“Solar Tracker”

Microprocessor and Interfacing
CSE2006

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Index

Certificate

This is to certify that the project work entitled “**Solar Tracker”** that is being submitted by “**Salonee Gupta, Rishab Gupta, Sahiba Bedi and Siddhant Vinayak Chanda**” for Microprocessors and Interfacing (CSE2006) is a record of bonafide work done under my supervision. The contents of this project work, in full or in parts have neither been taken from any other source nor have been submitted for any other CAL course.

Signature of Faculty

Professor Jimmy Mathew

Acknowledgement

We co-cordially thank our **Professor Jimmy Mathew**, Associate Professor SCOPE for his precious guidance, the **Dean of the School of Computer Science and Engineering** for their pleased permission and opportunity given to us for the completion of our project. We would also like to thank all the research scholars, seniors, students of VIT that have helped us in testing of the app and completion of our project. We would also like to thank all the laboratory assistants for their guidance and support in our project.

1. Abstract

This paper reports a survey of different techniques for solar tracking with gains in energy due to tracking and different MPPT algorithms. The non-renewable energy sources are non-inexhaustible, constrained and deplete. Accordingly, it is important to discover other sources of energy. As sunlight is available in abundance in nature, it can be used to generate clean energy. It is manageable, inexhaustible, adaptable and scalable.
The challenge in tapping this energy is to, expand the effectiveness and in addition to that decrease the overall cost of generation. Accordingly, an attempt to survey the different Maximum Power Point Tracking (MPPT) algorithm, various solar tracking methods and the energy gained by using these methods is made.

A single axis microcontroller based automatic tracker is implemented and tested for its performance in real time. The work focusses on the orientation of solar panel towards the direction of maximum radiation by using a stepper motor interfaced with ARM processor.

2. Introduction

In the recent years, there has been a dearth of fossil fuels, and one of the most daunting challenges is finding clean and renewable energy. Therefore, it is imperative to find alternative sources of energy. As solar energy is available abundantly in nature, it can be considered as a best alternative to meet the energy demand. It is sustainable, renewable and scalable. Increasing the efficiency of harnessing solar energy should be one of our foremost concerns as it is a renewable source. The challenge in tapping this energy is to increase the efficiency as well as to reduce the cost of production.

Several conservation methods have been suggested such as energy harvesting, energy recycling to reduce the energy used in commercial applications. Over the years, several methods have been implemented to use renewable sources of energy such as wind, hydro power, solar power, thermal power, tidal power, etc. One of the most popular natural sources is solar power due to its ubiquitous characteristic and low maintenance cost. Several techniques have been implemented in order to maximize the energy obtained from solar power. Among these, one of the most common techniques is solar tracking. The motion of tracking could either be about one axis (1 axis tracker) or two axes (dual axis tracker). Solar power plants need to be monitored for optimum power output. This helps retrieve efficient power output from power plants while monitoring for faulty solar panels, connections, and dust accumulated on panels lowering output and other such issues affecting solar performance.

Sun is an abundant source of energy and this solar energy can be harnessed successfully using solar photovoltaic cells and photovoltaic effect to convert solar energy into electrical energy. But the conversion efficiency of a normal PV cell is low. One of the main reason for this is that the output of PV cell is dependent directly on the light intensity and with the position of the sun in the sky changing continuously from time to time; the absorption efficiency of an immobile solar panel would be significantly less at certain time of the day and year; for the solar photovoltaic cells are maximum productive when they are perpendicular to the sun and less productive otherwise. So, to maximize the energy generation and improve the efficiency; solar trackers come into play.

3. Literature Review

The paper [1] proposes a microcontroller based active dual axis tracker which is inexpensive; consequently it can be used extensively. To reduce the cost of the system; Arduino uno; single-board microcontroller; servo motor instead of Stepper motor/ permanent magnet DC motor with gear arrangement has been used. The main component is Arduino uno; single-board microcontroller. It has an open source physical computing platform and a development environment for writing software for the board and is inexpensive.

The other main components are Light Dependent Resistors (LDRs); servo-motors; solar panel. this paper presented a scaled down active dual-axis solar tracker system design. The system was constructed and operated successfully. The built prototype ensures design feasibility. It was further tested in LabVIEW. The results show an average power gain of 13. 44% compared to an immobile solar panel.

Another paper [2] analyses the optimum orientation and tilt angle effects on photovoltaic (PV) module performance in Jeddah, Saudi Arabia. This analysis will begin with the description of solar radiation and tilt angle concepts.

These concepts are then used to investigate the performance of PV modules by determining the power output while varying the tilt and azimuth angles. Several azimuth and tilt angles have been analysed for monthly, bimonthly, trimonthly, quarterly, six-monthly, and yearly periods to determine how much power output can be generated and to select the best orientation angles for the PV system.
The results indicate that the highest monthly average output power of the PV is 0.225 kW, obtained in June at the 0° tilt surface of the 1-kW PV panel. However, bimonthly, trimonthly, quarterly, six-monthly, and yearly adjustments result in lower power output, with yearly adjustment giving the lowest power.

Therefore, the tilt angle should always be adjusted in the shortest time possible in the interest of achieving the maximum possible power output and improving the efficiency of the PV system. The optimum tilt angles of the solar photovoltaic system are determined when the tilt angle is varied from 0 degree to 90 degree in steps of 1degree.

It was found that the optimum tilt angle is 0 degree in April, May, June, July and August for six different sites (Minicoy, Thiruvanathpuram, Port Blair, Bangalore, Chennai and Panjim) in India and it is maximum in December. The first and second degree correlations of optimum tilt angles in terms of declination angle are developed for six different sites in India which is useful for installation of solar photovoltaic system. The statistical test shows that root mean square error varies from 4.16 to 5.46 for first degree correlation equation and for second degree correlation equation RMSE varies from 1.99 to 3.35.

This paper [3] concerns the design and construction of a Hybrid solar tracking system. The constructed device was implemented by integrating it with Amorphous & Crystalline Solar Panel, three dimensional freedom mechanism and microcontroller. The amount of power available from a photovoltaic panel is determined by three parameters, the type of solar tracker, materials of solar panel and the intensity of the sunlight.

The objective of this paper is to present analysis on the use of two different material of Solar panel like Amorphous & Crystalline in a Solar tracking system at Stationary, Single Axis, Dual Axis & Hybrid Axis solar tracker to have better performance with minimum losses to the surroundings, as this device ensures maximum intensity of sun rays hitting the surface of the panel from sunrise to sunset. In this paper, it has been presented a solar-tracking system which is an efficient system. It can be utilize anywhere such as house-hold activities in office even in industrial purposes.

Today's world is facing acute power crisis. We need to find new resource and also need to boost efficiency for the production of power from other renewable energy sources. We also need a better power system to give service to those people who live in remote area. Under this circumstance, this type of project can give a good result when energy crisis is one of the most vital issues in the world. A comparative analysis was performed using four systems, i.e., hybrid tracking, dual-axis, single-axis, and stationary.

The results showed that the use of the dual-axis tracking system produced 17.87% gain of power output, compared with a single-axis tracking system. The gain of output power with the hybrid tracking system was much higher (52%) when compared with a stationary system inclined at 23.5 deg to the horizontal.

The proposed system [4] changes its direction in two axis to trace the coordinate of sunlight by detecting change in light intensity through light sensors. Hardware testing of the proposed system is done for checking the system ability to track and follow the sunlight in an efficient way. Dual axis solar tracking system superiority over single axis solar tracking and fixed PV system is also presented. Dual axis tracker perfectly aligns with the sun direction and tracks the sun movement in a more efficient way and has a tremendous performance improvement.

The experimental results clearly show that dual axis tracking is superior to single axis tracking and fixed module systems. Power captured by dual axis solar tracker is high during the whole observation time period and it maximizes the conversion of solar irradiance into electrical energy output. The proposed system is cost effective also as a little modification in single axis tracker provided prominent power rise in the system. Through our experiments, we have found that dual axis tracking can increase energy by about 40% of the fixed arrays. With more works and better systems, we believe that this figure can raise more.

