

PAPER • OPEN ACCESS

A Review on Solar Tracking Methods

To cite this article: D V Nithin Kumar and M R Stalin John 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **912** 042045

View the [article online](#) for updates and enhancements.

You may also like

- [A comprehensive review on solar cooker tracking techniques for performance enhancement](#)
V Gokul, S Dhinesh, K Kalaiyarasu et al.
- [A review of automatic solar tracking systems](#)
A Mohamad, H Mhamdi, NAM Amin et al.
- [Increasing the efficiency of solar panel by solar tracking system](#)
A Imthiyas, S. Prakash, N Vijay et al.



ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

A Review on Solar Tracking Methods

D V Nithin Kumar¹ and M R Stalin John¹

¹Department of Mechanical Engineering, SRM Institute of Science & Technology, Kattankulathur, 603203.

E-mail: nithinkumardatti@gmail.com

Abstract. In the World, perhaps the most significant issue as far as people understood, non-renewable sources would be extinguished. Apart from that, non-renewable energy sources are one of the critical factors for pollution, global warming. To address such issues, it is vital to shift to sustainable power sources, for example - sunlight, wind, etc. are essential in the present century. To examine the available solar tracking methods and algorithm, which have better accuracy and high output power efficiency. Multiple databases were searched for English literature and limiting to last ten years. The keywords selected for the search were a combination of the solar tracking algorithm, PLC, maximum power point tracking system, and solar tracking. The search results suggested that research on solar tracking is required to increase the generation of electricity. Many International research institutions conducted research related to solar tracking systems and tracking algorithms. The solar tracking is done, by utilizing mechanical sensors to maintain the PV module perpendicular to the sun's irradiation. Proficient solar tracking methods are investigated by directing various analyses. The usage of renewable energy sources is lacking. Also, by designing an optimized solar tracking system for the generation of better output power is recommended.

1. Introduction

Solar energy is a clean, renewable source of energy which can be harnessed using various technologies like photovoltaic panels, solar heating, solar architecture etc. amongst which the most common for commercial use has been photovoltaic panels or solar panels. A solar panel is a device used for the production of electrical energy. The device was invented by Edmond Becquerel, a French Physicist. In the year 1839, Edmond discovered that the photovoltaic effect was produced when a cell was dipped in a conduction solution with two metal electrodes. The experiment resulted in the production of electrical energy when subjected to light energy. In the year 1873, Willoughby Smith's investigation concluded that selenium exhibited the property of a photoconductor. Three years after Willoughby's experiment, William G Adams and Richard E Day recorded in their research that, selenium generated electricity when subjected to the photovoltaic principle.

In 1883, Charles Fritz invented the first working selenium solar cell, a precursor to today's solar technology. In the year 1953, Calvin F, Gerald P and Daryl C discovered the application of silicon for the production of solar cells having higher efficiency and producing a net charge higher than selenium.

Today's PV cells contain silicon, and a typical solar cell contains n-type silicon (upper) and p-type(lower) silicon attached. It generates electricity by using sunlight to make electrons cross the different types of silicon. When light falls on a cell, it is bombarded with photons and these photons travel through the cell and transfer their energy to electrons in the lower layer which use this energy to cross the barrier into the upper layer and the circuit as electricity and to power the components



attached to the electric circuit. When multiple solar cells are connected, it is known as a module or panel. A connection of modules in series and parallel is known as a PV array.

A solar panel is stationary and usually placed at a particular angle so that maximum light falls on it. The efficiency of these solar panels in terms of rate of conversion of the light falling on them to the energy produced is very low and due to the high cost of solar panels, it wasn't feasible. Many methods have been introduced to increase the efficiency of the PV panels and one such is a solar tracker or solar tracking system. A solar tracking system is one which moves or tilts the panel accordingly, following the path of the sun, to face the sun perpendicularly at all times. This method has found to increase the efficiency of a solar panel when compared to that of a fixed one. The purpose of a solar tracker is to maintain the panel in a position where light intensity is maximum at all times during the day to increase the efficiency.

Solar tracking systems can be classified into two types. The first being a passive system which uses compressed gas fluid and the exposure to sunlight increases their temperature varying their weight and thus tilting the panel. Due to varying results and unreliability inaccuracy, this method isn't widely adopted. The second is the active solar tracking system which uses motors and gears to drive the system. Active systems can be further classified into two types, single-axis and dual-axis. Single-axis systems as the name suggests provides movement in one axis. That movement can be moving back and forth in a single direction, horizontal, vertical, tilted or even polar-aligned according to the needs of tracking. Dual-axis tracking is a more efficient form of tracking as it has two directions of movement and can effectively track and face the sun.

Multiple methods can be used to track the sun. The first among a few is the real-time tracking which uses the azimuth and zenith angles along with a combination of sensors to track the sun efficiently. This method involves a lot of data and calculations in finding the position of the sun accurately. The next process would be with that of sensors. The most common of these is LDR's or light dependant resistors which work on the principle of change in resistance according to intensity of light falling on it. This is one of the most cost-effective methods to track the sun effectively. Another type is the chronological tracking which is based on the position of the sun in a given area and given time during the year. This involves a lot of data on the sun's path in that particular area and it is based on the geographical position. The advantage of this method is that it is irrelevant to the weather conditions. Tracking the sun using a camera is another type of method. The camera captures images of the sky, processes it and locates the sun's position and aligns panel accordingly. This is yet another efficient tracking method.

This paper aims to find the optimal and efficient tracking method by reviewing various methods. In section 2 and section 3 techniques of single-axis and dual-axis solar tracking systems, respectively. Finally, the conclusion is summarized in section 4.

2. Single-axis tracking system

Sun tracking system with a uni-axis, i.e., single-axis rotates only in one direction concerning the axis which is more efficient than a fixed system.

Teolan Tomson [1] designed and examined the discrete two-positional control of photovoltaic collectors. The collector was revolved around its horizontal axis twice per day with predetermined positions. The seasonal and daily gain calculated the effect of the initial angle, azimuth angle, tilt positions, and initial azimuth with less input power for daily movement. The simulated and trail results appear that the increment of periodic power yield is about 10-20% in contrast with a fixed system.

Chin et al. [2] developed the prototype of uni-axis solar tracker and simulated the PV system at constant load by using MATLAB/Simulink software. A special design was incorporated to the tracker for a uni-axial moment with the help of a motor to enhance the system for one degree of freedom the fabricated design was shown in Figure 1. The LDR senses the light intensity and sends the signal to Arduino, which can rotate the PV module by utilizing the motor. Total setup was powered employing a battery in which produced power was stored by MPPT controller.

Peng Zhang et al. [3] designed a uni-axle sun tracker aided with a real-time and sensor-based system of tracking. When the weather condition is too sunny, system opts for sensor tracking else it opts time-based method. For the sake of rotation in this system, a stepper motor is equipped. After the sunset, the limit switch is activated, which indicates tracking end and resetting to the original position for the coming day. The study also estimated the resistance of the wind and the simulation of motion.

