimal sunlight exposure. Compared to fixed-panel systems, this system can enhance solar panel efficiency by 10% to 40% [2]. The significance of undertaking a project on dual-axis solar tracking lies in its ability to substantially increase energy generation from solar panels, leading to reduced electricity costs. Additionally, by promoting the utilization of renewable energy sources, it contributes to mitigating the environmental impact of power generation. The purpose of this project is to demonstrate the superior efficiency of the dual-axis solar tracking system in both capturing and converting solar energy into electrical energy.

This paper aims to achieve several objectives such as to maximize the electricity output by ensuring that the solar panel constantly receives the highest possible level of sunlight by using solar tracker system to make sure the solar panel can be in perpendicular with the sun almost all the time. Next, the aim is to enhance the efficiency of the solar panel by minimizing the occurrence of shading on its surface by allowing the solar panel to move away from shading to collect more sunlight on the panel surface. Lastly, this paper also aims to prolong the lifespan of the solar panel by minimizing the stress it experiences from natural elements by continuously adjusting the position and angle of the panels, solar trackers ensure that the panels receive maximum sunlight throughout the day. This increased exposure to sunlight helps in generating more electricity, making the system more efficient. Additionally, solar trackers can also reduce the impact of shading, which occurs when objects or structures obstruct sunlight from

This manuscript is submitted on 21 February 2025, revised on 25 March 2025, accepted on 22 September 2025 and published on 31 October 2025.
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reaching the panels. Shading can lead to localized heating and thermal stress on the panels, potentially causing performance degradation and reducing their lifespan. By actively tracking the sun's position, solar trackers mitigate shading effects and distribute the stress more evenly across the panel's surface. As a result, the solar panel experiences less strain from natural elements, leading to an extended lifetime and improved durability.

II. Methodology

In this methodology there are 3 important things involving theory, software, components and materials.

A. Theory

A solar tracker is a device designed to follow the path of light. Solar tracking system involves adjusting the position of the solar panel in relation to the Sun [3]. Based on [2], solar tracking devices able to increase the power generated by the solar panel by 10% to 40% compared to fixed angle solar panel. The main objective of this study is to improve the efficiency of solar power generation. Fig. 1 shows the traditional approach to solar tracking systems.

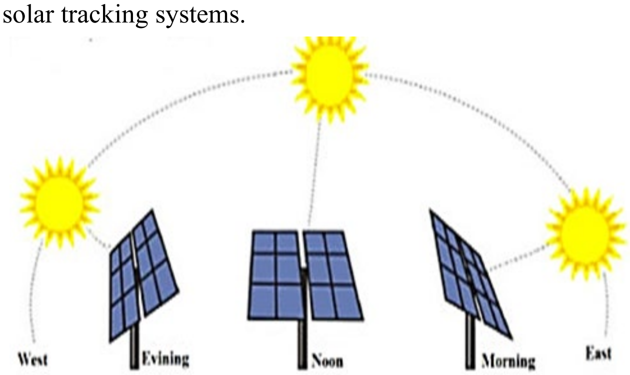

Fig 1. Solar tracking systems

To optimize energy generation, moving solar panel systems rely on efficient solar tracking mechanisms. Author in [7] proposing for this sun tracking system. The author had discussed that the sun tracking system can help the solar panel so that it can absorb maximum solar irradiance to enhance the power output. The sun rises in the East and sets in the West, and it continuously changes its position in the sky all-round the day. So, for solving this problem, an automatic solar tracking system will be beneficial [7]. Single-axis and dual-axis tracking systems have been extensively studied. Single-axis tracking adjusts the orientation of the solar panel along the azimuth axis to follow the sun's east-to-west movement, while dual-axis tracking systems provide more precise tracking by adjusting both azimuth and elevation angles. Research has shown that implementing tracking mechanisms significantly improves energy generation by maximizing the panel's exposure to sunlight. The choice of tracking system depends on factors such as cost, complexity, and energy generation efficiency. The authors had given an idea about implementing a single axis sun tracking system using Microcontroller (ATmega328) and servo motor [8]. A solar tracker produces 27% more output energy than a fixed solar PV tracking system by using an open-loop control system for the electric drive [9]. The two-axis tracker system is 81.68% more effective than the fixed PV modules, and the one-axis solar tracker is 32.17% more effective [10]. The solar tracker system generates 57.55% more energy than a static PV module [11].