In the paper presented by Vijayan Sumathi, et al [5], they have reported a review of different strategies of solar tracking with gains in energy due to tracking and different MPPT algorithms, different solar tracking methods and the energy gained by using these methods. A single axis microcontroller based automatic tracker is implemented and tested for its performance in real time. The work focuses on the orientation of solar panel towards the direction of maximum radiation by using a stepper motor interfaced with ARM processor.

In the paper published by Fabio Hoffmann, et al, they have proposed a monthly profile analysis based on a two-axis solar tracker proposal for photovoltaic panels. In this system, the tracker utilizes LDRs to recognize the sun's movement and direction and motors modify the board position, as indicated by the control performed by an electronic device. Every system is made by a mechanical structure, a solar panel and a resistive load. The electronic device, other than motors controlling, plays out the estimation and storage of luminosity and irradiation over the panel. The assessment of the two frameworks happened for 152 days, between 2016's June and November, in southern Brazil. The board with following framework introduced normal month to month increases changing from 17,20% and 31,1%, showing this is a contrasting option to make photovoltaic energy more alluring.

In their paper, Taehoon Hong, et al [6] investigated a solar tracking system applicable to the blind. The slope of PV panel tracked the sun from 0° to 90°, which does not limit the tracking. On the other hand, the azimuth of PV panel tracked the sun from -9° to 9° due to the limitation of the rotating angle of the vertical axis. The result of this study can be used to develop the 2-axis hybrid solar tracking system for the blind which can be adopted in the building sector.

In the paper presented by Jifeng Song [7], et al, they have proposed a system in which a single-axis solar tracking device is designed and explored, which is able to lift and lower the photovoltaic panels. The photovoltaic panels can be tilted to east-west directions in the process of tracking the sun. In windy weather, the solar panels can be placed close to horizontal rail by using stent, which can minimize the frontal area. This helps enhance wind resistance in windy weather. The device in this paper is suitable for PV power plants on building roofs because it can meet the strict requirements of wind resistance capacity and safety.

4. Project Plan

In this project, the Voltage sensor and Current sensor are used to measure the total power in the system. Along with these features, this project also uses inexpensive active dual -axis solar tracking system for tracking the movement of the sun so as to get maximum power from the solar panels as they follow the sun. It uses Light Dependent Resistors to sense the position of the sun.

Hardware Requirements

- LDR Sensor
- Servo motors

- Solar Panel

Software Requirements

- Arduino IDE
- Embedded C

5. Design and Implementation

5.1 Programming

The Arduino/Genuino Uno can be programmed with the Arduino Software (IDE). Select "Arduino/Genuino Uno" from the Tools > Board menu (according to the microcontroller on your board). For details, see the reference and tutorials.

The ATmega328 on the Arduino/Genuino Uno comes preprogramed with a bootloader that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol (reference, C header files).

5.2 Code Used

```
#define ldr1 2
#define ldr2 3
#define mot1 4
#define mot2 5
int l1;
int l2;
void setup() {
  // put your setup code here,
to run once:
 Serial.begin(9600);
  pinMode(ldr1, INPUT);
pinMode(ldr2, INPUT);
pinMode(mot1, OUTPUT);
pinMode(mot2, OUTPUT);
}
void loop() {
  digitalWrite(mot1,LOW);
  digitalWrite(mot2,LOW);
  l1=digitalRead(ldr1);
  l2=digitalRead(ldr2);
 if(l1==HIGH)
 {
  digitalWrite(mot1,HIGH);
  digitalWrite(mot2,LOW);
 }
 if(l2==HIGH)
 {
  digitalWrite(mot1,LOW);
  digitalWrite(mot2,HIGH);
 }

}
```

5.3 Implementation

5.3.1 Solar Panel

Solar panels absorb the sunlight as a source of energy to generate electricity or heat. A photovoltaic (PV) module is a packaged, connect assembly of typically 6x10 photovoltaic solar cells. Photovoltaic modules constitute the photovoltaic array of a photovoltaic system that generates and supplies solar electricity in commercial and residential applications. A single solar module can produce only a limited amount of power; most installations contain multiple modules.

A photovoltaic system typically includes an array of photovoltaic modules, an inverter, a battery pack for storage, interconnection wiring, and optionally a solar tracking mechanism. Photovoltaic modules use light energy (photons) from the Sun to generate electricity through the photovoltaic effect. The majority of modules use wafer-based crystalline silicon cells or thin-film cells.

The structural (load carrying) member of a module can either be the top layer or the back layer.

Cells must also be protected from mechanical damage and moisture. Most modules are rigid, but semi-flexible ones are available, based on thin-film cells. The cells must be connected electrically in series, one to another. Externally, most of photovoltaic modules use MC4 connectors type to facilitate easy weather-proof connections to the rest of the system.

Modules electrical connections are made in series to achieve a desired output voltage or in parallel to provide a desired current capability. The conducting wires that take the current off the modules may contain silver, copper or other non-magnetic conductive transition metals. Bypass diodes may be incorporated or used externally, in case of partial module shading, to maximize the output of module sections still illuminated. Some special solar PV modules include concentrators in which light is focused by lenses or mirrors onto smaller cells. This enables the use of cells with a high cost per unit area (such as gallium arsenide) in a cost-effective way.

Efficiencies of solar panel can be calculated by MPP (maximum power point) value of solar panels. Solar inverters convert the DC power to AC power by performing MPPT process: solar inverter samples the output Power (I-V curve) from the solar cell and applies the proper resistance (load) to solar cells to obtain maximum power. MPP (Maximum power point) of the solar panel consists of MPP voltage (V mpp) and MPP current (I mpp): it is a capacity of the solar panel and the higher value can make higher MPP.

5.3.2 LDR Sensor

An LDR is a component that has a (variable) resistance that changes with the light intensity that falls upon it. This allows them to be used in light sensing circuits. A photo resistor (or light-dependent resistor, LDR, or photo-conductive cell) is a light-controlled variable resistor. The resistance of a photo resistor decreases with increasing incident light intensity; in other words, it exhibits photoconductivity. Light Dependent Resistors (LDR) are also called photo resistors. They are made of high resistance semiconductor material. When light hits the device, the photons give electrons energy. This makes them jump into the conductive band and thereby conduct electricity.

A Light Dependent Resistor (LDR) or a photo resistor is a device whose resistivity is a function of the incident electromagnetic radiation. Hence, they are light sensitive devices. They are also called as photo conductors, photo conductive cells or simply photocells. However, when light shines onto the LDR its resistance falls and current flows into the base of the first transistor and then the second transistor.

List of components along with their cost

Component	Cost (In Rupees)
LDRs	100
Sensors	60
Arduino board	600
Motor driver	100
Wire	279
Transformer	184
Battery	220
Multi-meter	480
Solar Panel	2500
Welding	200
12V Battery	350