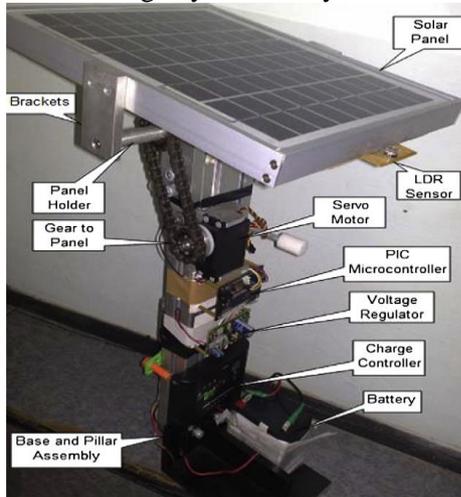


Figure 1. Fabricated model.



Figure 2. The constructed mirror reflected solar panel.

Iulia et al. [4] proposed a solar tracking algorithm to control the PV module movement to improve the output efficiency of the system. The virtual instrumentation program is developed in a graphical programming environment, LabVIEW, by using a tri-positional control strategy and implemented on the mechanical system. The designed programming language was more comfortable to acquire data collection, analysis, and control applications for the designer. This executed technique reduces the cost of the tracking method.

Sheik et al. [5] constructed and developed a tracking device with mirror reflection solar panel (MRSP) and automatic cooling for better efficiency shown in Figure 2. The proposed system was programmed based on azimuth angles with a fixed rotation angle of 525 steps per day for a specific time. Results state that higher power can be produced with alone reflection and a single cooling system than a conventional tracking system. Increased production of 59.71% is achieved with consideration and automatic cooling than any other combination.

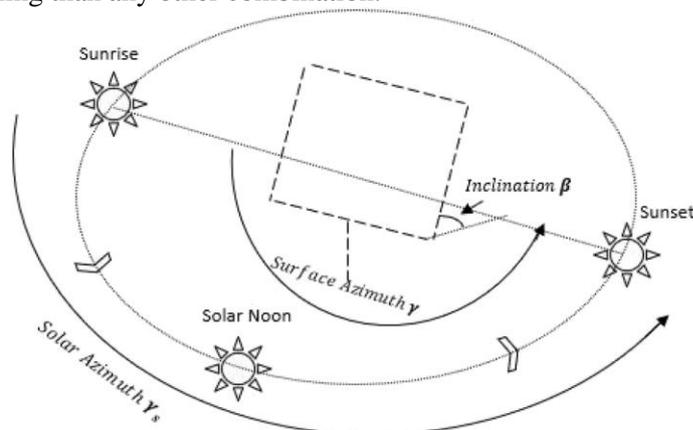


Figure 3. an illustration of tracking the sun throughout the day.

Batayneh et al. [6] developed a discrete uni-axis tracking device with tri-positions in the azimuth plane. The optimal angles for this system were defined based on the MATLAB simulation results adopting with weather data. Figure 3 shows the illustration of the tracking planes considered when tracking the sun throughout the day. The simulation outcomes of the three optimized angles show that

there is no significant change in power output in contrast to the continuous uni-axial sun tracking system. The results conclude that there is an 11-17% deviation between simulation and experimental data.

Al-Mohamad [7] designed a uni-axial solar tracking device depend on PLC (programmable logic controller) to improve output efficiency. Two sun sensors were installed and connected as input signals to PLC. The signal is used to generate an output signal for motors to rotate the panel. The block diagram of the PLC programmed system was shown in figure 4. A PLC is utilized to collect data, control, monitor the motor position and store the sun's radiation data. The total efficiency of the tracking system was 20% more when compared with the fixed module and exceeds 40% during peak period. This technique utilized to connect many PV panels in series/parallel and also cost-effective.

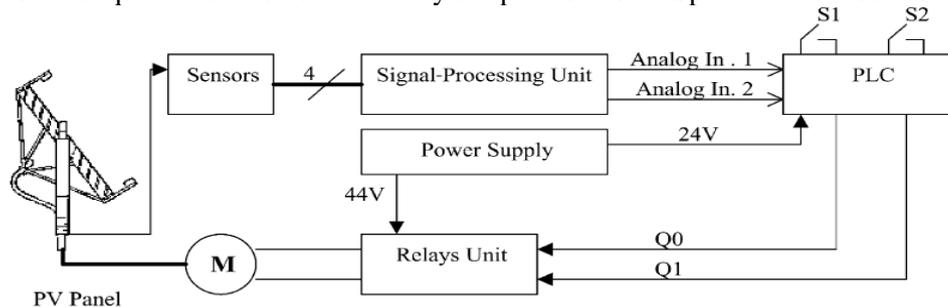


Figure 4. Block diagram of a tracking.

Ruben et al. [8] built a single axis solar tracker and developed a novel cascade control algorithm which can track the sun. The proposed diagram of the cascade control algorithm is indicated in figure 5. The proposed algorithm is contrasted with a proportional-integral controller obtained by eliminating the inner loop from the actual cascade controller. The results showed that the Filtered Mean Square Error (FMSE) for the proportional-integral controller and developed algorithm are 14.47 and 1.14, respectively, and the Maximum Tracking Error (MTE) for PI controller was 0.134+ and 0.014+ for the proposed algorithm. By considering the outcomes, he concluded that the tenfold increment by utilizing a cascade closed-loop control algorithm.

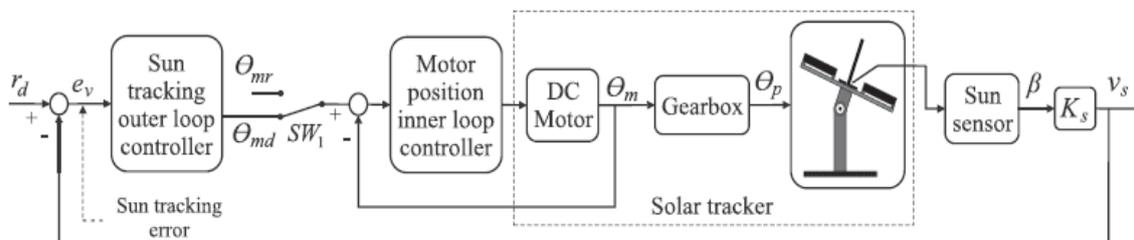


Figure 5. Proposed cascade control block diagram.

Guihua et al. [9] inspected the optical performance of horizontal uni-axial tracked photovoltaic modules, and based on the monthly radiation and sun geometry; a mathematical model is produced to calculate the daily gatherable radiation on PV panels. The analytical results state for a year gain on Uni-axial horizontal tracking from East-West is not that efficient while, South-North was best for boosted collection of power. It concludes that the South-North Uni-axial PV panel and Dual axial ratio decreases with the increment of the latitude of the site imply the horizontal.

