The Photovoltaic Active Dual Tracking Approach is Transforming Renewable Energy

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Abstract — **Background: Solar photovoltaic (PV) systems have gained traction in the renewable energy market as a clean, long-term electricity source. The static location of classic fixed PV systems, which limits ideal sunshine exposure, is a major obstacle.**

Objective: The article's main objective is to use the Photovoltaic Active Dual Tracking System (PADTS) proposed in this article to improve the efficiency and energy production of PV systems. The PADTS continually aligns PV panels to the sun's position through a dynamic dual-axis tracking system.

Methods: The PADTS has two motorized axes for azimuth and elevation, controlled by a sophisticated tracking algorithm. This algorithm uses real-time solar data to determine the optimal panel orientation. The use of Arduino microcontroller technology allows for more exact sun tracking. Experiment data was gathered to compare the system's performance to standard fixed PV systems.

Results: Initial findings indicate a significant increase in the PADTS's energy output, with efficiency increases reaching up to 30% annually. The system's flexibility enables steady energy output even under changeable sunshine circumstances.

Conclusion: The PADTS represents a major improvement in the PV industry, providing an efficient solution for increased energy efficiency and sustainable power production, with the potential to alter the renewable energy landscape.

I. Introduction

The increased need for renewable energy has resulted in major developments in solar photovoltaic (PV) systems, with the goal of improving energy generating efficiency and output. Solar power is a clean, sustainable, and abundant energy source, making it an attractive option to meet the growing global energy demands while mitigating environmental impacts [1]. One crucial aspect in maximizing the energy harvesting capability of solar PV systems is efficient solar tracking. The concept of solar tracking involves orienting solar panels or PV arrays towards the sun to ensure that they receive the maximum amount of solar radiation throughout the day. Implementing a solar tracking system can significantly improve the overall energy output and efficiency of PV installations [2], [3].

Solar PV systems typically consist of solar panels mounted on fixed structures that capture sunlight and convert it into electrical power. However, as the sun moves across the sky throughout the day, the incident angle of sunlight on the PV panels changes. The quantity of solar energy which can be received and transformed into power is affected by the shifting angle [4], [5]. To address this limitation and optimize the energy generation potential, researchers and engineers have explored the concept of solar tracking.

In recent years, several solar tracking techniques have been developed and studied to optimize the orientation of solar panels towards the sun. One such technique is the Photovoltaic Active Dual Tracking System (PADTS) [6], which combines the principles of solar tracking with active control mechanisms to precisely adjust the orientation of PV panels. The primary goal of the PADTS is to maintain the optimal angle of incidence between the solar rays and the PV panels, as a result, the quantity of solar energy gathered and transformed into electrical power increases.

Various authors investigated the integration of solar tracking techniques with photovoltaic energy systems to improve their efficiency and performance. In study by Gursoy et al [7], the concept of solar tracking and its impact on energy generation are discussed. Additionally, Pooja Jain and Tarlochan Kaur presented research on the optimization of solar PV systems and the analysis of tilt angles to enhance energy generation [8].

The development of smart and cost-effective solar tracking systems has been made possible through advances in microcontroller technology, such as Arduino. The Arduino microcontroller provides a versatile and accessible platform for implementing intelligent control algorithms in solar tracking systems. Researchers have utilized various intelligent control techniques, such as fuzzy-based controllers [9] and two-axis hybrid tracking methods, to optimize the tracking performance of solar PV systems [10].

In this article, we present the design and implementation of a Photovoltaic Active Dual Tracking System (PADTS) that utilizes Arduino microcontroller technology for efficient solar tracking. The proposed system incorporates elements of dual-axis tracking, enabling precise control of the PV panels' azimuth and elevation angles. By dynamically adjusting the orientation of the PV panels based on the sun's position, the PADTS attempts to maximize solar energy absorption and increase total energy generating efficiency [11].

To provide a comprehensive overview, we discuss relevant research studies on solar tracking techniques, including hybrid automatic solar tracking system, high-efficiency dual-axis tracking development using Arduino, and intelligent fuzzy-based tracking controllers. These studies highlight the potential of integrating advanced control algorithms to optimize solar tracking performance and enhance energy generation in PV systems.

Moreover, we explore the benefits of integrating solar tracking mechanisms with PV systems through the analysis of solar maps and dual-axis tracking strategies. Sun tracking strategies can significantly improve energy generation, especially in regions with varying solar irradiance patterns.

Furthermore, we examine the potential of cost-effective Perturb and Observe Maximum Power Point Tracking (MPPT) methods [12], [13] using Arduino microcontrollers for standalone photovoltaic systems. MPPT techniques are crucial in extracting the maximum power from solar PV panels under varying environmental conditions, ensuring efficient energy conversion.

The Photovoltaic Active Dual Tracking System (PADTS) demonstrates a promising solution for increasing the energy output and efficiency of solar PV systems [14] through precise solar tracking. By harnessing the capabilities of Arduino microcontrollers and intelligent control algorithms, the PADTS presents an innovative approach towards optimizing solar PV energy generation. This article aims to contribute valuable insights into the advancements in solar tracking technologies and their potential impact on renewable energy generation in the future. As the world seeks sustainable energy solutions, the PADTS represents a promising step towards harnessing the full potential of solar power and reducing our dependence on conventional energy sources.

A. *Aim of the Article*

The closed-loop optimization of the solar tracker is a critical aspect illustrated in Figure 1.1, with the primary goal of achieving optimal verticality between the incident sunlight and the surface of the PV panels. Utilizing the Arduino platform, the controller employs solar cell sensors and an operational amplifier to provide feedback. The comparator analyzes the output intensity, and the amplified error voltage is fed back through the solar cell sensors, comparing responses from the North, South, East, and West. This assessment leads to identifying any imbalance, which triggers radial differences. In a two-in-two activity, these differences influence the comparison process, resulting in either extension or retraction of the rod linear actuator to optimize altitude motion, or turning by a servo motor to enhance azimuth motion efficiency [15].

The controller's mechanism involves monitoring a solar photovoltaic panel alongside radiant cell. When a differential signal is detected due to discrepancies, it prompts a real-time adjustment of the solar panel's position until practically zero fault voltage is achieved. The Arduino platform effectively captures and stores pairs of data related to altitude and azimuth, further driving the motors' movement to maintain the optimal orientation of the solar PV system [7]. Through this closed-loop approach, the solar tracker continuously ensures that the PV panels capture the maximum available solar energy, contributing to improved energy generation efficiency and improving the effectiveness of the photovoltaic system.

B. *Problem Statement*

The article discusses a notable issue within the realm of solar energy generation. The issue statement centers on the inefficiencies and constraints of conventional single-axis tracking systems for photovoltaic (PV) panels.

The use of single-axis tracking systems has been extensively adopted to enhance the energy output of photovoltaic (PV) panels by effectively monitoring the sun's trajectory throughout the day. Nevertheless, these systems are intrinsically limited by their incapacity to monitor the azimuth and elevation of the sun concurrently. This constraint leads to less-than-ideal energy acquisition, particularly during the morning and evening when the sun's elevation angle is relatively low.

