Design Implementation & Optimization of A Motorized Maximum Power Point Tracking System.

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Abstract- One of the most important renewable energy sources is solar power and its emergence has revolutionized how we retrieve, store, distribute, and consume electrical power. However, tracking mechanisms have not been entirely effective in the past towards maximizing energy storage from solar energy. This project seeks to design, implement, and optimize a Motorized Maximum Power Point Tracking (MPPT) solar system to improve the efficiency of renewable energy generation. The project involved using a smart algorithm to drive a solar panel connected to light dependent resistors (LDRs) linked to a suitable power source. An Arduino microcontroller and other components were added to the MPPT system to guide its movements towards the sun's most intense ray region. A static solar panel was also designed to perform comparison of solar harvest between stationery and movable panels For 10 days each across sunny, partially cloudy, and cloudy weather, both systems were deployed to observe which solar panel would receive and generate more energy overall. The comparisons showed that the motorized MPPT system was more efficient in retrieving energy, with its setup getting as much as 16% more power across conditions deployed in different weather settings. The MPPT system's superior energy-capturing ability makes it a suitable option for implementation. Results obtained showed that the MPPT solar tracker is a financially feasible option in the long term and should be scaled to meet commercial needs for sustainable energy options.

Keywords: Arduino, Gear System, Micro Controller, MPPT System, Photovoltaic Cell.

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I. Introduction

The availability of solar energy and its clean nature is an indisputable fact. Consequently, solar technologies have evolved over the years. These technologies have affected industrial and domestic industries through the provision of lighting, heat and electricity positively. Recently, with the alarming rate of depletion of major conventional energy sources like petroleum, coal and natural gas, coupled with the environmental hazards caused by the process of harnessing these energy sources, it has become an urgent necessity to invest in renewable energy sources that can power the future satisfactorily[1]. The energy potential of the sun being so great and unlimited has been faced by numerous challenges in harvesting mainly because of the limited efficiency of available solar cells. The best efficiency of the majority of commercially available solar cells ranges between 10 and 20 per cent [2]. This shows that maximum tracking of the sun needs improvement, because the earth is rotating on a tilted axis and takes an elliptical path around the sun. A stationary solar panel's output will drastically vary throughout the day and even throughout the year [3]. Because of the sun's movement, a standard solar panel will only observe about 10% - 20% efficiency under ideal conditions, while solar tracking has been shown to potentially double that with 40% efficiency under ideal conditions [4].

When a solar panel with a specific solar cell is chosen, the only other way to increase power output is by increasing the amount of light falling on the panel [5]. The effectiveness of a solar panel in general, is directly correlated to the amount of sunlight that it is being exposed to. A solar panel is most effective when it is hit by a solar source at a perfectly perpendicular angle, i.e., the angle of incidence is zero. To keep the angle of incidence at zero in a real-world situation, the solar panel must move with the sun to maintain this perpendicular angle [6]. In this way, maximum power can be converted by the solar panel into usable electricity.

Over time, solar photovoltaic (PV) systems, have thus gained increasing popularity as a source of clean and sustainable energy due to their clean and sustainable features [7]. Despite these striking features, the PV system's efficiencies are observed to be affected by external factors such as temperature, shading, and irradiance variations. This consequently leads to reduced power generation [8]. To mitigate or eliminate the effects of these consequences, a technique called Maximum Power Point Tracking (MPPT) was improvised. MPPT is thus a technique used to extract the maximum available power from PV modules by continuously tracking regions of Maximum Sunlight rays. Conventional MPPT algorithms do not account for dynamic changes in environmental conditions [9], necessitating the development of an automatic MPPT system with mechanical actuators to optimize power generation [10].

II. Reviewed Articles Related to This Research

Solar energy is a crucial and sustainable resource that has garnered increasing attention due to its potential to mitigate the escalating challenges associated with normal everyday energy sources. The advantages of solar energy lie not only in its abundance but also in its environmental benefits and versatility as an energy source. The sun, as our primary source of solar energy, emits an astonishing amount of energy into space. Approximately 174 petawatts (PW) of solar energy reach the Earth's upper atmosphere continuously. This energy influx far exceeds global energy consumption, highlighting the untapped potential of solar energy [11]. One of the paramount reasons for the growing interest in solar energy is its inherent environmental benefits. Unlike fossil fuels, solar energy production is clean and does not release harmful greenhouse gases or pollutants into the atmosphere. It contributes to a reduction in carbon emissions and addresses concerns regarding global climate change [12].

