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A REVIEW OF SOLAR TRACKING CONFIGURATION AND OPTIMIZATION ALGORITHMS FOR THE DUAL AXIS SOLAR TRACKER SYSTEMS

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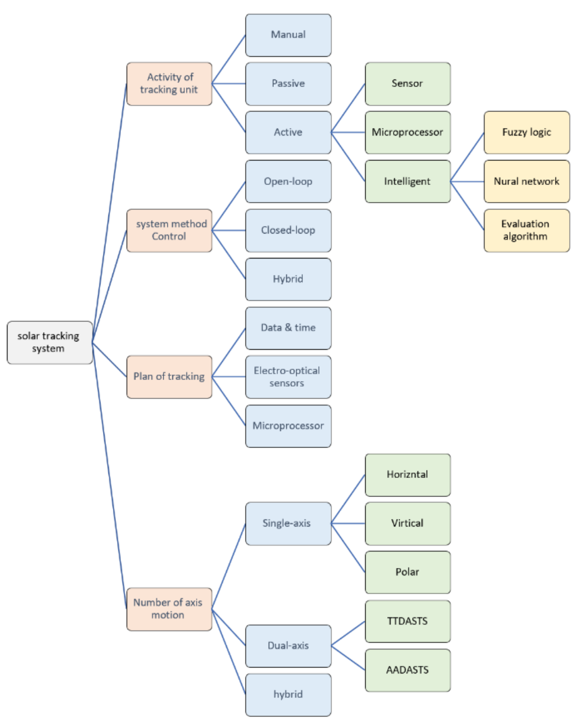
Graphical abstract



Abstract

Solar energy is considered one of the most important types of renewable energy resources due to its availability worldwide at wide times. Many researchers have been interested in developing many ways to obtain the highest efficiency and lowest cost of solar energy. The highest energy is obtained when the sun's radiation is incident perpendicular to the photovoltaic (PV) panel. The Earth revolves around itself daily and circulates the sun annually. Therefore, obtaining the perpendicularity of the radiation to the photovoltaic panel (PVP) is difficult. The dual-axis solar tracking is one of the most important methods proposed to maintain the perpendicularity of the radiation to the photovoltaic panel. There are several ways to improve the operation of the dual-axis solar tracker to ensure that the sunlight is perpendicular to the photovoltaic panel. This study reviews the evaluation algorithms and techniques for improving tracker systems' performance. From reviews, innovative technologies or expert systems can be employed to control the orientation of PVP to obtain maximum solar energy conversion. Innovative technologies can also be developed by mixing more than one technology to obtain the desired goal, such as hybridizing algorithms, fuzzy logic, neural networks, and others for solar tracking systems. In addition, the diversity of the optimization techniques using metaheuristic algorithms provided researchers with a comprehensive workspace to derive perfect results even in practical experiments.

Keywords: Evaluation algorithms, dual axis, optimization, photovoltaic panel, solar tracker

1.0 INTRODUCTION

Renewable energy (RE) is becoming increasingly popular and more efficient with time [1-4]. It is more sustainable and environmentally friendly than fossil fuels, making many researchers interested in developing it [5-7]. The RE contains more forms like solar, waves, wind, hydropower, and biomass [8-10]. In recent years, solar energy (SE) has been considered one of the important sources of RE [2, 11]. The SE is available in most countries at convenient times. It is used for more applications such as home and street lighting, electric vehicles, water pumping, power plants, hybrid systems, military, and aerospace applications [12, 13]. But the efficiency of SE is the main problem in many applications [14]. Therefore, many researchers have presented various methods to improve the efficiency of obtaining it. The factors that lead to reducing the efficiency of electric power generation from solar radiation are changing the sun's direction, the presence of clouds and dust, etc.

Electrical energy can be generated by converting SE without fuel consumption, which means generating clean energy that does not contain pollutants [15, 16]. A solar or photovoltaic cell [17] is used to obtain SE, but converting it to electrical energy is costly and ineffective [3, 11, 18]. Many solar cells are assembled to form the photovoltaic panel (PVP) [9, 19, 20]. The photovoltaic is a nonlinear system [21, 22]. Although the sun has immense potential energy, harvesting it is a great challenge, which depends on the panels' efficiency in harvesting and converting energy [23, 24]. Existing commercial panels have a conversion efficiency of 14% to 22% [25]. Some environmental factors affect the conversion efficiency of PVP, such as light intensity, the module's temperature, dust accumulation, shading, and soiling [24-26]. It is recommended to increase the output value of the PVP to the maximum value. The PVP is put face to face with the sun to obtain high rays, meaning that there is a perpendicular angle to the incidence of the sun's radiation on the PVP. This is done by using the so-called tracker system [11]. The movement of the PVP is controlled to obtain the highest efficiency in electrical energy conversion [16, 27].

Often this solution is more economical than buying more cells to get higher output. The estimated generated energy can grow between 30 and 60% when the tracker system is used. The solar radiation, quality of PVP modules, the relationship between cells, temperature, maximum power point tracker (MPPT), and the eligibility for power converters are essential factors through which the highest energy is obtained from a system of PVP [28]. Several researchers have suggested using evaluation algorithms and optimization techniques for global tracking of the MPPT of the PVP. Some prevalent techniques are available in the literature for these problems, such as Gravity Search Algorithm (GSA) [29], Ant Colony Optimization (ACO) [30], Particle Swarm Optimization (PSO) [31], Cuckoo Search Algorithm (CSA) [32], Firefly Algorithm (FA) [33], etc.