The issue statement emphasizes the need for a novel approach to improve the efficiency of photovoltaic (PV) panels. The proposed active dual-tracking system aims to address the limitations of single-axis tracking by concurrently modifying both azimuth and elevation angles. This approach guarantees that photovoltaic (PV) panels continually get optimal sunshine exposure. This study aims to investigate the shortcomings of conventional tracking systems and enhance the total energy efficiency of solar installations.

Fig. 1. Sun Tracking Solar Panel

II. LITERATURE REVIEW

The primary topic of the article pertains to the advancement and assessment of a dual-axis solar tracking system, intending to enhance the efficiency of photovoltaic (PV) energy harvesting. This literature review critically analyzes the primary research and notable developments in solar tracking systems, focusing on their significance in augmenting the efficiency of photovoltaic (PV) systems.

Solar photovoltaic (PV) power production has garnered considerable interest owing to its capacity to provide environmentally friendly and sustainable energy solutions. The authors Comello et al. examine the potential advancements of solar photovoltaic (PV) power and emphasize the significance of enhancing efficiency and performance within this domain [1]. It establishes the context for investigating novel solar tracking devices, such as the one discussed in the article.

The study's authors, Jamroen et al. [2], presented a new solar tracking system that uses UV sensors to follow the sun's movement in two axes. They emphasized the need for accurate tracking mechanisms to optimize energy capture. This study contributes to the field by introducing an innovative approach to solar tracking. The present study follows the aim of the paper titled "Photovoltaic Active Dual Tracking System" to enhance energy production using sophisticated tracking techniques.

Zhu et al. conducted a study examining a solar tracking system including a unique single-axis tracking construction to optimize energy harvesting [3]. The present study enhances the overall comprehension of solar tracking methodologies and their possible implications on energy efficiency.

The study conducted by Awad and Gül focuses on the design considerations for solar photovoltaic (PV) systems based on load matching. The authors emphasize the significance of aligning energy output with consumption to decrease reliance on the grid [4]. Solar tracking systems are of utmost importance in solar energy, as they contribute significantly to optimizing photovoltaic system performance.

Abdollahpour et al. investigate advancing a dual-axis solar tracking system using machine vision technology, aligning with the progressive strategy of incorporating technology into solar tracking systems [6]. The developments mentioned above are relevant to the study undertaken in the paper titled "Photovoltaic Active Dual Tracking System."

In their study, Gursoy et al. investigates sliding mode control in photovoltaic energy conversion systems. The authors discuss several control schemes that can potentially enhance the performance of PV systems [7]. The presence of efficient control mechanisms is crucial for ensuring the smooth functioning of solar tracking systems, hence making this study pertinent to the subject.

Kaur discusses optimizing solar photovoltaic (PV) systems, specifically focusing on studying tilt angles. The author emphasizes system design's significance in achieving efficient energy collection [8]. The design feature in question aligns with the aims outlined in the text.

The incorporation of cooling mechanisms and the implementation of maximum power point tracking, as elucidated by Zainal et al. [9], exemplify the amalgamation of several methodologies to augment the operational efficiency of photovoltaic systems. The significance of power management in solar tracking systems cannot be overstated since it directly influences energy conversion efficiency.

The article comprehensively analyzes an essential part of solar energy production. It focuses on enhancing the efficiency of photovoltaic systems by using sophisticated tracking techniques. The studies referenced in this study highlight the importance of solar tracking systems in boosting energy capture, optimizing the output of photovoltaic systems, and promoting the overall sustainability of solar power production. These studies jointly contribute to the progression of solar technology and its wider use as a sustainable energy source.

III. METHODOLOGY

The article aims to create a solar tracker demonstration using solar panels and Arduino Uno, which is an easily accessible microcontroller. Initially, photodiodes were used to measure light levels, but due to their limited view window, the decision was made to switch to Mini Solar Cells, which offer a larger surface area for capturing light. Although Mini Solar Cells may not be identical, they provide analog values indicating light levels. The Arduino Uno reads these values from Mini Solar Cells placed in different directions, namely north, south, east, and west [6], [16].

Pairs of Mini Solar Cells are set up for east-west and north-south directions. A separator between the Mini Solar Cells helps detect shadows if the panel is not facing the sun directly [17]. When one Mini Solar Cell in a pair is shadowed, its analog level differs from the other. If the analog levels are greater than a certain threshold, the Arduino Nano commands the Servo motors to rotate the solar panel 1 degree in the direction where the Mini Solar Cell has a lower level of light. The rotation continues until the panel aligns with the sun [18].

The system determines two values of degrees: north-south degree and east-west degree. By rotating the PV panel using these values, it achieves synchronized movement with the sun's trajectory. The main components utilized in this solar tracking system are Arduino Uno, Light Dependent Resistors, Mini Solar Cells, and servo motors [19].

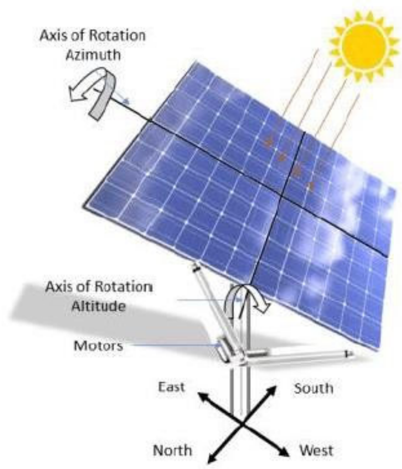

Fig. 2. Sun Tracking Solar Panel

Fig. 1 illustrates the adopted methodology, where five Mini Solar Cells are connected to Arduino's analog pins AO to A4, serving as inputs. The analog values from Mini Solar Cells are converted to digital using the built-in Analog-to-Digital Converter (ADC) of the Arduino Uno. The system ensures the solar panel remains optimally oriented towards the sun, maximizing its energy capture efficiency.

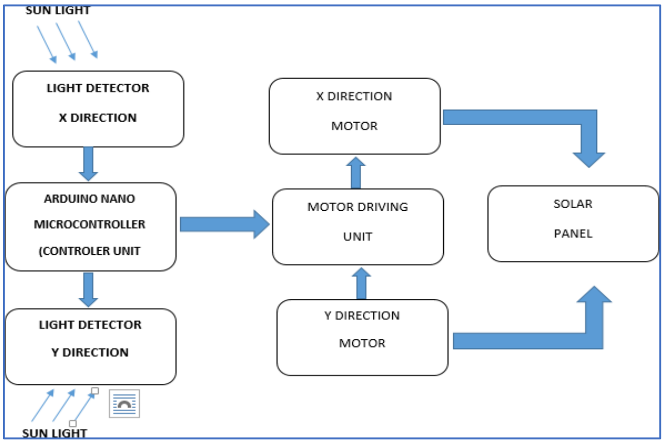

Fig. 3. Block Diagram of Hardware Implementation of Dual Axis Solar Tracker

The servo motors' movement in the solar tracker system is controlled by applying values of PWM pulses. Among the input Mini Solar Cells, the one capturing the maximum light intensity is selected, and the servo motor moves the solar panel to the corresponding position set up in the programming. The servo motor has three points of rotation: 0, 90, and 180 degrees.

