J. Electrical Systems 20-11s (2024): 1093-1105

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Reliable Dynamic Adoptive Dual Axis Solar Tracking Systems (DASTS) with Increased Efficiency

Abstract: - Traditional solar tracking systems typically depend on sunlight intensity to adjust the orientation of solar panels. However, these systems often neglect dynamic environmental factors such as wind, which can significantly impact the performance and safety of solar panels. The proposed Dynamic Adaptive Solar Tracking System (DASTS) aims to enhance energy capture efficiency and ensure the structural stability of solar panels by incorporating time-based data into its tracking algorithm. Utilizing precise geolocation coordinates and temporal data, the DASTS calculates the sun's position relative to the solar panel array. This system adjusts the panels' orientation in real-time to optimize energy capture. To validate the effectiveness of the DASTS, experimental tests were conducted at various times. The results indicate that the DASTS surpasses traditional fixed-tilt and single-axis tracking systems in terms of energy yield and structural stability. Furthermore, the DASTS demonstrated consistent performance across different geographic locations and seasons, underscoring its versatility and efficacy in maximizing solar energy utilization.

Keywords: Dynamic Adaptive Axis solar tracker, elevation angle, Real time clock, Solar panel orientation, Geoloation

I. INTRODUCTION

Solar energy has become a crucial element in the global shift towards sustainable and renewable energy sources. Solar photovoltaic (PV) systems, which convert sunlight directly into electricity, are extensively used in residential, commercial, and industrial settings. The efficiency of these systems is closely linked to their ability to optimally capture sunlight throughout the day. Although traditional fixed-tilt solar panels are simple and cost-effective, they operate at lower efficiency levels because they remain stationary and cannot adjust to the sun's changing position [1].

To overcome this limitation, solar tracking systems enable solar panels to continuously orient themselves towards the sun, thereby maximizing energy capture. These systems utilize various tracking mechanisms to keep the panels aligned with the sun's path, enhancing energy production. Solar tracking systems are generally classified into single-axis and dual-axis types, depending on the degrees of freedom they allow for panel movement.

1.1 Single-Axis Solar Tracking Systems:

Single-axis solar tracking systems allow solar panels to move along a single axis, which can be either horizontal (azimuthal) or vertical (elevation) [8]. Horizontal single-axis trackers rotate the panels from east to west, following the sun’s daily path, while vertical single-axis trackers adjust the tilt of the panels to optimize sunlight exposure based on the sun’s elevation angle. These systems enhance energy capture compared to fixed-tilt panels by maintaining a more favorable alignment with the sun.

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Figure 1: Single-Axis Solar Tracking Systems

1.2 Dual-Axis Solar Tracking Systems

Dual-axis solar tracking systems provide two degrees of freedom, enabling solar panels to adjust both azimuthally and elevationally. This allows panels to track the sun's movement more precisely in both horizontal and vertical planes, optimizing energy capture throughout the day and across different seasons. These systems are particularly advantageous in areas with significant solar variability or where maximizing energy yield is essential. Solar energy collection is more efficient when panels are tilted at a 30° angle from a fixed surface facing south [2].

Solar tracking systems can also be categorized based on their tracking strategies, such as Sun-Tracking Algorithms, Sensor-Based Tracking, and Hybrid Tracking Systems:

Figure 2: Dual Axis Solar Tracking Systems

Sun-Tracking Algorithms calculate the sun's position using time, date, and geographical coordinates to determine the optimal orientation of solar panels.
Sensor-Based Tracking systems use sensors, like light sensors or GPS modules, to directly measure sunlight intensity or position, adjusting the panel orientation accordingly.

Hybrid Tracking Systems combine both algorithmic and sensor-based tracking methods, providing enhanced accuracy and reliability by integrating multiple data sources.
For maximum solar power output, solar systems benefit from the ability to track the sun in both horizontal and vertical rotations [3]. Fixed-position solar panels, aligned to face south with an inclination angle based on longitude and latitude, can also be effective [4]. Additionally, factors such as wind speed and structural design can impact the voltage levels of solar panels [5].