Abadi et al. [10] proposed a uni-axial sun-tracking device with a fuzzy logic controller to orient the system according to the sun's direction. In this proposed model, the fuzzy logic controller controls the electromechanical motor movement based on data that occurred from the sensor. The experimental investigation of the solar tracking system had an energy gain of 47% in contrast with a rigid system.

Emre et al. [11] designed a uni-axle tracking device and investigated with fuzzy logic controller and PID (propositional integral derivative) controller. The PID controller is calculated by varying three different mathematical operations, and the Fuzzy logic controller is programmed by utilizing IF-THEN

rule. The overall power efficiency for a single-axis tracker of 15 days period for a fuzzy logic controller is about 21.2% more when compared with the PID controller.

Kavya et al. [12] fabricated a single hub solar tracking device by utilizing the LDR sensor for the positional arrangement of motors. PID algorithm had implemented on the PV board for minimizing tilt error. The wiper mechanism is presented to clean the PV board to attain panel efficiency. The experimental outcomes demonstrate that the execution of the cleaning system is capable of improving the power output by 30-40%.

3. Dual-axis tracking system

Sun tracking system with a double-axis, i.e., two-axis rotates which are perpendicular to each other, which is more accurate compared to uni-axial and equipped with a complex control system.

Sangani et al. [13] designed and developed different tracking modes such as seasonal, one axis N – S, and dual-axis for V-trough concentrator shown in figure 6. The power produced by utilizing a V-trough concentrator and a flat PV system is 157W/m² and 105W/m², respectively, which is noticed an increment of 40% by the developed system. The IV curve is shown in figure 7. The cost/unit watt of power generated from V-trough concentrator and a flat PV system is decreased by 24% from 7.72 to 5.88 \$/W.

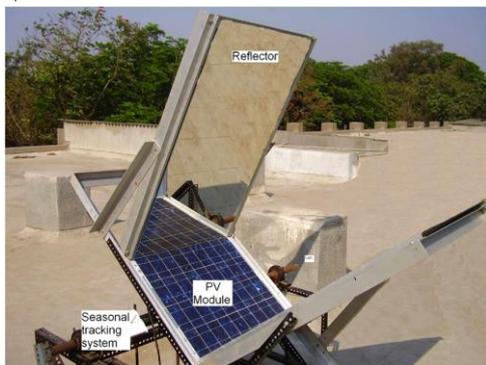


Figure 6. V trough concentrator system.

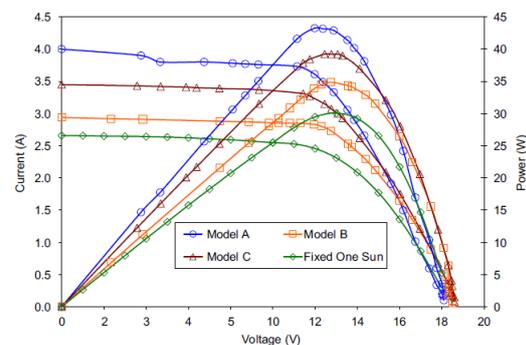


Figure 7. Voltage and current curve.

Oner et al. [14] designed and developed a spherical motor for the tracking system shown in figure 8, which can be controlled by a microcontroller. Instead of utilizing two stepper motors for both horizontal and vertical directions, the spherical motor can able to rotate in both directions. The experimental results demonstrated that there is an increment in this designed system when contrast to a rigid system during post meridian.

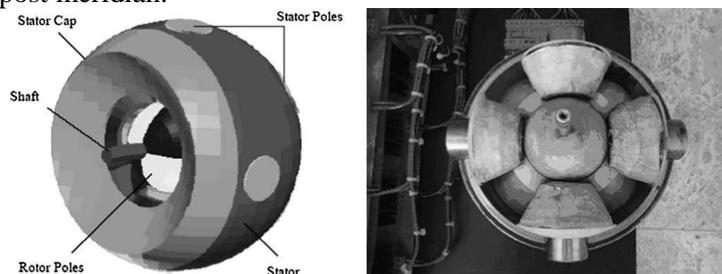


Figure 8. designed spherical motor.

Rustu et al. [15] analyzed and compared the experimental results for the double-axial sun-tracking device versus the rigid system. The performance measurement for both the system was carried out for the year between April-2010 to march-2011 shown in Figure 9. Annual electricity produced from a fixed system was 11.53MW with 1459kW h/kWp, and the tracking system was 15.07MW h with 1908 kW h/kWp, which was fed to the grid.

Mustafa et al. [16] built a dual-axial sun tracker accompanied by a controlled algorithm to enhance the energy production and reliability of the PV board. The proposed algorithm calculated the solar radiation time is utilizing GPS information and astronomical data and pulse width modular data to control motors. The outcome demonstrated that the energy for the proposed system had an increment of 40.7%.

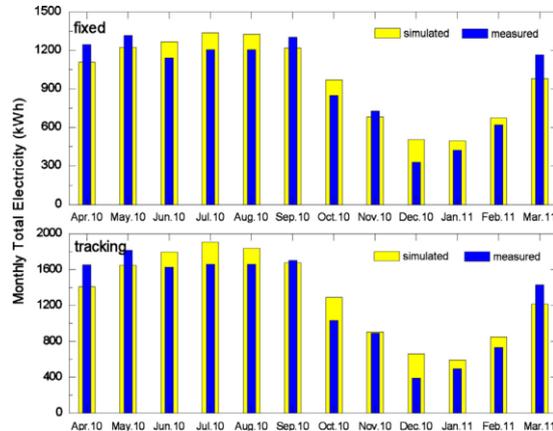


Figure 9. Monthly power electricity data with simulated and experimental for rigid and tracking systems.

Rashid et al. [17] constructed and examined a double-axle hybrid tracking system based on sensors and solar maps with continuous tracking. In this system, different algorithms and methodologies are utilized to track the sun, such as light-dependent sensors for daily movement at different climatic conditions and real-time clock modules for seasonal motion. The flowchart of the microcontroller programmed system is shown in figure 10. The experimental results have shown that the power gain for a hybrid tracking system has a 25.62% increment over the static system. In contrast, it has 4.2% more compared to a continuous tracking system.