To detect the highest intensity of sunlight, the positions of the Mini Solar Cell are divided into five categories: centered, right, left, up, and down. Each of these positions enables optimal sunlight detection. The microcontroller receives analog input from the Light Dependent Resistor (Mini Solar Cell), which is then converted into a digital signal using the Analog-to-Digital converter [20]. Based on this input, the servo motor is directed to move the solar panel, ensuring it aligns precisely with the sun's position for maximum energy capture efficiency.

A. Hardware components

1) Arduino Nano: The unit under discussion is an Arduino board known as the Nano, which offers 14 digital pins for connecting with external components. Additionally, it provides 6 analog pins, each with a resolution of 10 bits, along with 2 reset pins and 6 power pins, all integrated onto the board [21].

Operating at a voltage of 5V, the Nano has an input voltage range of 6V to 20V, with the recommended input voltage falling between 7V to 12V. The clock frequency of this device is 16MHz, allowing it to generate a clock of a specific frequency using a constant voltage. The Nano supports a USB interface, employing a mini-USB port, distinguishing it from most other Arduino boards that use a standard USB port. However, it's worth noting that the Nano lacks a DC power jack, preventing it from being powered directly from an external power supply.

Despite its compact size, the Nano remains breadboard-friendly, meaning it can be easily connected with breadboards, enabling a wide range of electronic projects to be undertaken.

Regarding memory, the Nano utilizes flash memory to store the program. For the Atmega168 variant, the flash memory size is 16KB (with 2KB reserved for the Bootloader), while for the Atmega328 variant, the flash memory size is 32KB. The Nano also has EEPROM of 512KB and 1KB, and SRAM of 1KB and 2KB for Atmega168 and Atmega328 respectively [22].

In comparison to the UNO board, the Nano shares similarities but is smaller in size and does not feature a DC power jack [23], [24]. This makes the Nano a versatile and compact option for various electronic projects.

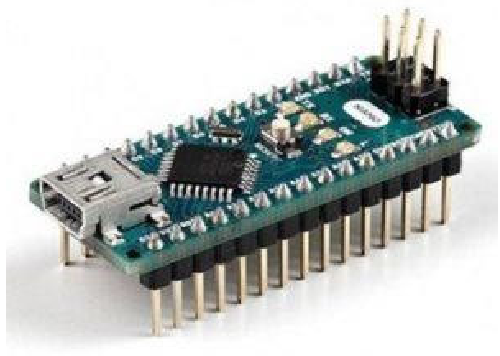

Fig. 4. Arduino Nano

*2) 5V 30MA Mini Solar Cell Polycrystalline Solar Panel/ 53*30mm:* To measure the intensity of light and darkness, we employ a sensor known as a Mini Solar Cell. This specialized sensor exhibits a unique behavior, allowing high voltages to flow through it (low impedance) in bright light conditions, while passing low voltage (high impedance) when it is dark. This distinctive property of the Mini Solar Cell makes it ideal for integration into our Arduino mini solar cell sensor project. By utilizing this sensor, we can effectively detect variations in light intensity and darkness, enabling precise solar tracking and optimization in our system [25].

Fig. 5. Small Solar Cell

Power: 0.66W Voltage: 5.5V current: 120mAh

Material: monocrystalline silicon Size: 85.5 x 58.5 x 3mm Weight: 20g

3) Performance test condition: Solar panel performance testing is vital for understanding their efficiency and output potential. Solar radiation, temperature, and other environmental parameters all have an impact on the output power of solar panels. To guarantee precise measurements, the assessment is carried out under standard circumstances (STC), which are as follows: The air quality is AM1.5, the light density is 1000 W/m2, and the temperature is 25°C.

The maximum power output of a solar panel is calculated and referred to as the maximum power under STC. A solar simulator is often used to measure this [13]. A solar panel's performance may be influenced by a number of variables, the most important of which are:

- Load resistance: The resistance linked to the output of the solar panel might affect its power generating capability.
- Sunlight intensity: The amount of solar irradiance received by the solar panel has a direct impact on its power output.
- Temperature: The solar panel's operating temperature might have an impact on its overall performance and efficiency.

The capabilities and limits of the solar panel may be precisely measured by taking these elements into account and performing performance testing under standardized settings, allowing for greater use of solar energy resources [26].

4) Operational Mechanism: The functioning of this system relies on the detection of light intensity in its surroundings, facilitated by a Mini Solar Cell sensor. This sensor is easily accessible and can be purchased from local electronics stores or online at a reasonable cost. When the Mini Solar Cell is connected to a voltage supply (VCC) of 5V, it generates an analog voltage that varies in proportion to the intensity of incident light on its surface. Consequently, higher light intensity leads to a correspondingly greater voltage output from the Mini Solar Cell [27].

Since the Mini Solar Cell produces an analog voltage, it is connected to one of the analog input pins on the Arduino board. The Arduino, equipped with a built-in Analog-to-Digital Converter (ADC) [28], converts the analog voltage (ranging from 0-5V) into a digital value within the range of 0 to 1023. When the environment or the surface of the Mini Solar Cell is sufficiently illuminated, the converted digital values read by the Arduino will typically fall within the range of 800 to 1023. This conversion enables the Arduino to effectively sense the light intensity and use this data to control the solar tracking system.

Fig. 6. Arduino Mini Solar Cell Sensor Working

The Arduino is then programmed to activate a relay. When the light intensity is low (this may be accomplished by covering the surface of the Mini Solar Cell with any item), switch on an appliance (light bulb), indicating that the digital values read are in a greater range than normal.

5) DC Motor 12 Volt: The actuator motor is designed to be used with a 24-inch positioner, suitable for antennas ranging from 180cm to 240cm and supporting weights up to 458kg. It can be installed with a positioner or a receiver that integrates a conventional 12-volt positioner equipped with reed sensors and limit switches. The package includes a mounting clip and screws for easy installation.

Fig. 7. DC Motor

The actuator motor comprises a DC motor, gear box, and a final worm screw, which collectively convert the motor's rotational motion into linear operation. When the actuator is supplied with a normal DC voltage polarity, it extends, represented by the "yellow" section in. Conversely, supplying the motor with "reverse polarity" causes the actuator's length to decrease.