II. PROPOSED SYSTEM & METHODOLOGY

A dual-axis solar tracker can be designed using precise mathematical formulations that take into account the sun's elevation and azimuth angles, tailored to a specific geographic location. This advanced system is equipped with an ATMEGA32 microcontroller, which serves as the brain of the operation, and a DS1307 real-time clock module that provides accurate time and date values. These components work together to ensure that the solar tracker knows exactly when and how to adjust the orientation of the solar panels.

III. SYSTEM DESIGN AND COMPONENTS

The mathematical basis for the dual-axis tracker involves calculating the sun's position in the sky using the elevation and azimuth angles. These angles change throughout the day and year, depending on the Earth's rotation and orbit around the sun. By accurately calculating these angles, the solar tracker can align the panels to face the sun directly, maximizing sunlight capture.

3.1 ATMEGA32 Microcontroller

The ATMEGA32 microcontroller is programmed with algorithms that compute the optimal orientation of the solar panels based on the calculated elevation and azimuth angles. It processes sensor data in real-time, making adjustments to the panel positions as needed.

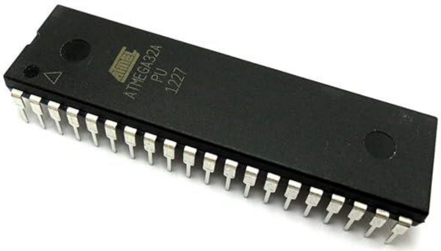

Figure 3: ATMEGA32 Microcontroller

3.2 DS1307 Real-Time Clock Module

The DS1307 module provides the current time and date, which are essential for calculating the sun's position. This ensures that the solar tracker can make precise adjustments throughout the day and across different seasons.

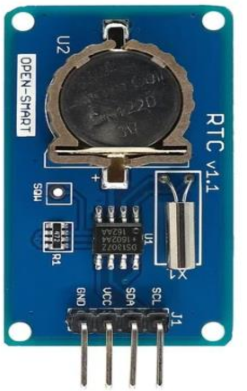

Figure 4: DS1307 Real-Time Clock Module

3.3 Sensor Data Collection

Various sensors are integrated into the system to gather data on sunlight intensity, panel orientation, and environmental conditions. This data is sent to the microcontroller, which uses it to refine the tracking algorithm and improve accuracy.

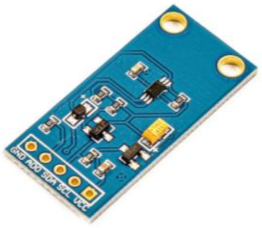

Figure 5: BH1750 - Light Intensity Sensor Module

3.4 Actuation Mechanism- High-Gauge Actuators

Given the significant weight of the solar panels, robust high-gauge actuators are necessary to facilitate their movement. These actuators are capable of handling the load and providing the necessary torque to rotate the panels.

Figure 6: High-Gauge Actuators

3.5 Relay Control

The actuators are operated by relays controlled by the microcontroller. The microcontroller sends signals to the relays, activating the actuators to move the panels until the desired zenith and azimuth angles are achieved. This process ensures that the panels are always positioned for optimal sunlight exposure.

Figure 7: Relay Control

3.6 Software Application Calculation of Angles

The system is supported by MATLAB application software that calculates the elevation and azimuth angles for every hour of every day. This software takes into account the geographic location and the current date to provide accurate positioning information.

3.7 Panel Rotation

Based on the calculated angles, the software directs the actuators to adjust the orientation of the solar panels. This continuous adjustment helps in maximizing the power generation throughout the day.

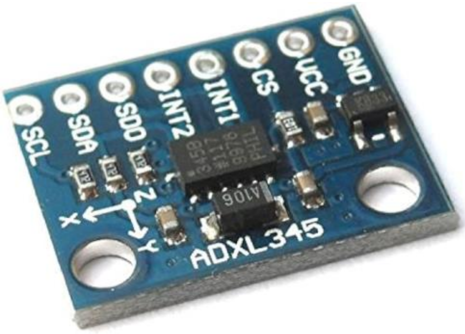

Figure 8: ADXL 345 Accelerometer Module

Integration with IoT Technology for monitoring and Control

The integration of Internet of Things (IoT) technology into the solar tracking system allows for advanced monitoring and control capabilities. Sensors, actuators, microcontrollers, and communication modules are all connected to enable remote management.

