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Review Article

A Review on Solar Tracking Systems and Their Classifications

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Abstract: The output power produced by high concentration solar thermal and photovoltaic systems is directly related to the amount of solar energy acquired by the system. Therefore, it is necessary to track the sun's position with a high degree of accuracy. This can be achieved by the system called solar tracking system. Solar tracking system is the most common method of increasing amount of solar radiation from the sun to the solar collectors either Flat plate or concentrated collectors. The main objective of this research is to review different tracking mechanisms for solar tracking system, 18 papers were reviewed. The result showed that solar tracking system can either be dual axis or single axis trackers depending on freedom degree of motion. Dual axis trackers are the best option for places where the position of the sun keeps changing during the year at different seasons. Single axis trackers are a better option for places around the equator where there is no significant change in the apparent position of the sun.

Keywords: Azimuth Angle, Tilt Angle, Dual Axis Sun Tracker, Single Axis Sun Tracker

1. Introduction

Solar energy is clean and available in abundance. Solar technologies use the sun for provision of heat, light and electricity. These are for industrial and domestic applications. With the alarming rate of depletion of major conventional energy sources like petroleum, coal and natural gas, coupled with environmental caused by the process of harnessing these energy sources, it has become an urgent necessity to invest in renewable energy sources that can power the future sufficiently. The energy potential of the sun is immense. Despite the unlimited resource however, harvesting it presents a challenge because of the limited efficiency of the array cells.

The best efficiency of the majority of commercially available solar cells ranges between 10 and 20 percent. This shows that there is still room for improvement. This research seeks to identify a way of improving efficiency of solar panels. Solar tracking is used. The tracking mechanism moves and positions the solar array such that it is positioned for maximum power output.

When it comes to the development of any nation, energy is the main driving factor. There is an enormous quantity of energy that gets extracted, distributed, converted and consumed every single day in the global society. Fossil fuels account for around 85 percent of energy that is produced. Fossil fuel resources are limited and using them is known to cause global warming because of emission of greenhouse gases. There is a growing need for energy from such sources as solar, wind, ocean tidal waves and geothermal for the provision of sustainable and power.

Solar panels directly convert radiation from the sun into electrical energy. The panels are mainly manufactured from semiconductor materials, notably silicon. Their efficiency is 24.5% on the higher side. Three ways of increasing the efficiency of the solar panels are through increase of cell efficiency, maximizing the power output and the use of a tracking system.

Solar tracking is a system that is mechanized to track the position of the sun to increase power output by between 30% and 60% than systems that are stationary [1]. It is a more cost effective solution than the purchase of solar panels.

The solar radiation affects the World civilization in many ways depending on the advanced technology of one country to another. Nigeria is among the countries blessed with solar energy resource abundantly, especially in the northern part of the country [2]. In Nigeria, renewable energy constitutes about 90% of the energy utilized by the rural population, who make up about 70% of the nation [3]. These renewable energy resources are presently not fully developed to generate electrical energy [4].

The cost of installation of solar power to industries and big houses is very expensive because of need of solar panels. So, this project is to fix the problem that occurs here. This solar tracking system can detect a 180 degree of rotation. So, the solar panel that can be generating here is very high compared to when the solar panel is fixed in one direction. So, the industries and families don't have to install more than one solar panel to generate enough power. One solar panel is enough to produce a lot of power.

There are various types of trackers that can be used for increase in the amount of energy that can be obtained by solar panels. Dual axis trackers are among the most efficient, though this comes with increased complexity. Dual trackers track sunlight from both axes. They are the best option for places where the position of the sun keeps changing during the year at different seasons.

Single axis trackers are a better option for places around the equator where there is no significant change in the apparent position of the sun.

The level to which the efficiency is improved will depend on the efficiency of the tracking system and the weather. Very efficient trackers will offer more efficiency because they are able to track the sun with more precision. There will be bigger increase in efficiency in cases where the weather is sunny and thus favorable for the tracking system [5].

2. Review on Solar Tracker

A reasonable amount of work in a field of solar tracking system has been carried-out, some of these are discussed below based on freedom degree of motion (Dual axis and single axis sun tracking) together with findings.

2.1. Review on Dual (Two) Axis Sun Trackers

In a recent study Abdulrahim [6] carried out the design analysis of solar bi-focal collectors with the basic units comprising the paraboloid concentrators, receivers and support/connectors. The design of the receivers is such that it works on thermo-siphon principle while the heat energy requirement for each receiver is 650kJ. Solar energy required to provide the needed power input in the collector's receiver is amounted to 0.967kJ/s. The results of the analysis revealed that each collector has diameter of the receiver of 0.3 m, aperture diameter of 1.4m and internal surface area of 1.53 m^2. In 1992, Agarwal [7] presented a two axis tracking system consisting of worm gear drives and four bar-type kinematic linkages to facilitate the accurate focusing of the reflectors in a solar concentrator system. Brown and Stone [8] developed a tracking system for solar concentrators in which a neural network was applied to an error model in order to compensate for tracking errors. The test data showed that the resulting system was capable of reducing the tracking error to a value of less than 0.01° (0.2 mrad).