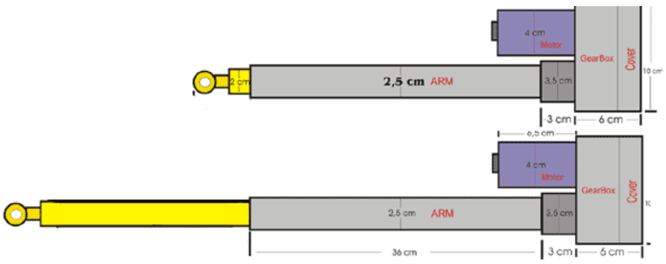

Fig. 8. DV Motor Size

To initiate the motor's operation, it requires a voltage range of 12-36 volts, depending on the specific model used. In this case, the 12V model is utilized, resulting in a smaller current in the feed cable between the positioner and the antenna.

One advantage of the actuator motors is their high sensitivity. In the present system, using only 12V and 0.25A, the actuator moves at a slow pace, which proves beneficial for making precise elevation angle corrections, especially when dealing with small adjustments.

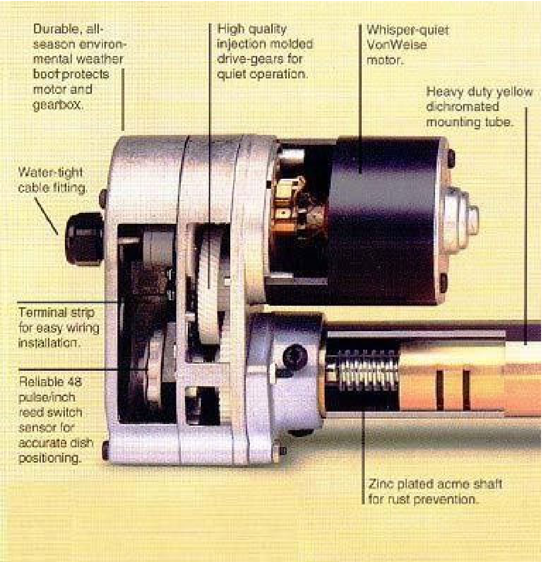

Fig. 9. Engine Internal Assembly

6) Power 12 Volt Car Batteries: In our experiment, we used a vehicle battery to power the motors, which we changed to 12 volts by altering the number of revolutions in the motor. The 12-volt battery is a flexible power source utilised in specialized electronic applications, and it comes in a variety of configurations depending on its intended usage. It represents one of the greatest diversified kinds of batteries accessible, with a broad variety of shapes and sizes, weights, and looks. Some 12-volt batteries seem like standard AA batteries, but others might be significantly bigger and heavier [29].

A 12-volt battery is often used in automobiles and watercraft. In such circumstances, the battery is often rechargeable since it is mostly required for starting the vehicle's engine. When the engine starts, an alternator takes over the functioning of the electrical system, thereby making sure the battery gets a charge while in operation.

Fig. 10. Power Battery 12 V

The size of 12-volt batteries may vary greatly depending on their amp-hour capacity, which determines how much energy they can provide. Because of their greater amp-hour ratings, vehicle batteries, for example, are often bigger and heavier. Smaller 12-volt batteries, on the other hand, are found in electric children's cars used in front yards, providing a lighter and more compact power supply for these applications.

7) Software Implementation: The software component includes a language for coding built using C programming. The programs are intended to be generated and uploaded to an Arduino UNO. Figure 3 depicts a flowchart illustrating the method used in Arduino code.

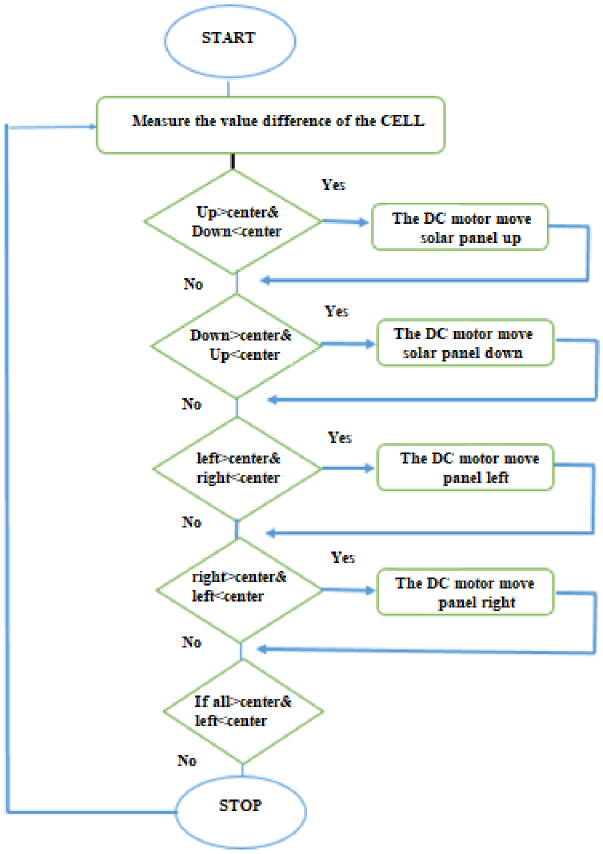

Fig. 11. Algorithm for Dual Axis Solar Tracker

The aforementioned hardware and software are used to build and construct the full dual-axis Solar Tracker. Figure 12 shows the completed Dual axis solar tracker.

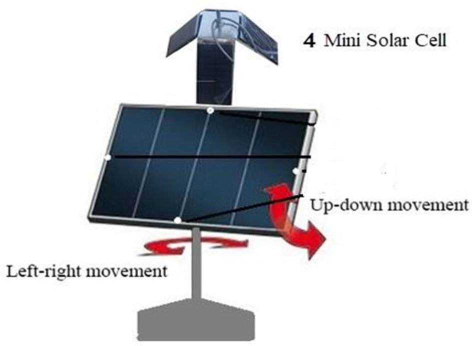

Fig. 12. Dual Axis Solar Tracker

B. Method

The main light sensors used in our setup are small solar cells. These solar cells are mounted on the structure that holds the solar panel, acting as a base for the stainless-steel plate installation. To enable efficient tracking, the solar panel is equipped with two DC motors.

For east-west tracking, we divide the small solar cells into four groups: top, bottom, left, and right. The analog values from the two small solar cells at the top and the two at the bottom are compared. If the top group of mini solar cells receives more sunlight, the vertical servo will move in that direction. Conversely, if the bottom small solar cells receive more sunlight, the support will move accordingly [30].

To adjust the solar panel's angular deflection, we compare the analog values from the two small solar cells on the left and the two on the right. If the left group of mini solar cells receives more light, the horizontal servo will move in that direction. Similarly, if the right group of mini solar cells receives more light, the servo will move accordingly [31].

To ensure each side has its own cell, the mini solar cells are connected at an acute angle, forming a voltage divider circuit with resistors. We then connect the circuit with resistors to wires and attach them to port A0, A1, A2, and A3 for proper monitoring and control.