In the past years, many researchers have addressed various research papers to review the literature in the field of solar tracker systems (STS), which covers most of the information about these systems, starting from classifications to the use of different types of methods and algorithms to improve the efficiency of PVP. In this paper, a significant contribution provides the reader with accurate information about the research using evaluation algorithms to improve the work of STS. In addition, a comprehensive and expanded classification for these systems is made by merging the most common classifications used in previous research. The current review differs from the previous reviews in finding a comprehensive and modern study using evaluation algorithms to solve the problems of improving the work of STS. Furthermore, there is no previous literature review regarding the use of these algorithms in solving tracking system problems. We believe this review will provide a comprehensive understanding of tracking systems and create a comprehensive classification of these systems and optimization algorithms.

The paper is divided into several parts: an introduction, solar tracker systems, classification of STS, evaluation algorithms optimization in STS, future trends and finally, the conclusion. The following acronyms will be used throughout the paper.

ACO - Ant Colony Optimization
ANFIS - Adaptive Neuro-Fuzzy Inference System
ARM - Advanced RISC Machine
BFO - Bacterial Foraging Optimization
CSA - Cuckoo Search Algorithm
DASTS - Dual-axis Solar Tracker Systems
FA - Firefly Algorithm
FPGA - Field Programmable Gate Array
GSA - Gravity Search Algorithm
MPPT - Maximum Power Point Tracking
PID - Proportional Integral Derivative
PSO - Particle Swarm Optimization
PVP - Photovoltaic Panel
RE - Renewable Energy
SE - Solar Energy
STS - Solar Tracking System
GPS - Global Positioning System
LFR - Linear Fresnel Reflector
SPA - Solar Position Algorithm

2.0 SOLAR TRACKER SYSTEM

The solar tracker system (STS) is an electromechanics system. The system can automatically direct the solar panels, tracking the sun's movement, making the solar radiation perpendicular to the PVP, and ensuring you get the highest benefit from the solar radiation throughout the day. The STS starts working and tracking the sun from the beginning of its sunrise, directing the solar panels towards it throughout the day until sunset. It starts over the next day, repeating the same process. Among the most important features of the solar tracker is that it provides you with the maximum benefit from solar radiation and the maximum use of the space in which the solar panel is located. The main objective of the STS is to discover the maximum output performance from solar cells.

2.1 The Review Methodology

IEEE Explore, Elsevier, Scopus, and Springer Google Scholar databases have been used for overall research concerning articles on solar tracker systems. The articles with the most citations were selected when discussing the topic of solar energy tracking. These articles focus on the best ways to improve solar energy, especially those that use evaluation algorithms. The articles present the tracking improvement problems researchers encounter and suggest ways to solve those problems. Also, review papers were used in this study that provided important information regarding tracking systems. The main objective of this study is to find an integrated review that includes a comprehensive classification, performance analysis, and methods for improving dual-axis solar tracking systems.

2.2 Constraints of STS Design

Some constraints faced by the STS design must be taken into consideration. The weight of the whole system is the first constraint [34]. Reducing the system's weight reduces the cost and power required to move the panel. But the weight of the system should be within a reasonable range. Design cost is the second constraint [35-40]. Therefore, new techniques, such as reducing weight and selecting an appropriate control system, must be used to reduce the design cost. The third constraint is the narrow space for placing the system or the proximity of the panels to each other [41-43]. The fourth constraint is shading. This occurs due to shading by other panels, dust, or clouds. The shading influences the effectiveness of STS [44, 45].

2.3 Terms and Different Angles

Several terms and angles are important in determining STS's appropriate locations and directions. Those are 1) Longitude: A measure of the east-west position of a point on earth. Where it is measured by imaginary lines that revolve around the earth perpendicularly and meet at the north and south poles [9], as illustrated in Figure 1. 2) Latitude: A measure of the north and south position of a point on earth with reference to the equator. This is measured in degrees, between 0 degree and 90 degrees [46], as shown in Figure 1. 3) The angle of fall (θ): It is the angle between the falling of the sunray on the earth's surface in a point and the line perpendicular to the same point [47], also its called incident angle, as shown in Figure 2. 4) Declination angle (δ): It is the angle between the equatorial plane and the line connecting the centre of the earth and the centre of the sun. The value of this angle ranges between +23.45 and -23.45, and it varies from day to day [48, 49], as illustrated in Figure 2.

5) Elevation/altitude angle (α): It is the angular height of the sun in the sky measured from the horizon [41, 50, 51]. This angle is zero at sunrise and sunset and 90� when the sun is directly above the observer, as displayed in Figure 3. 6) Zenith angle (z): It is the complement of the elevation angle and is measured from the vertical, or it is the angle between the incident radiation and the column to the surface of the earth [52, 53], $z = 90° - \alpha$ as shown in Figure 3. 7) Tilt angle: The angle a PVP makes with the horizontal axis when face to the sun [54]. The angle of fall is a type of tilt angle [9]. 8) Azimuth angle (β): It is measured in the plane of the plate horizon, which is the angle between the position of the earth line that is the sun on the horizon and the south of the plate (or the northern observer of the locations of the southern hemisphere). The azimuth angle is 90� at sunrise, 90° at sunset, and zero at noon [41, 44], as illustrated in Figure 3.

3.0 CLASSIFICATIONS OF STS

The types of STS can be categorized into four general categories, namely, the activity of tracking units (i.e., manual, passive, and active tracking), control system method (i.e., open loop, close loop, and hybrid), the number of axis motion (i.e., single axis and dual axis) and plan of tracking (i.e. (date and time), (electro-optical sensors and microprocessors) and (sensors, date, and time)).