Solar energy can be harnessed through various technologies, each serving specific purposes. Solar photovoltaic (PV) systems, in particular, have gained prominence in both industrial and residential applications. These systems convert sunlight into electricity through the photovoltaic effect, making them suitable for a wide range of energy needs [13]. Solar energy offers the advantage of decentralization, allowing individuals and communities to generate their electricity. This decentralization can enhance energy security by reducing dependence on centralized power grids and vulnerable energy sources [14].

The decreasing cost of solar PV technology, coupled with government incentives and subsidies, has made solar energy economically viable. This affordability has encouraged widespread adoption, especially in regions with ample sunlight [15]. Solar energy systems are known for their durability and longevity, often lasting 25 years or more with minimal maintenance. This sustainability aspect aligns to achieve a more sustainable and eco-friendly energy landscape [16]. In the context of the global transition towards renewable energy sources, solar energy plays a pivotal role. As nations aim to reduce their reliance on non-renewable fossil fuels, solar power emerges as a cornerstone of the renewable energy portfolio [17].

In [18], the authors opined a technique that can optimally reduce system power loss and improve efficiency. An improved MPPT Charge Controller system with Arduino micro controller system is developed with about 97.75% recorded. The developed system had several innovative features such as smart device charging, wireless data loggers etc.

Muhammad.R.H.et.al. [19] evaluated the implementation of MPPT system using switching power topology. This research followed a literature approach to finding constantly changing Maximum Power Points (MPP). The hill climbing algorithm is developed with oscillating results charts depicting output power derived at maximum power point.

The Authors in [20], proposed the application of MPPT System to a piezoelectric wind harvester. It was observed that the output energy of the piezoelectric wind energy harvester generates highly erratic voltage waveforms with high total harmonic distortion. The proposed system is able to mitigate the impact of distortion with increased efficiency rate of 98% and lower power consumption measured at 5.29µw. Finally, although the device generates low power amount in MW, it can run and harvest power at low wind speeds compared to the conventional electromagnetic alternators.

III. Materials and Methods

The project was conceptualized and designed using the top-down design approach. This approach involves the systematic breakdown of the system into smaller, more manageable units, providing the designer with a deeper understanding of its intricacies and functionalities.

A. Major Components

The key components of the solar tracking system include:

a. Photovoltaic cell
b. Power supply
c. Input light sensors (CDS)
d. Voltage regulator
e. Analog-to-digital converter
f. Microcontroller
g. Output mechanical transducer (Servo Motor)
h. Tracking software
i. Mechanical structure

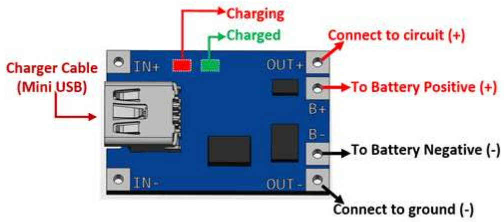

Fig. 1: TP 4056 Pin – Out

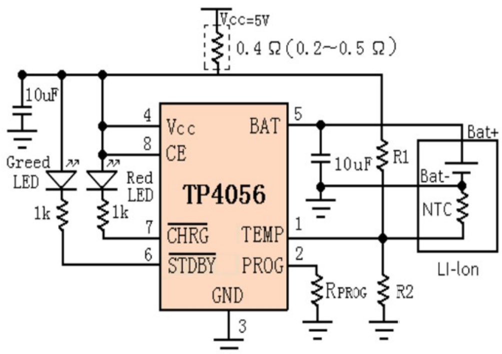

Fig. 2: Circuit diagram representation

1. *Light Sensor*

A Cadmium Sulphide photocell is chosen as the light sensor for this project due to its cost-effectiveness and simplicity. This passive component is characterized by a resistance that varies inversely with incident light intensity.