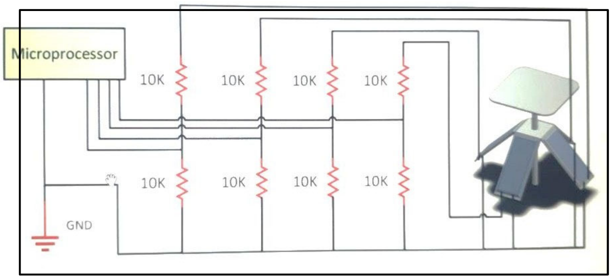

Fig. 13. Connecting Mini Solar Cells

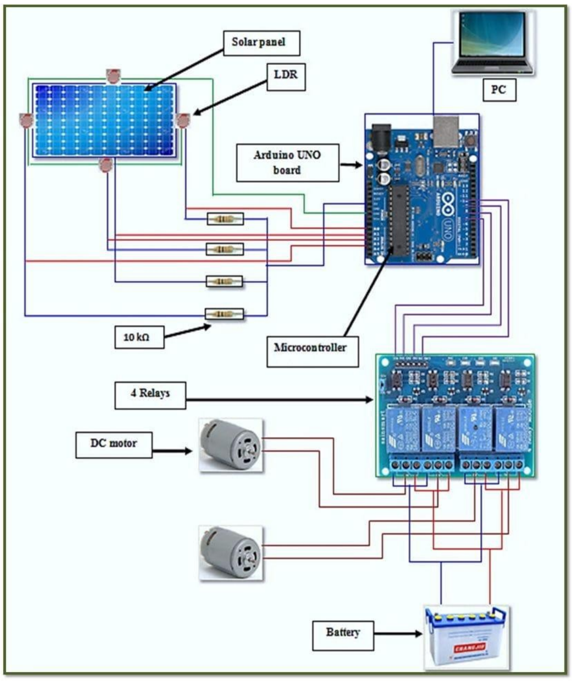

Fig. 14.System Circuit

In the schematic, we can see that the four photocells are connected to the Arduino Nano via its analogue inputs (A0, A1, A2, and A3) so that it may collect light-related data. In addition, the configuration has four channels of relays, with one pair of relays governing the forward or reverse motion of a given motor. The microcontroller determines the motor's rotational direction by controlling the polarity of the motor through the relays and the battery. The microprocessor causes the motor to revolve clockwise when power is supplied to its positive terminal and anticlockwise when power is supplied to its negative terminal [29].

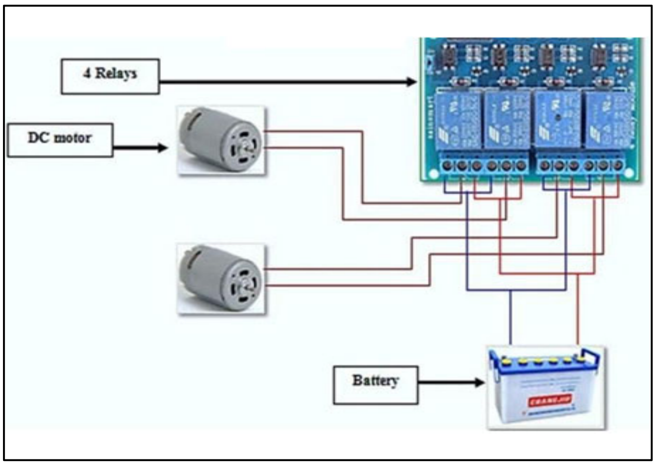

Fig. 15. Connect Relay with Battery

In our setup, we establish a connection between the Arduino board and the digital ports (D7, D8, D9, and D10). This enables us to transmit commands from the solar cells to the digital ports and subsequently to the 4-channel relays responsible for motor control.

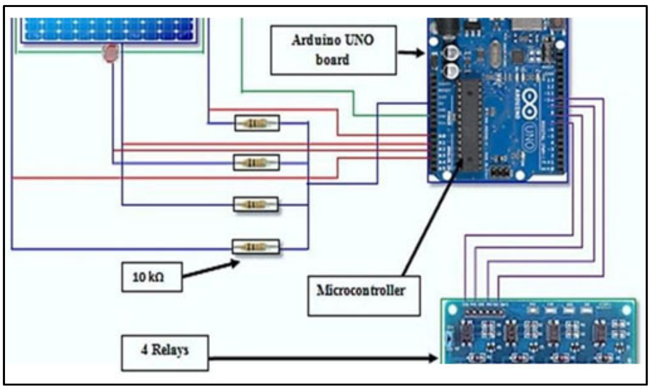

Fig. 16. Connect Ports to Arduino

C. *Dual Axis Solar Tracker Sensor*

The circle comprises four small solar cells, each representing a side (top, bottom, right, and left). When a sensor detects light, the corresponding DC motor moves in the same direction, responding to sunlight or specific light conditions [30].

Fig. 17. Solar Tracker

We also note from the figure that it contains a circuit that contains all the electronic components and wires connected between the solar cells and the Arduino Nano chip.

IV. Results

The solar tracker system plays a crucial role in optimizing the performance of solar panels by accurately positioning them relative to the angle of the Sun. By ensuring that the solar panels remain perpendicular to the Sun's rays, more sunlight is effectively captured, minimizing light reflection, and maximizing energy absorption. This efficient tracking mechanism results in increased power generation, making the solar tracker an essential component in solar energy systems.

The dual-axis solar tracker, integrated with Arduino, 4 LDRs (Light Dependent Resistors), 100k resistors, and 2 servo motors, is designed to provide two-dimensional movement. Unlike single-axis trackers that only move along one axis, dual-axis trackers can adjust both vertically and horizontally. This capability allows them to continually face the Sun throughout the day, optimizing solar panel orientation and significantly improving energy output [21].

There are various types of dual-axis trackers, including tip-tilt and azimuth-altitude trackers. The tip-tilt design allows the solar panels to tilt upward or downward and rotate sideways, while the azimuth-altitude type enables rotation along both the azimuth (horizontal) and altitude (vertical) axes. These versatile trackers ensure precise alignment with the Sun's position at any given time, allowing for maximum energy capture.

Dual-axis trackers are particularly valuable for applications where precise solar panel positioning is critical. For instance, in concentrated solar power systems, where mirrors concentrate sunlight onto a fixed receiver, dual-axis trackers ensure that the mirrors continuously track the Sun's movement to maintain optimal concentration. This significantly enhances the overall energy generation efficiency of such systems.

Moreover, dual-axis solar trackers are beneficial for regions with varying solar angles throughout the year due to changing seasons. By continuously adjusting the solar panels according to the Sun's position, they can harvest maximum solar energy regardless of the time of year or location.

The integration of dual-axis solar trackers with Arduino and the sensors allows for accurate and automated Sun tracking, which is essential for enhancing the performance and efficiency of solar energy systems. As renewable energy sources become increasingly vital in combating climate change, solar trackers play a crucial role in harnessing the Sun's potential to provide clean and sustainable power.