In 1998, Khalifa and Al-Mutawalli [9] developed a two-axis sun tracking system to enhance the thermal performance of a compound parabolic concentrator. The system was designed to track the sun's position every three to four minutes in the horizontal plane and every four to five minutes in the vertical plane. Abdallah [10] investigated the respective effects of four different electro-mechanical sun-tracking systems on the current, voltage and power characteristics of a flat-plate photovoltaic system. The results showed that tracking systems comprising two axes, one vertical axis, one east-west axis and one north-south axis, and one north-south axis, increased the electrical output powers of the photovoltaic system by around 43.87%, 37.53%, 34.43% and 15.69%, respectively, compared to that obtained from a photovoltaic system with a fixed surface inclined at 32° to the north. In 1983, Al-Naima and Yaghobian [11] developed a solar tracking system featuring a two-axis equatorial mount and a microprocessor, in which the tracking operation was performed on the basis of the astronomical coordinates of the sun. The experimental results demonstrated that the proposed system yielded a significantly better tracking performance than that obtained by a conventional sensor controlled system. In 2004, Abdallah and Nijmeh [12] developed an electro-mechanical, two-axis tracking system in which the motion of the sun tracking surface was controlled by an open-loop control algorithm implemented using a PLC unit. The proposed system incorporated two separate tracking motors, namely one motor to rotate the sun tracking surface about the horizontal north-south axis, i.e. to adjust the slope of the surface and the other to rotate the sun tracking surface about the vertical axis, i.e. to adjust the azimuth angle of the surface. The experimental results indicated that the two-axis tracking system increased the total daily energy collection by approximately 41.34% compared with that obtained from a fixed surface tilted at 32° towards the south.

Helwa [13] studied the solar energy captured by different solar tracking systems. They calculated the solar energy collected by using measured global, beam and diffused radiations on a horizontal surface. Four systems were used in their experiments: fixed system with tilt angle of 40° due south, one-axis azimuthally tracking with tilt angle of 33°, one-axis tracking oriented in the N – S direction with 68 tilt angle and two-axis tracking system, one axis vertical and the other horizontal. They developed formulas for three modes of radiation that come in contact with the surfaces and wrote a computer program in BASIC to calculate and store daily radiation for each system. The comparison between calculated and measured data showed the annual average for the hourly root mean square difference (RMSD) values of 5.36, 9.07, 7.92 and 5.98 for the fixed, vertical axis tracker, tilted axis tracker and two-axis tracker systems, respectively. All values were in the acceptable range. In 1995, Mumba [14] developed a manual solar tracking system for a PV powered grain drier working in two positions. A 12 V, 0.42 A, DC suction fan powered with PV was placed in the air inlet. To improve collector module efficiency, the sun was tracked 308 from the horizontal. Mumba investigated the performance under four cases: PV fan-off without sun-tracking, PV fan-on without sun-tracking, PV fan-off with sun-tracking and PV fan-on with sun-tracking. In the sun tracking cases the collector module angled manually eastward at 8.00 a.m. and westward at 2.00 p.m. while the collector module was tilted 15° from the horizontal to match the sun's elevation. It was concluded that from uniform air temperature point of view, the fanon sun-tracking case was the best, giving a temperature of 60.8°C. From uniform energy gain point of view, the sun-tracking cases performed superior to that of non-tracking ones. It was concluded that a solar air heater with manual sun-tracking facility can improve the thermal efficiency up to 80%.

Felske [15] evaluated the variation of azimuth and tilt angle on effectiveness of flat plate solar collectors. It was concluded that for a given tilt angle, the yearly energy collection is almost insensitive to azimuth angle until the vertical orientation is approached at which the collected energy actually increases with increasing the azimuth angle. In this case, the optimum tilt angle is quite insensitive to azimuth angle. For a given azimuth angle, an optimum collector tilt angle is between 3^{o} and 10^{o} less than the latitude. Finally, it was mentioned that even for locations having symmetric irradiation about solar noon it is desirable to orient the collector west of south, since afternoon temperatures are usually higher than morning temperatures. Comsit and Visa [16] designed a synthesis linkage, based on multi-body systems method for dual axis sun-tracking in solar energy conversion systems. They identified all possible graphs based on spatiality of the multi-body system, type of the geometrical constraints (simple and/or compound), number of bodies and the mobility of the multi-body system. To be more reliable, they recommended decoupled motions for these tracking systems.