Other features of the Photocell include;

a. Resistance in the presence of light: 1KΩ
b. Dark Resistance: 10MΩ to 100Ω
c. Illuminance Range: 3 lux to ~ 4,000 lux
d. Spectral Response: sensitive to wavelengths in the visible spectrum (400 nm to 700 nm)
e. Temperature Coefficient: Typically around - 0.05%/°C to - 0.1%/°C
f. Operating Temperature Range: Approximately - 30°C to 70°C
g. Maximum Power Dissipation: Around 100mW to 200mW

Some two 220Ω resistors were selected to act as translators, converting subtle changes in sunlight intensity via the LDRs into electrical signals understood by the microcontroller, ultimately guiding the system's movement to maximize solar panel efficiency. It also helps to regulate current passing through the system onto connected LED indicators.

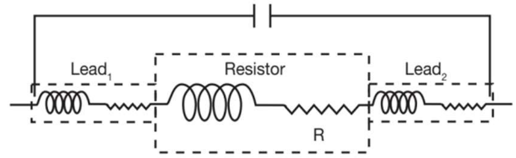

Fig 3: Circuit Representation of a typical 220Ω, 0.5W resistor.

To calculate the resistance in the circuit, an account for the total resistance throughout its components has to be made as this will influence the current flow and ensure adequate power dissipation. Consequently Two (2) 220Ω resistors connected in parallel were included in the circuit. Therefore, to calculate the equivalent resistance for the parallel combination of the 220Ω resistors:

$$R_{parallel} = \frac{1}{\frac{1}{R_1}+\frac{1}{R_2}} \quad (1)$$

where $R_1 = R_2 = 220\ \Omega$

$$R_{parallel} = \frac{1}{\frac{1}{220}+\frac{1}{220}} = \frac{1}{\frac{2}{220}} = 110\Omega$$

Two (2) light-dependent resistors connected to the circuit also possess 1,000Ω resistances and will play a role in current flow and overall power dissipation capacity. Given that there are two LDRs of 1,000Ω each, the total resistance will be 2110Ω in the circuit.

The microcontroller used, was programmed with a code that controls the servo motor based on readings obtained from two the 2 light sensors. The servo motor being controlled is attached to pin 9 of the microcontroller and is used to adjust the position of the PV cell based on the difference in light intensity detected by the two sensors. Some features of the microcontroller used include;

a. Clock speed of up to 16MHz.
b. 32 programmable input/output ports.
c. 32K Bytes of self-programmable flash program memory.
d. 1024 Bytes of EEPROM and 2K Bytes of SRAM.
e. Multiple timers, counters, and PWM channels.
f. 8 channels with a 10-bit ADC.
g. Serial communication interfaces.
h. Operating voltage range: 2.7-5.5 V.

2. *Microcontroller Pin Configuration*

Fig. 4 shows the pin configuration of the Arduino Uno R3 board, highlighting the functions and mappings of its input/output (I/O) pins.

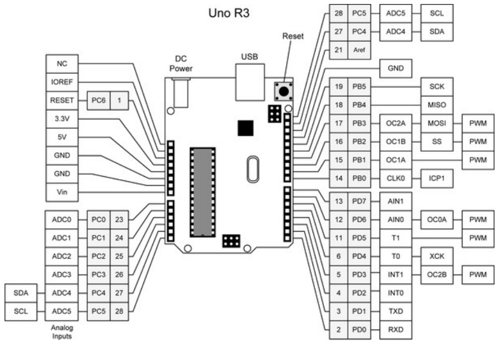

Fig. 4: Pin Configuration of Arduino Uno R3

3. *Servo Motor*

The servo motor weighs 220 with a torque of 58 kg·cm at 6V. The operating speed is 0.17 seconds per 60 degrees at 6V, offering a good balance between power and responsiveness. Additionally, its wide operating voltage range of 4V to 12V provides flexibility for different power supply setups.