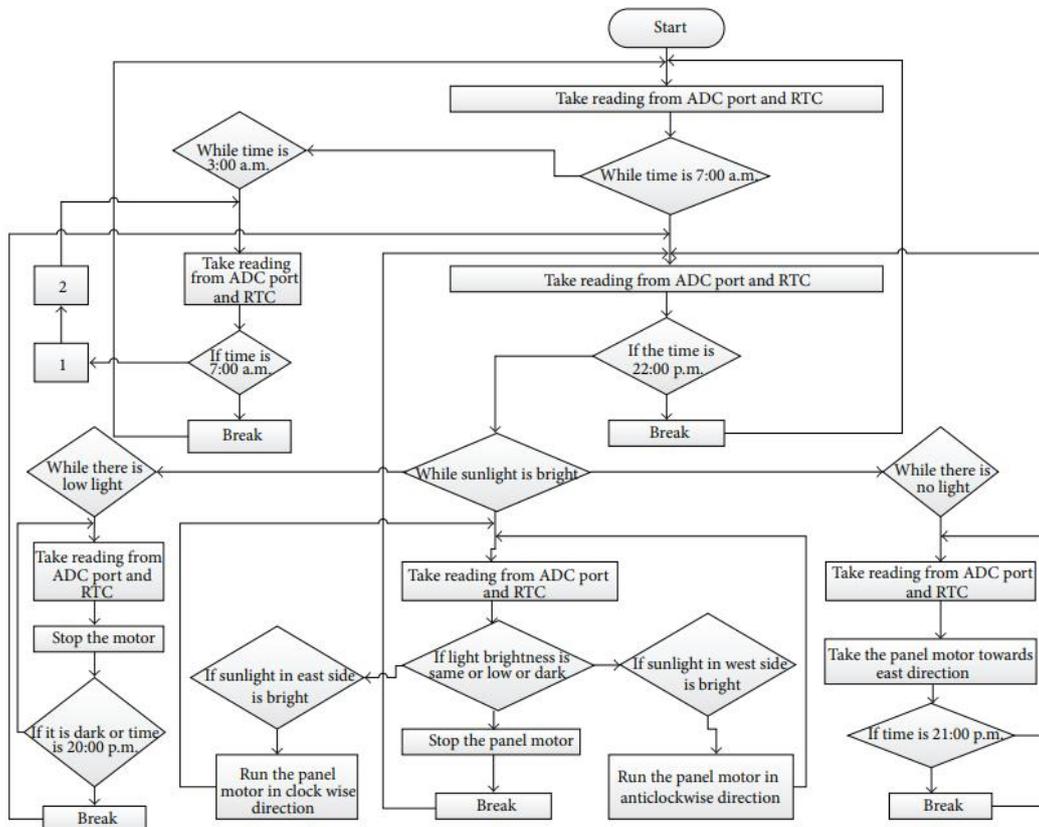


Figure 10. Flowchart of microcontroller programming.

Taehoon et al. [18] designed and constructed dual-axis smart photovoltaic blind based on the azimuth-altitude tracking system. The manufactured SPB is shown in figure 11. This prototype has the slope of the panel (horizontal axis) rotation between 0° to 90° and the azimuth of the panel between -9° and $+9^\circ$ due to limitation of the vertical axis. In conclusion, based on study results, it is observed that smart photovoltaic blind has potential applications in the building sector shortly.

Hassan [19] built a new offline sensorless double axel sun tracker that can be utilized in a PV system and solar concentrator. This offline sensorless tracker extracts the data from the solar map equation and can locate the sun position with the maximum solar radiation and also attain a less tracking error of only 0.430. Since the method is offline, it does not utilize any feedback loop and can work under any environmental conditions like a cloudy sky. By using this solar tracker, it was observed that 24.59% of additional energy was collected for one year.

Abdallah et al. [20] designed various models of tracking system to find the effects of a multi-axis system on voltage-current characteristics and output of a flat PV. After an illustration of individual power generation, characteristic and IV curves for separate solar tracking devices then inferred that power gain from various models, i.e., one axis N – S tracker, E – W tracker, one axis vertical and dual-axis were increased up to 15.69%, 34.43%, 37.53%, and 43.87% respectively in contrast with a stand-alone system.



Figure 11. fabricated PV blind.

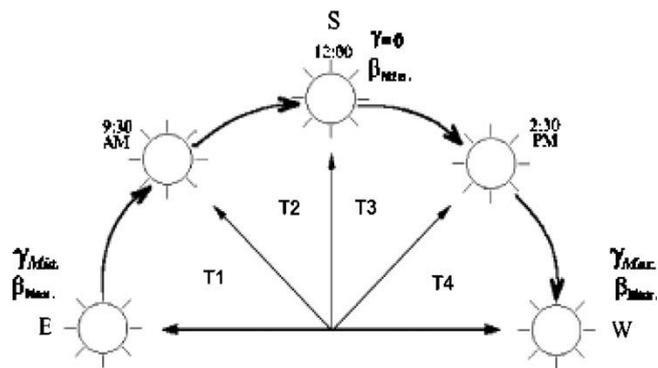


Figure 12. dividing daylight into four intervals.

Mamlook et al. [21, 22] constructed a model of double axial solar tracked system with open-loop and PLC controlled device. The program of the controlled system depended on the numerical model of plate direction, which is determined by the azimuth angle and slope of the panel (zenith angle). The PLC was coded with the defined motor speed at four intervals during daylight is shown in Figure 12. They concluded that the experimental results for a dual-axial sun tracking system were efficient and an increment of 41.34% energy yield in contrasted with a rigid system.

Abu-Khader et al. [23] designed and investigated the multi-axis tracking system in Jordanian climate. The tracking controller program was depending on the azimuth angles of the sun and divided into four regular intervals concerning the speed of motors. The overall energy produced is about 30 – 45% in N-S axis tracking compared to the stand-alone mode. Power obtained for various systems shown in figure 13. The optimal solar tracking system to attain maximum power was the N – S direction in Jordanian region.

Cemil [24] designed and performed a dual-axis mechanical device for sun tracking. The Programmable Logic Control was programmed by calculating the altitude angle and azimuth angle per hour for one year. The PLC output signal controlled the actuator motor. This system can reduce errors that are caused by sun sensors in different seasons.

George et al. [25] built two photovoltaic prototype systems with tracking and fixed system and investigated for 30 days span. This paper aims to examine the increment of solar energy from the tracking system, also the power utilized by the tracking motor. The tracking system was programmed by using PLC. Each system consists of an MPPT charge converter and battery for power saving.

Estimated that 50W power consumed by motors for sun tracking. The experimental results point out the gradual increment of 12-20% of electricity by using solar tracker.

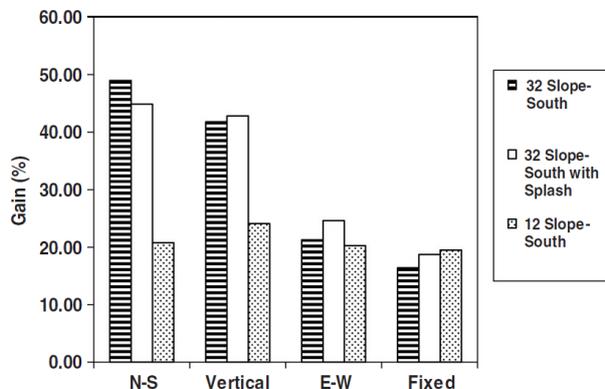


Figure 13. Power obtained at various models, i.e., N-S, Vertical, E-W, Fixed axis system.