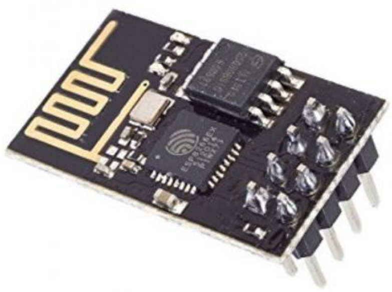

Figure 9: ESP-01 ESP8266 Serial WIFI Wireless Transceiver Module.

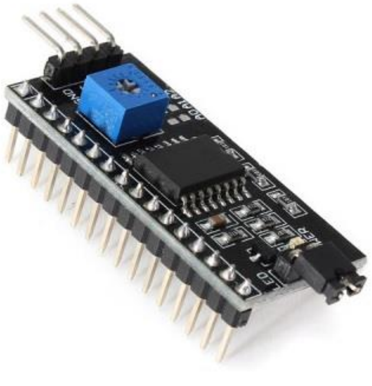

Figure 10: I2C Communication Protocol

The step by step implementation and execution of the implemented work is depicted below.

Step 1: Initialize the hardware as per requirement and program the microcontroller as per the needs to get the input parameters from various sources and process the output requirements.

Step 2: Initialize Wi-Fi for the purpose of IoT establishment and date and time using DS1307 RTC module for accurate timings.

Step3: Update time values on LCD display on every consecutive time and send time, date and position values to the server using IoT.

Step 4: ATMEGA32 microcontroller used to monitor the azimuth angle and altitude of the sun on the day and time. Updated time values used to rotate the actuator that is placed at solar panels.

Step 5: Tilt the solar panels according to the angles provided by the microcontroller using DAST that are placed for tilting solar panel.

Step 6: Voltage and current readingss are recorded.

3.9 Data Collection and Upload

The solar tracker collects various types of data, including sensor readings (sunlight intensity, temperature, etc.), tracking angles, energy production metrics, and system diagnostics. This data is transmitted to a cloud-based platform for storage and analysis.

3.10 Web-Based Dashboard

A web-based dashboard allows users to remotely monitor the performance of the solar tracker. Through this dashboard, users can view real-time data, historical trends, and system performance metrics.

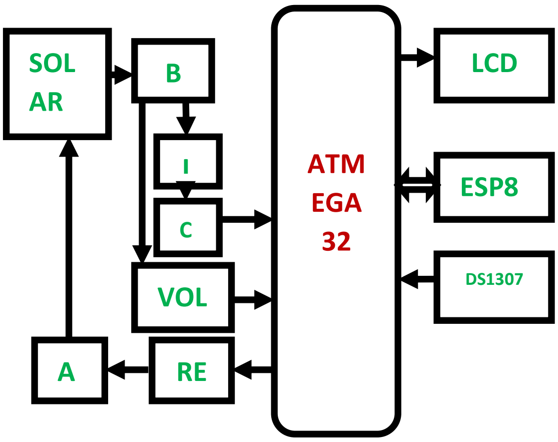

Figure 11: Proposed system for DASTS

By analyzing the data, solar power generation can be synchronized with energy demand patterns and grid requirements. This ensures that the maximum value is extracted from the solar energy produced, improving overall efficiency and effectiveness.

The dual-axis solar tracker, designed with advanced mathematical formulations and integrated with IoT technology, represents a significant improvement over traditional fixed-tilt systems. By continuously adjusting the solar panels to follow the sun’s path, it maximizes energy capture. The system's ability to monitor and adjust based on real-time data ensures high efficiency and reliability, making it a valuable asset in the pursuit of sustainable and renewable energy solutions.

3.11 Analysis and Data Optimization

The data collected from IoT-enabled solar trackers is analyzed to identify trends, patterns, and performance metrics. This analysis helps in understanding how the system performs under different conditions and in different locations.