B. Components and Materials

There are some main components used in this research to develop a dual axis solar tracking system.

1. Solar Panel

From [4], it states that the materials used in the construction of a solar system can impact its output, and the efficiency can vary depending on the type of materials employed. Monocrystalline cells have a greater conversion efficiency than polycrystalline. However, this study uses a small polycrystalline as it tends to have a slightly higher tolerance for shading [4]. If a small portion of the panel is shaded, the performance of the entire panel is not as severely impacted as with monocrystalline panels. This study uses 0.75 Watt with 5V solar panel. Solar photovoltaic (PV) technology is at the heart of solar energy conversion. It involves the direct conversion of sunlight into electricity using photovoltaic cells. There are different types of PV cells according to their construction materials such as monocrystalline, polycrystalline, thin-film amorphous silicon, concentrated solar PV cells, etc [12]. PV systems are composed of solar panels, which consist of multiple interconnected PV cells. The efficiency and performance of solar panels have improved significantly over the years, with advancements in materials, cell designs, and manufacturing processes. Research in solar PV has focused on enhancing the efficiency, durability, and cost-effectiveness of PV cells, as well as exploring emerging technologies such as perovskite and tandem solar cells.

2. *Light Dependent Resistor (LDR*)

The light-dependent resistor (LDR) sensor is considered a suitable circuit device for use as a sun-pointing sensor [5]. The LDR can be used as a sensor as it can produce an analog value from 0 to 1023 depending on intensity of light. Therefore, it can be used as an input for the microcontroller. LDRs are constructed using a semiconducting material that exhibits high resistance in the dark and low resistance when exposed to light. The resistance of an LDR increases as the intensity of light decreases. By incorporating a fixed resistor into a basic circuit, the resistance of an LDR can be measured, and the voltage across the LDR can be used to determine the light intensity. LDRs find application in industrial and scientific settings for tasks such as measuring light intensity, regulating light levels, and detecting variations in light intensity. LDRs are inexpensive and simple to use. They are inexpensive and simple to interface with other electronic components. Thus, this is the reason why LDR is chosen to be used as the light sensor for this research.

3. Arduino UNO

Arduino is a platform that enables the creation and programming of electronics through an open-source approach. It facilitates data communication with various devices and allows control over specific electrical devices via the internet. Programming an Arduino involves using an Arduino Uno circuit board and a software program based on Simplified C++. In today's world, Arduino has gained widespread popularity in microcontroller programming due to its user-friendly nature. Like other microcontrollers, an Arduino consists of a circuit board with a programmable chip capable of performing a range of tasks. It facilitates the transmission of information from a computer program to the Arduino microcontroller and subsequently to specific circuits or machines comprising multiple circuits to execute specific commands. With an Arduino, one can read data from input devices like sensors and deliver data to output devices such as motors and LEDs [6]. For this research, the Arduino board is used as a microcontroller.

4. Servo Motor

For this research, a motor was needed to allow it to accurately detect and move at moderate speeds to maximize the capture of sunlight by the panels. Two types of motors well-known for their precise tracking applications are the stepper motor and servo motor. Each of these motor drives offers satisfactory performance but comes with its own advantages and disadvantages. The stepper motor is easy to operate in an open loop, cost-effective, mechanically simple, and responds well to digital input. However, it has limitations in step resolution, exhibits high overshot response, has limited power output, and lower efficiency with regular drives. To achieve higher efficiency, a more advanced drive, such as a chopper drive, which supplies high currents in a short time, must be implemented. On the other hand, a DC servo motor provides linear speed-torque characteristics, quick response, and is available in various power ranges. However, they tend to be more expensive compared to stepper motors, and an additional cost is incurred for implementing a closed-loop control system.

