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2018 5th International Conference on Electrical Engineering, Computer Science and Informatics

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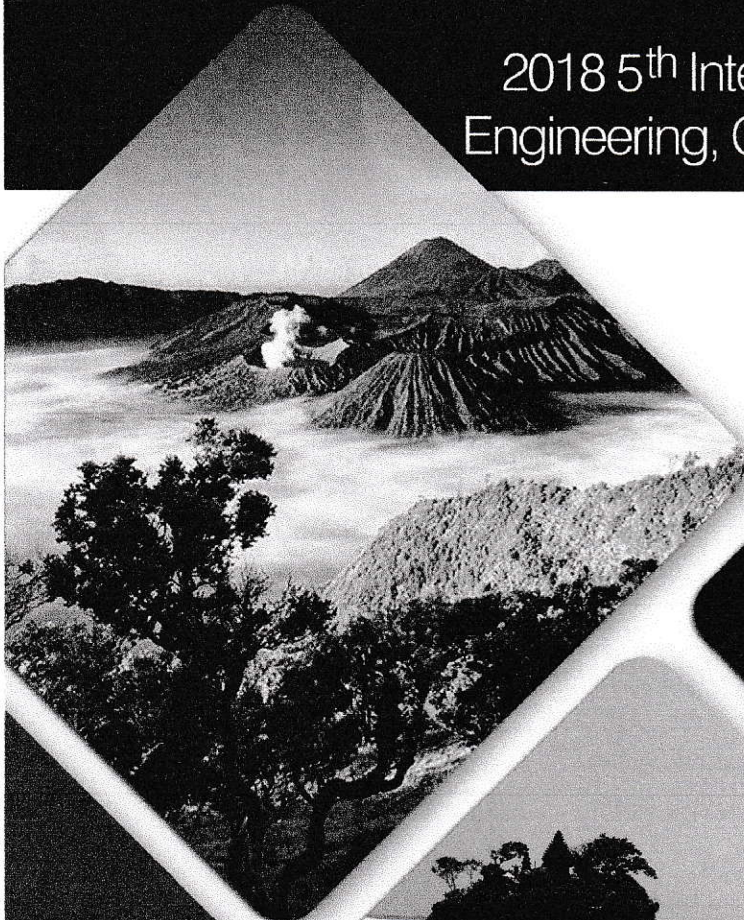

October 16 - 18, 2018

Ijen Suites Resort & Convention
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EECSI 2018 CONFERENCE
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A Riview of Solar Tracking Control Strategies

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***Abstract*—This paper presents the use of sunlight trackers to increase the efficiency of solar panels. The sunlight tracking is done by passive and active tracking method with one or two axis. The active trackers use an electrical motor as a driver and can be controlled by a microcontroller or a programable logic controller (PLC) according to the direction of sunlight. The use of this controller in sunlight tracking system performed in real time or periodically. The position of the sun as a controller input can be obtained based on azimuth angle and solar elevation angle or by direct measurement using sensors. From the discussion is obtained an increase of efficiency of 29.37% in avarage using the active tracker.**

Keywords*— *solar cell, tracker, microcontroller, programable logic controller

I. INTRODUCTION

The depletion of fossil energy sources and the ever-increasing demand for energy have prompted intensive research for the development of renewable energy source that is more efficient and green energy sources. Some renewable energy sources such as wind, micro-hydro, geothermal, biomass, biogas and diesel fuel are used as stand-alone electrical energy sources or interconnected through electricity networks. Solar energy, i.e the sunlight and heat energy has been exploited by humans for a long time by using various technologies ranging from simple to sophisticated. This is due to the fact that the sun as a source of energy can generate more amount of the power until 27.000 times bigger compare to the other sources[1]. The current technology enables to convert the solar radiation into electrical energy known as photovoltaic systems. This conversion system is expected to make a significant contribution which sholved some of the energy problems facing the world today.

The energy conversion efficiency especially in photovoltaic systems is an interesting issue, since the system has a low overall efficiency of less than 20% [2]. The overall increased efficiency of solar panels can be done by maximizing power output, increasing cell efficiency, and implementing a tracking system [3]. The efficiency is also affected by weather conditions, irradiation and temperature levels. For example, clouds that pass through some solar cells or sub-modules will reduce the total output power of the PV arrangement [4].