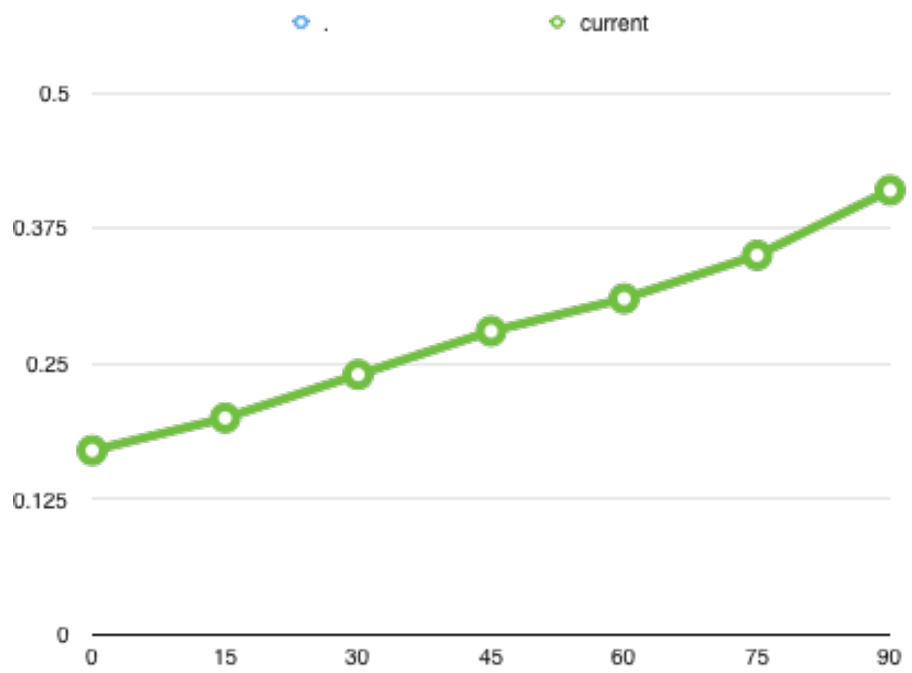
Total cost: Rs. 4,874

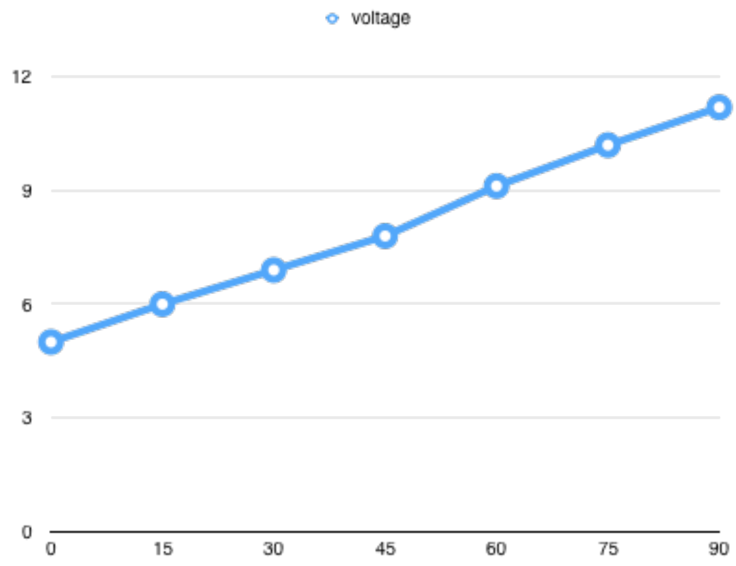
The pre-set resistor can be turned up or down to increase or decrease resistance, in this way it can make the circuit more or less sensitive. Thermistors and LDRs. You should be able to recognise the circuit symbols for the thermistor and the LDR (light-dependent resistor), and know how the resistance of these components can be changed.

5.3.3 Observations

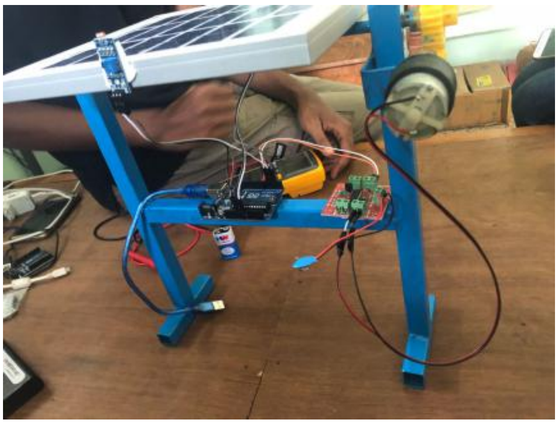
RATED VALUE: 12V
CURRENT: 0.45 A

ANGLE (degree)	VOLTAGE (Volts)	CURRENT (Amperes)
~0	5	0.17
15	6	0.20
30	6.9	0.24
45	7.8	0.28
60	9.12	0.31
75	10.2	0.35
90	>11V	0.41





5.4 Hardware Implementation



6. Conclusion

Through this project we can clearly conclude that active panels are more efficient than passive ones. We were able to implement the dual axis solar tracker, and when we obtained the graph we did in fact reach the same conclusion as the review paper we took from. That, when the collar tracker was able to face the incoming rays directly in the perpendicular direction is when we were able to attain the maximum intensity of the sunlight. This is beneficial in general, in terms of not wasting resources and also maintain efficiency. More energy created, is more energy utilised.

7. Self-Assessment

We were able to implement the base paper, to the extent of using active trackers instead of passive ones. We were able to gauge the change in intensity of the energy crated, with various angles of the solar panel.
We were able to implement most of the base paper.

8. Modules

Documentation: The documentation was mainly handled by Sahiba and Salonee. The observations were done by all the 4 members, together.

Design: The designing was done by Rishab, and Siddhant. They also went to acquire most of the parts used in the project.
Implementation: The implementation was done by all 4 members together, we met in the library every weekend.

9. Summary

We learned Arduino coding, and the proper connection making between the hardware and software. We also learned that the usage of different sensors, and how to use a multi-meter to gauge the energy produced in a solar panel.

10th January – Final base paper reading, and design calculus

10th February – Getting material, and starting implementation

12th March- Second round of additions, testing and observations

2nd April- Final deployment

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Solar tracking methods to maximize PV system output – A review of the methods adopted in recent decade

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ABSTRACT

This paper reports a review of various methods of solar tracking with gains in energy due to tracking and different MPPT algorithms. The fossil fuels are non-renewable, limited and deplete. Therefore, it is imperative to find alternative sources of energy. As solar energy is available abundantly in nature, it can be considered as a best alternative to meet the energy demand. It is sustainable, renewable and scalable. Increasing the efficiency of harnessing solar energy should be one of our foremost concerns as it is a renewable source. The challenge in tapping this energy is to increase the efficiency as well as to reduce the cost of production. Therefore an attempt is made to review the various Maximum Power Point Tracking (MPPT) algorithms, different solar tracking methods and the energy gained by using these methods. Further, a single axis microcontroller based automatic tracker is implemented and tested for its performance in real time. The work focusses on the orientation of solar panel towards the direction of maximum radiation by using a stepper motor interfaced with ARM processor.

1. Introduction

In the recent years, there has been a dearth of fossil fuels, and one of the most daunting challenges is finding clean and renewable energy. Several conservation methods have been suggested such as energy harvesting, energy recycling to reduce the energy used in commercial applications. Over the years, several methods have been implemented to use renewable sources of energy such as wind, hydro power, solar power, thermal power, tidal power, etc. One of the most popular natural source is solar power due to its ubiquitous characteristic and low maintenance cost.

Several techniques have been implemented in order to maximize the energy obtained from solar power. Among these, one of the most common technique is solar tracking. The motion of tracking could either be about one axis (1 axis tracker) or two axes (dual axis tracker). This paper presents the different types of solar trackers along with their pros and cons and also the energy gain differences among the different tracking techniques.

2. Methods of solar tracking

Solar tracker is a mechanism, which follows sun direction to extract maximum power. There are different drive types, which are as follows.

2.1. Passive trackers

The principle behind passive trackers is to make use of the solar heat to cause an imbalance, which leads to a movement in the tracker. They work on thermal expansion and commonly employ a low boiling point compressed gas fluid or shape memory alloys. For Concentrating Solar Power (CSP) applications requiring high precision, passive trackers are not generally used. However, they can be employed for common flat PV systems. The degrees of complexity with passive trackers are lesser than active trackers, but it fails to give high efficiency at low temperature.

Poulek designed a low-cost single axis passive tracker based on Shape Memory Alloy (SMA) actuators. The SMA actuator can easily be deformed even at relatively low temperatures (by tracker actuators below 70 °C). It produces mechanical work by returning back to its original shape when heated above transformation temperature. The study found that the tracker worked very well in the short term field tests and the SMA actuators provided an efficiency of approximately 2% [1].

