Technologies of solar tracking systems: A review

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Abstract. Solar energy is abundantly in nature and sustainable energy resources around the world. The main challenge with the solar field is less amount of sun energy captured by photovoltaic (PV) systems. The great performance of the PV systems can be achieved if the panel is kept perpendicular to the direction of the radiations of sun. Hence, solar tracker system is the method to keep the optimum position of the PV panel for always perpendicular to the solar radiation. This paper aims to review on various technologies of solar tracking to determine the best PV panel orientation. The various types of technologies of solar tracking system have been discussed which includes passive solar tracker, active solar tracker and chronological tracker system. The movement degrees of solar tracking system also have been addressed which consisting single-axis solar tracking system and dual-axis solar tracking system. This paper is also overviews the tracking technique performance, construction, performance, advantages, and disadvantages of existing solar tracking system. The limitations of solar tracking systems are also highlighted for future action improvement. Through this research studies, the most favorable solar tracking system was identified as active solar tracker with the dual axis rotation.

1. Introduction
Nowadays, the concentration in using renewable energy instead fossil fuel has expanded throughout the world. Producing electric energy from renewable energy sources provides environmental protection and sustainability [1]. The solar energy is currently holds incredible promises for renewable energy to meet the world energy demand. Solar energy can be transformed into electricity in photovoltaic (PV) system using PV panels. However, energy generated from PV panels is related with atmospheric factors such solar radiation intensity, ambient temperature, wind speed and humidity [2]- [5]. Higher efficiency produced from PV panel will be generated when sunlight is perpendicular to the surface of the PV panel during the operation. This can be achieved by means of using a PV panel mount which tracks the movement of the sun throughout the day. Therefore, many investigations have been attempted to increase the efficient usability of PV panel using the solar tracking system [6]- [8].

In fixed PV panel operation, the tilt angle is location dependent. Instead of, using the solar tracking system, the PV panel can be keep in optimum position perpendicular to the solar radiation during daylight hours in order to increase the electrical energy generated. An ideal solar tracker would allow PV panel to align with the sun, compensating for both changes in the altitude angle of the sun and changes in the azimuth angle [9]. These both tracking angels depends on latitude and atmospheric conditions of the site location. The motion of tracking system could either be about one-degree freedom
(single axis tracker) and two-degree freedom (dual axis tracker). By using either single or dual axis, the tracking system can be classified into the three main type of their technologies, namely as passive solar tracker active solar tracker and chronological tracker system [10].

Over the years, the researchers had developed of solar tracking system with various designs to maximizes the energy production from PV panel. Many investigations have been attempted to improve the solar tracking performance using effective mechanical drives and efficient control systems. This study seeks to review different types of solar tracking systems considering their technologies to implement and drive the solar tracking systems. The rest of this review paper is organized as follows. The preliminaries study on solar tracking system in Section 2. The technologies of solar tracking system will be presented in Section 3 which divided into three parts. There is passive solar tracker, active solar tracker and chronological solar tracker. Then, the limitation of the solar tracker system will be discussed in Section 4 and the paper is concluded in Section 5.

2. Solar tracking systems

Solar tracking systems are mainly designed to keep the surface of the PV panel perpendicular to direction of the solar radiation beam. The solar tracking should be positioned that can achieve the optimum angle of incidence, thereby electrical energy produced by the PV panel can be maximized [11]. Solar irradiance, solar azimuth angle, elevation angle, inclination angle, declination angle and zenith angle are the important parameters that identify the best position of solar tracking system [12]. The most important angles in determining the position of the sun is altitude (elevation) and azimuth angle.

Solar irradiance can be determined by measuring either the power of the light sources or the luminous flux. Elevation ($\alpha_s$) and zenith ($\theta_z$) angles have close definition to the declination angle [13]. Declination angle ($\delta$) is the angle between equator and a line drawn from the centre of the sun to the centre of the earth. Meanwhile, elevation angle is the angle between solar radiation and the horizon. According to definition, an elevation can be calculated using the Eq. 1 [12].

$$\alpha_s = 90 - \theta_z$$  \hspace{1cm} (1)

Solar azimuth angle ($\gamma_s$) is the angle showing the tilt of the sun’s ray to the north in the direction of the clockwise. Meanwhile, surface azimuth angle ($\gamma$) is the angle showing the deviation of the vertical surface to the local longitude. Inclination angle ($\beta$) represents as the angle between the surface and horizon, positive value for the surface facing to the equator. Fig. 1 shows the diagram illustrating the solar angle. Moving solar tracking systems can be manually or automatically motion. In most of the cases, solar tracking system includes several considerations such one or two motors, different type of optical sensor and independent or auxiliary power supply. The classification of these aspects depends on various parameters including the force driving their moving fixtures and mode operation.