Yan et al. [26] developed a microcontroller-based double axial sun-tracking device with a fuzzy logic controller. The solar sensor is utilized to detect the sun, and fuzzy logic control drives the stepper motors to align the PV panel perpendicular to the sun. The test results showed that the suggested tracking device could attain higher power efficiency of PV panel. The proposed method can be utilized not only for solar power generation but also for solar water heater application.

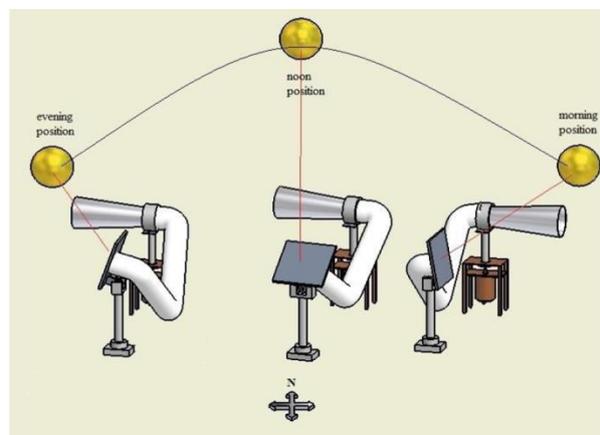
Batayneh et al. [27] designed a fuzzy logic controller for a tracking system by utilizing four light sensors. The objective of this controller is to increase the power efficiency by aligning the PV cell perpendicular to sunlight. For this fuzzy logic controller simulation study was carried out; additionally, the prototype is designed and tested. The experimental results acquired from the model and simulation data shows that the system can track the sun the whole day.

A double axis sun-oriented tracking device dependent on light intensity was developed and examined with fuzzy logic and non-tracking methods by azwaan et al. [28]. For maximum tracking of the sunlight, the IF-THEN rule was used from the fuzzy logic controller having a rule base and a database. The investigation was carried out for a week. The experiment was conducted between 8.00 am to 6.00 pm; it is observed that the generated power efficiency of this system was an improvement of 18.13% when contrasted with the stationary module.

Bentaher et al. [29] designed, tested, along with optimized double hub simple tracking device depending upon the LDR sensor. The system precision versus angle between LDR was calculated and amended by evaluating experimentally and numerically. If the system works in closed-loop operation mode, precise results could occur. The outcomes resulted from the sun tracking system are satisfactory.



Figure 14. (a) The fabricated prototype



(b) Actual tracking system.

Masoud et al. [30] fabricated and examined a hybrid solar and wind tracking system to attain higher efficiency is shown in figure 14. A wind vane is arranged on top of the air tunnel, which collects air

and blows to the PV module to decrease the panel temperature by this technique, panel efficiency increased. The test results show the overall daily output energy efficiency of the hybrid system was increased by 49.83% and 7.4% when contrasted with a fixed system and bi-axial tracking system.

Masoumeh et al. [31] proposed the camera-based double axes tracking device to adjust the PV board perpendicular to the sun's radiation. The proposed sun-based tracker dependent on processing pictures of a bar shadow by utilizing the image processing technique. The examination results demonstrated that the tracker pursued the sun with a precision of about $\pm 2^\circ$ and aligned the PV board opposite to the sun's radiation.

Rubio et al. [32] developed a hybrid tracking control system for double-axial tracking device. This hybrid tracking system integrated with both open-loop controller by evaluating sun movement and closed-loop tracking with a feedback controller. The simulation and experimentation were done and concluded that 55% more electric power was generated by a hybrid strategy than open-loop one.

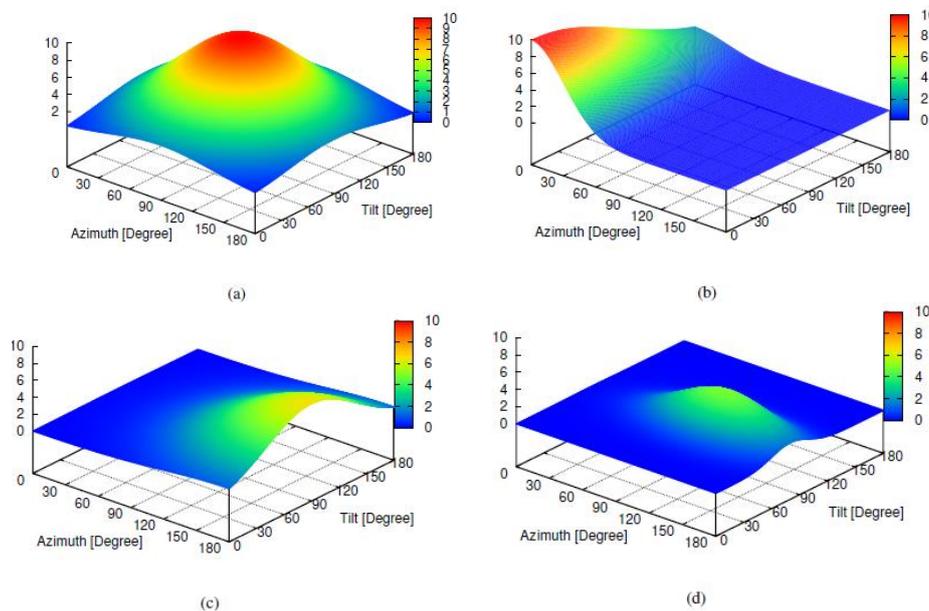


Figure 15. solar tracking simulation using a bi-variant normal distribution function.

Syamsiah et al. [33] developed a sun tracking device with a Genetic algorithm (GA) to obtain optimal azimuth and tilt angles. Figure 15 shows the simulation of acquired power by oriented PV system at a specific tilt and azimuth angles. Figure 15(a) and 15(b), a maximum gain of 10W at [90,90] and [0,0] position respectively and Figure 15(c) and 15(d), power obtained of 6.5W and 4.9W. The simulated results concluded that the Genetic algorithm tracked solar system can be used to increase the power efficiency at different climatic conditions and sun positions.

Nelson et al. [34] analyzed the data of solar irradiance during overcast conditions and proposed three embodiments for optimal tracking. This work described the improvement of solar energy during cloudy conditions by calculating the solar irradiance during such conditions. An improved solar tracking algorithm can track the sun by sensors with dual-axis during cloud-free state and opts the horizontal configuration in the cloudy times. The experimental results point out that the solar energy captured during cloudy conditions is approximately 50% more than the simple tracking system without considering any weather conditions.

Duy et al. [35] was analysed and contrasted the open and closed-loop solar tracking systems. The open-loop controlled device determines the location of the sun by considering the real-time and date, without any feedback loop mechanism. The closed-loop controlled system detects the sun's location based on the light sensor without considering any initial conditions. Generated power by rigid angle type, closed and open-loop system of tracking is shown in figure 16. The trial results demonstrate that there is no considerable change between closed-loop and open-loop tracker.