2.2. Active trackers

Active Solar Trackers make use of motors and gear mechanisms to maintain control over the tracker. These motors are usually fed by a

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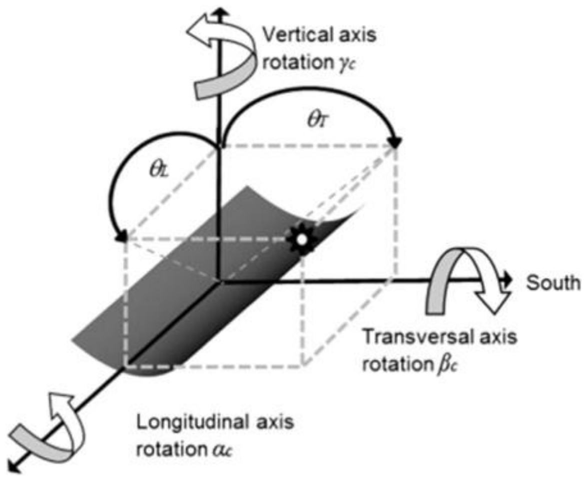

Fig. 1. Scheme of the rotation angles.

control signal which provides the magnitude and direction of the tracking to be performed. Active trackers are more accurate and more frequently used but they need to be powered and consume energy. They also lead to a higher increase in efficiency as compared to passive trackers.

2.2.1. Active trackers with single-axis system

A single axis system provides for only one degree of freedom which acts as the axis of rotation. As a result, they usually consume lesser energy and have lesser complexity than a multi-axes system.

Huang et al. built a 1-axis 3-position sun tracking PV which could be easily mounted on the wall of a building. The 1A-3P sun tracker was designed to operate at only 3 different angles as shown in Fig. 1. The tracker involves a simple structural design and a DC motor to turn the PV mounting frame. The turning of the tracker was made possible by a timer IC which provides the time signal to trigger the motor to turn at the turning angle. The measuring functions for tracker motion, PV generation and all the control algorithms are implemented using microcontroller PIC18F452 [2].

A standalone single axis active solar tracker and presented the modeling and simulation of the photovoltaic system under a constant load using MATLAB/Simulink was designed by Chin et al. [3]. The PV standalone system consisted of a PV panel, a servo motor, a battery, a charger, two LDR sensors, an external load and a microcontroller. The tracker was designed to have a single axis rotation (East-West) and the motor was mounted in such a way that the tracker systems had a single-axis freedom of rotation. The sunlight intensity was sensed using the LDR sensors, which would then send a signal to the microcontroller to rotate the panel using the servo motor. All the components were powered by the Lead Acid battery, in which the generated electrical energy was stored via the charge controller.

Konar et al. designed a single axis microcontroller based automatic position control scheme. The flat PV panel or the cylindrical parabolic reflector was optimally tilted across one axis and the tracker controls the other axis by changing the azimuth angle. The tracking system was designed to search for the maximum solar irradiance in the whole azimuth angle of 360° during the locking cycle, and hence the system was not constrained by the geographical location of installation. The system also employed step tracking scheme instead of continuous tracking which keeps the motors idle for a longer time to save energy [4].

Sallaberry et al. reported a single-axis solar tracker on a small size Parabolic-Trough Collector (PTC). The algorithm calculates the position of the sun at different times and is classified as an active open-loop type actuator. The angular tracking error was accurately characterized using a digital inclinometer. The transversal Incidence Angle Modifier (IAM) curve is determined by ray tracking simulation for all longitudinal incidence angles as well as the transversal incidence plane. The proposed procedure gives a better accuracy for the tracking error than the theoretical acceptance angle [5].

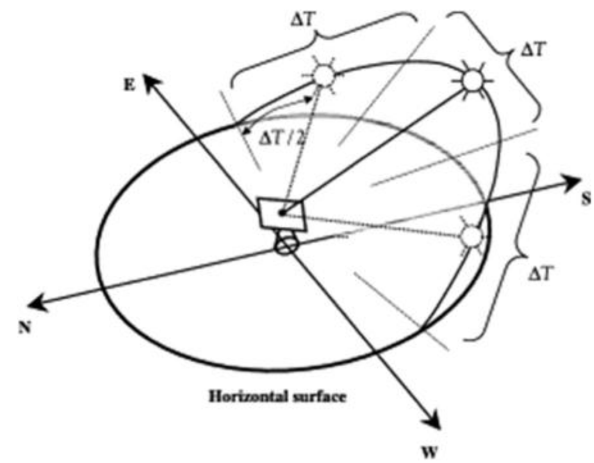

Fig. 2. Schematic diagram of azimuth three step tracking.

Ai et al. derived formulae to evaluate the daily and hourly radiation incident on azimuth three step tracking system, hour angle three step tracking systems and compared the results with the radiation received by a horizontal surface. They concluded that, a horizontal surface tilted at an optimal angle receives 30.2% higher radiation than a horizontal surface over a year. In comparison, a two axis azimuthal three step tracking performed better with a 72% higher radiation [6]. The schematic diagram of azimuth three step tracking is shown in Fig. 2.

A theoretical study to analyze the performance of an east-west oriented single-axis tracking panel was done by Chang [7]. The study compared performance of the tracking panel with a fixed horizontal surface by accounting different time periods, latitudes and radiation types. It was concluded that the yearly gains obtained in an east-west oriented single-axis tracked panel were far less in comparison to a north-south oriented single-axis tracked panel. The study also found that though the irradiation received decreases with latitude, the relative gains from a tracked panel increases from 12% at the equator to 143% in the Arctic.

Grass et al. proposed and compared a one-axis tracking system with a non-tracking Compound Parabolic Concentrator (CPC) collector. A tracking evacuated tube collector with a trough like concentrating mirror was presented, with a magnetic mechanism employed to achieve the single axis tracking of the mirror. Using ray tracking analysis, it was seen that optical efficiencies for direct radiation could be increased by employing tracking systems. However, it was also observed that small tracking errors could have significant effects when the acceptance angle was small [8].

Li et al. investigated the optical performance of Inclined South-North (ISN) single-axis tracked solar panels using a mathematical formula which estimates the annual collectible radiation on fixed and tracked panels. For most areas of China with abundant solar resources, their study found that the maximum annual collectible radiation on ISN-axis tracked solar panels was about 96–97% of that on dual-axis tracked panels. They also found that sun-tracking techniques were unsuitable for areas with low solar resources, with there being a strong correlation between solar resources in a region and the increase seen in annual solar gain. In comparison to traditional fixed solar panels inclined at an optimum tilt-angle, ISN-axis sun tracking techniques saw an increase of over 30% in annual solar gain at areas with high solar resources, whereas the increase was less than 20% in areas with low solar resources [9].

An analysis of the performance of PV modules with daily two-positional tracking was presented by Tomson [10]. The study evaluated

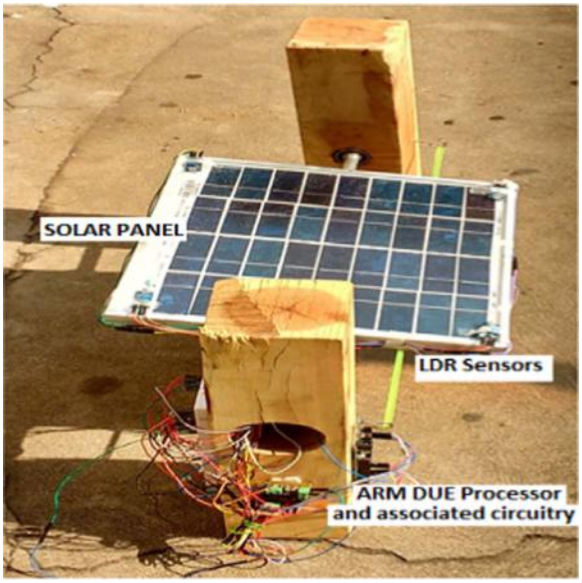

Fig. 3. ARM processor based single axis tracker.

the symmetrical and asymmetrical positions along the north-south axis, and derived the optimal positions for the two-position tracking. It was found that two positional exposure guarantees more gain as compared to fixed collector inclined at an optimal position. The possibilities for the South-East directed and 45° tilted collector, the most feasible was eastward deflection of −30° and a westward deflection of +60°.

Sumant Malav has used a single axis solar tracking system that implements a control algorithm to move the panel in both directions. The power consumption is reduced by using a stepper motor which switches on at singular intervals compared to the conventional tracking system [54].