The use of large-scale PV systems depends on the cost and efficiency of energy conversion. Based on the latest technological developments, the utilization of PV tracking system is an optimal choice to improve system efficiency and to reduce costs.

II. SUN TRACKING METHODES

The amount of energy absorbed by the solar panel can be increased through the implementation of a solar tracking system. The sunlight tracking system can be installed by using one or two axis. Actually, the two-axis trackers are most efficient to use but it can increase more complexity. It can be the best choice for locations where the position of the sun continues to change throughout the year in different seasons. While, one axis tracker can be a good solution for places located around the equator that have no significant changes in the sun's position throughout the year [5]. The use of a tracking system will allow PV cells to lead to the sun accurately, which is able to compensate for changes in the height of the sun (throughout the day), to latitude of the sun (during seasonal changes) and to change in azimuth angle. The sun tracking systems using either two axes or one axis can be categorized into two classifications, i.e. passive (mechanical)and active (electrical) tracking methods [6].

A. Passive (Mechanical) Tracking

The passive trackers work on the principle of thermal expansion. The utilization of solar heat will cause an imbalance in the tracker, so that the movement of the tracer will arise. The level of complexity of passive trackers is lower when compared to the active trackers, but fails to provide high efficiency at low temperatures. In the tropical region with plenty of sunlight available throughout the year and small variations in azimuth angle, it is possible to develop Passive (mechanical) Tracking [7]. In addition, the use of passive tracking fits perfectly with the slow sun movement so as to avoid oscillatory motion [6]. In terms of performance shows that passive trackers can improve PV efficiency and are cheaper in terms of cost, but not widely used by consumers.

Poulek, designed a low-cost passive tracker with one axis using SMA (Shape Memory Alloy). The materials used in the test are NiTi, CuZnAl and CuAlNi, carried out at a short time following the movement of the sun starting at an angle of 60^0. The results of the study obtained that this tracker works very well in short testing periods and there is an increase in efficiency of about 2% [8]. However, this tracker design obey to the effect of gear transmission (the self-locking transmission) and cannot be used at an angle position of less than 60^0.

Mwithiga et al., has designed and tested a dryer with limited sunlight tracking capability that is manually operated. The drying unit is installed, so that it can face east-west. A disc is used as a position tilt angle regulator with a minimum multiplication of 150. This position would let the collecting plate to be adjusted appropritately to trace the sun during the day. The sun tracking is made with four settings, Dryer is set at 45^0 to horizontal angle facing east at 8:00 AM. The data was collected by empty drying and coffee dryers. The results showed that the proccess to dry the coffee beans took 2 until 3 days compared to the drying process without using a tracking system, which took 5 until 7 days. Moreover, the temperature in the room could increased up to the maximum value which is 70.4^0C [9].

Noel Leon et al, conducted a research on Semi-Passive Solar Tracking Concentrator (SPSTC) which aggregated the sunlight with minimum mechanical effort and slight movement. This system consists of Micro-heliostat, Fresnel lens and receiver which is a mirror arrangement positioned above the Fresnel lens. The Micro-heliostat serves to reflect sunlight toward the lens by tracing the path of the sun based on the angle of altitude and azimuth. The test is done by determining the three values of the slope angle with the aim of getting the value of effectiveness on the Fresnel lens and can reduce the influence of blocking and shading on the receiver, so that the amount of solar energy received can be maximized. In this study the effectiveness of Fresnel lenses can still be improved by taking into account the factor of the distance between Micro-heliostat, the number of Micro-heliostat and the slope of the array [10].

Clifford et al., designed a new passive solar tracker modeled by using the computer. This model combines two bimetal strips made from aluminum and steel which is located on a wooden frame, symmetrically on both sides of the horizontal axis. While, the open biometallic strip gets hotter, aluminum is more bending than steel because its thermal expansion coefficient is higher. This bending will cause maximum deflection at the midpoint of the strip, the unbalanced moment and the resulting movement. Then they compared the results obtained from computer models and experiment from bimetal strip deflection due to the effects of thermal radiation. They also observed the required time for solar trackers to accomplish reorientation of the east-west. Both results are similar to each other. The designed solar trackers have potential to increase the efficiency of solar panels until 23%. They also recommend multiple axis system mechanisms for future development [11].