Figure 1. Solar angles in tracking sun position [12].
3. Categorization of solar trackers based on technologies

Solar tracker systems can be classified into three main categories based on the techniques that control the PV panel movement. It can be either passive, active or chronological tracker system [14].

3.1. Passive solar tracker

Passive solar trackers have capability to orient their sensing units towards the direction of the solar radiation beam without using any mechanical drives [15]. Most of these trackers consists a pair of actuators and filled with expansible gas or an on-shape memory alloy. This system utilizes the concept thermal expansion, or an imbalance in pressure between two points at the both ends of the tracker. When the PV panel is perpendicular with the sun, the two sides are at equilibrium. Once the sun moves, one side is heated and causes one side to expand and the other to contract, causing PV panel to rotate [16].

The first commercial passive solar tracking system was introduced by Zomeworks Corporationn in 1969. In Zomeworks Track Racks, the PV panel with tracking system can increase their electrical production output by 25% when compares with the fixed PV panel. Track Racks systems are highly cost-effective components for water pumping systems, industrial power systems, utility applications and cathodic protection systems [17]. In other work, Clifford and Eastwood introduced an economic passive solar tracker model mounted on a wooden frame, symmetrically on either side of a central horizontal axis. The movements of the system were activated by both aluminium/steel bimetallic strips and controlled by a viscous damper. Simulation results and real time measurements stated that more 23% energy gain by the proposed solar tracker when compares to a fixed PV panel [18].

Few years later, Narendrasinh et al. proposed a passive solar tracker system that has been implemented and tested using three types of gasses: thinner, acetone and methanol. The proposed solar tracker which working in the Zomework principle able to increase the power up to 23% when compared to the fixed PV system [19]. In the same year, Elmaged et al. evaluated the performance of solar pumping systems by installing the PV panels in two different modes. The first mode is fixed PV panel with its installation facing due to the South. Meanwhile, the other mode is the PV panel with passive solar tracker, which installed facing due to the South and inclined with the horizon. This passive solar tracker system was designed to be rotated from east to west throughout the day (daily movement). The results illustrate that when using the passive solar tracker system, the incidence of solar radiation and accumulated power can be increased by 14% and 16%, respectively [20].

Using the passive solar tracker system, the operation is less complex, most of them have a pair of actuators, filled with expansible gas or an on-shape memory alloy, working against each other and balanced by equal illumination [21]. However, this method of sun tracking is low in accuracy and relies mainly on weather conditions of the site location. The selected location for solar tracker installation is very crucial because the location must attain adequate continuous sunlight for an efficient heating process. The type of active solar tracker system can solve the problem of using passive solar trackers.

3.2. Active solar tracker

Active solar tracking system determines the position of the sun during the day with existing of the sensors, continuously [22]. Sensor will trigger the motor or actuator to move their fixture following the solar radiation. If the sunlight not perpendicular to the tracker, then there will be a different illumination on one light sensor compared to another. This difference can be used to determine the direction in which tracker has to be directed in order to be perpendicular to the sun [23]. Active solar trackers are further categorized in four categories based on their tracking strategies. There are microprocessors and electro-optical sensor, based on date and time, based on auxiliary bifacial PV cells as well as the combination of the three types above [24]. This paper is focused on the movement technologies of the solar tracker. The number of the axis that is commonly used to move the PV panels is the most crucial factor for all solar trackers system. Currently, the solar trackers are categorized into two main groups based on their movement technologies which are single-axis trackers system and dual-axis trackers system.
### 3.2.1. Active solar tracker with single-axis system