Single axis microcontroller based automatic solar tracker is implemented. The designed system has been tested in Vellore a small town in Tamil Nadu, India having latitude of 12.91°N. The use of a single axis tracker proves to be more efficient as it saves the complexity and energy required to drive a dual-axes system. The single-axis system is mounted on rigid ends, which provide stability while the panel moves from facing the east to the west direction as the day progresses. The experimental set up is shown in Fig. 3.

The Solar Panel is mounted on the axis between the two rigid wooden blocks. The LDR sensors, placed on the four corners of the panel, detect sunlight and the analog input is sent to the ARM Processor. The flow chart implementing single axis tracking system is shown in Fig. 4.

Since it is a single axis tracker, the sensors in effect only compare values over two directions – east and west. The microcontroller takes an average of the sensor values of the two east oriented sensors, and the two west oriented sensors.

The microcontroller compares these two average values corresponding to the two directions. If the difference in these values is greater than a threshold value, it sends a command to the motor driver. The motor driver moves the stepper motor in the direction of greater illumination, one step at a time. The motor continues to move until the difference between the sensor values falls below the threshold.

Multiple instances of the Solar Tracker working under different weather conditions were carried out. The tracking mechanism functioned more efficiently when a significant difference in the incident sunlight was detected between the east and the west sensors.

Sunny Weather:

The solar tracker was tested at different times of the day on a mostly sunny day. The readings were as follows (Table 1):

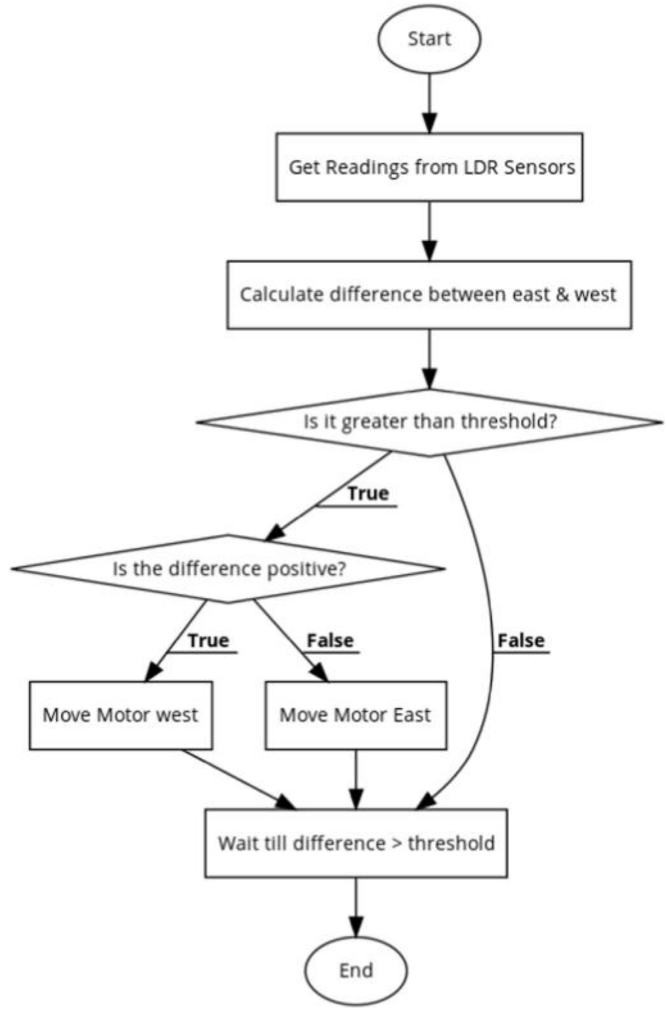

Fig. 4. Flow chart for single axis tracking system.

Table 1
Readings during sunny weather.

	9 am	1 pm	5:30 pm
Without Tracking	20.5 V	21.5 V	18 V
With tracking	21.8 V	22.6 V	19.5 V

Cloudy Weather:

Under partly cloudy conditions, the Solar Tracker showed the following readings:

	9 am	1 pm	5:30 pm
Without Tracking	18.4 V	18.6 V	18 V
With tracking	18.8 V	19 V	18.2 V

It was observed that the difference in the voltage readings was more pronounced under sunny conditions. In peak afternoon, under heavy sunlight, the tracker moves only occasionally. As the day progresses, and the sun starts to set, the tracker moves the panel in the direction of the sun. The difference now observed is more prominent.

2.2.2. Active trackers with dual-axis system

In a dual axis system, there are two degrees of freedom which act as axes of rotation and are usually perpendicular to each other. They tend to be more accurate than a single axis system, and require a more complex control system.

Yao et al. applied a system with fine motion ability named as declination-clock mounting system. This dual axis system used two automatic tracking strategies – one was the normal tracking strategy and the other was a daily adjustment strategy. The normal tracking strategy was aimed to keep the tracking errors smaller than pre-specified values, in order to improve the performance of concentrating photovoltaic systems. They used a hybrid strategy involving time-based control as well as sensor-based control. Based on the local time, the tracker was controlled to reach a calculated position and then the sun position sensor would provide a feedback to correct the tracking error. For flat PV systems, a high degree of accuracy is not essential and hence, a simple daily adjustment strategy was employed. The declination angle was adjusted once a day such that the PV panel was perpendicular to the solar beams at noon. The secondary axes was then adjusted by 0.5° every 2 min until the stop time [11].

A low-profile two axis solar tracker with new actuation geometry has been developed by Barker et al. [12]. Their design aimed to reduce installation costs by securing the tracking system to the ground, and also improved the packing density by creating a smaller shadow footprint than the conventional mast type trackers.

Zhang et al. proposed a new active solar tracker which combined the photoelectric tracking mode mainly with the time-based auxiliary mode. The weather condition is estimated by the tracking system using four photo electric sensors. In case of a sunny day, the system opted for photoelectric tracking, else it chose the time tracking mode. The tracking system made use of stepping motors to rotate at a certain angle after a set time interval. At the time of sunset, the solar panel would touch the limit switch signaling the end of tracking. It would then be reset to be ready for the next day. This study also analyzed the mechanical properties including motion simulation and wind resistance [13].

Sungur designed and implemented a multi-axes electromechanical system to track the sun by using a Programmable Logic Control (PLC). In this study, the solar azimuth angle and the solar altitude angle were calculated for each day and hour of the year and using these, the PLC was programmed. The output of the analog module of the PLC was given to the control input of the actuator motors. The tracking system developed in this study minimized the errors which are otherwise caused by using photo sensors in cloudy conditions [14].

An automatic closed-loop sun tracker was designed and tested by Roth et al. [15]. A dual axes system was used to measure direct solar radiation automatically with a pyrheliometer and two small DC motors moved the instrument platform to keep the sun's image at the center of the four-quadrant photo detectors. During cloudy conditions, when the sun was not visible, a computing program calculates the position of the sun and took control of the movement. The system was found stable for solar irradiation of above 140 W/m^2.

Gholinejad et al. studied the effects of tracking modes on the performance of a solar Multi- Effect Distillation (MED) plant using a two-axis tracking system. It consisted of two parts, namely the solar field and MED system, in the solar field the Heat transfer fluid is fed into the PTC which absorbs the sun's heat. A comparative study is conducted between full tracking, polar, N-S and E-W tracking for MED plants to find the most efficient tracking method [16].

Njoku incorporated two axis tracking collectors to improve the energy generation by solar PV system. From previous studies conducted in Southern Europe, it was concluded that the 2-axis tracking had the highest efficiency (among 1-axis, 2-axis and CPV), and the outputs were about 25.2% greater than the outputs of a fixed system. A comparative study between beam radiation gains, diffuse radiation gains and ground reflected radiation gains shows that, the least among them is ground reflected radiation giving an efficiency between 6% and 10% of the total gains. The highest and least contributions are from beam and diffuse components respectively. The average proportion of the total irradiation gains which is beam radiation is in the range of 82–88%, while average diffuse radiation proportions are between 2% and 12% depending on the period of the year [17]. The illustration of a two-axis tracking PV collector surface showing rotation about the central axes is shown in Fig. 5.