B. *Active (electrical) Tracking*

The Active Solar Trackers use motors and gear mechanisms as electric actuators to move PV positions. These motors are usually given input by the control signal in the form of the magnitude and direction of tracking to be carried out. The controlling of motor drive can be done by using microcontroller and Programable logic controller (PLC) based on sensor or data which is already available.

Active trackers are claimed to be more accurate and more frequently used and higher efficiency improvements compared to passive trackers [12]. Yet, this tracker requires power and energy consumption.

1) One-Axis System with Microcontroler

The one-axis system in active tracker has a one-degree freedom movement on the axis rotation, this will make the energy consumption lower than the multi-axis system.

Huang et al., created a three-axis position for tracking system (1S-3P) on the roof of the building. The tracking of sunlight in 1S-3P operation is designed only for three different angles. This tracker, consisting of a simple structure design and a Photovoltage (PV) dc rotator motor. The use of this tracker can increase the generated power by 23.6% compared to conventional tracking systems. The measurement of tracker movement, PV generated power and control algorithm is done by using PICI8F452 microcontroller [13].

J. Beltrán A et al., designed a one-axis sunlight tracking system using two PV modules mounted on a symmetrical structure with a central axis by using a microcontroller as an embedded control system. This sensorless type of tracker operates as an open loop electronic control system. The Tracker control system is oriented to the position of the sun based on the angle of elevation or the sun's inclination to the plane and the angle of the daily movement of the sun or azimuth angle. This tracking system can increase 26% power gain for 8 working hours. This tracker is said to have advantages over closed-loop sensor types, which are not limited by geographic location tracking, this is because the system has been designed and programmed by providing azimuth angle during the day to obtain maximum solar radiation [14].

Tracker with one axis has also been done Priyanjan et al. Trackers designed using a microcontroller as a system control center, from the tests performed, obtained the average value of power generated 13% larger than the fixed position [15].

Abadi. I et al.. created and implemented a single axis solar tracking system oriented to the intensity of solar radiation and ambient temperature. The whole system is controlled by a microcontroller as a main control unit and it worked based on the Fuzzy Logic Controller (FLC). The experimental mechanism is based on a DC motor controlled intelligently by a fuzzy logic controller that drives the prototype according to the input received from the LDR sensor. The tracking system performance was carried out experimentally by comparing the output of energy resulted from two different systems (tracking vs. fixed PV panels), the location of data collection is established in Surabaya - Indonesia. The results showed that the output of energy was increased up to 47 % compared to the fixed system [16].

Adel Abdulrahman et al, designed a single axis sunlight by developing an electromechanical system. The main purpose of this design is to model and create an automatic solar tracking system using an Arduino microcontroller, four LDRs to find the light intensity and two PMDC motors for horizontal and vertical movements. The mechanical component design is focused on static analysis of all parts of the system, such as forces that affect the balance of the tracking system and the calculation of the torque needed to lift the solar panels in the horizontal and vertical axes. In addition, static analysis also considers the wind effect on solar panels. The efficiency of this design is better than fixed PV cells, based on the results of the tests that have been done there is an increase of about 31%. Yet, this can still be improved by paying more attention to the accuracy of the sensor position [17].

Md. Tanvir Arafat Khan, designed and built a prototype microcontroller based on an automatic tracking system with a control mechanism based on weather conditions and the direction of the sun. The main components used in the prototype are Photo resistors, Microcontrollers and Stepper motors. The solar tracker works with three operating times, i.e. during normal daytime weather, when the sky is cloudy and the two-way rotation i.e. east-west and west-east. This prototype is said to have a simple mechanism for controlling systems at relatively low cost through software-based solutions [18].

Tiberiu Tudorache et al, designed a single-axis solar tracking system using the backs of tilted PV panels and an electric motor as a panel drive on the expected trajectory relative to the Sun's position. The model of tracking system is operated by using a DC motor by an intelligent drive unit according to the received signal obtained from the two simple and efficient light sensors. The minimum energy consumption in received since the electricity supply is only given in the period of movement of PV panels. Instead, the optimum position of the intensity for the signal of light is achieved by maximizing the energy output generated by the PV panel. [19].

