Improving the performance of solar panels by the used of dual axis solar tracking system with mirror reflection

Mohd Alif Ismail, Kreshnaveyashadev A/L Ramanathan, Muhd Hafizi Idris, Kumuthawathe Anandà-Rao, Mazwin Mazlan, Nur Fairuz

School of Electrical System Engineering, Universiti Malaysia Perlis (UniMAP), Kampus UniMAP Pauh Putra, 02600 Arau, Perlis, Malaysia

E-mail: alifismail@unimap.edu.my

Abstract: This work proposes the dual axis solar tracker with mirror reflection for optimum output of solar panel by using arduino unoR3 as the control unit. The objectives of this work are to track and optimize the maximum output power of the solar panel by designing and developing a dual axis solar tracker with mirror reflection. The system includes a 10 watt solar panel, an arduino unoR3 and a customized mechanical body to carry the solar panel. This system will track and detect the angle of the sun to locate the surface of solar panel at the position and the angle where it can get maximum amount of energy. The sensors will detect the position of the sun and servo motors act as free moving neck to make it easier to move freely depending on the angle detected. The Light Depending Resistor (LDR) will be used in tracking system. These LDR will detect the existence of sunlight and therefore the mechanical hardware will move horizontal and vertical axis depending on the value of LDR detected to follow the angular degree of sun in order to get maximum and best result of absorbing energy. The final result obtained from dual axis solar tracker showed that the output power has been maximized compared to stationary panel. Based on the experimental result, it show that the designed system successful improve the performance of the solar panel.

1. Introduction

The solar cell’s output is depends on its production quality. However, the cell’s output is also depends on its orientation to the sun where the cell absorbing surface should be oriented 90˚ or perpendicular to the sunlight. Since, sun is moving throughout the day, the solar panels need to track the sun path in order to produce maximum output. To meet these criteria, smart solar trackers are used to track the sun path. Azimuth and zenith angles are used to plot the position of the sun on the sky. Azimuth is the compass angle of the sun which moves from east to west over the daytime. It is also can be defined as horizontal angle measured clockwise from any fixed plane angle. Zenith is the angle of the sun looking up from the horizon or ground level. This angle of the sun varies throughout the day in the arc form which is from sunrise to sunset. For the zenith angle of the sun, the sun elevation roughly at 0˚ for sunrise, 90˚ for midday when the sun is directly overhead and 180˚ for sunset. Both angles are clearly illustrated in Figure 1 below.
Mainly, there are two types of smart solar trackers which is single axis solar tracking system and dual axis solar tracking system to maximize the power generation. Before introducing solar trackers, static solar panels are fixed in the reasonable angle to produce maximum output. In sun tracking technology, single axis solar tracking system was first used to track the daily motion of sun path (zenith angle). Then, dual axis solar tracking system developed to track both daily motion and annual motion (azimuth angle, due to season) of sun path. So the maximum efficiency of the solar panel can obtained when the panel’s tilt angle synchronized with the seasonal changes of sun’s altitude.

In smart solar tracking system, sensors are used to determine the position of the sun in the sky continuously during the daytime. When the sun is not perpendicular to the panel, sensors read different light intensities and it will trigger the motor or actuator to reposition the solar panel so that the panel will always face the sun throughout the day.

Solar panels are absorbing photon rays with certain amount of heat from the sun. This temperature rise will affect the solar panel efficiency negatively. Generally, photovoltaic modules are tested under 25˚C and every increase in temperature will reduce the output power significantly. When the solar panel temperature rises, the voltage decreases linearly.

Solar array construction
Fixed solar arrays used in a lot of applications, but they cannot take full advantage of the sunlight. The performance can be improved by shine more light on array. One way is placing the array, so it can face the sun squarely or towards an image of the sun. Besides that, mirrors also can be used to shine extra light onto the panel. To gather the sunlight, focusing mirrors or lenses can be used, so they increase the light intensity fall on the array. However, all this kind of methods has advantages and disadvantages, so using this method requires an understanding of what they can and can’t accomplish.

Array with mirror reflection
Adding mirrors to fixed plane is an easy way to enhance the performance of an array. Mirrors are fixed at the side of the array at an angle. The light gain from the mirrors to the array is about one-third. For flat arrays, mirrors are easy to install to them. The mirrors are lightweight reflectorized sheets and strips of thin polyester plastic film that is really a low cost material, but it can improvise the array performance drastically. Since mirrors are lightweight compared to panels, then the tracking system using mirrors to track the sun will consume less energy. Another solid reason is that the mirrors can enhance the light striking the array by three times more than stationary array.