Due to their ability to achieve highly accurate and precise positioning, servo motors are widely considered advantageous for tracking applications. They rely on feedback mechanisms, such as encoders, to continuously monitor their position and make necessary adjustments, ensuring precise control. Therefore, this research will use SG90 servo motors to control the vertical movement of the solar panel while for the horizontal axis will be using S3003 servo motors since it has higher torque output so that it will be able to handle a larger load which is all the solar tracker system.

5. Current Sensor

In order to measure current in a circuit, the utilization of a sensor is necessary. The ACS712 Current Sensor is a suitable option for measuring and determining the magnitude of current flowing through a conductor, while ensuring minimal impact on the system's performance. Current value generated by the solar panel will be measured using AC712 current sensor so that it can be recorded for comparison purposes between both fixed angle and dual axis solar tracker solar panel. The value measured by the sensor will be sent to the microcontroller so that it can be displayed on LCD screen.

6. LCD Screen I2C

The I2C display interface is a widely used communication protocol for various types of LCDs, including character, graphic, and segment displays. An I2C display comprises an LCD controller and a display module. Communication between the display and other devices occurs over a two-wire interface, which consists of a data line and a clock line. Voltage values that have been converted from analog input from the solar panel using microcontroller will be displayed on the LCD so do the current value from the current sensor. This will reduce the time needed to collect the data compared to just using a multimeter.

7. Finish Product

Fig.2 shows the LDR position for the project prototype. The position used makes 1 LDR responsible for one direction which is top, bottom, right, and left. Fig. 3 shows the prototype for the dual-axis solar tracking system.

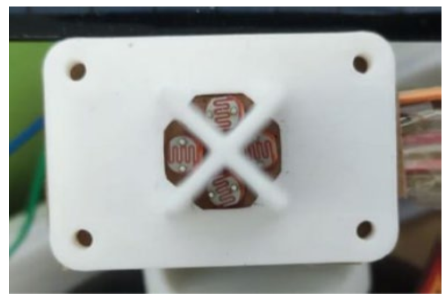

Fig. 2. Position of the LDR

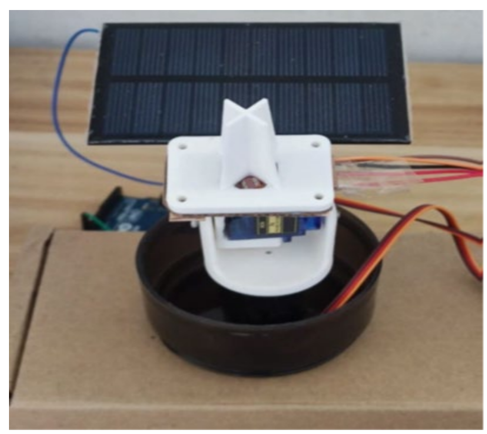

Fig. 3. Dual axis solar tracking system prototype

C. Software

The Arduino Software, an Integrated Development Environment (IDE), is utilized for writing and uploading code to the Arduino board. The Arduino language bears a strong resemblance to the C/C++ language, making it straightforward to use.

D. System Implementation

The algorithm implemented in the system for its effective operation is based on the Arduino programming code. Fig. 4

represents the flow chart for the dual axis solar tracker.