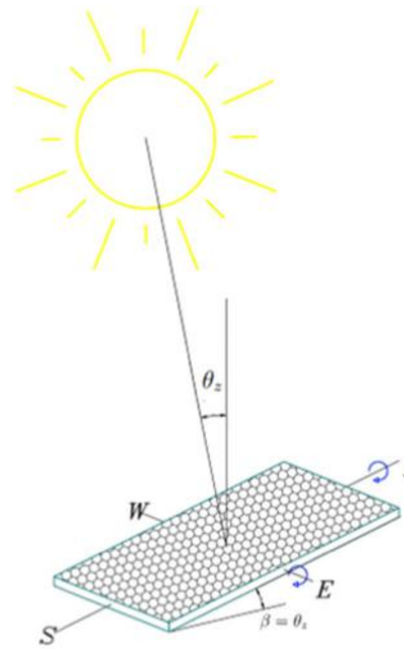

Fig. 5. Illustration of a 2-axis tracking PV collector surface.

Quesada et al. performed a study to develop the optimum tracking strategy for photovoltaic solar systems in high latitudes. The methodology estimates the theoretical value of the integrated solar radiation incident on a horizontal plane in which the PV panel is present and it produces more energy than a panel that follows the sun. It was concluded that tracking is a viable option only when the sky is clear or partly cloudy [18].

The performance of crystalline silicon PV panels is known to be influenced by the conditions in which it operates, particularly underperforming when overheated. A research conducted by Moharram et al. [19] concluded that temperature coefficient of the PV panels that they used is −0.5%/°C, which indicates that every 1° of temperature rise corresponds to a decrease in efficiency by 0.5%.

Eldin et al. investigated the feasibility of solar tracing systems in hot and cold regions and reported the results. A mathematical model was developed to determine the performance of crystalline silicon PV panels as a function of tracking the sun and operating conditions. They found that the results of this model were in agreement with the experimental observations. By calculating the increased power output from PV panels installed in Berlin and Stuttgart in Germany, Cairo and Aswan in Egypt, and accounting for the energy losses due to the tracking system, it was concluded that solar tracking is beneficial in cold and cloudy countries, but is unadvisable in Sun-belt countries [20].

Arlikar et al. suggested a three dimensional solar tracker with a special arrangement of LDRs in order to enhance the working range of the solar tracker. For three dimensional tracking, two stepper motors are used, one to move the plane of the solar panel and the other will move this plane in a third dimension. The paper discusses about the two axis control of the solar tracker using the LDR sensor, however the panel is fixed and reflectors are used in order to maximize the incident light intensity. The latitude and longitude position of the sun is calculated throughout the year and accordingly the set point for the solar panel is fixed and controlled. A PLC is used to control the position of the solar tracker. It is found that the 3D solar panel produces more energy than a traditional solar panel [21].

A spherical motor controlled by a microcontroller for precisely tracking the sun was designed by Oner et al. The spherical motor alone is capable of moving in both horizontal and vertical axes, as compared to employing two stepper motors for each axis. The control system was designed to direct the PV system in such a manner so as to face the sun at 90°. The results showed an improvement in performance when the tracking system was employed, as compared to a fixed tilted PV panel during afternoon [22].

Rahimi et al. designed and tested a novel hybrid sun-wind-tracking system to enhance the performance of PV panels, as opposed to the conventional sun-tracking systems. The new hybrid system combined a dual-axes solar tracking system with a wind-tracking system, aimed to cool down the PV panel. The experimental study showed an increase in power generation using this system. The conventional dual-axes sun-tracking showed an increase of 39.43% in total daily collection over a fixed mount system, whereas the hybrid tracking system yielded an increase of 49.83%. The wind-tracking system acts as an auxiliary system, which complements the dual-axis tracking in case of windy conditions [23].

The optimum geometry for fixed and tracking surfaces are calculated by Braun et al. The sun azimuth, zenith, surface azimuth and slope angles were calculated for one-axis and two-axis trackers respectively. It was concluded that the maximum possible radiation beam is obtained for a two-axis tracking surface when the surface azimuth is equal to the sun azimuth and when the surface slope is equal to the zenith [24].

Koyuncu et al. designed a two-axis microprocessor based sun-tracking system. A pair of limit switches were used to control the maximum angular positions in the east and west and limit the panel movement. It was concluded that as long as the plane for the panel was kept normal to the sun, the optimum amount of energy was obtained [25].

Smart dual axes solar tracking method was reported by Divya Mereddy et al. Dual axes trackers are used to track the sun irrespective of the sun's path. The tracking mechanism consists of LDRs to detect the sun's position. During cloudy atmosphere automatically activated timer controls the tracking. There is a significant increase in the efficiency by using dual axes LDR sensor mechanism and Timer [51].

2.2.3. Maximum power point tracking

Maximum Power Point Tracking (MPPT) algorithms are very useful to get the theoretical means to achieve the Maximum Power Point (MPP) of solar panels and improve the efficiency of the PV systems.

Huang et al. proposed a MPPT technique to improve the efficiency of photovoltaic systems. A cost effective analog MPPT circuit is proposed. A boost converter controller and a grid synchronous controller are used to control the DC-DC converter and the DC-AC inverter respectively. In order to raise both the tracking speed and accuracy, an open circuit tracking operation and a Slope Detection Tracking (SDT) operation are implemented. It is established that SDT helps increase the switching duty cycle and thereby increases the current in the solar panel and ensures that the system is operating at MPP [26].

Mei-xia et al. suggested a distributed MPPT module to optimize the efficiency of Photovoltaic systems. A comparative study between centralized and distributed MPPT shows that the distributed system is more efficient in the case of partial shading on solar photovoltaic generation systems. The issue with the battery mismatch in Centralized Maximum Power Point Tracking (CMPPT) is rectified using a Distributed module. It is designed such that the batteries communicate with each other in an indirect way, with self- awareness and organizational capacity. It is observed that the Distributed Maximum Power Point Tracking (DMPPT) compensates up to 50% generating capacity loss due to the mismatch problems [27].

Kheldoun et al. suggested a new gold-section method-based MPPT algorithm for PV systems. It makes use of an algorithm based on Golden Section Optimization (GSO) technique. It is used to track the MPP under fast changing conditions and partial shading. It is preferable over other MPPT techniques because only addition/subtraction and multiplications are used in the algorithms, the convergence of the algorithm is very fast and the MPP is reached within seven steps. Also, once the MPP is reached, the PV module operates at a steady voltage without any oscillations [28].

A new method for tracking a global maximum power point under partially shaded conditions using a neural network was presented by Ranjbar et al. They made use of the voltage, current and temperature of the solar panels and applied basic solar panel equations instead of directly measuring radiation intensity by using sensors. These were then taken as inputs to train the neural network and the MPP was obtained as the output. The response obtained from MATLAB/ Simulink model of the proposed method was found satisfactory in partial shaded condition [29].

Li et al. designed and implemented a novel MPPT controller which trackers the sun by driving two DC motors in two axes. They aimed to overcome the limitations of the traditional Perturbation and Observation (P & O) method by presenting an Improved Perturbation and Observation (IP & O) method. The experimental results concluded that the new controller was able to maintain the PV array in an optimal position to the sun and also adjusted the load on the array to track the MPP [30].

Makbul A.M. Ramli et al. have reviewed the influence of different MPPT methods in PV systems for normal and partial shading conditions. This review further discusses the use of different artificial intelligent techniques to maximize the PV system output [52].

A modified P & O MPPT method with reduced steady-state oscillation and improved tracking efficiency was proposed by Jubaer Ahmed and Zainal Salam. They suggested unique technique to dynamically alter the perturbation size with defined boundary conditions to converge the problem at faster rate. The proposed technique is validated using DC-DC converter powered by PV system and gives efficiency 1.1% greater than the conventional P & O when irradiance changes slowly and about 12% higher under fast change of irradiance [53].

P. Chinna et al. implemented a GMPPT of Solar PV Array under Partial Shading Condition using FPGA controller. The value of solar PV array voltage is calculated at the global maxima of the PV characteristics and duty cycle control is performed by using P & O method. The results are validated with boost converter using FPGA controller in LabVIEW platform [55].