In our project, we modified the DC motor from 36 volts to 12 volts by winding the coils again, based on the universal law for winding coils for motors, and this law is:

$$\frac{12V}{18T} \qquad \text{After winding the motor}$$

$$\frac{36V}{56T} \qquad \text{Before winding the motor}$$

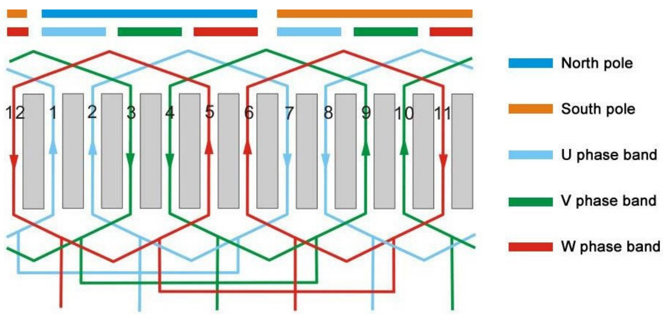

Fig. 18. Winding the Motor

When working on the project, several software problems appeared to us, and the programming was modified correctly, as well as determining each LDR sensor and its location in the solar cell to adjust the movement correctly for each location. Errors appeared when connecting the wires because the connection or wires were many in the project and each wire was correctly connected to the correct port.[22].

The main benefit of moving the solar panels up and down and to the right and left is to obtain the highest amount of light extracted from sunlight, thus obtaining the highest energy and then storing the energy in large batteries for later use.

We note from the figure that the solar cell that moves with the movement of the sun, the energy extracted from it is greater and better compared with the solar cells remaining stable and obtaining less energy, because the sun’s rays fall on certain areas of the solar cell.

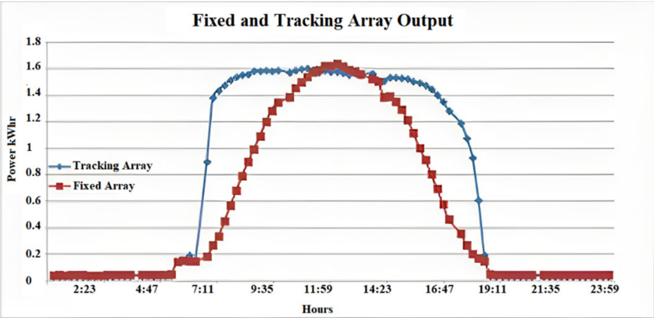

Fig. 19. The Amount of Energy with the Tracer and Without the Tracer

The article incorporates an Arduino-based control code to enable efficient solar tracking for maximum solar energy harvesting. The code uses light sensors to detect sunlight intensity in different directions and actuates motors to adjust the tilt angles of the solar panels accordingly. The main loop in the code continuously calls the "Tracking" function, which calculates the differences in light intensity readings between pairs of sensors in vertical and horizontal directions. Based on these differences and a predefined threshold, the code determines the need for solar panel adjustment. By comparing the light intensity differences with the threshold, the code activates specific motors to either tilt the solar panels up or down in the vertical direction or left or right in the horizontal direction. Additionally, the code ensures that the solar panel remains centered if the light intensity differences are within a smaller range. Moreover, the system includes a "Night Mode" feature that detects low light intensity readings on all sensors, indicating nighttime or shaded conditions and turns off both vertical and horizontal adjustment motors.

```
#define sensUP A0 #define sensDN A1 #define sensL A2 #define sensR A3 #define motorUP 7
#define motorDN 8
#define motorL 9
#define motorR 10 boolean nmode=0; int diffH = 0;
int diffV = 0; #define thresh 40
#define nightmode 10

void setup() { pinMode(motorUP,OUTPUT); pinMode(motorDN,OUTPUT); pinMode(motorL,OUTPUT); pinMode(motorR,OUTPUT); digitalWrite(motorUP,HIGH); digitalWrite(motorDN,HIGH); digitalWrite(motorL,HIGH); digitalWrite(motorR,HIGH);
}
void loop() { Tracking();
}
void Tracking(){
diffV = analogRead(sensUP)- analogRead(sensDN); diffH = analogRead(sensL)- analogRead(sensR);
if (diffV > thresh)
{
digitalWrite(motorUP,LOW); digitalWrite(motorDN,HIGH);
}
if (diffV < (thresh*-1))
{
digitalWrite(motorDN,LOW); digitalWrite(motorUP,HIGH);
}
if (diffH > thresh)
{
digitalWrite(motorL,LOW); digitalWrite(motorR,HIGH);
}
if (diffH < (thresh*-1))
{
digitalWrite(motorR,LOW); digitalWrite(motorL,HIGH);
}
if (diffV < (thresh/4) && diffV > (thresh/-4))
{
digitalWrite(motorUP,HIGH); digitalWrite(motorDN,HIGH);
}
if (diffH < (thresh/4) && diffH > (thresh/-4))
{
digitalWrite(motorL,HIGH); digitalWrite(motorR,HIGH);
}
if(analogRead(sensUP)<nightmode && analogRead(sensDN)<nightmode && analogRead(sensL)<nightmode && analogRead(sensR)<nightmode){
digitalWrite(motorUP,LOW); digitalWrite(motorL,LOW); nmode=1;
}
else nmode=0;
}
```

The Arduino-based control code plays a vital role in the Photovoltaic Active Dual Tracking System by enabling real-time and precise solar tracking, leading to enhanced energy efficiency and optimized performance of the PV system.

V. Discussion

Photovoltaic (PV) solar energy has attracted considerable attention due to its promise as a clean and sustainable power source. A PV system's effectiveness depends on sun-tracking mechanisms.

Solar PV systems are becoming more popular as clean energy [1]. To maximum effectiveness, they must capture sunlight effectively throughout the day. Traditional fixed PV systems are less efficient since they do not follow the sun. Solar tracking devices like the Photovoltaic Active Dual Tracking System address this problem.

According to Comello, Reichelstein, and Sahoo, solar PV power's future depends on technological advances [1]. Solar tracking systems may boost PV installation efficiency and output. The discussed dual-axis tracking technology aligns solar panels with the sun to maximize daytime sunlight.

Dual-axis solar tracking systems can follow the sun horizontally and vertically, which is a significant benefit. It permits the PV panels to face the sun at the best angle, boosting energy gathering. Jamroen et al. tested a UV sensor-based dual-axis solar tracking system. Dual-axis tracking systems have a higher energy production rate than fixed installations [2].

Solar tracking system design and performance analysis have also been extensively studied. Zhu, Liu, and Yang developed a single-axis tracking structure to maximize energy collection. Although it focuses on single-axis tracking, the research emphasizes tracking methods' role in energy-collecting efficiency [3]. The two-axis method mentioned here increases efficiency by monitoring the sun in two dimensions.

Location and climate affect PV system performance. Awad and Gül found that load-match-driven solar PV system design at high latitudes stresses location-specificity [4]. Dual-axis solar tracking systems optimize energy output in places with variable sun angles by adapting to changing solar positions.