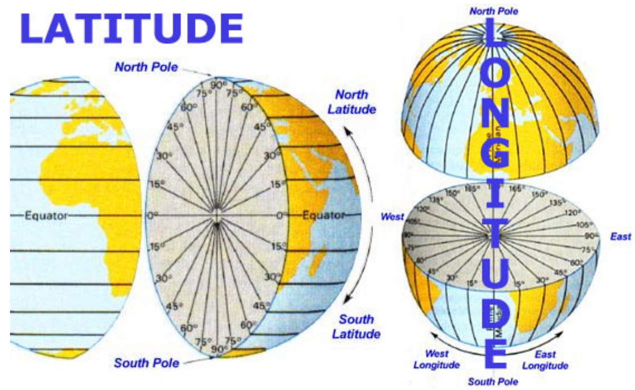


Figure 1 Latitude and longitude [9]

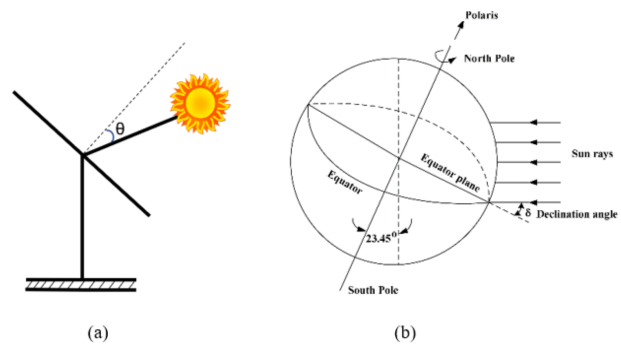


Figure 2 a) The angle of fall, b) Declination angle [47]

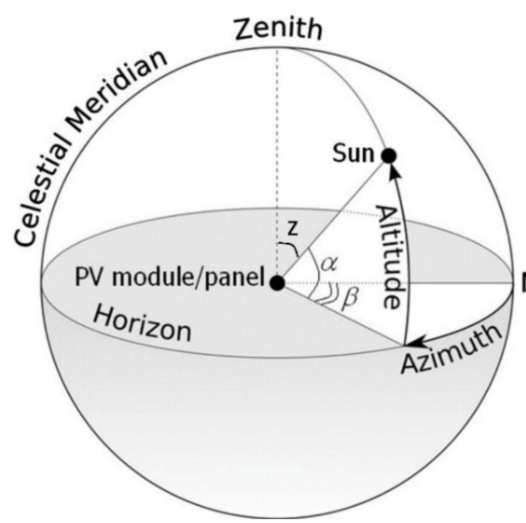


Figure 3 Altitude, azimuth, and zenith angles diagram [55]

3.1 The Activity of Tracking Units

3.1.1 Manual Tracker System

In this type, the sun's rays are tracked through human operation, where the photovoltaic panels are physically directed, depending on the shape of the mechanism available. Sometimes, this type is used with the active or passive dual-axis to reduce the complexity of the DASTS [9].

3.1.2 Passive Tracker System

This type does not use electrical energy to move the panel, but it uses mechanical capabilities and thermal energy principles to move the PVP to obtain the best energy capture. The mechanical types are represented by thermal fluids [56], shape memory alloy [57], and mechanical stress systems (lever, springs, and weight) [58]. The idea of this type of work depends on the thermal expansion of materials or a compressed gas liquid with a low boiling point. The sun's heat heats a type of liquid stored in containers installed on the sides of the panel and turns it into gas. The panel is in an equilibrium state when the sun's rays are perpendicular to it. When the sun moves, the sunny side will heat up. Then the panel is moved or rotated by the expanding gas to the sunny side. The output power can be increased by 23% [59]. Although this type is cheap compared to an active tracker system, it does not enjoy commercial popularity [60]. It can also prevent excessive movement due to wind gusts because it contains viscous dampers [61].

3.1.3 Active Tracker System

An active tracker system is namely continuous tracking [62]. This type uses electrical drivers and mechanical gear to automatically move the PVP to face the sun. It is more efficient and accurate than a passive tracker system. It contains sensors for determining the sun's position, mechanical sub-systems, algorithms for determining its position, limit switches, DC motors, and a control unit for the tracking process [63]. The main objectives of this type are to obtain an output with high accuracy and efficiency, strong anti-turbulence, high stability, smooth control signals, and ease of implementation. The sensors receive a differential signal when the rays are not perpendicular to the panel. The control unit uses this signal to move the panel in the appropriate direction that achieves the perpendicularity of the rays on it. The process stops when the sensors' signals are equal lightning state. More researchers are using intelligent controllers to optimize the tracking process, such as fuzzy logic controllers [64-66], neural networks [67-70], and evaluation algorithms [71].

Kiyak et al. [64] designed and compared fuzzy logic and PID controllers for SASTS by using Atmega 328 microcontroller. The panel is directed to the angle at which the solar energy is highest through two sensors and a motor. The main objective of this proposal is to find the highest energy by finding a specular reflection of the rays on the panel. MATLAB SIMULINK was used to simulate the proposed. The results showed that using fuzzy logic controller has high-efficiency results compared to the PID controller. Huang et al. [72] proposed a fuzzy logic intelligent controller for developing DASTS to maximise panels' output efficiency. The hardware system contains solar cells, lead-acid batteries, a gearbox, a stepping motor, and a light detection circuit. At the same time, the software includes a detection system, a fuzzy tracking controller, and a database system. The fuzzy logic controller determines the time of the tracking system. The database is used to get the closest position to the perpendicular sunlight. The system considers the contingent variables and automatically adapts to those variables. Starting motors are reduced, leading to reduced power loss in all conditions.