IV. IMPLEMENTATION OF DASTS

In the system design, we utilized an Arduino Uno, a DS1307 RTC (Real-Time Clock), relays, and actuators. The DS1307 RTC module is used to store time and date values within the controller. The calculated data is displayed on an LCD regularly for monitoring purposes. Given the widespread locations of solar plants, collecting data manually from each site is impractical. To address this, we designed a system capable of sending information to a server using the ESP8266 Wi-Fi module in access point mode, connected to the controller. The figure 2 below, illustrates the data updated on the web server.

Figure 12: Experimental setup for DASTS

Figure 13: Mechanical setup for tilting the solar panel

Figure 14: Actuator used for tilting the solar panel and Relays used to operate the solar panel tilt in both directions using clockwise and anticlockwise shifting

Based on date and time values the system will calculate the azimuth and elevation angles of the sun. According to azimuth and elevation angles the solar panels moves into the angles measured. 3 axis MEMS Gyro sensors were used for measuring the existing angle of solar panel. Here we were used actuators for tilting the solar panel according to the existing angle and measured angle. These actuators can work upto 1.5 ton. We were used relays to operate the actuators in both clockwise and anticlockwise direction as per the requirement

V. RESULTS & DISCUSSIONS

Experimental Analysis was done with respect to theoretical and practical positional variation of both mono crystalline and poly crystalline type solar panels. Considered a 24V solar panel connected to a load with resistance of 26 Ohms in the circuit. Measured voltage and current at various intervals of time, date with fixed and dual axis of solar panel.

Table I: Voltage generated at various timings using mono and poly crystalline type solar panels

Sl. No	Time	Mono crystalline solar panel			Poly crystalline solar panel		
		Voltage	Current	Power	Voltage	Current	Power
1	9:00AM	17.2	0.1	1.72	11.3	0.1	1.13
2	10:00AM	18.5	0.2	3.7	12.8	0.1	1.28
3	11:00AM	18.9	0.3	3.78	13.3	0.2	2.66
4	12:00PM	19.1	0.35	5.73	14.6	0.2	2.92
5	1:00PM	19.9	0.4	5.97	15.5	0.2	1.55
6	2:00PM	19.1	0.35	3.82	12.7	0.2	1.27
7	3:00PM	18.6	0.3	3.72	11.6	0.1	1.16
8	4:00PM	17.3	0.2	1.73	10.5	0.1	1.05
9	5:00PM	16.5	0.1	1.65	10.2	0.1	1.02

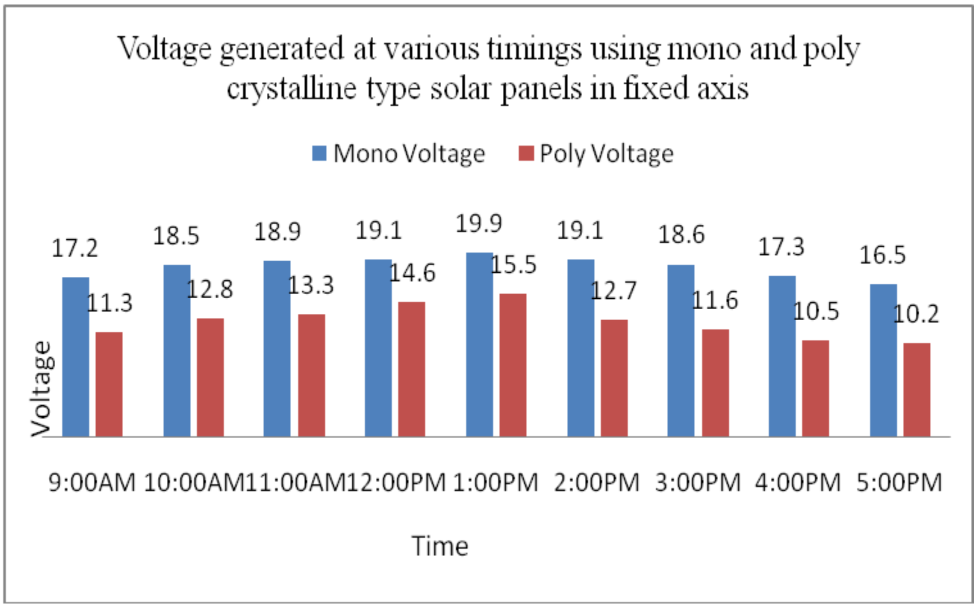

Figure 15 a: Solar panel voltage reading for both poly and mono crystalline panels