B. Mechanical Structure

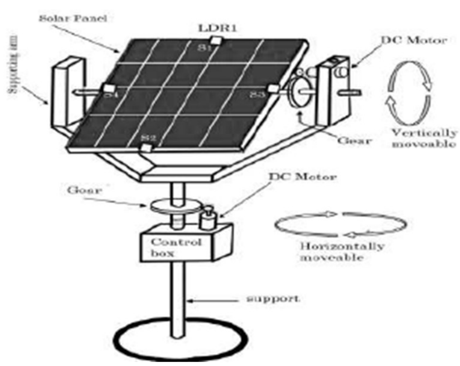

Fig 5: Sketches of Solar Panel Configuration With Gear System

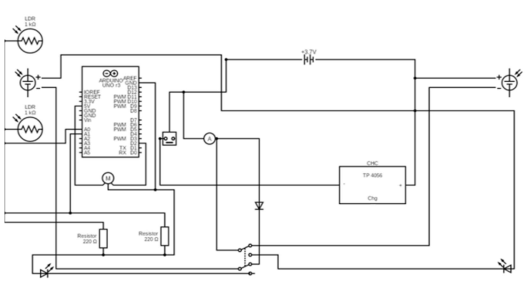
Fig. 6: Complete Circuit Diagram

Fig. 6 shows a complete circuit diagram of the microcontroller-based single-axis solar radiation tracker. This system tracks the radiation of the sun directly by tilting the photovoltaic cells at an angle of 90 degrees for maximum exposure to the sun's rays. The system uses two light-dependent resistors and one battery source of 3.7V. When a DC voltage comes from the battery, it is converted by the TP 4056 charge module to produce 5V. The 5V goes to the microcontroller which feeds same to the servo motor when its services are needed owing to changes in light rays sensed by the LDRs.

At night, the LDRs detect no solar ray and are hence idle. But once solar radiation increases the two LDRs which work in pairs convert the solar radiation into analog signals and send it to the microcontroller through pins A0, A1, and 5V which do the comparisons. The microcontroller does its comparison and sends a signal to the servo-motor through pin GND to carry out adjustments, when necessary, to make the solar panel to face the direction with the highest intensity of solar radiation.

Fig. 7 below shows the flowchart describing how the solar PV system with Arduino-controlled operation will operate:

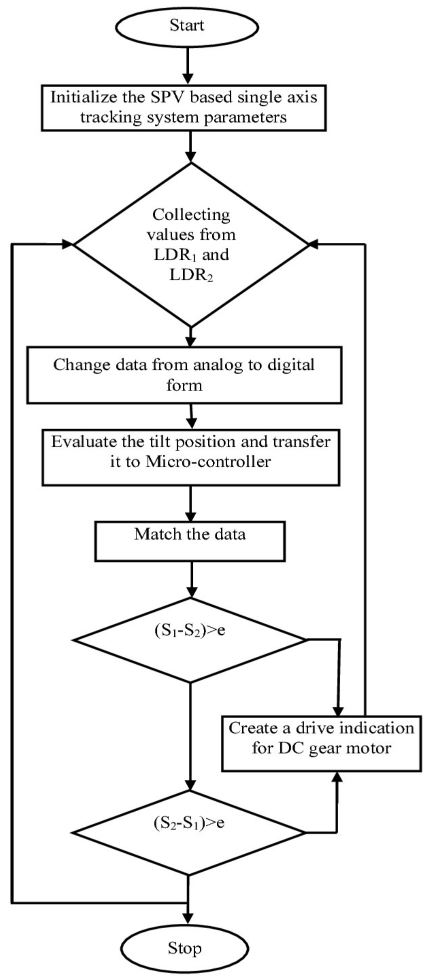

Fig. 7: Flowchart showing basic operation of Arduino -controlled solar tracking system with two LDRs.

IV. Implementation & Testing

A. Hardware Implementation

1. Photovoltaic Cell Mounting

The implementation of the hardware components began with the secure mounting of the polycrystalline solar cell. The key objective was to provide stability and ensure optimal exposure to sunlight. The following steps were undertaken:

a. The solar cell was carefully positioned on the designated mounting area of the mechanical structure.
b. Appropriate fasteners were used to secure the solar cell in place, taking into consideration the need for structural integrity.

2. Power Supply Connection

The power supply module, which included a 3.7V battery and a voltage regulator (TP 4056), were integrated to guarantee a stable power source, these components were selected to ensure uninterrupted operation, a vital factor in achieving optimal results. The implementation proceeded as follows:

a. The positive and negative terminals of the battery were connected to the input of the voltage regulator to maintain the desired voltage levels.
b. Proper connection of a battery power module was introduced to enhance the regulation of voltage and minimize fluctuations.