Al-Rousan et al. [68] used ANFIS to optimize two intelligent STS. The aim was to implement and design a control system for single-axis and dual-axis STS to improve the tracking process and increase PVP output power. The study also focused on the accuracy of determining the sun's path and decreasing the tracking error.

3.2 Control System Method

3.2.1 Open Loop Tracker System

This type is called an open-loop because it does not contain a return of a sensor signal which means no feedback control signal. In other words, there is no relationship between input and output signals, as shown in Figure 4. Also, it used a control unit that depended on the solar position algorithm and current state data. The algorithm is based on geographic coordinates (altitude, latitude) for the sun's position. Power losses depend on the tracking error. The acceptable percentage of tracking error is smaller than 0.06°, leading to less than 1% of power losses, while a tracking error larger than 0.36 causes greater than 3% of power losses [73].

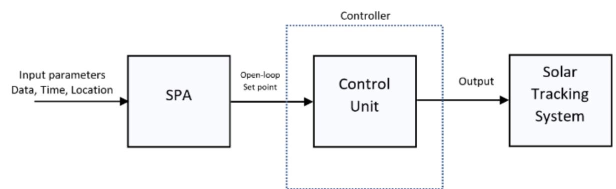


Figure 4 Open-loop STS

Barbón et al. [73] designed open-loop STS for small-scale LFR. The controller is ruled by Raspberry Pi and additional devices that involve GPS offline data used by the STS. Astronomical equations are used to track the sun's trajectory by special software. The STS can state itself automatically using the solar position algorithm and the GPS with a precision of ±0.006°. On the other hand, the system's performance has been evaluated through the annual energy, error of tracking, a ratio of energy-to-area, and energy cost. This method gives a 16.64% increase in energy, a 78.46% higher ratio of energy-to-area, and a 4.62% less energy cost compared to the classic tracking system used in large-scale LFR.

Mi et al. [74] provided high-efficiency open-loop STS to active control and switched between altering the tracking frequency and fixed frequency. The rise of the tracking frequency in the solar tracking method enhances the accuracy of tracking, as well as the rise in moving frequency and mechanical wear in the tracking system. The algorithm code of the tracking was based on the theoretical solar velocity at different times and dates. The total moving frequency has been reduced because the movement from azimuth and altitude freedom is correlated. The results of this method are high performance in decreasing the moving frequency, which saves the external power and improves its reliability.

3.2.2 Closed Loop Tracker System

The closed-loop tracker system uses multi-type solar sensors to detect the sun's position in real-time by using feedback signals, as shown in Figure 5. This strategy may be used with one or two solar sensors. The sensors are directly faced with sun irradiation to transform to signal to compare with the set point and then send the result to the controller. Therefore, the feedback regulates the position of the PVP to get the maximum rays of the sun. Despite the use of solar sensors leading to an increase in the cost of a PVP, the closed-loop tracker system tactics can track the visible orientation of the sun without consideration of the solar tracker at any of the geographical locations and show hardiness with external troubles. Moreover, the calibration does not need to be infrequent, which makes the maintenance costs decrease.

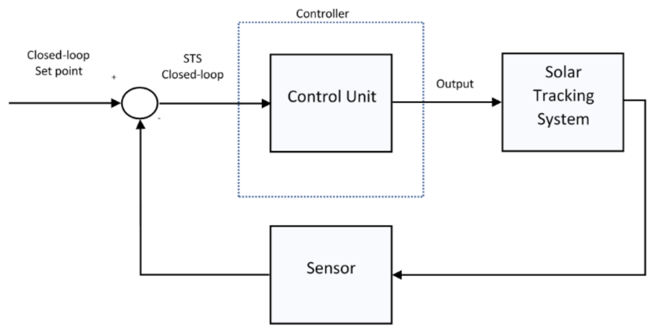


Figure 5 Closed-loop STS

To get the highest energy conversion in high-concentration photovoltaic (HCPV) thus, there must be a high-accuracy tracker system. Garrido et al. [75] proposed a closed-loop algorithm with a cascade controller design that contains an inner and outer loop for an optimum single-axis tracker system. It used a light sensor to track the light of the sun. The inner loop regulates the angular velocity of the DC motor by a nonlinear proportional PI controller. The outer loop used the sensor to track the position of the sun. The cascade algorithm performance appears to have a better experimental result than the PI controller without an inner loop, such as less wear of actuator, smoother control signal and reduced consumer energy.

Jamroen et al. [63] designed an active closed-loop low-cost automatic DASTS to accurately adjust the power output from PVP. The proposed method used LED sensors as input units. It simply rotates around two-axis (north-south and east-west) using a microcontroller and sensors. The tracking process for the sun's path employed the pseudo-azimuthal system that utilizes the coordinate system. The pseudo-azimuthal system provides excellent stability to the movement system. The performance validation of the proposed method was made in Rayong Province, Thailand. This proposed technique increased the output power efficiency by 44.89% compared with the fixed system.

In the same context, Saeedi et al. [76] designed a simple closed-loop DASTS with a Wheatstone bridge circuit and LEDs to increase the efficiency of the production power of the PVP. This design has adjusted the PVP with high efficiency based on the concentration of the solar rays by moving the panel through two axes simultaneously.