A single-axis tracker system provides only one degree of freedom which acts as the axis of rotation [25]. The single-axis tracking system is the simplest tracker, they usually use less energy and have minor complexity than a multi-axis system [26]. In 2012, Deb et al. proposed a solar tracker system with two sensors to measure the temperature in eastern and western locations. By using the LABVIEW, the authors calculate the light intensity with the data of the temperature collected. The movement direction of the solar tracker system through a stepper motor directly was determined when there is a difference between one direction of the light intensity into the other direction [27]. Kamala et al. designed a single-axis solar tracking driven by a PIC microcontroller to maximize energy harvesting. The two PV panels are arranged in the form of a triangle located opposite of each other. Two levels of the threshold are implemented to drive the PV panel movement. The first threshold is designed to activate tracking and indicate the availability of solar power. Meanwhile, the second threshold is utilized to switch off the peripherals during the cloudy or rainy weather condition for a long period. The authors have designed the economic system but facing with the problem when the system stops operate after sunset. It is due to the PV panel needs to be positioned back to east side for the next tracking day [28].

Recently, Dian et al. proposed and designed a GPS-based solar tracker system, that can move the vertical solar still follow the azimuth angle of the sun. They compare the power of 2 solar cells placed in different positions. The first solar cell was located upright and rotated with the solar tracker system. Meanwhile, the second solar cell was located fixed horizontally. The results show that the first solar cell generates about 22% larger than second solar cell in term of average output power. Besides that, the authors also state that solar tracking systems become faster with the use of GPS and astronomical calculations [29]. After a year, Sebastián and Pedro carried out two very simple tracking strategies, North-South horizontal single-axis tracker for latitudes up to 50°. In this study, they change the tracker positions considering 2 positions in morning/afternoon or 3 positions in morning/noon/afternoon at pre-defined daily schedules. Results indicate that the 3 position tracker can provide significant energy gains with respect to fixed photovoltaic system with the high percentage for annual irradiation gains [30].

### 3.2.2. Active solar tracker with dual-axis system

The earth follows a complex motion that consists of two motions which are the daily motion and the annual motion. The daily motion causes the sun to appear in the east to the west direction over the earth. Meanwhile, for the annual motion, the sun to tilt at particular angle while moving along east to west direction [31]. Therefore, extensive research has been conducted to improve the efficiency and promote the use of dual axis solar tracker. In a dual axis solar tracker, there are two degrees of freedom which act as axes of rotation. There are two variants of dual axis tracking systems namely as a polar-altitude and azimuth-altitude [10]. These solar tracking systems usually consisting of four Light Dependent Resistors (LDRs), two motors and a controller [32].

Chabuk et al. proposed a dual-axis solar tracking system based on microcontroller principle working. By using an algorithm, the microcontroller used to determine the positions and directions of the PV panel. Meanwhile, the best angle was obtained using a real time clock microcontroller then has been feed directly to the stepper motor for PV panel movement. The proposed system does not rely on the clearness of the sky or the position of the sun, thereby able to work even in bad weather. The results generated by this system are more efficient when compared to the single axis and fixed panels [33]. Fathabadi develop a novel offline sensorless dual-axis tracker with high accuracy for tracking the sun position. The simple structure with low cost tracker consists of a controller, stepper motors for adjusting altitude angle and azimuth angle and gear box that function to rotate the PV panel. This proposed solar tracker also used offline data without any feedback signal. Therefore, the solar tracker is robust to external disturbances. The experimental results verified that 24.59% more solar energy is captured during one year with the existing solar tracker [6].

Sebastian et al. proposed a dual-axis tracking system which able to move either horizontally or vertically based the selected zenith and azimuth angles. The LDRs were used to determine the position and direction of the PV panel to trigger the DC motor. The performance of the proposed system was
compared with the fixed PV panel under a few selected sunny days. The results show that the output energy of the dual-axis tracker can be improved by 27% when compared to the fixed PV panel [34]. In the similar year published, Sidek et al. introduced a dual-axis tracking system that implement the sun trajectory path algorithm to identify the solar tracker’s position. The proposed system uses the GPS sensor to identify the best position of the PV panel referring to the longitude and latitude lines. Meanwhile, the azimuth and altitude angle are utilized to directly feed the positioning controller which leads the motors to move either clockwise or counter clockwise. The results indicated that in clear and cloudy sky conditions, more 26.9% and 12.8% energy output can be generated by the proposed system when compared to the fixed PV panels [35].