Shrishti [17] developed automatic dual axis solar tracker system is a design and implementation of a polar single axis solar panel tracker. It has a fixed vertical axis and an adjustable horizontal motor controlled axis. This setup is similar to an office swivel chair. The tracker actively track the sun and change its position accordingly to maximize the energy output. To prevent wasting power by running the motor continuously, the tracker corrects it's position after 2 to 3 degrees of misalignment. The sensors compare the light intensities of each side and move the panels until the tracker detects equal light on both sides. Additionally, it prevents rapid changes in direction that might be caused by reflections, such as cars passing by. A rear sensor circuit is also incorporated to aid in repositioning the solar panels for the next sunrise. The gear motor has overturn triggers to prevent the panel from rotating 360° and entangling wires. The motor control and sensing circuitry runs on batteries charged by the solar panel. This system uses three small 10W solar panels of approximately 15 inches by 10 inches to model larger panels used in industry.

2.2. Review on Single (One) Axis Sun Trackers

Kalogirou [18] presented a one-axis sun tracking system utilizing three light-dependent resistors (LDRs). Lorenzo [19] designed a single vertical axis (azimuth axis) PV tracker and evaluated backtracking features. Each of 400 trackers installed in Spain used a 0.25 hp standard AC motor. The tilt angle of the PV surfaces remained constant. They mentioned that the energy collected by an ideal azimuth tracker was about 40% higher than that corresponding to an optimally tilted static surface and 10% higher than that of horizontal axis tracking. They calculated the E–W and N–S shadowing between two adjacent trackers occurred in the morning or afternoon. They recommended that when shadowing occurs, it can be avoided by moving the surface's azimuth angle away from its ideal value, just enough to get the shadow borderline to pass through the corner of the adjacent surface (backtracking). Their comparison showed that the azimuth tracking land was 40% greater than static surface while the corresponding energy cost can be significantly reduced. Chicco [20] experimentally assessed the production of the PV plants in the sun-tracking and fixed modes in three different sites. In the first site, 15 individual systems controlled by one coordinate tracking system were compared with a 0° azimuth and 36° elevation angles as fixed cases. In the second site, 90 individual systems with separate coordinate-controlled tracking were compared with 0° azimuth and 30° elevation fixed system. For the third site, the position of the sun-tracking system was being updated every 15 min and the fixed system maintained at a tilt angle of 30° with 35° elevation angle. The results showed that the average improvement, using the sun-tracking system, was 32.9 and 35.1% from the simulated values and 37.7 and 30.4% from the actual data for the first and second sites, respectively. For the third site, an annual improvement of 31.5% for the sun-tracking system was obtained.

In 1996, Ibrahim [21] constructed an electronically one-axis concentrating collector with an electric motor for forced circulation. The collector was hinged at two points for its tilt adjustment with a tightening screw to continuously track the sun from east to west through a range of 180°. The collector efficiency was measured for different values of mass flow rates. It was concluded that the collector efficiency increases (reaching the maximum value of 62%) as the mass flow rate increases. In 2006, Mwithiga and Kigo [22] designed and constructed a dryer with limited sun-tracking capability that operated manually. The dryer consisted of a gauge 20 mild steel flat absorber plate formed into a topless box. The drying unit was bolted onto a shaft which in turn was mounted on to a stand so as to face E–W direction. A selector disc on the stand allowed the tilt angle that the drying unit made with the horizontal, to be easily adjusted in increments of at least 158. This way, the collector plate could be intermittently adjusted in order to track the sun during the day. Four dryer settings for tracking the sun were created. The dryer was set at an angle of 60° to the horizontal facing east at 8.00 a.m. They adjusted the angle of the dryer made with the horizontal either one, three, five or nine times a day when either loaded with coffee beans or under no load conditions. The results showed that the solar dryer can be used to successfully dry grains. Drying of coffee beans could be reduced to 2–3 days as opposed to sun drying without tracking system, which takes 5–7 days and the temperature inside the chamber could reach a maximum of 70.48°C

Khalid [23] constructed Single Axis Automatic Solar Tracking System and demonstrated a novel method which will automatically track the sun's position and accordingly change the direction of the solar panel to get the maximum output from the solar cell with the help with IC LM339N, Sensor (LDR) and DC geared motor. The paper offers a dependable and reasonable strategy for adjusting a aligning a solar module with the sun keeping in mind the end goal to maximize its energy output.