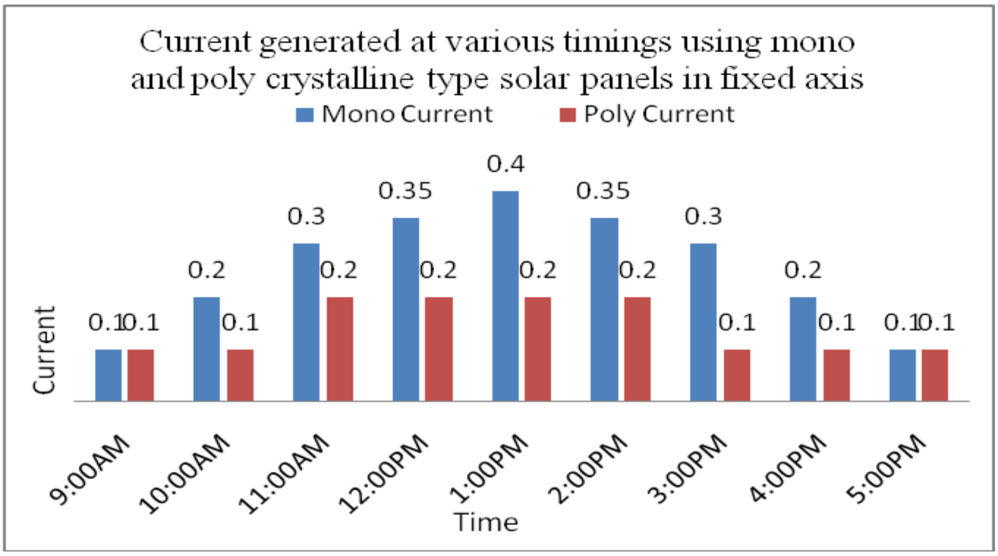

Figure 15b : Current reading for both poly and mono crystalline panels

The Graph 15a illustrates the relationship between time and voltage generated by a mono and poly crystalline solar panels over a period from 9:00 AM to 5:00 PM. From 9:00 AM to 12:00 PM**,** there is a gradual increase in voltage, starting around 17.2 volts and rising steadily as the day progresses, likely due to increasing sunlight intensity. Between 12:00 PM and 1:00 PM**,** the voltage reaches its peak at approximately 19.9 volts, which suggests that this time frame represents the period of maximum solar irradiance. After 1:00 PM**,** the voltage drops sharply, returning to around 19.1 volts by 2:00 PM and continuing to decrease gradually until the end of the observation period at 5:00 PM, where it dips to about 16.5 volts. This decline likely corresponds to a reduction in sunlight intensity as the afternoon progresses. Overall, the Graph shows that the solar panel's voltage output increases with rising sunlight intensity, peaks around midday, and then decreases as sunlight wanes in the afternoon.

The Graph 15b, shows the relationship between time and the current output of a mono and poly crystalline solar panel from 9:00 AM to 5:00 PM. From 9:00 AM to around 12:00 PM, the current gradually increases from approximately 0.1 amperes to a peak of about 0.4 amperes. This increase indicates that as sunlight becomes more intense during the morning, the solar panel generates more current. Between 12:00 PM and 1:00 PM**,** the current reaches its highest point, reflecting the period of maximum solar irradiance when the panel is most efficient at converting sunlight into electrical current. After 1:00 PM**,** there is a noticeable decline in current output. The current decreases sharply after 1:00 PM, dropping from around 0.4 amperes to 0.35 amperes by 2:00 PM, and continues to fall throughout the afternoon. By 4:00 PM, the current has reduced to approximately 0.1 amperes. This decline is likely due to the decreasing intensity of sunlight as the day progresses towards the evening. Overall, the Graph reflects how the solar panel's current output increases with sunlight intensity, peaks around midday, and then gradually decreases as sunlight diminishes in the afternoon.