3. Light Sensor Placement

Two CdS photocells were strategically positioned on the mechanical structure to detect changes in light intensity. These passive components, known for their cost-effectiveness and simplicity, exhibit a resistance that varies inversely with incident light intensity. The implementation of the light sensors involved:

a. Securely mounting the CdS photocells to ensure exposure to sunlight without obstructions.
b. Establishing connections between the photocells and the microcontroller's analog input pins, allowing for precise data acquisition.

4. Microcontroller Wiring

The Arduino Uno R3 microcontroller played a pivotal role as the central processing unit of the system. Its high performance and low power consumption made it a suitable choice. The implementation consists of the following steps:

a. The microcontroller was connected to the power supply, ensuring that it operated within the specified voltage range.
b. Wiring was established between the microcontroller and various system components, including the light sensors and servo motor.

5. Installation of the Servo Motor

The servo motor was securely attached to the mechanical structure at the designated mounting point. Control wires from the servo motor were connected to the relevant pins on the Arduino Uno R3 microcontroller.

a. The servo motor was attached securely to the designated mounting point.
b. The servo motor's control wires were connected to the microcontroller.

6. Assembly of the Mechanical Structure

The mechanical structure, including the gear system, was assembled to provide support for all system components. The assembly process ensured that all components were correctly aligned and securely attached to allow for free movement of the solar panel around a horizontal axis.

a. The gear system was assembled with precise alignment.
b. The stability of the mechanical structure was then verified.

7. Initial Testing and Calibration

To confirm the system's accurate sun tracking and optimize its performance, the solar tracker underwent testing and calibration. The steps that were followed included the conducting of tests to verify its ability to accurately track the sun's movement and iteratively adjusting its parameters to achieve optimal tracking precision. Algorithmically, the tests were carried out as follows;

a. Initial tests were conducted to confirm accurate sun tracking.
b. The parameters were then calibrated for optimal tracking precision.

B. Software Implementation

The software implementation of the MPPT solar tracking system was carried out by writing the code after achieving the wiring of the system. This was done to ensure accurate tracking of the sun's rays at 90^o to the PV cells at all times. The provided code defines a program that reads data from the two light sensors (LDR1 and LDR2) and adjusts the position of the system's servo motor (myservo) based on the difference between the sensor readings. The servo motor will then move to the left or right depending on which sensor is detecting more light rays.

1. Arduino Uno R3

The Arduino Uno R3 which serves as the system's microcontroller and hence the core of the system's intelligence has a software running on it. The software controls the microcontroller to take sensor readings and decide on how to control the servo motor, thereby orienting the solar panel to maximize solar energy harvest.

2. Tracking Algorithm

The code snippet provided for the Arduino Uno R3 sets up a servo motor, reads data from the 2 LDR sensors, and includes placeholders for the solar tracking algorithm. The algorithm should adjust the servo motor's position based on the LDR sensor data to ensure the solar panel remains aligned with the Sun.

3. Dual LDR Sensors with Arduino

The second code snippet is designed for Arduino and makes use of dual LDR sensors. It reads data from the LDRs and calculates the maximum value among them to determine the orientation of the Sun.

a. **Servo Motor Configuration**: In both code snippets, the servo motor is configured and controlled using the defined Servo library. This is done with reference to the fact that the servo motor is a crucial component for adjusting the solar panel's position.
b. **Light Sensor Data**: The code reads data from the 2 Light Dependent Resistors (LDRs) connected to the Microcontroller’s analog pins. These sensors measure light intensity and provide the necessary input for the tracking algorithm.
c. **Solar Tracking Algorithm**: The provided code is a framework that can be expanded with a custom solar tracking algorithm. This algorithm is responsible for calculating the optimal orientation of the solar panel based on the LDR readings.
d. **Servo Control**: Both code snippets include servo motor control commands. The servo's position is adjusted in real-time to ensure that the solar panel follows the Sun's movement accurately.