Rashid et al. design built and tested a hybrid dual-solar tracking system. This working operation of the solar tracker is based on the solar map combining with the light sensor based continuous tracking mechanism. The light sensors used to compare the darkness, cloudy and sunny conditions for daily tracking. Meanwhile, a real time clock device was required by the electrical controlling device to track the sun’s apparent position at different months and seasons. The capability of this proposed hybrid solar tracker was compared with a static and continuous solar tracking systems. Results revealed the power saved in system operation by the hybrid solar tracking is 44.44% more when compared to the continuous tracking system even though their power gain is almost similar [31]. Sathis designed a dual-axis solar tracking system that can maximize the incident of the sun through the PV panel. This system used the LDRs reading to determine the direction of the PV panel through microcontroller. The Op-Amp comparator is used to collect the readings of the LDRs for operating microcontroller. In this proposed system, the drive and stepper motors are used to move the PV panel from one side to another side. The results were evaluated by comparing the performance between the proposed system and the fixed PV system. Results indicate that the output power can be increased by 40% and 45% for fixed and dual-axis tracking system, respectively [36].

Masoud et al. combined a dual-axis tracking system with a wind-tracking system. The wind-tracking system acts as an auxiliary system, which complements the dual-axis tracking in case of windy conditions. By using this proposed system, the power generation has been increased throughout the experimental study. The conventional dual-axis tracking system presents an increase of 39.43% in total daily collection over a fixed PV system meanwhile, the hybrid tracking system yielded an increase of 49.83% [37]. In order to improve the operation of the solar tracking system, Arlikar et al. proposed a three-dimensional solar tracker system with a special arrangement of LDRs. A PLC is used to control the position of the solar tracker system with the existing of LDRs. Meanwhile, the PV panel is fixed and reflectors are used in order to maximize the incident light intensity. The two stepper motors are used for three-dimensional tracking, one to move the plane of the PV panel and the other will move this plane in a third dimension. The results identified that the three-dimensional PV panel produces more energy than a traditional PV panel [38].

Bentaher et al. develop a simple tracking system based on LDRs working principle. A mechanism of PV and parabolic concentrator with dual-axis movement was taken into consideration to identify the difference of the LDRs against its direction towards the sun. The DC motors are used to actuate and move the two axis as well as control the movement of the two axis by the two angular sensors [39]. Juang et al. designed and built a dual-axis solar tracking system to maximize irradiance and limit the battery voltage consumption. This proposed system consisting microcontrollers, LDRs, actuators, an Arduino Uno R3, and a Pololu Dual Motor Shield. The linear actuators are adjusted when the absolute value of the calculated difference is greater than the dead band value provided by LDRs. The proposed system implemented for real-time responsiveness, and the increase efficiency of the output power at least between 15% and 20% [40].

Yao et al. used two automatic tracking strategies for their dual-axis tracking system. The first type was the normal tracking strategy and the other was a daily adjustment strategy. A hybrid strategy involving time-based control as well as sensor-based control was used in this proposed system. The solar tracker was designed to reach a calculated position based on the local time while the sun position sensor would provide a feedback to correct the tracking error. For flat PV systems, a simple daily adjustment
strategy was employed since a high degree of accuracy is not necessary [41]. Assaf develop a dual axis solar tracking system to measure accumulate solar radiation. The proposed system consists of four LDRs, a programmable logic controller (PLC) device and two servo motors. The function of LDRs as usual to identify the sun position, thereby provide a voltage signal to the PLC. The Soft Comfort V6.1 software was used to develop the control software in order to identify the optimum PV panel’s position during daylight. The proposed solar tracking system was tested and implemented for the duration of three days. The results show that the accumulated solar radiation hen using the two-axis tracking system was higher than the solar radiation collected using the fixed PV system [42].