Yingxue et al. [36] developed two tracking strategies depends on mounting setup; a daily adjustment strategy and a normal tracking strategy for flat PV systems. Among this Normal tracking, the strategy is a sensor-based system and the Daily adjustment strategy was done by rotating the primary axis for 15°/hour. After examining, it is seen that the average power efficiency of standard and daily adjusted PV system is more than 23.6% and 31.8% respectively. The output of the analysis states that both the tracking systems are helpful for tracking.

Jerin et al. [37] proposed and tested an automatic solar tracker with a hybrid tracking algorithm and compared it with a standalone system. The hybrid tracking algorithm was incorporated with mathematical models and sensors to identify the sun's position in all seasons. The experimental results showed that the voltage increment to 14% during cloudy days and 13% higher during sunny days.

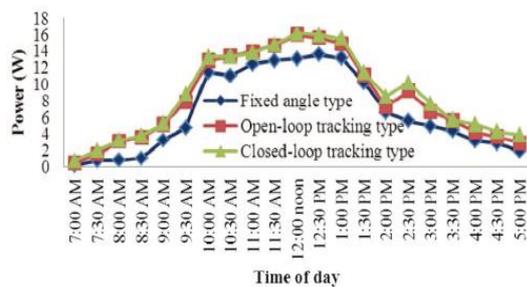


Figure 16. power outputs of fixed, open and closed-loop tracking.

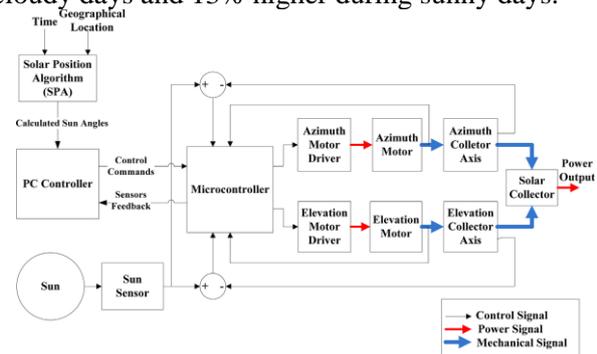


Figure 17. control system configuration.

Yasser et al. [38] simulated and analysed a double-axis sun-tracking device by implementing a hybrid control system. The simulation was done by utilizing MATLAB\Simulink software. Figure 17 shows the block diagram of the control system. The experimental results showed that the proposed sun tracker has $\pm 0.18^\circ$ of pointing error, $\pm 0.12^\circ$ typical tracked accuracy and gained 23.3% more power generation than the rigid system.

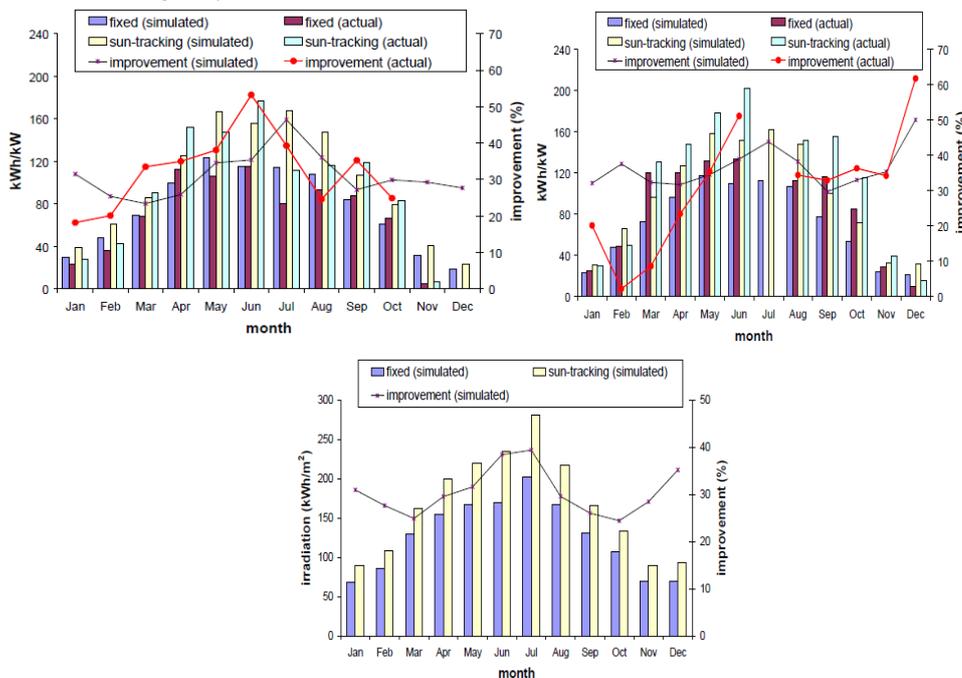


Figure 18. Differentiation of monthly energy production of simulated and actual of Rigid Solar tracking systems of plant A, B and C.

Fernandez-Ahumada et al. [39] proposed a novel backtracking strategy to increase power efficiency and to prevent the shadows. The proposed strategy was investigated with separate tracking strategies, such as astronomical tracking with no shading (ATNS) and maximum irradiance tracking with no shading (MITNS). In this system, when the collectors are shaded due to plants, etc., run the backtracking algorithm else tracking trajectory for maximum irradiance is suggested. Test results showed that the power output for the backtracking strategy is 1.31% more than ATNS and 0.89% more than MITNS.

Chicco et al. [40] investigated that the power gained from the solar plants by solar tracking and fixed system at three separate areas. Primarily, 15 separate systems with a single coordinate-controlled tracking system were contrasted with a 36° elevation and 0° azimuth angle as stand-alone cases. Consequently, co-ordinate controlled self-determining tracking with 30° elevations rigid systems were compared on ninety different devices. PV system position updating for every 15 minutes, 30° tilt angled stand-alone system with an angle of elevation of 35° was finalized at the end. Results achieved from respective Plants are shown in Figure 18 and concluded that the annual improvement for plants A, B, and C was 37.7, 30.4, and 31.5%, respectively.

The various sun tracked devices, i.e., uni and two-axis tracking systems were reviewed in this current study, listed in Table 1, shows the methods and power gain.

Table 1. Energy gain for various tracking methods.