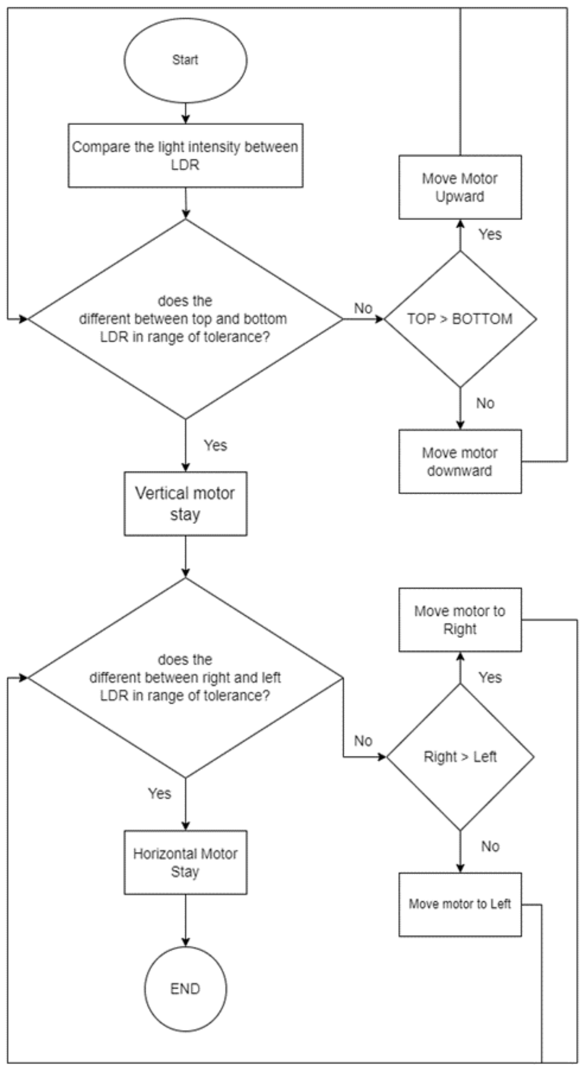

Fig. 4. Flowchart for Dual Axis Solar Tracker

When the solar tracking system is exposed to the light, the LDR will act as light sensor to lead and control the motor to move to the highest light intensity. This will allow the solar panel to stay perpendicular to the sun for the longest time possible. The analysis was done by comparing the power received by solar panels mounted on a fixed tilt with solar panels using a solar tracker. The data is being collected every 30 minutes from 10.00 a.m. until 4.30 p.m. The most suitable tilt angle in Malaysia is 0° until 15° facing south. Thus, the fixed solar panel is installed with 15° tilt angle. However, the LCD only shows voltage and current generated by the panel. Thus, power will be calculated using formula in equation (1).

$$P = I\text{sc} \times V\text{oc} \quad (1)$$

III. Result and Discussion

This section presents the result gained from the comparison between a fixed angle solar panel and dual axis solar tracking system solar panel. When a solar panel measurement taken with a solar tracker yields the highest output voltage and electric current, it indicates that the solar tracker also yields a high-power output. Voltage collected on the LCD screen is shown in Table I while current reading will be displayed on Table II. Table III will illustrate the power calculation.

TABLE I. SOLAR PANEL VOLTAGE

Time of Day	Without Tracking System V_{oc} (V)	With Tracking System V_{oc} (V)
10.00 AM	4.88	4.95
10.30 AM	4.91	4.98
11.00 AM	5.00	5.00
11.30 AM	5.00	5.00
12.00 PM	5.00	5.00
12.30 PM	5.00	5.00
1.00 PM	5.00	5.00
1.30 PM	5.00	5.00
2.00 PM	5.00	5.00
2.30 PM	5.00	5.00
3.00 PM	5.00	5.00
3.30 PM	5.00	5.00
4.00 PM	5.00	5.00
4.30 PM	5.00	5.00

Based on the data from Table I, voltage produced by the solar panel only differs in the early morning. It causes by the shading on the solar panel from where the sun rises causing the solar panel to generate less voltage however for solar panel with tracking system it tries to position the panel to the highest light intensity position to make the solar panel able to produce more voltage compared to fixed angle solar panel. But from 11.00 AM until 4.30 PM, can be seen that the solar panel produces the maximum voltage it can produce which is 5V whether it is embedded with solar tracking system or not. This happens because of diffuse sunlight. Even if the solar panel is not facing the sun directly, it can still receive diffuse sunlight. Diffuse sunlight is light that has been scattered by the atmosphere or reflected off nearby surfaces. While the light intensity is lower than that of direct sunlight, it can still generate some voltage in the solar panel. This also can be caused by the design of the solar panel. When the intensity of the sunlight drops, such as when the sun is not directly overhead, the current output of the solar panel may decrease. This is because fewer photons are reaching the panel, leading to fewer electrons being excited and consequently a lower current. The voltage, on the other hand, remains essentially constant if the panel receives some sunshine. Fig. 5 shows the graph of Voltage Comparison between fixed angle solar panel and dual axis solar tracker.