H.S. Akbar et al. proposed the dual-axis solar tracker to track the to track the position of the sun in both azimuth and altitude axis. A tracker system consists mainly of the ATmega 328 controller, DC motors, LDRs sensor and relays. The authors also studied on the effect of temperature and panel covering by colored cellophane on the performance of the tracker system. The results indicated that the production output power for single axis solar tracker and dual axis solar tracker are 24.05% and 26.22%, respectively higher energy than fixed PV panel [43]. El Hammoumi et al. designed and implemented the low cost of an active dual-axis solar tracker. Two servo motors facing the highest intensity of sunlight captured by four units of LDRs sensors used to track the sun’s movement. In order to minimize the cost, ATMega328 microcontroller which is integrated into a low-cost board, Arduino Uno was implemented for this proposed system. The results were evaluated by comparing the performance between the energy produced by the proposed tracker and a fixed PV panel. By using an active dual-axis solar tracker, more 36.36% energy was produced when compared to the fixed PV panel [44].

3.3. Chronological solar tracker
A chronological solar tracking system is a time-based tracking system where the structure is moved at a fixed rate and angle throughout the day as well for different months. Therefore, the motor or actuator is controlled to rotate at a slow average rate of one revolution per day (15° per hour) [31]. This method of sun tracking is more energy efficient because no energy losses at this tracking calibration due to low tracking error. Roong and Chong using the chronological method with angle of rotation 15° per hour for single axis solar tracking system. The solar tracking system plant with the total surface area is around 70m² was constructed in University Teknikal Malaysia Melaka (UTeM). The experiments started from 8:00 a.m. to 3:00 p.m. throughout a day for duration of 5 days with the fixed angle rotation of the solar tracker with 15° per hour [45].

Sidede et al. presents the dual axis solar tracking system using electronic control system. The working principle of the algorithm for the proposed method is based on the GPS and astronomical equation. Furthermore, the microcontroller based tracking system embedded with a PID controller. By using SolidWorks, the biaxial solar tracker structure was designed. The power generated between two systems fixed-tilted PV panel and the solar tracker system were compared with each other in order to evaluate the performance of the solar tracer system [46]. A single-axis solar tracking system was designed by Samantha et al. to maximize the efficiency of PV cells. By following the working principle of chronological solar tracking system, allow the PV panel to track the position of the sun with the assistance of a motor controlled by a microcontroller. In order to identify the position of the sun, a PIC18252 microcontroller is connected to an L293D motor driver thereby the PV panel can be moved to the desired directions. The maximum-intensity of solar energy can be produced when the rays of the sun is perpendicular to the surface of the PV panel [47].

4. Limitations of solar tracking system
As for passive and active tracker differ with way of deploying the design trade off. Passive tracking system require virtually no extra power supply because this system works alone with the solar radiation. This tracking technology is less complex and economic, the construction developed without any electronic controls or motors. However, it is low in accuracy and relies mainly on the weather conditions. Lower energy has been produced by this tracking system when compared to the active tracker system. Moreover, this technology of the solar tracker cannot be favourite for the regions hit by the extreme cold
weathers because they easily stop working at very low temperatures. Therefore, they have not yet been widely accepted on their application and a few bit literature available about this type of technologies of solar tracking system. Meanwhile, the active tracking is based on accuracy while there is consumption of generated energy. This technology of sun tracking is reasonably accurate except on very cloudy days. It is because the sensors facing the problem in determining the position of the sun in the sky. In addition, the active solar tracking system are more accurate and frequently used, but they require the extra power used for sensors, microcontroller or motors. For the chronological tracking system, the continuous rotation of the motor or actuators leads the system used more power consumption. Besides, this system also unnecessary when operate under the very cloudy day.

By considering the movement degree of freedom in solar tracking system, the single-axis solar tracker is the simplicity when compared to the dual axis rotation. In addition, the single-axis solar tracker used lower cost and energy consumption since this system only use one motor for tracking the sun horizontally or vertically. However, this system can only track the sun during the daily movement and not the yearly movement. In addition, the efficiency of the tracking system is reduced by a large amount due to the rotation around only single-axis caused by the cloudy days. Although single-axis solar tracker is less complexity construction, but their efficiency is lower than that of dual-axis solar tracker. The main advantage of using dual-axis tracking in comparison with single one is tracking the sun movement not only during the day, but also for the yearly movement. Although dual-axis solar tracker is more expensive construction, they deliver efficient performance when compared to the single axis solar tracker. Table 1 conclude the operation, advantages and disadvantages for each type of technologies for solar tracking system.