3.2.3 Hybrid Tracker System

To obtain accuracy in STS, several researchers proposed hybrid-loop strategies that combine closed-loop tracking and open-loop tracking [77-79]. At all events, the loops are activated at different times. The priority of determining the work of the loops depends on the weighting algorithms to calculate the signal of controllers in the tracking system. Also, the control algorithms are different when using closed and open loops. The hybrid controller can switch between modes in real-time based on the completion of the positioning process of the solar tracker [80].

Furthermore, this tactic is not influenced by decreased accuracy factors of tracking prosses such as installation errors, estimation position errors of the sun, and weather conditions errors. Also, it does not need accurate installation or re-calibration. Consequently, this method shows greater accuracy, performance, and reliability in the tracking mechanism than open-loop and closed-loop tactics. Figure 6 illustrates the hybrid STS.

Zhang et al. [78] designed a hybrid loop of DASTS to decrease the different tracking errors. The system utilizes an orientation algorithm to open-loop, a photodiode sensor to closed-loop, and GPS-BeiDou to geological location. The calculation results are less than one between solar hour, altitude, and azimuth angles with SOLPOS calculation. An initializing calibration corrected the error by photodiodes mismatch. Also, implementation of the analysis and correction for installation error, the installation deviation, geolocation error, and actual north meridian deviation to the orientation algorithm. The geological location, path sensing, and auto-corrections for wind load and weight provide the tracking system with easy installation and low cost if the photosensors are set in a deflection location.

Safan et al. [77] implemented a hybrid control tactic tracking system to optimize STS to boost the production power of PVP. The optimization was conducted by reducing the fallen angle of rays on the panels. The main aim is to keep the maximum power of PVP with fewer requirements. It used MDOF-SUI PID to implement the tracking process. Matlab-Simulink was used for modelling and simulating the design.

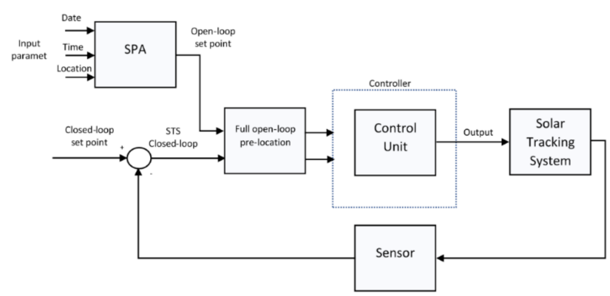


Figure 6 Hybrid STS

3.3 Number of Axis Motion

There are two types of STS based on the number of axis motions. The first type is a one-axis STS with a single axis for rotation around it, in which the sun's radiation is vertical to the PVP. The second type is DASTS which includes two axes for rotation around it. Dual-axis accuracy is higher than one-axis [49, 60, 81]. The dual-axis required a more complex control system than a single axis.

3.3.1 Single Axis Solar Tracker System (SASTS) Motion

In this type, the panels are installed at an angle of inclination to bring the angle of incidence of solar radiation closer to the vertical. The movement of the axis is either from east to west or from north to south, according to the location and orientation of the panels. This type of tracking device is considered a practical, simple, and low-cost way to improve the performance of solar power plants. It is possible to increase the electrical energy by more than 30% compared to the panels fixed at a specific angle [53]. These trackers can improve the performance of solar panels during the summer and spring seasons when the sun is higher in the sky.

a) Horizontal SASTS

This configuration is divided into two types. The first type is in which the panels are parallel to the ground, where the panel is installed on a motor that passes through one of its horizontal axes to rotate from east to west all day long on a fixed axis. It is considered one of the most cost-effective tracking tools in many applications. The design requirements are less compared to other types. As for the second type, the panels are tilted at a certain angle, where the solar panel is installed on a motor in one of the horizontal axes [81, 82]. Tilted horizontal tracking systems are more complex than regular uniaxial horizontal tracking devices. It usually requires a solid foundation for it.

b) Vertical SASTS

Also, this configuration can be divided into two types. The first type is that the panels are parallel to the ground, making it easy to maintain a constant angle to the sun's position when it is low in the sky. The solar panels are mounted on a motor that rotates around a vertical axis. In other words, it rotates east to west to follow the sun all day. These systems are frequently used when installing panels in tall or mountainous locations. As for the second type, the panels have a parallel inclination to a horizontal position and rotate vertically. This type can improve power output compared to horizontal systems. As well as subject to increased wind load compared to horizontal systems.

c) Polar Aligned SASTS

This type of device is similar in its structure to the installation of a telescope. The tilted axis is in the direction of the pole star. Therefore, it is called the polar-aligned single STS [83, 84].

3.3.2 Dual Axis Solar Tracker System (DASTS) Motion

These devices include two degrees of the axis of rotation. They are called the primary and secondary axis, and the axis of rotation can move down or up to adapt to the sun's angles throughout the day. It can be precisely oriented, and these devices keep the solar panels constantly facing the sun as they can be moved in two different directions. These devices are more complex and expensive compared to single-axis devices. It can be classified into two types, the tip-tilt type and the azimuth-altitude type [85]. DASTS in which both the tilt and azimuth angles are changed. Azimuth angle change during the day, while the tilt angle change throughout all year days [18, 60]. The DASTS tracks four directions, north-south and east-west motions of the sun [18]. The block diagram of DASTS is presented as shown in Figure 7. Two DC motors are used for azimuth and tilt angle movement, and two PID controllers for DC motors are controlled. The PID parameters are optimized by two swarm intelligent algorithms [71].