Authors	year	Location latitude	Tracking type	Tracking method/algorithm	Evaluation way	Compared to	Gain
Tomson [1]	2007		Single axis	Azimuth angle	Computer simulation and experimental	fixed south-facing	10 – 20%
Chin et al. [2]	2011		Single axis	Azimuth	Computer simulation	fixed	
Zhang et al. [3]	2013	china	Single axis	Azimuth	Computer simulation	fixed	36% yearly
Iluca et al. [4]	2013		Single axis	Azimuth	experimental	fixed	
Sheikh et al. [5]	2016		Single axis	Azimuth	experimental	fixed	59.71 %
Batayneh et al. [6]	2019		Single axis	Azimuth plane	Computer simulation and experimental	fixed	11 – 17%
Al-Mohamad [7]	2004		Single axis	PLC	experimental	Fixed system	20%
Ruben et al. [8]	2016	Mexico	Single axis	cascade control algorithm	experimental	fixed	

Guihua et al. [9]	2012		Horizontal Single axis S – N tracking		experimental	E – W tracking and Dual axis	10 – 24%
Abadi et al. [10]	2014		Single axis	LDR and Fuzzy logic controller	experimental	Fixed panel	47%
Emre et al. [11]	2016		Single axis	Fuzzy logic controller	experimental	Single axis PID controller	21.2%
Kavya et al. [12]	2017		Single axis	PID controller with cleaning system	Simulation and experimental	Fixed system	30-40%
Sangani et al. [13]	2006			V-trough concentrator	experimental	Fixed system	40%
Oner et al. [14]	2009		Dual axis	Designed spherical motor	experimental	Fixed system	
Rustu et al. [15]	2012	Mugla, Turkey	Dual axis	azimuth and solar altitude angles	Simulation and experimental	Fixed system	30.79 % yearly
Mustafa et al. [16]	2013	38°27.0' N, 27°13.2' E	Dual axis	GPS and astronomical data	experimental	Fixed system	40.7%.
Rashid et al. [17]	2014		Dual axis	Sensor and solar map	experimental	Fixed system	25.62 %
Taehoon et al. [18]	2016		Dual axis	azimuth-altitude tracking system	experimental		
Hassan [19]	2016	37.9667° N, 23.7167°	Dual axis	Sensorless (solar map	experimental	Fixed system	24.59 %

		E		equation)			yearly
Abdallah et al. [20]	2004		N-S tracker, E-W tracker, one axis and dual-axis	PLC	experimental	Fixed system	15.69 %, 34.43 %, 37.53 %, and 43.87 %
Mamlook et al. [21]	2006		Dual axis	PLC controller (Azimuth and zenith angle)	experimental	Fixed system	41.34 %
Abu-Khader et al. [23]	2008		Dual axis	PLC	experimental	Fixed system	30 – 40%
Cemil [24]	2009	37.6 ⁰ latitude Konya, Turkey	Dual axis	PLC	experimental	Fixed system	42.6%
George et al. [25]	2015		Dual axis	PLC tracking	experimental	Fixed system	12–20% monthly
Yan et al. [26]	2010		Dual axis	fuzzy logic control	experimental	Fixed system	
Batayneh et al. [27]	2013		Dual axis	fuzzy logic controller	simulation		
Azwaan et al. [28]	2015		Dual axis	Fuzzy logic controller	experimental	Fixed system	18.13 %
Bentaheer et al. [29]	2014		Dual axis	LDR sensor	Numerical simulation and experimental	Fixed system	
Masoud et al. [30]	2015	Iran	dual axis hybrid system	Photo sensors	experimental	Single and dual axis	7.4%
Masoum	2018		Dual axis	Vision			±2°

eh et al. [31]			based sensor			precisi on
Rubio et al. [32]	2007	Dual-axis	Hybrid tracking system	Simulation and experimental	Open loop system	
Syamsiah et al. [33]	2008	Dual-axis	Genetic algorithm	Simulation		
Nelson et al. [34]	2009	Dual axis	Improved solar tracking algorithm during cloudy conditions	experimental	Fixed system	30–50%
Duy et al. [35]	2013	Dual axis	Open and closed loop tracking	experimental	Fixed system	25.96% and 33%
Yingxue et al. [36]	2014	Dual axis	Normal tracking strategy (clock mounting) and A daily adjustment strategy	experimental	Fixed system	23.6% and 31.8%
Jerin et al. [37]	2017	Dual axis	Hybrid tracking algorithm	experimental	Fixed system	14%
Yasser et al. [38]	2018	Dual axis	Hybrid controller	experimental	Fixed system	23.3%
Fernandez-Ahumada et al. [39]	2019	Dual axis	backtracking strategy	experimental		

4. Conclusion

The inference from the review of literature is that the sun tracking technologies can enhance the power yield and efficiency of the solar applications. The reviewed article aims to examine the viability of the

sun-tracking device utilizing various systems of axes and methods. The solar tracking systems encompassed two categories on the degree of freedom, i.e., single and dual-axis. The mechanism is categorised further based on the tracking mechanism: (1) Manual Tracking (2) Sensor Tracking (3) Azimuth or Zenith Angles Tracking (4) PLC, Fuzzy Logic Controller Tracking Algorithms.

In conclusion:

- About 40% of the articles presented and discussed a single-axis tracking system while 60% of the articles tended towards dual axes tracking system. Study states there is no much difference between single and dual axes tracking system because of increased output of power which covers high cost also.
- About 75% of the systems were used to drive solar tracker to active tracker type, and next chronological solar trackers were used. High efficiency of output and the overall cost can be decreased by using the active tracker.
- Recent studies state Azimuth and latitude tracking and Horizontal tracking are most used, followed by Azimuth tracking and Polar tracking.
- Power yield from the single-axis solar tracking system, minimum of 10-24% efficiency by horizontal tracking done by calculated solar geometry and monthly radiation and a maximum of 47% efficiency by utilizing the fuzzy logic controller. As well as for dual-axis solar tracking system, a minimum of 14% gain with tracking algorithm based on sensor and mathematical modelling and maximum of 49.83% with sensor-based dual-axis tracking along with air cooling system.

There is still room for improvement for tracking systems with a proper cooling system, hybrid tracking during cloudy etc. Thus, it is necessary that a thorough test and experiments are to be conducted to determine the substantial increase in the production of electrical energy by considering the mentioned tracking systems.

5. References

- [1] Teolan Tomson 2008 Discrete two-positional tracking of solar collectors *Renewable Energy* **33**(3) 400-05
- [2] Chin C S, Babu A and McBride W 2011 Design, modeling and testing of a standalone single axis active solar tracker using MATLAB/Simulink *Renewable Energy* **36** 3075-90
- [3] Peng Zhang, Gongbo Zhou, Zhencai Zhu, Wei Li and Zhixiong Cai 2013 Numerical study on the properties of an active sun tracker for solar streetlight *Mechatronics* **23** 1215-22
- [4] Stamatescu I, Făgărășan I, Stamatescu G, Arghira N and Iliescu S S 2014 Design and implementation of a solar-tracking algorithm *Procedia Engineering* **69** 500-07
- [5] Alam S M S and Mizanur Rahman A N 2016 *Performance comparison of mirror reflected solar panel with tracking and cooling* 4th International Conference on the Development, in Renewable Energy Technology (ICDRET) 1-4
- [6] Batayneh W, Bataineh A, Soliman I and Hafees S A 2019 Investigation of a single-axis discrete solar tracking system for reduced actuators and maximum energy collection *Automation in Construction* **98** 102-9
- [7] Al-Mohamad A 2004 Efficiency improvements of photo-voltaic panels using a Sun-tracking system *Applied Energy* **79** 345-54
- [8] Garrido R and Díaz A 2016 Cascade closed-loop control of solar trackers applied to HCPV systems *Renewable Energy* **97** 689-96
- [9] Li G, Tang R and Zhong H 2012 Optical performance of horizontal single-axis tracked solar panels *Energy Procedia* **16** 1744-52
- [10] Abadi I, Soeprijanto A and Musyafa A 2014 *Design of single axis solar tracking system at photovoltaic panel using fuzzy logic controller* 5th Brunei International Conference on Engineering and Technology (BICET 2014) 1-6
- [11] Kiyak E and Gol G 2016 A comparison of fuzzy logic and PID controller for a single-axis solar tracking system *Renewables: Wind, Water, and Solar* **3** 7