As Jawada et al. noted in [5] IoT technology may improve solar tracking systems. The dual tracking system can optimize energy harvesting using IoT's real-time weather and sunshine data. An active dual-tracking system adapts to environmental variables, and this integration fits.

Machine vision technology improves solar tracking system accuracy and efficiency. A machine vision dual-axis solar tracking system by Abdollahpour et al. might enhance tracking accuracy. Such advances allow the active dual-tracking system to align precisely with the sun, increasing energy yields [6].

Sliding mode control and MPPT are used to improve PV systems. Gursoy et al. recommend sliding mode control for PV energy conversion. Active dual tracking systems may use sliding mode control to govern solar panel movement, reducing tracking errors and optimizing energy production [7].

To maximize PV panel efficiency, MPPT is essential. Multiple MPPT algorithms have been suggested to monitor PV module maximum power point under various situations [11]. An effective MPPT algorithm in the dual tracking system assures maximal panel performance independent of sun position and ambient conditions.

The article advances solar energy production. This technology optimizes energy collecting and PV installation efficiency by actively adjusting solar panels to the sun's horizontal and vertical position. The collection of references shows how technical advances, accurate tracking systems, and integrated control approaches optimize solar energy output. Solar energy is vital to the shift to sustainable power sources, and the active dual-tracking system is a promising technology for boosting efficiency and dependability.

Fitriaty and Shen work on estimating energy production from residential building-attached PV cells stresses precise sun tracking for maximum energy output [17]. The research suggests integrating a dual-axis tracking system to maximize PV cell energy production [17].

Its simplicity and efficiency in conception and execution make the study significant. Mustafa et al. stress simple solar tracking devices in high-solar-potential areas like Baghdad [19]. The article's methodology follows this idea, making it suited for many locales.

The efficacy of solar tracking systems depends on sensors and controllers. Mustafa et al. describe a solar tracking system with four sensors to monitor the sun's position, emphasizing the need for exact sensor data. The article mentions Arduino Nano's ADC pin measuring voltage, emphasizing sensor technology's role in monitoring and control [21].

Power management must be efficient to sustain PV system dependability and performance. Bansal et al. stress the necessity for efficient energy conversion methods in PV systems' DC-DC converters [23]. The study focuses on active dual tracking, which involves efficient power management to position PV panels.

PV energy creation also affects the environment. Life-cycle assessments of solar-photovoltaic systems by Mahmud et al. revealed considerable environmental consequences [26]. Improve solar energy generation's environmental impact using sophisticated tracking systems like the one in the article.

According to Gadre and Gupta, PV system monitoring and control need data collection systems that include analog-to-digital converters (ADC) [28]. In the presented study, ADCs are vital for adequately detecting the sun and altering PV panel orientation.

Risk management is also crucial to PV system implementation and operation. Christensen et al. emphasize the need for life-cycle risk management for lithium-ion batteries in electric cars [29]. PV systems may not employ lithium-ion batteries, but risk management is still essential in complicated systems like active dual-axis tracking.

The article advances sustainable energy production. The study uses a dual-axis sun-tracking device to increase PV energy production efficiency. This technology promotes simplicity, sensor-based monitoring, power efficiency, and sustainability.

VI. CONCLUSION

In this article, we present a comprehensive analysis of a Photovoltaic Active Dual Tracking System, which aims to enhance the efficiency of solar power generation by utilizing a dual-axis solar tracker. The increasing demand for clean and renewable energy solutions has led to a growing interest in solar energy as a viable alternative. To harness the abundant solar energy available, it becomes imperative to maximize the efficiency of solar PV systems. The concept of dual-axis tracking provides an innovative solution by dynamically aligning solar panels with the sun's position throughout the day, thereby optimizing solar power generation.

Our paper builds upon the work of various scholars and experts in the field. By integrating the Polar code-OFDM technique, we enhance the reliability of underwater communication systems, addressing challenges in deep fading and multipath environments. The implementation of the proposed system is based on a combination of Photovoltaic (PV) technology, a dual-axis tracking mechanism, and an Arduino microcontroller. The dual-axis solar tracker compensates for the sun's movement, ensuring that solar panels receive maximum sunlight exposure, resulting in a substantial increase in energy output.

The experimental results demonstrate the effectiveness of our approach. The system's performance is evaluated in terms of the Block Error Rate (BER) with respect to the Signal-to-Noise Ratio (SNR). By varying the constraint length of the symbol in the polar code and changing the CRC bit values, we analyze the system's behavior under different coding rates (R). The graphical representations illustrate the system's efficiency under varying conditions.

The combination of PV technology with a dual-axis solar tracker, controlled by an Arduino microcontroller, provides a cost-effective and efficient solution for maximizing solar power generation. Sun-tracking methods are essential for optimizing solar system output, as highlighted in relevant studies. The integration of these technologies opens up new possibilities for advancing solar power generation and fostering sustainable energy practices.

While the results obtained in our article are promising, there is still room for further improvement and optimization. Future investigations should include more extensive real-world experiments to validate the findings in practical scenarios. Additionally, efforts can be made to enhance the dual-axis solar tracking mechanism to further optimize solar energy harvesting.

The article contributes to the development of efficient solar power generation systems by incorporating the Photovoltaic Active Dual Tracking System. The integration of PV technology with a dual-axis solar tracker and the use of an Arduino microcontroller offers a viable solution for maximizing solar energy harvesting. Moreover, the implementation of the Polar code-OFDM technique addresses the reliability challenges of underwater communication systems. This research paves the way for advancements in solar power generation technology, bringing us closer to a sustainable and eco-friendly energy future.

REFERENCE

[1] S. Comello, S. Reichelstein, and A. Sahoo: ''The road ahead for solar PV power'', *Renewable and Sustainable Energy Reviews*, 92, 2018, pp. 744-56

[2] C. Jamroen, C. Fongkerd, W. Krongpha, P. Komkum, A. Pirayawaraporn, and N. Chindakham: ''A novel UV sensor-based dual-axis solar tracking system: Implementation and performance analysis'', *Applied Energy*, 299, 2021, pp. 117295

[3] Y. Zhu, J. Liu, and X. Yang: ''Design and performance analysis of a solar tracking system with a novel single-axis tracking structure to maximize energy collection'', *Applied Energy*, 264, 2020, pp. 114647

[4] H. Awad, and M. Gül: ''Load-match-driven design of solar PV systems at high latitudes in the Northern hemisphere and its impact on the grid'', *Solar Energy*, 173, 2018, pp. 377-97

[5] A. M. Jawada, Nameer Hashim Qasim, Haider Mahmood Jawada, Mahmood Jawad Abu-Alshaeera, Rosdiadee Nordinc, and Sadik Kamel Gharghand. : ''Near Field WPT Charging a Smart Device Based on IoT Applications '', *CEUR Workshop Proceedings*, 3149, 2022, pp. 61-72