3. Gains in energy due to tracking

In photovoltaic systems, the angle of incidence is reduced by using trackers (the angle that a ray of light makes with a line perpendicular to the surface) between the incoming light and the panel, this helps in increasing the amount of energy produced by the system. Concentrated solar photovoltaics and concentrated solar thermal are having optics that directly accept sunlight, so solar trackers must be angled correctly to collect maximum energy.

Bentaher et al. designed and constructed a simple solar tracking system using Light Dependent Resistors (LDR). The precision of the system was calculated and the optimal angle between the two LDRs was optimized numerically and experimentally. The results obtained from solar tracking system are found good [31]. The sensor geometry and incidence angles are shown in Fig. 6.

Huang et al. built and tested a 1 Axis-3 Position (1A-3P) sun tracking PV and used solar powered LED lighting systems to compare it with a fixed PV. The tests performed over 13 months in Taipei showed that the 1A-3P tracking PV showed an increase of 23.6% over a fixed PV, which was very close to the performance of a 1-axis continuous tracking PV. When the 1A-3P tracking PV was used in a high irradiation area, the increase in energy generation was higher than

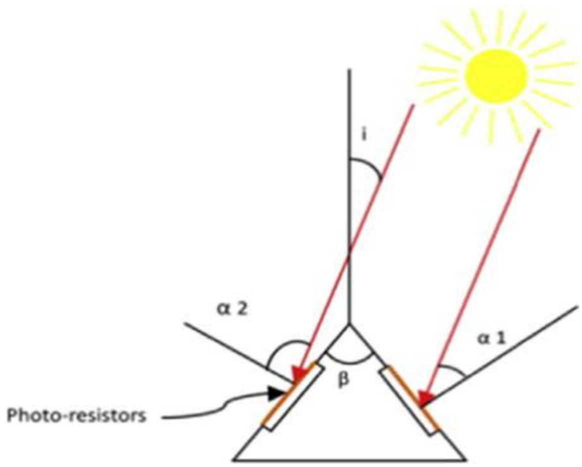

Fig. 6. Sensor geometry and incidence angles.

37.5%, a result close to that of a 2-axis continuous tracking PV. They also concluded that the cost of a building mounted 1A-3P system was not more than a fixed rooftop PV system [2].

Chin et al. presented the design, modeling and testing of an active single axis solar tracker. Their experimental results showed a 20% increase in efficiency over a fixed panel design. This was close to the simulated results obtained using MATLAB/Simulink model. There was only a slight deviation during the noon and evening period due to unmodelled external disturbances such as mechanical friction and wind loading. Their accumulated data also showed that a PV system is efficient where small amounts of energy are required at a place far away from the electric grid [3].

Yao et al. employed a declination-clock mounting system and compared the output using 2 strategies – a normal tracking strategy for a flat PV system; and a daily adjustment strategy for a Concentrating Solar Power system. Both the strategies yielded a higher power output as compared to a fixed PV system. However, the daily adjustment strategy simplified the tracking process and reduced the energy consumption, leading to higher efficiency of more than 31.8%. On the other hand, the normal tracking strategy reduced the tracking error and kept it within 0.15°. Both these strategies proved to be effective for flat PV systems as well as concentrated solar power systems [11].

Zhang et al. developed an available energy absorption model to study the energy efficiency of their tracking system. Theoretically, a 36% increase in the average value of energy efficiency in a year was calculated as compared to the fixed mode. However, the year theoretical value of energy efficiency was found to be affected by the latitude at which the system was installed. When the latitude is too high, between 85° and 90°, the available energy absorption was estimated to be too little and unsuitable for tracking [13].

Sungur designed and implemented a multi-axes sun tracking system controlled by a PLC and an analog module. The study was performed at 37.6° latitude and an energy gain of 42.6% was observed from the PV panels which tracked the sun as compared to PV panels at fixed positions. To increase the sensitivity of such a tracking system, it was also concluded that high-bit analog modules could be used [14].

Eke and Santurk analyzed the performance results of two double axis sun tracking PV systems after a year of operation. The performance measurements were first carried out when the PV systems were in a fixed position and then while they tracked the sun in two axes. The double axis sun tracking system yielded a 30.79% increase over the latitude tilt fixed system. Annual PV electricity yield was calculated to be 11.53 MW h with 1459 kW h/kWp energy rating for 28 fixed tilt angle for each system, as compared to the double axis sun-tracking PV system which fed to grid 15.07 MW h with 1908 kW h/kWp [32].

Arlikar et al. conducted a comparative study between simple panel without solar tracker, 3D solar tracker and solar tracker response in a dark room. Upon experimentation it was found out that when the solar panel is not used, the energy peaks at a particular hour of the day, but on the other hand, when a solar tracker is implemented, the energy gain is uniformly distributed throughout the day, making it more efficient [21].

Huang et al. proposed a MPPT technique in order to increase the efficiency of the solar tracking operations. It is noted that there are several MPPT techniques to do the same which are P & O, incremental conductance, load current/ load voltage maximization and model based tracking. The proposed technique is fabricated by a 0.25 µm BCD process. The highest tracking effectiveness achieved was 97.3% [26].

Mei-xia et al. analyzed the output characteristics of photovoltaic model in CMPPT and DMPPT. They found that even at the 10% power point (i.e. 30 W), the DMPPT could deliver an efficiency of 96.54% and at full capacity the efficiency was found out to be 98.41%, which exceeds the CEC and the European efficiency. The electricity generation efficiency of an unshaded photovoltaic system was found to be 78.46%. At 10% shading the total output voltage was basically the same and the current slightly reduced, however the efficiency was maintained at 77.31%. From the tests and experimentation it was observed that the system efficiency had almost no difference, indicating that DMPPT can greatly improve the generation efficiency [27].

Eldin et al. conducted experiments in Egypt and Germany to test the energy gains of a PV panel in different climatic conditions, in order to find the efficiency of solar tracking in hot and cold climates. In hot climates the average energy gained from tracking as compared to that from a no tracking PV panel is higher by about 8.16%. The low energy gain from tracking is because of the overheating of the panel. Moreover, a tracker would consume 5.89% of the total energy generated on a sunny day, along with the maintenance costs included tracking is not a viable option in extremely hot climates. When the same experiment was conducted in Berlin with relatively lower ambient temperature and solar irradiance, it was concluded that the energy gain was roughly around 40% more than that of a non-tracking panel. Even after taking into consideration the tracker consumption of 10%, the total energy gain would be nearly 30% [20].

Njoku implemented a 2-axis tracking PV in Nigeria, it was found that the average PV system performance ratio (r_p) was approximated to 0.75. The seasonal and annual E/P_k was found to increase with increase in location latitudes. The results also showed that depending upon the location and the season of the year, at least 20% and as much as 40% more energy was produced by using the 2-axis tracking systems, as compared to the non-tracking systems [17].

Quesada et al. conducted experiments on tracking the sun on a cloudy day and high altitudes. It was found out that sun-tracking on cloudy days in summer is disadvantageous. It occurs when the levels of global solar radiation incident on the horizontal plane (I_H) are below the critical radiation values(I_c). The experiment also confirmed that a solar tracking panel could produce up to 25% less energy than fixed horizontal panels on cloudy days in springtime [18].

Gholinejad et al. conducted a comparative study between different tracking systems for a MED plant. From the experiments it was found that for all characteristic days of a year, the collectors receive maximum radiation when full tracking mode is available, since the sun rays are perfectly perpendicular to the collectors(θ=0). It was also found that the collectors with N-S tracking mode receive maximum radiation on the first day of summer, whereas polar axis tracking mode receives maximum radiation on the first day of spring and fall. In summer, the daily rate of production of N-S system was higher than polar axis system by approximately 10% [16].

Kheldoun et al. Conducted experiments and comparative studies between different MPPT techniques under static and dynamic conditions. In the case of static tracking results it was noted that the proposed golden section tracking technique gave a better efficiency rate of 99.43% in a very low response time when compared to conventional

P & O method and hill climbing fuzzy logic method. In the case of dynamic tracking it was concluded that the proposed technique was more preferable, as it gave an efficiency of 99.602% in a convergence time of 0.025 s and at a very low complexity level [28].