Chin CS et al., made a design, model, and test a stand-alone single axis solar tracking. The solar radiation is detected by two light sensors (LDR) placed on the surface of the photovoltaic panel (PV). The intelligent tracking system is operated in different modes to provide the flexibility in the different weather conditions. The PV panel rotates automatically based on the daylight of the sun. This solar tracker system is modeled first using MATLAB ™ / Simulink ™. The tracker is designed as a single axis tracker having an East-West rotation. The intensity of sunlight is detected using an LDR sensor, which then sends a signal to the microcontroller to rotate the panel using a servo motor. Based on the test results obtained there are irregularities in experimental results with simulation, this can occur due to mechanical friction in the tracking motion [20].

2) One-Axis System with Programable Logic Controller

Al-Mohamad, designed a single axis solar tracking system using a programable logic-controller (PLC) unit which control the movement of PV modules to follow the direction of solar radiation. The performance of the system has been tested and it can be said that the system worked properly. The movement of the PV module runs smoothly without a lag to the presence of detected radiation. The acquired daily PV power output is increased by more than 20% compared to fixed modules. The PV tracking system can be operated as a stand-alone device and it also can be connected to a personal computer to monitor the entire process and performances via the RS232 serial port. [21]

3) Two-Axis System with Microcontroler

Roth et al., Designed and tested a closed-loop automatic two-axis tracker. The amount of sunlight radiation is measured by using a pyrheliometer and two small dc motors is installed there as an instrument to keep the sunlight falling in the middle position of the beam detector. This system get the stability of solar radiation above 140 w/m2 [22].

Jeng-Nan Juang et al., designed a dual-axis tracking system with real-time semi-portable criteria, increased efficiency by at least 15% and could charge a battery less than eight hours. The motor controller used is The Pololu Dual VNH5019 Motor Shield which allows for controlling two DC motors with Arduino usage. The method used in tracking sunlight is a real-time system, despite the fact that the sun's azimuth does not change significantly in one minute. The sun tracking is carried out in a 12 hour period where the system will check every minute for voltage differences between LDR [23].

SC Ribeiro built innovative solar trackers based on azimuth motion and elevation movements, which main specifications are low cost, small power consumption and flexibility. This platform has two freedom axes with two direct current motors operating in the vertical and horizontal axes controlled by the microcontroller. There are two pairs of LDR for each axis that is vertical and horizontal. The output of the LDR pair is the variable used by the microcontroller to control movement around the vertical axis (azimuth) and horizontal (elevation). This system has been field tested for five days in cloudy winter (end of July and early August 2012), the result is quite good with the total tracker consumption with both motors operating at 67.8 mA. Thus, in such weather conditions there is a relative surplus of 38.98% [24].

Oner et al, designed a solar tracking system which is capable to move on both axes by using a spherical motor controlled by a microcontroller. The spherical motors have the ability to move across both horizontal and vertical axis, compared to using two stepper motors for each axis. The purpose to build this control system is to direct the PV system in such a way that able to face the sun at 90°. The results showed the improvement of the system performance when the tracking systems were used mainly after mid-day during the day compared to fixed-tilt PV panels [25].

Arlikar et al., designed and implemented a three-dimensional two-axis solar tracking system consisting of two stepper motors, two sensors and solar panels. Two stepper motors are Vertical and Horizontal stepper motors are used for 3D movement of solar panels, while each sensor consists of 2 Light Dependent Resistors (LDR). The change of LDR value according to the intensity of the light falling on it which will cause voltage variations. This information will be used by the microcontroller to rotate the stepper motor, so the Panel will always face the sun. It was concluded that 3D solar panels produce more energy than traditional stationary solar panels [26].