V. Test Results & Discussion

A. Testing of Stationary Solar Panels With No Load Attached

TABLE I
DATA COLLECTED IN SUNNY WEATHER (STATIC SOLAR PANEL)

No of observation	V_{in} (V)	I_{in} (A)
1	1.89	0.40
2	1.89	0.36
3	1.91	0.44
4	1.90	0.36
5	1.90	0.33
6	1.91	0.32
7	1.78	0.48
8	1.78	0.46
9	1.89	0.33
10	1.88	0.40

TABLE II
DATA COLLECTED IN PARTLY CLOUDY WEATHER (STATIC SOLAR PANEL)

No of observation	V_{in} (V)	I_{in} (A)
1	1.89	0.33
2	1.88	0.31
3	1.89	0.36
4	1.89	0.31
5	1.90	0.32
6	1.89	0.35
7	1.90	0.32
8	1.89	0.32
9	1.91	0.34
10	1.90	0.37

TABLE III
DATA COLLECTED IN CLOUDY WEATHER (STATIC SOLAR PANEL)

No of observation	V_{in} (V)	I_{in} (A)
1	1.97	0.23
2	1.93	0.24
3	1.99	0.22
4	2.02	0.25
5	1.59	0.26
6	1.94	0.21
7	1.93	0.21
8	1.99	0.20
9	1.91	0.23
10	1.93	0.23

B. Testing Auto Tracking Panels

TABLE IV
DATA COLLECTED IN SUNNY WEATHER (MPPT AUTO-TRACKING PANEL)

No of observation	V_{in} (V)	I_{in} (A)
1	1.89	0.48
2	1.89	0.43
3	1.91	0.52
4	1.90	0.43
5	1.90	0.40
6	1.91	0.39
7	1.81	0.57
8	1.82	0.55
9	1.89	0.40
10	1.88	0.48

TABLE V
DATA COLLECTED IN PARTLY CLOUDY WEATHER (MPPT AUTO-TRACKING PANEL)

No of observation	V_{in} (V)	I_{in} (A)
1	1.88	0.40
2	1.88	0.38
3	1.89	0.43
4	1.89	0.38
5	1.90	0.39
6	1.89	0.42
7	1.90	0.39
8	1.89	0.39
9	1.90	0.41
10	1.89	0.42

TABLE VI
DATA COLLECTED IN CLOUDY WEATHER (MPPT AUTO-TRACKING PANEL)

No of observation	V_{in} (V)	I_{in} (A)
1	1.96	0.33
2	1.93	0.40
3	1.98	0.37
4	2.00	0.35
5	1.59	0.32
6	1.94	0.35
7	1.93	0.34
8	1.98	0.33
9	1.91	0.37
10	1.93	0.35

C. *Comparison of Static and Motorized MPPT Auto-Tracking Solar Panels*

In this phase of testing, the performance of stationary solar panels without a load attached was assessed as a reference point. The key comparison between the MPPT (Maximum Power Point Tracking) system and static solar panels is summarized in Table VII to X. In the tables below, the percentage difference in voltage may assume negative Fig. to show how much energy is lost from a static solar panel's inability to track the sun's direction. The power difference column shows how much energy the auto-tracking solar panel receives on average across each observation over static panels.

TABLE VII
COMPARISON OF STATIC SOLAR PANEL AND MPPT AUTO-TRACKING PANEL IN SUNNY WEATHER

Observation	V_{in} (V) Difference	I_{in} (A) (% Difference)
1	N/A	8.00
2	N/A	7.00
3	N/A	8.00
4	N/A	7.00
5	N/A	7.00
6	N/A	7.00
7	3.000	9.00
8	4.000	9.00
9	N/A	7.00
10	N/A	8.00

TABLE VIII
COMPARISON OF STATIC SOLAR PANEL AND MPPT AUTO-TRACKING PANEL IN PARTLY CLOUDY WEATHER

Observation	V_{in} (V) Difference	I_{in} (A) (% Difference)
1	-1.000	7.000
2	N/A	7.000
3	N/A	7.000
4	N/A	7.000
5	N/A	7.000
6	N/A	7.000
7	N/A	7.000
8	N/A	7.000
9	-1.000	7.000
10	-1.000	5.000