3. Discussion

Taking into consideration all reviewed articles, dual (two) axis sun trackers are the best option for places where the postion of the sun keeps changing during the year at different seasons, whereas the single axis trackers are a better option for places around the equator where there is no significant change in the apparent position of the sun. Sun trackers are categorized solely in one-axis or two-axis trackers. However, the tracking surfaces including passive or active trackers may also be classified as in figure 1 below:

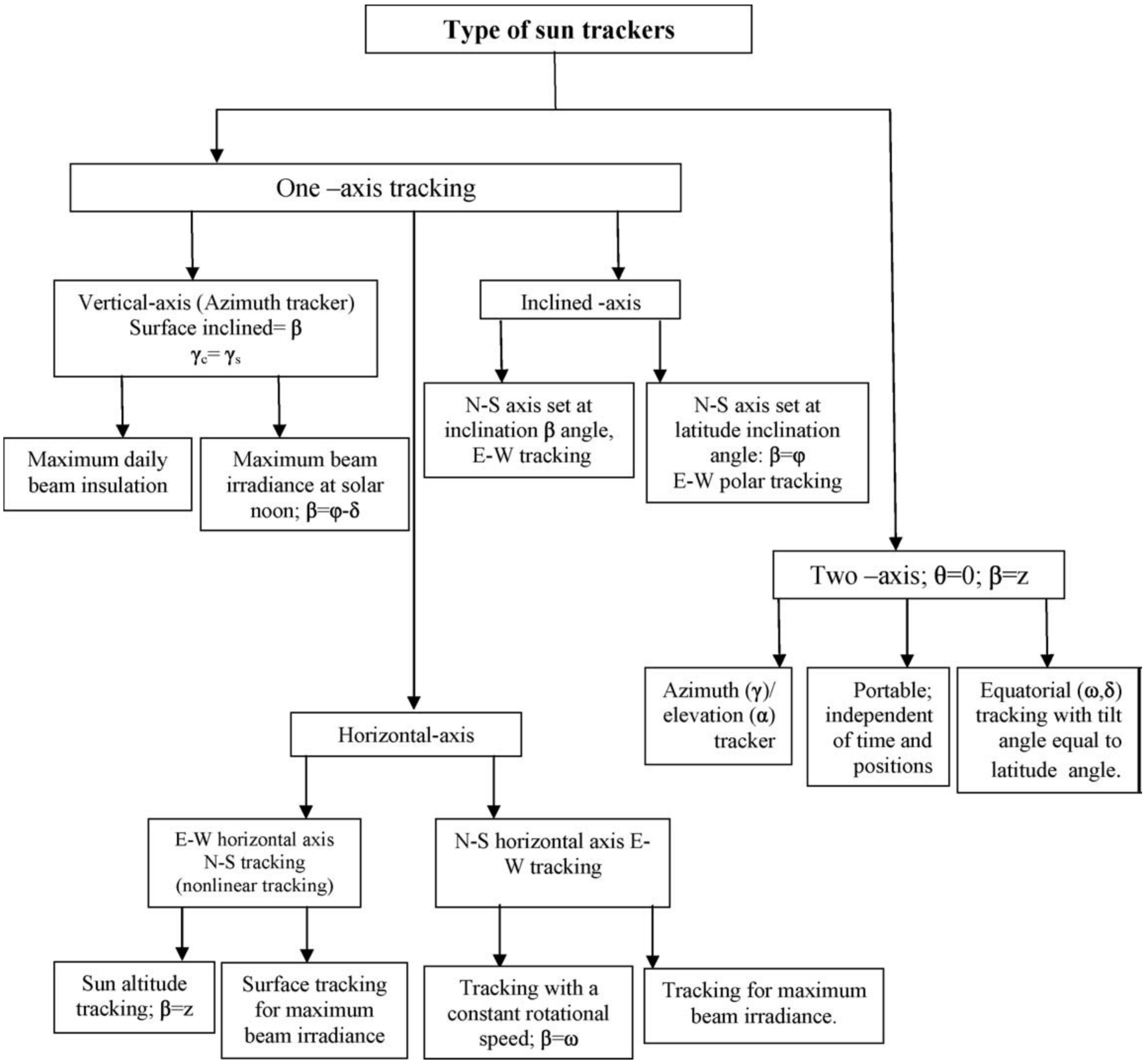

Figure 1. *Types of Sun Trackers.*

4. Conclusion and Recommendations

4.1. Conclusion

This paper has presented a review of different tracking mechanisms for sun tracking systems developed over the past 20 years. It has been shown that these sun tracking mechanisms can be broadly classified as either dual (two) axis or single (one) axis sun trackers, depending on their freedom degree of motion. The tracking mechanisms of each type have been reviewed and their performance discussed. Overall, the results presented in this review confirm the applicability of sun tracking system for a diverse range of high performance solar-based applications.

4.2. Recommendation

After the review of different tracking mechanisms of sun tracking system, the following recommendations have been drawn:

a) There is a need of another review that includes more papers on sun tracking system.
b) There is also need for design and construction of these types of trackers to test the efficiency of each.

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