2. Design of dual axis solar tracking system with mirror reflection

The complete circuit unit can be divided into three major units which are sensing unit, control unit and the panel position adjustment unit. A 10 watt solar panel was selected for use during the experiment. Figure 2 shows the illustration of the system.
Figure 2. Illustration of the system

Sensor
A sensor is a device used to convert some kind of changes in physical environment into electrical signal. The changes in physical environment could be from light, moisture, pressure, motion, light and so on. These changes will read and converted into electrical signal by suitable sensors. A temperature sensor was used to monitor the solar panel’s temperature continuously.

Control Unit
Control unit in a circuit is the central processing department. In this design, control unit senses the environmental changes by using sensors. The sensor signals will continuously monitored by the control unit. It will give signal to the motor to rotate at correct direction based on input from sensor.

Position Adjustment Unit
These parts consist of few motors and gears. The motor waits for the command signals from control unit. After received the signals, the motors will reposition the panel accordingly. Panel will be rotate in both vertical axis and horizontal axis to face the sun directly.

Mirror Reflections
Reflecting surfaces used to redirect more sunlight irradiance onto the solar panel to produce maximum power output. Right mirror reflection angle will give maximum output of solar panel. Figure 3 presents the position of mirror and solar panel.

- Calculation for mirror angle, $\theta$

\[
\text{Angle, } \theta = \left( \frac{135^\circ - 90^\circ}{2} \right) + 90^\circ
\]

\[
\text{Angle, } \theta = 22.5^\circ + 90^\circ
\]

\[
\text{Angle, } \theta = 112.5^\circ
\]
2.1. Development of Hardware

Development of hardware of this work is divided by two sections which is electrical hardware and mechanical hardware. The electrical hardware developed with 4 sensors to track the sun, 1 temperature sensor, 1 control unit, 3 servo motors and a battery pack. For mechanical hardware, the main structure of the body can be developed with any strong material like steel, aluminium, stainless steel, PVC, wood and etc. Figure 4 show the final design of the dual axis solar tracker with mirror reflector.

3. Results and discussion

The experiment was conducted and the results was discussed to compare the efficiencies between stationary solar panel, dual axis solar tracking system without mirror reflection and dual axis solar tracking system with mirror reflection. The results are recorded. From the line graphs, the differences between the parameters from each system can be seen clearly.
### Table 1. Outputs from Stationary Solar Panel

| Time   | V (V) | I (A) | W (W) | T (°C) |
|--------|-------|-------|-------|--------|
| 7:30 am| 0.56  | 0.02  | 0.0112| 25.5   |
| 8:00 am| 0.97  | 0.02  | 0.0194| 25.8   |
| 8:30 am| 2.05  | 0.04  | 0.0820| 28.2   |
| 9:00 am| 4.18  | 0.12  | 0.5016| 30.3   |
| 9:30 am| 5.65  | 0.19  | 1.0735| 35.2   |
| 10:00 am| 7.34 | 0.21  | 1.5415| 38.2   |
| 10:30 am| 9.58 | 0.30  | 2.8740| 41.5   |
| 11:00 am| 11.00| 0.35  | 3.8500| 42.4   |
| 11:30 am| 13.09| 0.40  | 5.2365| 43.8   |
| 12:00 pm| 13.80| 0.45  | 6.2104| 44.8   |
| 12:30 pm| 15.40| 0.49  | 7.5460| 45.9   |
| 1:00 pm| 15.58| 0.52  | 8.1016| 46.0   |
| 1:30 pm| 15.71| 0.52  | 8.1692| 50.5   |
| 2:00 pm| 15.82| 0.50  | 7.9100| 54.6   |
| 2:30 pm| 15.73| 0.48  | 7.5504| 57.8   |
| 3:00 pm| 14.14| 0.42  | 5.9392| 57.8   |
| 3:30 pm| 12.41| 0.38  | 4.7156| 57.2   |
| 4:00 pm| 8.63 | 0.31  | 2.6753| 56.7   |
| 4:30 pm| 7.11 | 0.29  | 2.0619| 55.2   |
| 5:00 pm| 7.00 | 0.20  | 1.4000| 53.8   |
| 5:30 pm| 5.52 | 0.19  | 1.0488| 48.5   |
| 6:00 pm| 4.45 | 0.15  | 0.6675| 47.1   |
| 6:30 pm| 2.11 | 0.09  | 0.1899| 43.7   |
| 7:00 pm| 2.00 | 0.07  | 0.1400| 38.5   |
| 7:30 pm| 1.55 | 0.03  | 0.0465| 37.8   |