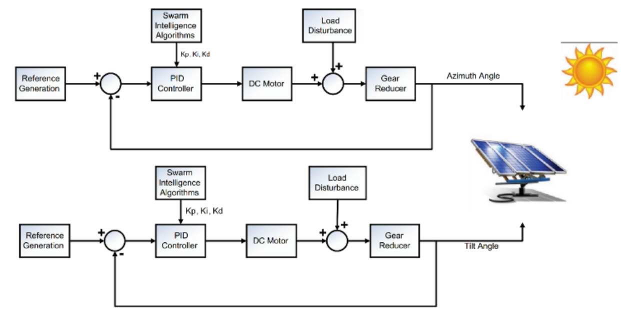


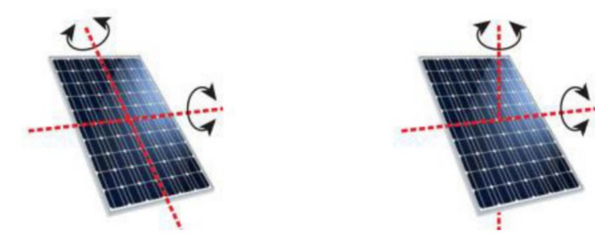
Figure 7 Example of DASTS block diagram [71]

a) Azimuth Altitude Dual Axis Solar Tracker System

This type consists of the main axis (the azimuth axis) and is perpendicular to the ground. Another axis is called the axis of height, and it is normal for the main axis. Like tilt systems in their work but differ in how the panels rotate to follow the sun's daily path. This is done by rotating a large ring fixed to the ground with auxiliary rotating tools. The azimuth-altitude type offers a tracker centred on the rotatory axis of the slope of PVP and the vertical axis. This type of tracker is shown in Figure 8(a). One of the advantages of this type is that the weight of the panels is distributed over the large ring, which allows it to support the panels.

b) Tip-tilt Dual-axis Solar Tracker System

This type can follow the path of the sun due to the flexibility of its movement in all directions. This feature makes it ideal for obtaining the highest output of solar energy. Therefore, it is used in many types of applications [86]. The panels are installed on a pole. It is moved from east to west through sensors and motors. The tip-tilt type offers a tracker centred on both the rotatory axis of the slope of the panel and the horizontal axis [87]. This type of tracker is shown in Figure 8(b).



(a) Azimuth altitude dual axis tracker (b) Tip-tilt dual axis tracker

Figure 8 Dual-axis tracker types [87]

3.4 Plan of Tracking

3.4.1 Tracker based on Date and Time

In this type of tracker, the sun's position is determined through an algorithm prepared in advance based on accurate mathematical calculations to direct the panels to the actual place that harvests the highest solar energy. The algorithm is relied on to determine the sun's position only because the tracker does not contain sensors or feedback to correct the disturbance errors [41]. The precision of this tracker is very conditioned by stable deviations [10]. Pourderogar et al. [88] proposed the MOPSO algorithm to obtain the highest solar energy by determining the performance characteristics of a single-tracker system.

This method controlled the angles of deflection, azimuth, and inclination of the panels. The total solar radiation for fixed and single-axis was calculated to evaluate the performance of the PVP. The researcher found that the proposed method's energy generation of the panels is 35% higher than the fixed panels. Pandey [89] proposed the simulation and design of DASTS. This system does not contain sensors; thus, it depends on time and location to calculate the sun's position. Snow reflection and other factors slightly affect the PVP's orientation from the sun's position. So, the PVP is moved to get the optimum position. The output power is compared with each change in tilt angle. Hence the optimum tilt angle at which power is maximum is determined. The process is repeated to obtain the best azimuth angle.

3.4.2 Tracker based on Microprocessor and Sensors

In this type of tracker, the sun's position is located by measuring the sunlight by the sensor. Then the sensor sends the signal to the microprocessor to generate the command to drive the motor. This type is expensive and intricate [41]. Rahimoon et al. [51] utilized Arduino, LDR-type sensors, and two 12V DC motors to design parabolic DASTS. The correct location of the dish is determined by sending a signal from the sensors to the control unit to be directed to the correct location that gives the highest power. The proposed method indicates 3.43% energy efficiency.

Abdulhussein et al. [90] used ATMAGA328P, two LDR sensors, and two servo motors to design an intelligent system that tracks the sun's movement and keeps the incident rays perpendicular to the panels. Also, the control unit relies on the reading of sensors to determine the sun's location. The aim is to find an innovative and efficient system to obtain the highest energy at a low cost. Abdollahpour et al. [41] developed an image processing of a bar shadow to optimize DASTS. The length of the shadow determines the zenith angle and height. The captured images were by the webcam in the shadow. The system followed the sun's path with precision ± 2° and kept the radiation perpendicular. Also, it can be used in all regions because it does not depend on its initial settings. The tracker was companied of a shadow casting object, two stepper motors, a webcam, a control unit, and other electronic circuits. In cloudy conditions, the system is ineffective due to the acquisition of blurred images. A high-resolution camera can be used to solve this limitation.