Table 2: Voltage and Current generated at various timings using mono and poly crystalline solar panels

Sl. No	Time	Mono crystalline solar panel			Poly crystalline solar panel		
		Voltage	Current	Power	Voltage	Current	Power
1	8:00AM	18.1	0.2	3.62	10.1	0.1	1.01
2	9:00AM	18.2	0.21	3.88	11.3	0.1	1.13
3	10:00AM	18.4	0.32	5.88	12.8	0.1	1.28

4	11:00AM	18.6	0.35	6.51	13.3	0.2	2.66
5	12:00PM	19.2	0.4	7.68	14.6	0.2	2.92
6	1:00PM	19.9	0.5	9.95	13.5	0.24	3.24
7	2:00PM	19.3	0.4	7.72	12.7	0.19.	2.413
8	3:00PM	18.5	0.3	5.55	11.6	0.1	1.16
9	4:00PM	18.0	0.28	5.04	10.5	0.1	1.05
10	5:00PM	17.3	0.2	3.46	10.2	0.1	1.02

Considered a 24V solar panel connected to a load with resistance of 26 Ohms in the circuit. Measured voltage and current values at various intervals of time and date with variable position of solar panel from east to west north to south.

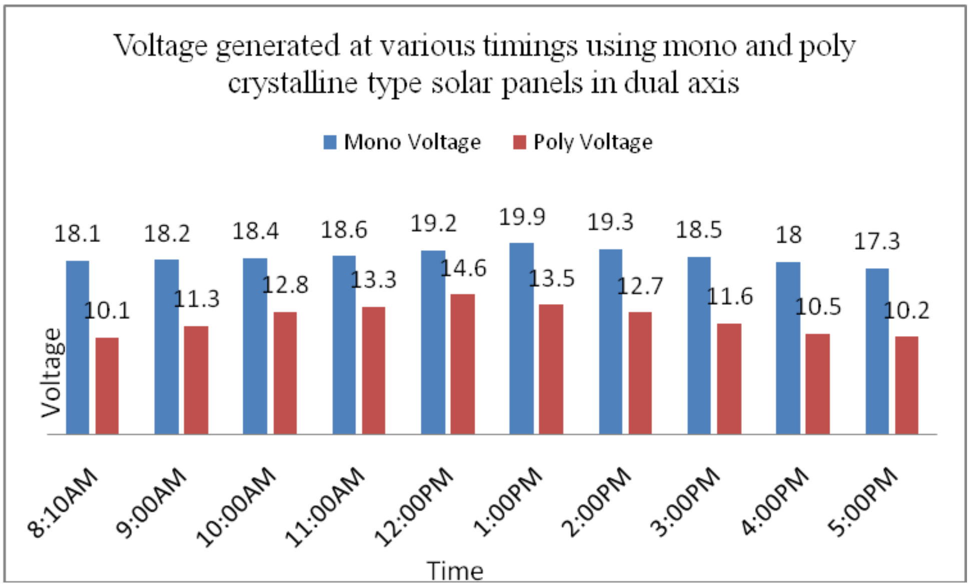

Figure 16 a: Voltage generated for both mono and poly crystalline panels

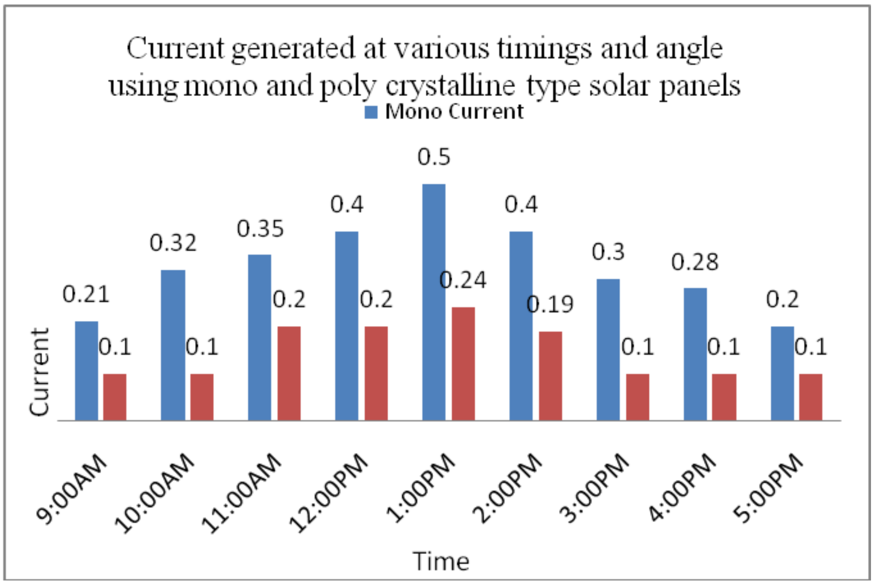

Figure 16b :Current generated for both mono and poly crystalline panels

The Graph 16a illustrates the relationship between time and voltage generated by a mono and poly crystalline solar panels over a period from 8:00 AM to 5:00 PM. From 8:00 AM to 12:00 PM, there is a gradual increase in voltage, starting around 18.1 volts and rising steadily as the day progresses, likely due to increasing sunlight intensity. Between 12:00 PM and 1:00 PM, the voltage reaches its peak at approximately 19.9 volts, which suggests that this time frame represents the period of maximum solar irradiance. After 1:00 PM, the voltage drops sharply, returning to around 19.3 volts by 2:00 PM and continuing to decrease gradually until the end of the observation period at 5:00 PM, where it dips to about 17.3 volts. This decline likely corresponds to a reduction in sunlight intensity as the afternoon progresses. Overall, the Graph shows that the solar panel's voltage output increases with rising sunlight intensity, peaks around midday, and then decreases as sunlight wanes in the afternoon.