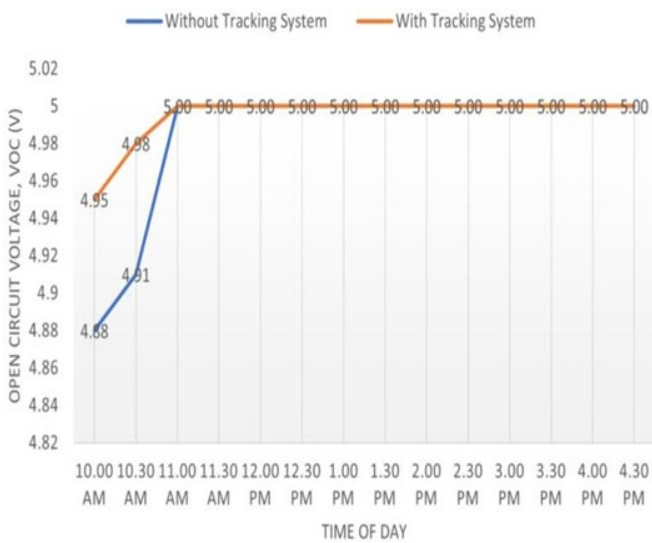

Fig. 5. Voltage Comparison

Table II shows that every measurement from solar panel with solar tracking system produces higher value of current compared to fixed angle solar panel.

TABLE II: SOLAR PANEL CURRENT

Time of Day	Without Tracking System I_{sc} (A)	With Tracking System I_{sc} (A)
10.00 AM	0.096	0.104
10.30 AM	0.099	0.107
11.00 AM	0.104	0.118
11.30 AM	0.110	0.123
12.00 PM	0.118	0.131
12.30 PM	0.139	0.145
1.00 PM	0.131	0.139
1.30 PM	0.126	0.137
2.00 PM	0.121	0.134
2.30 PM	0.118	0.129
3.00 PM	0.115	0.126
3.30 PM	0.107	0.121
4.00 PM	0.104	0.115
4.30 PM	0.109	0.113

This happens because Dual Axis solar tracker are able to position the solar panel all the time the experiment was held making the solar panel receive the maximum sunlight intensity compared to fixed angle solar panel which unable to position the solar panel directly perpendicular to the sun. The angle at which sunlight reaches the solar panel's surface determines the intensity of sunlight hitting the panel. The solar panel receives the most sunlight when it is directly overhead which is at a 90-degree angle. The intensity of sunlight reaching the panel reduces as the angle falls, such as in the early morning or late afternoon when the sun is lower in the sky. The intensity of light has a direct impact on the current output of a solar panel. A solar panel's current output is directly proportional to the amount of light (photons) landing on its surface. More photons impact the panel as the light intensity increases, resulting in a larger current output. When the intensity of the light diminishes, fewer photons reach the panel, resulting in a lower current production.

Fig. 6 shows the graph of current comparison between fixed angle solar panel and dual tracker solar tracking system.

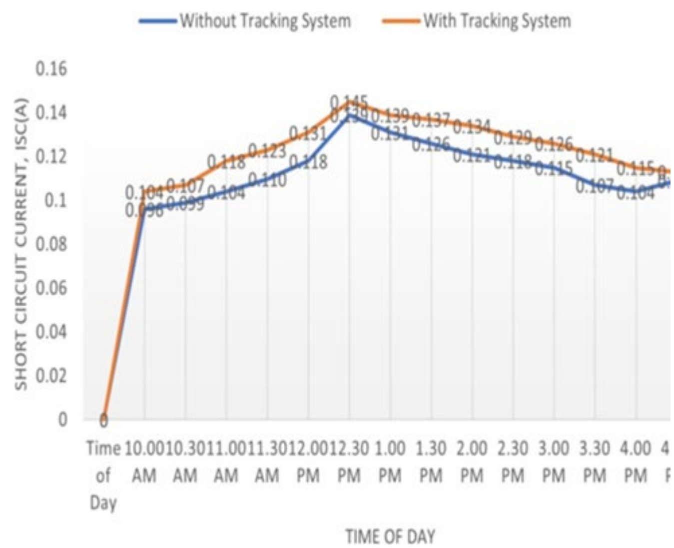

Fig 6. Current Comparison

Table III shows the power calculated from the solar tracking system is higher every time the data were taken compared to the fixed angle solar panel. This happens because solar tracking system is able to receive more sunlight which produce higher current compared to fixed angle solar panel resulting in higher power generation from the dual axis solar tracking system. Fig.7 shows the graph of comparison between power generations between fixed angle solar panel and dual axis solar tracking system. Fig.7 also shows solar panel with tracking system able to produce more power compared to solar panel without tracking system since it is plotted higher in the graph.