4) Two-Axis System with Programable Logic Controller

Abdallah et al., designed and built a two-axis electromechanical solar tracking system, an open-loop control system using a PLC to control the motion of the solar tracker. The PLC programming is based on solar angle analysis and motor speed calculation. This solar tracker works based on the surface position which is defined by the slope of the surface and the azimuth angle of the sun. Two tracking motors are used, one for joint rotation of the north-south horizontal axis and the other for the joint rotation of the vertical axis. Tracking mode is carried out in stages to simplify system work without losing a lot of power and it is very effiecient since the amount of power consumed by the electric motor and the control system will not be more than 3% from the total power obatined by the tracking system. They concluded that the tracking system by using two-axis could increase the daily power up to 41.34% compared to fixed surfaces. [27]

Rosell et al., designed and built systems based on Fresnel concentrators and PV/T collectors using water as a working fluid. The two-axis solar tracking system uses two DC linear actuators to move the concentrator and reed sensor. This system has the characteristics of a fairly simple electromechanical arrangement. The mirror reflects light into focus bands and solar cells. To obtain greater accuracy and to calculate the position of the sun, the PLC system is designed and constructed. Two sensors are positoned to determine the temperature rising in the collector and measure the temperature of the water in and out. Another sensor is used to measure air temperature. The average daily results are measured under different conditions, PV/T system efficiency is affected by flow rates and concentration ratios. The increase of 50% in energy compared to an optimally tilted static surface [28].

Sungur, designed and implemented two-axis solar trackers using electromechanical systems controlled through programmable logic control (PLC). This study is based on the azimuth angle of the sun and the angle of the sun's height is calculated in every hour for each day during the year. The performance measurement of solar panels is carried out in two solar panel conditions, firstly the solar panel is placed in a fixed position and then then it is controlled when it was tracking the sun at azimuth angle and the height of the sun. Based on the data resulted from the measurements, it was shown that a two-axis solar tracking can produce 42.6% more energy compared to a fixed system. [29]

Abu-Khadera et al., Designed a multi-axis solar tracking system that is PLC controlled. They claimed that this system used a simple electromechanical settings, low cost, easy installation and maintenance. The piranometer as a device to measure the availability of solar radiation is installed on a platform on the tracking surface. This study proves that the control programming method works efficiently in all weather conditions regardless of the presence of clouds. The values calculated from the surface position as a function of time are trasfered to the PLC program to control the solar position tracking actuator. The motor is used as a solar multi-axis tracking drive, one for rotation with the north-south horizontal axis (N-S) or the east-west axis (E-W, and the other motor for rotating along with the vertical axis. The use of MAST results in an increase in total power output of around 30-45% compared to 320 fixed slope PV cells [30].

III. Discussion

Taking into account all reviewed articles, a microcontroller or programable logic controller as a control instrument is an option that can be used for active tracking systems, either single or double axis. The use of both passive and active tracers can increase the efficiency of solar panels, with a greater increase in active trackers with an average of 29.37%. The tracking is done in different places with varying weather conditions, the position of the sun can be determined using data obtained by azimuth angle and elevation or through direct detection using sensors.

The use of active trackers has been claimed to be a better tracker in terms of efficiency improvement, but not many discuss that electric motors as active tracking drivers require electrical power. In fact, that the motor power is supplied by the panel itself, this can certainly reduce the power produced by PV. Other problems, the mechanical influence on the device, for example friction, tracking force and oscillation that might arise due to the movement of the tracker which is relatively faster than the relative slow position of the sun. This is an interesting study, how the design of a solar tracking system can produce high efficiency with very low energy consumption, meaning that mechanical losses can be minimized. This problem can be overcome by the development of a tracking mechanism system that integrates electronic control systems in mechanical models, namely aspects of mechanical, kinematic and dynamic structures.

IV. Conclusion

From the reviewed articles, it can be concluded that active trackers are more commonly used than passive trackers. The active trackers can increase efficiency by an average of 29.37%, this tracker consists of one axis and two axis active trackers, generally using a microcontroller or PLC as a controller. The use of this controller allows automatic tracking in real time or periodic.

Recommendation

After reviewing various mechanisms for tracking sunlight, the following recommendations should be suggested in the future research:

- There should be another review which includes more papers on the sun tracking system.
- It is necessary to design and construct trackers that integrate electronic control systems in mechanical models i.e. mechanic, kinematic, and dynamic structural aspects to improve efficiency.

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