### Table 1. Passive, active and chronological solar tracker

| Technology     | Descriptions                                                                 | Advantages                                      | Disadvantages                                      |
|----------------|------------------------------------------------------------------------------|-------------------------------------------------|--------------------------------------------------|
| Passive        | - Thermal expansion in material or imbalance in pressure between two points at the both end of tracker. | - work without using motors or actuators        | - strong dependence on weather conditions         |
|                |                                                                               | - easy installation                             | - low in accuracy                                  |
|                |                                                                               | - low maintenance cost                          |                                                  |
| Active         | - use sensors and motors                                                     | - more accurate                                 | - require the extra power consumption             |
|                |                                                                               | - efficient in tracking the position of the sun  | - not very accurate under cloudy day              |
| Chronological  | - timed based tracking system                                                | - no energy losses                               | - continuous rotation requires more energy        |
|                | - rotate at 15° per hour                                                      | - low tracking error                             | - unnecessary work under cloudy day              |

### 5. Conclusion

In conclude, the power generated and efficiency of the PV panel could be improved with the existing of the solar tracker systems. This work present and categorize different types of solar tracking systems based on their technologies and degree movement of rotation. Active solar tracking systems use sensors and motors to track the position of the sun and control PV panel’s position. Meanwhile, the passive tracking systems use a low-boiling-point compressed gas fluid that originates from solar heat. Available previous literature introduced the various performance components, use of controller, system efficiency and tracking control strategies. The review reveals that the active trackers were more commonly used in PV panel application as compared to passive trackers. The conclusion from the literature review that active solar tracker with dual-axis system are vital for implementation to PV system with maximum efficiency gained.
References

[1] Yasser M. Safan, S. Shaaban and Mohamed I. Abu El-Sebah 2018 Performance evaluation of a multi-degree of freedom hybrid controlled axis solar tracking system, Solar Energy vol. 170 pp 576-585

[2] Swapnil D., Jatin N S and Bharath S. 2013 Temperature dependent photovoltaic (PV) efficiency and its effect on pv production in the world- A review, Energy Procedia vol. 33 pp 311-321

[3] W.Z. Leow, Y.M. Irwan, M. Asri, M. Irwanto1, A.R. Amelia, Z. Syafiqah and I. Safwati 2016 Investigation of solar panel performance based on different wind velocity using ANSYS, Indonesian Journal of Electrical Engineering and Computer Science, vol. 1 pp 456-463

[4] Chegaar, M., Hamzaoui, A., Namoda, A., Petit, P., Aillerie, M., and Herguth, A. 2013 Effect of illumination intensity on solar cells parameters, Energy Procedia vol. 36 pp 722-729

[5] W.Z. Leow, Y.M. Irwan, M. Isa, A.R. Amelia and I. Safwati 2016 Temperature Distribution of Three-Dimensional Photovoltaic Panel by Using Finite Element Simulation, International Journal on Advanced Science, Engineering and Information Technology vol. 6 pp 607-612

[6] Hassan Fathabadi 2016 Novel high efficient offline sensorless dual-axis solar tracker or using in photovoltaic systems and solar concentrators, Renewable Energy vol.95 pp 485-494

[7] W. Batayneh, A. Owais and M. Nairoukh 2013 An intelligent fuzzy based tracking controller for a dual-axis solar PV system, Automation in Construction vol. 29 pp 100-106

[8] Nadir Barsoum 2011 Fabrication of Dual-Axis Solar Tracking Controller Project, Intelligent of dual-axis solar tracking controller project vol. 2 pp 57-68

[9] C.S. Chin, A. Babu and W. McBride 2011 Design, modelling and testing of a single axis active tracker using MATLAB/Simulink, Renewable Energy vol.36 pp 3075-3090

[10] R. Singh, S. Kumar, A. Gehlot and R. Pachauri 2018 An imperative role of sun tracker in photovoltaic technology: A review, Renewable and Sustainable Energy Reviews vol. 82 pp. 3263-3278