Michaelides et al. analyzed the performance and cost effectiveness of different solar tracking modes, when used to operate a thermosyphon solar water heater. The three different modes studied were – traditional configuration with the surface fixed at 40° to the horizontal, single axis tracking with variable azimuth, and seasonal tracking in which the slope is adjusted twice per year. Using the TRYNSYS simulation program, the study concluded that the single axis tracking mode performed the best, with its annual solar fraction being 87.6% as compared to 81.6% for seasonal tracking and 79.7% for fixed tracking. However, due to the high initial cost of the tracking mechanism, the fixed surface mode was found to be the most cost-effective [33].

Bione et al. made use of a PV pumping system and compared the pumped water volume, for tracking systems, with and without concentration, against fixed systems. They estimated the long term gains and concluded that for the city of Recife in Brazil, the annual pumped water volume for a tracking system is 1.41 times the fixed value, while a tracking V-trough concentrator brings an annual benefit of 2.49 times [34].

Koussa et al. compared the performance of flat plate PV systems using five different configurations of tracking systems and two traditional fixed panels, and investigated the main parameters affecting the electrical energy output. They further quantified the daily cumulative energy produced by each system for different sky states – completely clear day, partially clear day, and a completely cloudy day. Their work found that on a completely clear day, two-axis sun tracker systems provided the highest gains followed by the panels mounted on an inclined rotating axis, and then those mounted on a vertical rotating axis, if the same optimum slope was considered. However, for a cloudy day, it was concluded that all the systems under consideration nearly produced the same amount of electrical energy, with the horizontally positioned PV panel performing the best [35].

Sangani and Solanki designed and fabricated a V-trough PV concentrator system for 3 different tracking modes – seasonal, one axis and two axes. Commercial PV modules were then tested with this system to obtain cost reductions using PV. The V-trough designs with a lower trough angle provided higher generated power as compared to higher trough angles. The use of the V-trough system yielded a minimum increase of over 40% in the output power, while the cost/unit was reduced by 24% in comparison to a flat PV system [36].

Ghosh et al. performed a study to determine hourly and seasonal optimum tilt angles, by employing three mathematical models – the Isotropic, the Klucher and the Perez model. A theoretical study of solar radiation on differently oriented, single and multi-axis tracking surfaces was performed and compared with measured data for Nov 2007 to Oct 2008 at Dhaka. They concluded that an average increase of 15% over the whole year can be seen if the surface is mounted at a slope equal to the mean monthly slope, adjusted every month [37].

Lazaroiu et al. evaluated the performance of a fixed and a sun tracking PV system and analyzed the increase of the daily produced energy by using the latter, after taking into account the energy consumption of the sun tracker. They built two PV lab prototypes and investigated them over a 30 day period, with the results concluding an increase of 12–20% by using the sun tracker [38].

Rubio et al. presented a new hybrid control strategy for sun-tracking with high accuracy that aimed to reduce the sun tracking errors. The developed algorithm worked in 2 modes – normal tracking mode in case of sufficient sunlight, and a search mode otherwise. The tracking strategy design also incorporated energy saving factors. In comparison to an ordinary open loop control strategy, the simulated and experimental results showed a benefit in employing the new hybrid strategy [39].

Peng et al. designed a new servo tracking system, combining electro-optical tracking and sun trajectory tracking to keep solar panels perpendicular to the sun. The proposed method used a T-S fuzzy system to reduce the computation and employed it during rainy or cloudy conditions. Under sunny conditions, the electro-optical tracking was chosen. Experimental results proved that the system is accurate as well as more efficient than a fixed panel system [40].

Rizvi et al. proposed an algorithm to calculate the sun position in order to track the sun without the use of sensors. The proposed algorithm was a compilation of different equations that calculated the azimuth and elevation angle of the sun in horizontal coordinates. The algorithm was found to be energy efficient, showing an approximate improvement of 49% as compared to a system without tracking. In situations where high accuracy is not required, the proposed simpler algorithm could be implemented [41].

Hossain et al. designed and implemented a Compound Parabolic Concentrator (CPC) with a sun tracking system, aimed at increasing the efficiency of the solar cell. They proposed to make use of Machine Vision (MV) and Data Acquisition (DAQ), using a web-camera as a sensor to observe and track the sun. The study implemented a closed loop control system to provide an output to a sound card which would drive the motor in the direction of the sun. Experimental results of the study showed an increase in the efficiency of the solar cell using a CPC as compared to a normal solar cell, in all three tested parameters – the current, the voltage and the power received [42].

Tejwani and Solanki designed and tested a novel sun-tracking cum cleaning system to track the sun and clean the solar panel automatically. The system comprised of an 8051 microcontroller, stepper motor coupled with a gearbox, and a sliding brush mechanism. The daily energy generation was seen to increase by about 30% in this tracking-cum-cleaning system as compared to a system kept stationary without cleaning [43].

Nann evaluated the difference between the potential of using a tracking system and a fixed system. A comparative study between a stationary, one-axis and two-axis systems showed that the irradiation received by one-axis tracker was nearly the same as that of a two-axis tracker, however the cost of the former was significantly lesser than that of the latter. It was also observed that the irradiance on the normal surface of a fixed tracker was lesser by 54%, also the surplus energy received by the one-axis and two-axis trackers were 34% and 38% respectively, which could be a major reason to implement tracking in order to increase the effectiveness of the PV plant [44].

Shaltout et al. implemented a V-trough concentrator on a PV tracking system. It was noticed that the gain in the amorphous Si solar cell's power was relatively higher by approximately 40% as compared to without a concentrator. A graphical comparison between concentrated horizontal and tracking radiation showed an increase in gain by about 23% for the latter [45].

Huang et al. conducted a feasibility study on a one-axis three position tracker suggested in the paper. The analytical results lead to the conclusion that the optimal stopping angle β in the morning or afternoon is about 50° from the solar noon position. The power generation increased by approximately 24.5% as compared to a fixed PV module. The analysis conducted showed that the PV power generation can increased by about 23% by using low concentration reflectors. Combining this with the power output increase of 24.5%, using this system, a total increase of 56% can be obtained [46].

Bakos conducted an experimental study to investigate the energy gain differences between a two-axis solar tracker and a fixed surface tilted at an angle of 40° towards south. It was observed that the solar energy tapped by the two-axis tracker was significantly more (up to 46.46%) than a fixed panel. It was found that when the solar intensity is low and the tracking system only operates on sensor mode, the solar reflector cannot follow the sun orbit and the efficiency is decreased significantly, the tracking system behaviour improves significantly when the software and sensor mode is used [47].

Alata et al. developed a multipurpose sun tracking system implemented using fuzzy control. To generate the fuzzy rules, subtractive clustering algorithm was used along with least square estimation. A theoretical study about the same showed that there is about 50% degradation in the maximum potential performance of a fixed collector, while it is 5–10% for the one-axis tracker [48].

Brunotte et al. conducted a study on a two-stage concentrator based on a one-axis tracking system along the N-S axis. The first concentrating stage's half rim angle was chosen as the sun's maximum declination of 23.5°. The system was tested for plenty of conditions along with theoretical study on concentration factor for E-W and N-S tracking. It was concluded that thermodynamically the concentration factor increases by a factor of three. At normal incidence, the concentration optical efficiency was found to be 77.5% [49].

Ibrahim constructed a one-axis concentrating collector with an electronic motor used for forced circulation. It was used to track the sun from East to west over a range of 180°. The efficiency of the collector was measured for different mass flow rates. It was found out that the collector efficiency increases to maximum of 62% and it is directly proportional to the mass flow rate [50].

4. Conclusion

Presented a review of various methods of solar tracking with gains in energy due to tracking and different MPPT algorithms. From the review carried out it was found that, active trackers were more commonly used as compared to passive trackers. Among the active trackers it was found that irrespective of maintenance issues dual axes active trackers maximize the efficiency of the PV system and allows controlled and competent collection and distribution of energy. The review further concludes that the increase in gain due to active tracking is approximately 30% with respect to the fixed system. The prototype of ARM processor based single axis tracker is developed and results are reported. From the results it is clear that, there is an appreciable increase in power generation due to the introduction of solar tracking system.

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