TABLE III. SOLAR PANEL POWER CALCULATIONS

Time of Day	Without Tracking System Power (W)	With Tracking System Power(W)
10.00 AM	0.46848	0.5148
10.30 AM	0.48609	0.53286
11.00 AM	0.52	0.59
11.30 AM	0.549	0.615
12.00 PM	0.59	0.655
12.30 PM	0.695	0.725
1.00 PM	0.655	0.695
1.30 PM	0.63	0.685
2.00 PM	0.605	0.67
2.30 PM	0.59	0.645
3.00 PM	0.575	0.63
3.30 PM	0.535	0.605
4.00 PM	0.52	0.575
4.30 PM	0.545	0.565

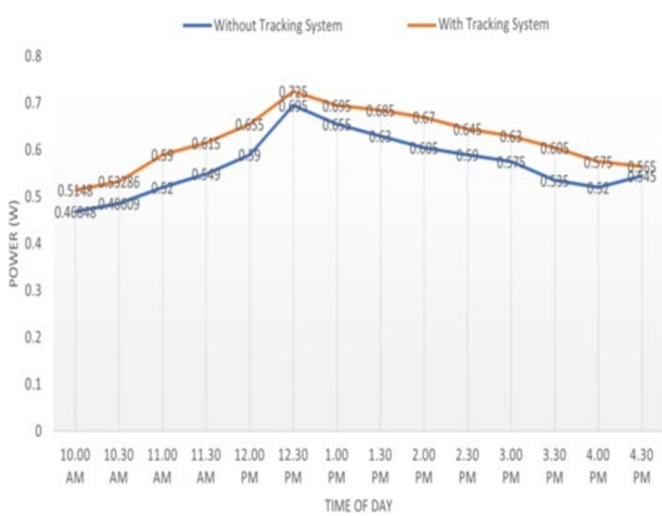

Fig.7. Comparison Power Calculation

IV. CONCLUSION

The Arduino Uno-based solar tracker prototype with LDR light sensor can steer solar panels to the sun throughout the day by tracking the sun's orientation. The output power supplied by solar panels is more when utilizing this solar tracker prototype than when using a fixed angle solar panel. The use of a solar tracker on solar panels results in higher power output than a fixed angle solar panel.

V. RECOMMENDATION

Following the creation and performance study of the solar panel with a solar tracking system, multiple major recommendations for improving the system's efficiency and overall performance were made. As part of the recommendations, it is suggested that higher-rated power solar panels be used. The usage of higher-rated power solar panels can greatly increase the solar panel system's overall energy generation capability. Solar panels with higher power ratings may convert a greater quantity of solar irradiation into electrical energy, resulting in higher energy production. This is especially useful in areas with plenty of sunlight or for applications with high energy demands.

Other than that, it is recommended that additional sensors be integrated into the system to further optimize the performance of the solar panel with a solar tracking system. Sensors, such as light sensors or weather sensors, can be integrated to offer real-time data on ambient light conditions, cloud cover, and other environmental parameters. This information can be used to improve the accuracy and efficiency of the solar tracking system by allowing it to dynamically modify the location of the solar panel based on the weather. The solar tracking system can maximize energy generation by accurately aligning the solar panel with the sun's position by continuously monitoring and responding to changes in environmental conditions. Furthermore, the incorporation of weather sensors can aid in the prediction of unfavorable weather conditions, allowing the system to respond proactively by altering the tracking mechanism or using suitable preventive measures. To enable seamless integration and accurate data collecting, the compatibility and reliability of the selected sensors and the implementation of appropriate data processing and control algorithms must be considered.

The solar panel system can achieve higher energy outputs and enhanced overall performance by including sensor integration, making it a worthwhile improvement for future installations.

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