The Graph 16b, shows the relationship between time and the current output of a mono and poly crystalline solar panel from 8:00 AM to 5:00 PM. From 8:00 AM to around 12:00 PM, the current gradually increases from approximately 0.2 amperes to a peak of about 0.5 amperes. This increase indicates that as sunlight becomes more intense during the morning, the solar panel generates more current. Between 12:00 PM and 1:00 PM, the current reaches its highest point, reflecting the period of maximum solar irradiance when the panel is most efficient at converting sunlight into electrical current. After 1:00 PM, there is a noticeable decline in current output. The current decreases sharply after 1:00 PM, dropping from around 0.5 amperes to 0.4 amperes by 2:00 PM, and continues to fall throughout the afternoon. By 4:00 PM, the current has reduced to approximately 0.2 amperes. This decline is likely due to the decreasing intensity of sunlight as the day progresses towards the evening. Overall, the Graph reflects how the solar panel's current output increases with sunlight intensity, peaks around midday, and then gradually decreases as sunlight diminishes in the afternoon.

VI. CONCLUSION

The Dynamic Adaptive Solar Tracking System presented in this paper offers a promising solution for enhancing the efficiency and reliability of solar power generation systems. By integrating real-time sun direction data with precise location and time values, the DASTS provides adaptive tracking capabilities that optimize energy capture while ensuring the structural integrity of solar panel installations. This innovative approach holds significant potential for advancing the adoption of solar energy as a sustainable power source.

The efficiency of mono and poly crystalline solar panels with fixed and dual axis are analyzed. The mono crystalline panel produces consistently higher voltage and current output when compared to poly crystalline panel. The voltage and current generated by dual axis solar panel has higher efficiency when compared to the fixed axis solar panel. This indicates that mono crystalline panel allows to operate more efficiently under optimal condition. By keeping the mono crystalline panel is maintaining a higher level of efficiency. In conclusion, mono crystalline solar panels can lead to substantial gains in performance, both in terms voltage and current and the overall efficiency of the energy conversion process. By combining sustainable energy source, we create a more resilient and efficient system, contributing to the broader goal of improving the reliability and effectiveness of renewable energy solutions.

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