[11] Adarsh S., Abhishek Anand and Jayant Singla 2015 Increasing the efficiency of a PV system using dual axis solar tracking, Proceedings of 11th IRF International Conference pp. 37-41

[12] S. Yilmaz, H.R. Ozcalik, O. Dogmus, F. Dincir, O. Akgol and M. Karaaslan 2015 Design of two axes sun tracking controller with analytically solar radiation calculations, Renewable and Sustainable Energy Reviews vol 43 pp. 997-1005

[13] Nadia Al-Roslan, Nor Ashidi Mat Isa and Mohd Khairunaz Mat Desa 2018 Advances in solar photovoltaic tracking system: A review, Renewable and Sustainable Energy Reviews vol. 82 pp. 2548-2569

[14] Dhanabal. R, Bharathi.V, Ranjitha. R, Ponni. A, Deepthi. S, Mageshkannan. P 2013 Comparison of Efficiencies of Solar Tracker systems with static panel SingleAxis Tracking System and Dual-Axis Tracking System with Fixed Mount International Journal of Engineering and Technology (IJET), vol.5 no. 2 pp. 1925-1933

[15] J. Ya’u Muhammad, M. Tajudeen Jimoh, I. Baba Kyari, M. Abdullahi Gele, and Ibrahim Musa 2019 A review on solar tracking system: a technique of solar power output enhancement, Engineering Science, vol. 41, pp 1-11

[16] R.S. Zulkafli, A.S. Bawazir, N.A. M.Amin, M.S.M. Hashim, M.S.A. Majid and N.F.M. Nasir 2018 Dual axis solar tracking system in Perlis, Malaysia, Journal of Telecommunication, Electronic and Computer Engineering vol. 10 pp 91-94

[17] M.S. Sabry and B.W. Raiiche, 2014 Characteristics of residential tracker accuracy in quantified direct beam irradiance and global horizontal irradiance, Journal of Technology Innovations in Renewable Energy vol. 3 pp 44-57

[18] Clifford MJ and Eastwood D. 2004 Design a novel passive solar tracker, Solar Energy vol.77 pp 269-280

[19] Narendrasinh J, Parmar ANP and Gautam Vinod S. Passive solar tracking system. International Journal Emerging Technology and Advanced Engineering vol.5
Elmaged A, and Kamal H 2015, Passive solar tracking system.

S. Degeratu, S. Rizescu, L. Alboteanu, C. Caramida, P. Rotaru, I. Boncea and C. Iancu 2014 Using a shape memory alloy spring actuator to increase the performance of solar tracking system, Annals of the University of Craiova, Electrical Engineering series no. 38 pp 116-121

A. Razif Hamid, A. Khusairi Azim and M. Hafizuddin Bakar 2017 A review on solar tracking system, e Proceeding National Innovation and Invention Competition Through Exhibition (iCompEx’17), pp 1-9

W. Indrasari, R. Fahdiran, E. Budi, L. Jannah, L. Kadarwati, Ramli 2018 Active solar tracker based on the horizon coordinate system, The 8th International Conference on Theoretical and Applied Physics, pp 1-6

V. Sumathi, R. Jayapragash, Abhinav Bakshi and Praveen Kumar Akella 2017 Solar tracking methods to maximize PV system output – A review of the methods adopted in recent decade, Renewable and Sustainable Energy Reviews, vol 74 pp. 130-138

M. Salaheldin Elsherbiny, Dr. Wagdy R. Anis, Dr. Ismail M. Hafez and Dr. AdelR. Mikhail 2017 Design of single-axis and dual-axis solar tracking systems protected against high wind speeds, International Journal of Scientific & Technology Research, vol.6 iss 9 pp 85-89

Deb G and Roy AB 2012 Use of solar tracking system for extracting solar energy, International Journal Computer Electrical Engineering, vol.4 pp 42-46

Kamala J and Joseph A. 2014 Solar tracking for maximum and economic energy harvesting, International Journal Engineering Technology, vol.5 pp 5030-5037

Dian Artanto, A. Prasetyadi, D. Purwadianta and Rusdi Sambada 2016 Design of a GPS-based solar tracker system for a vertical solar still, International Conference on Smart Green Technology in Electrical and Information Systems (ICGTEIS), pp 140-143