3.4.3 Tracker based on Sensor, Data and Time

This type contains a sensor, a microprocessor, and a motor. The position of the sun is determined by the processor based on the signal from the sensor or through geographical algorithms. Then the processor sends the signal to the motor to move the panels in the desired direction, producing the highest energy harvest [83, 84]. Tharamuttam et al. [91] used a hybrid algorithm with a microcontroller in the solar tracking system to determine the sun's position. The algorithm combines sensors and mathematical models to determine the exact position of the sun to get the highest solar energy from the panels in all conditions. The researcher found that the experiment results of the hybrid algorithm are better than the traditional algorithms in producing solar energy. In summary, the overall classification of solar tracking systems can be deduced, as shown in Figure 9. The advantages and disadvantages of the solar tracking system classification are shown in Table 1.

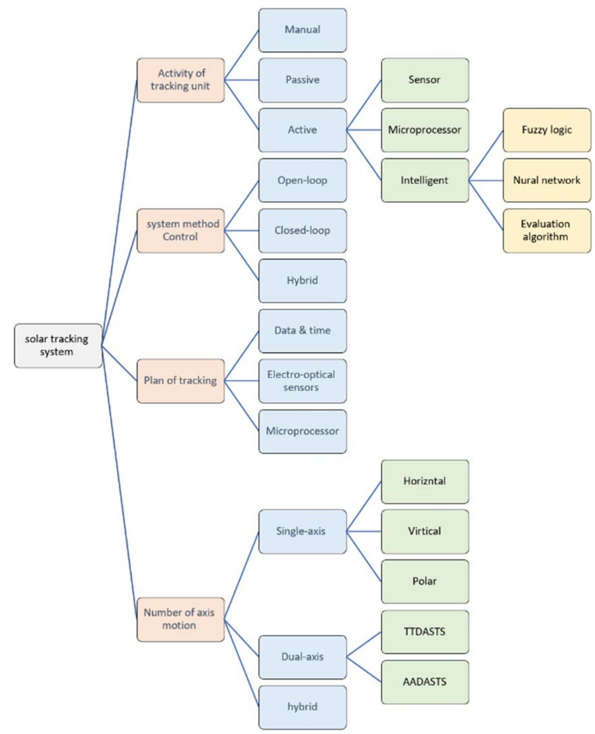


Figure 9 Classification plant of the solar tracking system

4.0 EVALUATION ALGORITHMS OPTIMIZATION IN SOLAR TRACKING SYSTEMS

Evolutionary algorithms often do well in finding approximate solutions to all kinds of problems. Generally, an evolutionary algorithm consists of a starting point and a loop that iterates until a predetermined precision is achieved. Selection and synthesis methods vary with the type of evolutionary algorithm. Also, many researchers used these algorithms to optimize complex systems such as tracker systems [92] and obtained good results compared to other methods. Sabir et al. [71] designed PID controllers for two DC motors of DASTS and used three evaluation algorithms: CSA, FFA, and PSO, to optimize the PID parameters. The CSA is a small variance, the rate of convergence is fast, and the standard deviation obtained of design parameters compared with other algorithms.

Table 1 Advantages and disadvantages of solar tracking system

STS	Advantages	Disadvantages
Activity of Tracking		
Passive	Low cost; electrical energy independent	Less accurate; Limited movement; mechanical wear and tear
Active	More accurate	High cost due to sensors use
Control System		
Open Loop	No return of a sensor signal; Low cost and ease of achievement; Weather disturbances do not affect its work	Low accuracy of tracking; Requires SPA, data, and time; Constant calibration required; Unstable with mechanical or electrical disturbance
Closed Loop	High accuracy of tracking; Regular calibration not required	High cost
No. of Axis Motion		
Single Axis	Practical, simple, and low-cost. The energy produced is 30% higher than the fixed system.	Low performance in cloudy weather
Dual Axis	It follows the sun constantly and provides constant energy throughout the day; Smaller space is needed for installation; The energy produced is 45% higher than the fixed system; Be an ideal solution for areas that may hinder solar energy production.	It contains technical complexity, which makes it easy to break down; Shorter life and lower reliability; Low performance in cloudy weather

Ali et al. [17] studied four methods applied to the dual-axis photovoltaic tracking system to increase the efficiency of electricity production of PVP. These methods are listed as the system without a controller, the system with PID-PSO controllers, the system with PID-FA controllers, and the system with ANFIS-FA controllers. The last method shows the best results from other methods as a simulation is done. Abadi et al. [93] used MATLAB/SIMULINK as a simulator for a solar tracking system with controlling two-degree freedom for yaw and pitch angles. This design is controlled by three controllers listed as PID, Fuzzy Logic, and PSO-Fuzzy. The membership functions were set as three for the Fuzzy Logic controller and five for the PSO-Fuzzy controller. This design shows that the solar tracking system can track and find the best position from the elevation angle and the sun azimuth.

Chen et al. [94] used the PSO method to search for parameter optimization of the PI controller and frequency of the reflex changing in a DASTS with MPPT. This method significantly reduces loss and oscillation of charging, improving charging efficiency and temperature rise experimentally compared to traditional charge mode. Te-Jen et al. [95] developed a system that combines bacterial foraging optimization (BFO) with the PSO algorithm to optimize the solar tracking accuracy, which is implemented in an Advanced RISC Machine (ARM) based system. The proposed (BFO-PSO) algorithm grows the system's output power by up to 5%.

Jallal et al. [96] proposed a new machine-learning model as DNN-RODDPSO to optimize the real-time prediction accuracy of four DASTS. This model combines a DNN model with a PSO. This model integrates two hidden layers. The proposed model showed better performance as compared with the previous literature work. Chen et al. [97] proposed an intelligent sun-tracking system using the FPGA. The NI-9642 controller combined the DASTS with an MPPT to give the solar panels the highest energy. Moreover, it is equipped with multiple intelligent functions to automatically track the sun's movement at the beginning of the day to return to its first position at night. A PI controller is used for DASTS, and the PSO algorithm is used for optimizing the parameters of the PI controller.