TABLE IX
COMPARISON OF STATIC SOLAR PANEL AND MPPT AUTO-TRACKING PANEL IN CLOUDY WEATHER

Observation	V_{in} (V) Difference	I_{in} (A) (% Difference)
1	-1.000	10.000
2	N/A	16.000
3	-1.000	15.000
4	-2.000	10.000
5	N/A	6.000
6	N/A	14.000
7	N/A	13.000
8	-1.000	13.000
9	N/A	14.000
10	N/A	12.000

In the analysis of the data collected during sunny weather conditions, the auto-tracking solar panels outperformed the static solar panels significantly in all 10 observations. On average, the Motorized MPPT auto-tracking panels retrieved up to 9% more energy at 1.91W compared to the static panels, which retrieved less energy under similar conditions. This notable difference can be attributed to the ability of the motorized MPPT auto-tracking panels to efficiently orient them toward the sun, ensuring they capture a greater amount of solar energy when compared to their static counterparts in the same weather conditions.

Similarly, under partly cloudy weather conditions, the Motorized MPPT auto-tracking panels continued to demonstrate their superior efficiency, achieving an average of 7% more energy at 3.69W compared to the static panels, which retrieved 7% less energy at around 1.9W. This enhanced performance further underscores the advantage of utilizing auto-tracking technology, as it ensures that the panels are optimally positioned to harness available sunlight even when clouds partially obscure the sun.

Even during cloudy weather, which typically poses a greater challenge for solar panels, the Motorized MPPT auto-tracking panels maintained their lead in efficiency across all 10 observations. On average, the Motorized MPPT auto-tracking panels generated an impressive 16% more energy at approximately 2W compared to the static panels, which retrieved 16% less energy at 1.9W at a point during the observations. This is a testament to the adaptability of auto-tracking systems, as they continue to maximize energy production even when sunlight is limited due to cloudy skies.

VI. Conclusion

The comprehensive testing and analysis of the MPPT (Maximum Power Point Tracking) solar tracker system, as well as the comparison with static solar panels, have provided valuable insights into the system's performance and its advantages. The MPPT system consistently demonstrated superior energy efficiency when compared to static solar panels. By precisely tracking the sun's movement, it increased energy production by a high 16%, contributing to substantial cost savings and improved energy yield. The MPPT system showcased high tracking precision, ensuring optimal alignment with the sun's position throughout the day. This precision results in more stable energy production and reduces dependency on environmental conditions. The system exhibited remarkable adaptability to varying environmental conditions, such as changes in solar angles due to cloud cover. It continued to optimize the solar panel's orientation even during partially cloudy days, thereby enhancing reliability.

While the initial investment for the MPPT system may be higher due to additional components like the Arduino Uno R3 microcontroller and servo motor, the potential for long-term cost savings became evident. The increased energy production and potential for reduced energy costs justify this investment. The MPPT system contributes to a more sustainable and eco-friendly approach to energy generation. It reduces the overall environmental impact by harnessing more energy from the same solar panel area, aligning with the principles of green energy solutions.

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Conflict of Interest

The Authors declare that no conflict of interest exists with regards to the publication of this article.

Authors Contribution

Author 1 conceptualized the research and designed the system and prepared the paper while, Author 2, performed detailed analysis, full supervision, reviewed the process until final results were obtained and wrote the original draft

References

[1] Abidi, H., Abdelghani, A. B. B., and Montesinos-Miracle, D. (2012). MPPT algorithm and photovoltaic array emulator using DC/DC converters. In 2012 16th IEEE Mediterranean Electro Technical Conference pp. 567-572.

[2] Samawel Abed-Alhaleem Obais, Alaa Abed-Alameer Obais, Mohammad Hamid Kadhim, Ali Talib Murad, Haider Jabbar Mohsen, Thamer Mohammed Hani. Determining the efficiency of solar photovoltaic power system using solar panels prepared from recycled materials: Case Study in Iraq Supervised by: Murtadha M. M. Al-Masoudy (M.Sc.) Prepared. 2022.

[3] Ejiko S. O., Ogunlowo M. and Ukachi P. A World Journal of Engineering Research and Technology. Overview of solar tracking device and development of light positioning detector 2020.