- [12] Gogi K S, CM M and Kumar H P 2017 Automatic Solar Tracker with Dust Wiper Using PID Controller *International Journal of Trend in Scientific Research and Development* **2** 1422-27.
- [13] Sangani C S and Solanki C S 2007 Experimental evaluation of V-trough (2 suns) PV concentrator system using commercial PV modules *Solar Energy Material and Solar Cells* **91** 453-59
- [14] Oner Y, Cetin E, Ozturk H K and Yilanci A 2009 Design of a new three-degree of freedom spherical motor for photovoltaic-tracking systems *Renewable Energy* **34** 2751-56
- [15] Eke R and Senturk A 2012 Performance comparison of a double-axis sun tracking versus fixed PV system *Solar Energy* **86** 2665-72
- [16] Engin M and Engin D 2013 Optimization controller for mechatronic sun tracking system to improve performance *Advances in Mechanical Engineering* **5** 146352
- [17] Ferdaus R A, Mohammed M A, Rahman S, Salehin S and Mannan M A 2014 Energy Efficient Hybrid Dual Axis Solar Tracking System *Journal of Renewable Energy* 1-12
- [18] Hong, Taehoon Jeong, Kwangbok Ban, Cheolwoo Oh, Jaeyoung Koo, Choongwan Kim, Jimin Lee and Minhyun 2016 A Preliminary Study on the 2-axis Hybrid Solar Tracking Method for the Smart Photovoltaic Blind *Energy Procedia* **88** 484-90
- [19] Fathabadi H 2016 Novel high efficient offline sensorless dual-axis solar tracker for using in photovoltaic systems and solar concentrators *Renewable Energy* **95** 485-94
- [20] Abdallah S 2004 The effect of using sun tracking systems on the voltage-current characteristics and power generation of flat plate photovoltaics *Energy Conversion and Management* **45** 1671-79
- [21] Mamlook R, Nijmeh S and Abdallah S M 2006 A programmable logic controller to control two axis sun tracking system *Information Technology Journal* **5** 1083-87
- [22] Abdallah S and Nijmeh S 2004 Two axes sun tracking system with PLC control *Energy Conversion and Management* **45** 1931-39
- [23] Abu-Khader M M, Badran O O and Abdallah S 2008 Evaluating multi-axes sun-tracking system at different modes of operation in Jordan *Renewable and Sustainable Energy Reviews* **12** 864-73
- [24] Sungur C 2009 Multi-axes sun-tracking system with PLC control for photovoltaic panels in Turkey *Renewable Energy* **34** 1119-25
- [25] Lazaroiu GC, Longo M, Roscia M, Pagano M Comparative analysis of fixed and sun tracking low power PV systems considering energy consumption *Energy Conversion and Management* **92** 143-48
- [26] Yan Z and Jiaying Z 2010 *Application of Fuzzy Logic Control Approach in a Microcontroller-Based Sun Tracking System* (WASE International Conference on Information Engineering) 161-64
- [27] Batayneh W, Owais A and Nairoukh M 2013 An intelligent fuzzy based tracking controller for a dual-axis solar PV system *Automation in Construction* **29** 100-06
- [28] Zakariah A, Jamian J J and Yunus M A M 2015 *Dual-axis solar tracking system based on fuzzy logic control and Light Dependent Resistors as feedback path elements* (IEEE Student Conference on Research and Development SCORED) p 139-44
- [29] Bentaher H, Kaich H, Ayadi N, Ben Hmouda M, Maalej A and Lemmer U 2014 A simple tracking system to monitor solar PV panels *Energy Conversion and Management* **78** 872-75
- [30] Rahimi M, Banybayat M, Tagheie Y and Valeh-E-Sheyda P 2015 An insight on advantage of hybrid sun-wind-tracking over sun-tracking PV system *Energy Conversion and Management* **105** 294-302
- [31] Abdollahpour M, Golzarian M R, Rohani A and Abootorabi Zarchi H 2018 Development of a machine vision dual-axis solar tracking system *Solar Energy* **169** 136-43
- [32] Rubio F R, Ortega M G, Gordillo F and López-Martínez M 2007 Application of new control strategy for sun tracking *Energy Conversion and Management* **48** 2174-84

- [33] Mashohor S, Samsudin K, Noor A M and Rahman A R A 2008 *Evaluation of genetic algorithm based solar tracking system for photovoltaic panels* (IEEE International Conference on Sustainable Energy Technol ICSET) p 269-73
- [34] Kelly N A and Gibson T L 2009 Improved photovoltaic energy output for cloudy conditions with a solar tracking system *Solar Energy* **83** 2092-02
- [35] Huynh D C, Nguyen T M, Dunnigan M W and Mueller M A 2013 *Comparison between open- and closed-loop trackers of a solar photovoltaic system* (IEEE Conferene on Clean Energy and Technology) p 128-33
- [36] Yao Y, Hu Y, Gao S, Yang G and Du J 2014 A multipurpose dual-axis solar tracker with two tracking strategies *Renewable Energy* **72** 88-98
- [37] Tharamuttam J K and Ng A K 2017 Design and Development of an Automatic Solar Tracker *Energy Procedia* **143** 629-34
- [38] Safan Y M, Shaaban S and Abu El-Sebah M I 2018 Performance evaluation of a multi-degree of freedom hybrid controlled dual axis solar tracking system *Solar Energy* **170** 576-85
- [39] Fernández-Ahumada L M, Ramírez-Faz J, López-Luque R, Varo-Martínez M, Moreno-García I M and Casares de la Torre F 2020 A novel backtracking approach for two-axis solar PV tracking plants *Renewable Energy* **145** 1214-21
- [40] Chicco G, Schlabbach J and Spertino F 2007 *Performance of grid-connected photovoltaic systems in fixed and sun-tracking configurations* (IEEE Lausanne POWERTECH, Lausanne) p 677-82