Yahyazadeh et al. [98] proposed optimization control parameters of DASTS using an enhanced PSO alternative named CCPSO. This algorithm is used to optimize the parameters of the PID controller. Also, it has good properties that make it efficient, faster, and strong. From the results, the activity utilizing the CCPSO algorithm was compared with algorithms (PSO, ABC, GA-PSO, PSO-SA, ELPSO) in a different climate, with the tracking speed, low energy consumption, and high energy production. Pervez et al. [99] proposed GSA to improve the tracking of MPPT for the operation of the PVP in max output power in a situation of partial shading. This method is proposed to solve the problem of the cell's behaviour that receives the least insolation as a load in the case of partial shading. It used MATLAB/SIMULINK for performance validation of the suggested algorithm.

Mahdi et al. [100] used GSA to develop a parabola optimization tool to find the optimal solution for energy production. The research provided essential results by finding a low-cost system with access to the largest solar radiation concentration within the parabola. The focused flux of sunlight is maximized by geometric and geographic parameters using the algorithm. The motors are controlled by the ATMEGA328, programmed in C language. Elevation and azimuth angles are calculated using the DNI value to control the start-up moment. The combined card consists of two ATMEG boards that control the movement of the motor and store data for the system via a sensor and storage card.

Zaghba et al. [101] proposed P&O-PI MPPT techniques optimized by the GA algorithm to compare the performance of single-axis and dual-axis STSs with a stationary photovoltaic system. The research had two objectives, the first was to find MPPT using the proposed method, and the second was to compare the performance of STSs and the fixed system in terms of efficiency. The system was simulated using MATLAB / SIMULINK. The researcher obtained superior results for the proposed method, in which the efficiency of the tracking systems increased by about 25% of the energy produced. A summary of the evaluation algorithm that applies to DASTS is shown in Table 2.

5.0 FUTURE TRENDS OF STS

Today and in the future, we see most countries turn to the use of SE in all sectors of life instead of the energy that depends on fuel. Therefore, many researchers went to find different ways to improve solar tracking systems to obtain the highest efficiency of solar energy with the lowest conversion cost. It is possible to suggest new ways to improve the work of tracking systems, such as depending on innovative technologies or expert systems to control the orientation of PVP to obtain maximum solar energy conversion. Innovative technologies can also be developed by mixing more than one technology to obtain the desired goal, such as hybridizing algorithms, fuzzy logic, neural networks, and others for solar tracking systems.

The use of artificial neural networks in solar tracking devices increases the accuracy of directing PVP, thus obtaining the highest power generation from these panels in a short time. Neural network techniques and fuzzy logic can be combined to obtain the maximum energy tracking point in PV systems. Also, sequential control algorithms are used to reduce tracking errors. Despite the many ways to improve the work of solar tracking systems and the many developments, this field still faces many obstacles in terms of operating efficiency and design cost, which researchers should pay more attention to in this field.

Table 2 Summary of evaluation algorithm applies to DASTS

Paper	Year	Algorithm	Objectives	Exp./Sim	Accuracy	Motor type	Sun location	Controller
[71]	2016	CSA, FFA, and PSO	Optimum energy by azimuth and tilt angles control.	Sim	-	Servo motor	-	PID
[17]	2019	PSO, FA	Increase the efficiency of production	Sim.	-	DC motor	-	PID, ANFIS
[93]	2018	PSO	Pitch and yaw angles control.	Sim.	-	DC motor	LDR	PID, fuzzy
[94]	2016	PSO	Implement Reflex charge control	Sim/Exp.	-	DC motor	-	PI, NI9642
[95]	2013	BFO, PSO	Improve the solar tracking accuracy	Sim/Exp.	Up 5%	Stepper motor	gyroscope	ARM
[96]	2020	DNN-RODDPSO	Improve the real-time prediction accuracy	Sim.	-	-	-	DNN
[97]	2015	PSO	Increase the output power	Sim/Exp.	-	Servo motor	-	PI, NI9642, Fuzzy
[98]	2021	CCPSO	Control parameters of DASTS	Sim/Exp.	-	DC motor	Sensor.	PLC, PID
[99]	2019	GSA, PSO	MPPT under partial shading condition	Sim	-	-	-	PC
[100]	2020	GSA	Find an optimal solution for solar systems at a low cost.	Sim/Exp.	-	DC motor	Sensor	ATMEGA328
[101]	2019	P&O, GA	1. Find MPPT by P&O-PI and GA. 2. Performance comparison between tracker systems and fix systems.	Sim	25%	-	-	PI

6.0 CONCLUSION

This review aims to analyze the feasibility of using modern technologies to improve the work of solar tracker systems. From this, we conclude that it is possible to depend on solar energy as a renewable energy source. The highest energy efficiency can be obtained at the lowest cost by using evaluation algorithms techniques to improve the operation of the dual-axis solar tracker systems. These systems are difficult to control. The diversity of these algorithms, such as (PSO, GSA, ACO, FA, etc.) provided researchers with a comprehensive workspace to derive perfect results even in practical experiments. The accuracy of working with the proposed algorithms made it possible to obtain accurate DC motors for obtaining the perpendicularity of the sun's rays to the photovoltaic panel. That means obtaining solar energy with high efficiency and relatively low cost.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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