[4] Anshul Awasthi, Akash,Kumar Shukla, Murali Manohar S. R., Chandrakant Dondariya, K.N. Shukla, Deepak Porwal, Geetam Richhariya, Review on sun tracking technology in solar PV system. February 2020

[5] Alexander E.Emmanuel, John A.Orr, David cyganski and Edward M.Gulachenski(1993),''A survey of Harmonic voltages and currents at customer's Bus'' IEEE Transactions on Power Delivery.Vol.8, No.1, pp.411-421

[6] Ali, A. N. A., Saied, M. H., Mustafa, M., and Abdel-Moneim, T. (2012). A survey of maximum PPT techniques of PV systems. Proceedings of the IEEE Energy tech, pp.1-17.

[7] Antonello, C. Andrea, P., Rocco, V. and Marco, F. (2015). Airborne Wind Energy Systems: A Review of the Technologies. Renewable and Sustainable Energy Reviews. Vol. 51. pp. 1461-1476. *10.1016/j.rser.2015.07.053*.

[8] Jalal A Assadeg, Kamaruzzaman Bin Sopian and Ahmad Fudholi Performance of grid-connected solar photovoltaic power plants in the Middle East and North Africa Oct 2019.

[9] Bouziane, K., Dris, K., Boubeker, A., and Noureddine, S. (2014). Optimization of a Solar Tracker System for Photovoltaic Power Plants in Saharian Region, Example of Ouargla. Energy Procedia, 50, https://doi.org/ 10.1016/ j.egypro. 2014 .06 .075

[10] Bründlinger, R., (2009). PrEN 50530 – The new European standard for performance characterisation of PV inverters. In 24th European Photovoltaic Solar Energy Conference.

[11] Esram, T., and Chapman, P. L. (2007). Comparison of photovoltaic array maximum power point tracking techniques. IEEE Transactions on Energy Conversion, 22(2), 439-449.

[12] Hiyama, T., and Kitabayashi, K. (1997). Neural network based estimation of maximum power generation from PV module using environmental information. IEEE Transactions on Energy Conversion, Vol. 12, pp.241-247.

[13] Hohm, D., and Ropp, M. (2000). Comparative study of maximum power point tracking algorithms using an experimental, programmable, maximum power point tracking test bed. In Photovoltaic Specialists Conference, 2000. Conference Record of the Twenty-Eighth IEEE pp. 1699-1702.

[14] Hussein, K., Muta, I., Hoshino, T., and Osakada, M. (1995). Maximum photovoltaic power tracking: an algorithm for rapidly changing atmospheric conditions. IEE Proceedings-Generation, Transmission and Distribution, Vol. 142, pp. 59-64.
[15] Issaquah, K., and Salam, Z. (2013). A deterministic particle swarm optimization maximum power point tracker for photovoltaic system under partial shading condition. IEEE Transactions on Industrial Electronics, Vol. 60, pp. 3195-3206.
[16] Jain, S., and Agarwal, V. (2004), A new algorithm for rapid tracking of approximate maximum power point in photovoltaic systems. IEEE Power Electronics Letters, Vol. 2, pp. 16-19.
[17] Jung, Y., So, J., Yu, G, and Choi, J (2005) Improved perturbation and observation method (IPandO) of MPPT control for photovoltaic power systems, In Conference Record of the Thirty-First IEEE Photovoltaic Specialists Conference pp. 1788-1791.
[18] Md. Rokonuzzman and Md Hossen-E-Hailder, Design and Implementation of Maximum Power Point Tracking Solar Charge Controller, "3rd International Conference on Electrical Engineering and Information Communication Technology. Vol. 3 pp. 1-5, 2016. Doi: 10.2209/CEEKT. 2016.7873139.
[19] Mohammed Rszul Hamd, Jakaria Rahim, Sabrina Chowdhury , and T.M. Moniruzzaman Sunny, "Design and Development of a maximum power Point Tracking (MPPT) Charge Controller for Photo-Voltaic (PV) Power generation system," American Journal of Engineering Research, Vol. 5, no 5, pp.15-22, 2016
[20] Erol Kurt, Dauut Ozhan, Nicu Bizon and Jose Manuel Lopez-Quede, "Design and Implementation of maximum power point tracking system for a piezoelectric wind energy harvester generating high harmonity, sustainability, Vol. 13, no. 14, pp. 7709, 2021