Sebastián Gutiérrez and Pedro M. Rodrigo 2017 Energetic analysis of simplified 2-position and 3-position North-South horizontal single-axis sun tracking concepts, Solar Energy, vol. 157, pp 244-250

R.A. Ferdaus, M. AsifMohammed, S. Rahman, S. Salehin and M.A. Manan 2014 Energy efficient hybrid dual axis solar tracking system, Journal of Renewable Energy, vol. 2014 pp 1-12

Jing-Min Wang and Chia-Liang Lu 2013 Design and implementation of a sun tracker with a dual-axis single motor for an optical sensor-based photovoltaic system, Sensors, vol. 13, pp 3157-3168

A. Chabuk, A. Shinde, M. Narale, P. Gonjari and Prof. Mr. P. S.Magdum 2017 Dual axis solar tracking system using microcontroller, International Research Journal of Engineering and Technology (IRJET), vol. 4 pp 796-800

Sebastian Seme, Gregor Srpčič, Domen Kavšek, Stane Božičnik, Tomislav Letnik, Zdravko Praunseis, Bojan Štumberger and Miralem Hadžiselimović 2017 Dual-axis photovoltaic tracking system- Design and experimental investigation, Energy, vol. 139 pp 1267-1274

M.H.M. Sidek, N. Azis, W.Z.W. Hasan, M.Z.A.Abd Kadir, S. Shafie and M.A.M. Radzi 2017 Automated positioning dual-axis solar tracking system with precision elevation and azimuth angle control, Energy, vol. 124 pp 160-170

Sathis and Vatumalai 2016 Arduino based solar tracking system, Faculty of Manufacturing Engineering, University Malaysia Pahang

R Masoud, B Meisam, T Yaghoub and Valeh-e-Shyda Peyvand 2015 An insight on advantage of hybrid sun–wind-tracking over sun-tracking PV system. Energy Conversion Management, vol.105 pp 294–302.

A Pratik, B Abhijit, P Manoj and D Amruta 2015 Three dimensional solar tracker with unique sensor arrangement, In: Proceedings of the international conference on smart technologies and management for computing, communication, controls, energy and materials (ICSTM). pp 509–513
[39] Bentaher H, Kaich H, Ayadi N, Ben Hmouda M, Maalej A and Lemmer U. 2014 A simple tracking system to monitor solar PV panels, *Energy Conversion Management*, vol. 78 pp 872-875

[40] Juang J-N, and Radharamanan R. 2014 Design of a solar tracking system for renewable energy, *In: Proceedings of Zone 1 Conference of the American Society for Engineering Education (ASEE Zone 1)*

[41] Yao Yingxue, Hu Yegua, Gao Shengdong, Yang Gang and Jinguang Du 2014 A multipurpose dual-axis solar tracker with two tracking strategies. *Renewable Energy*, vol. 72 pp 88–98.

[42] Assaf EM 2014 Design and implementation of a two axis solar tracking system using plc techniques by an inexpensive method. *International Journal Academic Science Research*, vol. 2, pp 54–65

[43] Akbar HS, Siddiq AI and Aziz MW 2017 Microcontroller based dual axis sun tracking system for maximum solar energy generation. *American Journal Energy*, vol. 5 pp 23–27.

[44] A.El Hammoumi, S. Motahhir, A.El Ghzizal, A. Chalh and A. Derouich 2018 A simple and low-cost active dual- axis solar tracker, *Energy Science & Engineering*, vol. 6 pp 607–620

[45] Roong ASC and Chong S-H. 2016 Laboratory-scale single axis solar tracking system: Design and implementation, *International Journal Power Electronic Drive System* vol. 7 pp 254–264

[46] M.H.M Sidek, W.Z.W Hasan, M.Z.A.Ab. Kadir, S. Shafie, M.A.M. Radzi, S.A. Ahmad and M.H. Marhaban 2014 GPS based portable dual-axis solar tracking system using astronomical equation. *IEEE International Conference Power Energy*, pp 245–249

[47] Arnab Samanta, Rachit Varma and Shrikant Bhatt 2015 Chronological single axis solar tracker, *International Journal of Engineering Trends and Technology (IJETT)*, vol. 21 pp 204-207