[6] M. Abdollahpour, M. R. Golzarian, A. Rohani, and H. Abootorabi Zarchi: ''Development of a machine vision dual-axis solar tracking system'', *Solar Energy*, 169, 2018, pp. 136-43

[7] M. Gursoy, G. Zhuo, A. G. Lozowski, and X. Wang: ''Photovoltaic energy conversion systems with sliding mode control'', *Energies*, 14, (19), 2021, pp. 6071

[8] P. J. T. Kaur: ''Optimization of Solar PV System and Analysis of Tilt Angle'', *ACM Conference Proceedings eEnergy IS14'h_ 17'hJuly* 2015

[9] N. A. Zainal, A. R. Yusoff, and A. Apen: ''Integrated cooling systems and maximum power point tracking of fuzzy logic controller for improving photovoltaic performances'', *Measurement*, 131, 2019, pp. 100-08

[10] J. J. Ontiveros, C. D. Ávalos, F. Loza, N. D. Galán, and G. J. Rubio: ''Evaluation and Design of Power Controller of Two-Axis Solar Tracking by PID and FL for a Photovoltaic Module'', *International Journal of Photoenergy*, 2020, 2020, pp. 8813732

[11] N. Bhatnagar: ''Maximum Power Point Tracking for PV System'', *International Journal for Research in Applied Science and Engineering Technology,*, 6, 2018, pp. 1395-401.

[12] N. A. Windarko, M. Nizar Habibi, B. Sumantri, E. Prasetyono, M. Z. Efendi, and Taufik: ''A new MPPT algorithm for photovoltaic power generation under uniform and partial shading conditions'', *Energies*, 14, (2), 2021, pp. 483

[13] M. Derbeli, C. Napole, O. Barambones, J. Sanchez, I. Calvo, and P. Fernández-Bustamante: ''Maximum Power Point Tracking Techniques for Photovoltaic Panel: A Review and Experimental Applications'', *Energies*, 14, (22), 2021, pp. 7806

[14] N. M. Kumar, S. S. Chopra, M. Malvoni, R. M. Elavarasan, and N. Das: ''Solar cell technology selection for a PV leaf based on energy and sustainability indicators—a case of a multilayered solar photovoltaic tree'', *Energies*, 13, (23), 2020, pp. 6439

[15] I. M. Dharmadasa, A. A. Ojo, H. I. Salim, and R. Dharmadasa: ''Next generation solar cells based on graded bandgap device structures utilising rod-type nano-materials'', *Energies*, 8, (6), 2015, pp. 5440-58

[16] M. M. Akther, M. A. Islam, M. S. Rahman, M. R. Karim, and D. Nandwani: 'Nutrient Management and Effects of Netting on Growth and Yield of Indian Spinach (Basella alba)', in Editor (Ed.)^(Eds.): 'Book Nutrient Management and Effects of Netting on Growth and Yield of Indian Spinach (Basella alba)' (Preprints, 2018, edn.), pp.

[17] P. Fitriaty, and Z. Shen: ''Predicting energy generation from residential building attached Photovoltaic Cells in a tropical area using 3D modeling analysis'', *Journal of Cleaner Production*, 195, 2018, pp. 1422-36

[18] J. Chen, T. Zhou, and S. Yang: ''Photovoltaic Generation Solar Automatic Tracking System'', *IOP Conference Series: Earth and Environmental Science*, 170, (4), 2018, pp. 042029

[19] F. I. Mustafa, S. Shakir, F. F. Mustafa, and A. T. Naiyf: 'Simple design and implementation of solar tracking system two axis with four sensors for Baghdad city', in Editor (Ed.)^(Eds.): 'Book Simple design and implementation of solar tracking system two axis with four sensors for Baghdad city' (2018, edn.), pp. 1-5

[20] K. Zhang, C. Si, Z. Zhu, C. Guo, and Q. Shi: ''A Two-Dimensional Solar Tracking Stationary Guidance Method Based on Feature-Based Time Series'', *Mathematical Problems in Engineering*, 2018, 2018, pp. 3420649

[21] M. Pauzan, and I. Yanti: ''UTILIZATION OF ADC PIN ON ARDUINO NANO TO MEASURE VOLTAGE OF A BATTERY'', *TEKNOKOM*, 2021

[22] L. Chin Kim, Y.-S. Lim, and F. Abd-Rahman: ''New integrated simulation tool for the optimum design of bifacial solar panel with reflectors on a specific site'', *Renewable Energy*, 81, 2015

[23] S. Bansal, L. M. Saini, and D. Joshi: 'Design of a DC-DC converter for photovoltaic solar system', in Editor (Ed.)^(Eds.): 'Book Design of a DC-DC converter for photovoltaic solar system' (IEEE, 2012, edn.), pp. 1-5

[24] N. Hinov: ''Quasi-Boundary Method for Design Consideration of

Resonant DC-DC Converters'', *Energies*, 14, (19), 2021, pp. 6153
[25] N. Hashim, A. Mohsim, R. Rafeeq, and V. Pyliavskyi: ''New approach to the construction of multimedia test signals'', *International Journal of Advanced Trends in Computer Science and Engineering*, 8, (6), 2019, pp. 3423-29
[26] M. A. P. Mahmud, N. Huda, S. H. Farjana, and C. Lang: 'Environmental Impacts of Solar-Photovoltaic and Solar-Thermal Systems with Life-Cycle Assessment', in Editor (Ed.)^(Eds.): 'Book Environmental Impacts of Solar-Photovoltaic and Solar-Thermal Systems with Life-Cycle Assessment' (2018, edn.), pp.
[27] D. K. Nandakumar, J. V. Vaghasiya, L. Yang, Y. Zhang, and S. C. Tan: ''A solar cell that breathes in moisture for energy generation'', *Nano Energy*, 68, 2020, pp. 104263
[28] D. V. Gadre, and S. Gupta: 'Analog to Digital Converter (ADC)', in Gadre, D.V., and Gupta, S. (Eds.): 'Getting Started with Tiva ARM Cortex M4 Microcontrollers: A Lab Manual for Tiva LaunchPad Evaluation Kit' (Springer India, 2018), pp. 183-209
[29] P. A. Christensen, P. A. Anderson, G. D. J. Harper, S. M. Lambert, W. Mrozik, M. A. Rajaeifar, M. S. Wise, and O. Heidrich: ''Risk management over the life cycle of lithium-ion batteries in electric vehicles'', *Renewable and Sustainable Energy Reviews*, 148, 2021, pp. 111240
[30] M. Abu-Khader, O. Badran, and S. Abdallah: ''Evaluating multi-axes sun-tracking system at different modes of operation in Jordan'', *Renewable and Sustainable Energy Reviews*, 12, 2008, pp. 864-73
[31] K. Kumar, L. Varshney, A. Ambikapathy, I. Ali, A. Rajput, A. Bhatnagar, and S. Omar: ''Vision based solar tracking system for efficient energy harvesting'', *International Journal of Power Electronics and Drive Systems (IJPEDS)*, 12, 2021, pp. 1431