### Table 2. Outputs from Dual Axis Solar Tracker without Mirror reflection

| Time   | V (V) | I (A) | W (W) | T (°C) |
|--------|-------|-------|-------|--------|
| 7:30 am| 2.54  | 0.06  | 0.1524| 26.5   |
| 8:00 am| 3.31  | 0.12  | 0.3972| 26.8   |
| 8:30 am| 6.63  | 0.21  | 1.3923| 29.2   |
| 9:00 am| 9.92  | 0.29  | 2.8768| 33.3   |
| 9:30 am| 11.80 | 0.30  | 3.5400| 38.2   |
| 10:00 am| 13.14| 0.42  | 5.5188| 40.2   |
| 10:30 am| 14.35| 0.48  | 6.8880| 43.5   |
| 11:00 am| 15.10| 0.48  | 7.2480| 44.4   |
| 11:30 am| 15.20| 0.48  | 7.2960| 45.8   |
| 12:00 pm| 15.25| 0.48  | 7.3200| 46.8   |
| 12:30 pm| 15.30| 0.50  | 7.6500| 47.9   |
| 1:00 pm| 15.68| 0.52  | 8.1555| 48.0   |
| 1:30 pm| 15.71| 0.52  | 8.1695| 51.0   |
| 2:00 pm| 15.82| 0.52  | 8.2264| 54.5   |
| 2:30 pm| 15.74| 0.52  | 8.1848| 57.2   |
| 3:00 pm| 14.38| 0.52  | 7.4760| 58.3   |
| 3:30 pm| 13.63| 0.50  | 6.8140| 58.2   |
| 4:00 pm| 12.78| 0.50  | 6.3900| 57.7   |
| 4:30 pm| 12.44| 0.45  | 5.5998| 56.2   |
| 5:00 pm| 12.72| 0.41  | 5.2160| 54.8   |
| 5:30 pm| 10.99| 0.40  | 4.3945| 50.5   |
| 6:00 pm| 8.92 | 0.32  | 2.8560| 49.1   |
| 6:30 pm| 5.60 | 0.17  | 0.9520| 45.7   |
| 7:00 pm| 5.01 | 0.15  | 0.7515| 39.5   |
| 7:30 pm| 4.35 | 0.10  | 0.4350| 38.8   |
Table 3. Outputs from Dual Axis Tracker with Reflecting Surfaces

| Time   | V (V) | I (A) | W (W) | T (˚C) |
|--------|-------|-------|-------|--------|
| 7:30 am| 3.19  | 0.09  | 0.2871| 27.5   |
| 8:00 am| 4.65  | 0.15  | 0.6975| 27.8   |
| 8:30 am| 9.45  | 0.29  | 2.7405| 30.8   |
| 9:00 am| 12.13 | 0.44  | 5.3372| 34.7   |
| 9:30 am| 15.35 | 0.45  | 6.9075| 38.9   |
| 10:00 am| 16.52 | 0.53  | 8.7556| 41.4   |
| 10:30 am| 17.04 | 0.58  | 9.8832| 44.4   |
| 11:00 am| 17.35 | 0.58  | 10.0630| 45.4  |
| 11:30 am| 17.42 | 0.58  | 10.1036| 46.8  |
| 12:00 pm| 17.43 | 0.58  | 10.1094| 47.8  |
| 12:30 pm| 17.49 | 0.58  | 10.1442| 49.5  |
| 1:00 pm| 17.50 | 0.58  | 10.1500| 50.0  |
| 1:30 pm| 17.48 | 0.58  | 10.1384| 53.0  |
| 2:00 pm| 16.59 | 0.58  | 9.6222 | 56.5  |
| 2:30 pm| 16.28 | 0.58  | 9.4424 | 58.2  |
| 3:00 pm| 16.18 | 0.58  | 9.3844 | 60.3  |
| 3:30 pm| 15.31 | 0.54  | 8.2674 | 60.2  |
| 4:00 pm| 15.20 | 0.51  | 7.7520 | 59.7  |
| 4:30 pm| 15.10 | 0.50  | 7.5500 | 58.2  |
| 5:00 pm| 15.04 | 0.47  | 7.0688 | 56.8  |
| 5:30 pm| 11.28 | 0.43  | 4.8510 | 55.5  |
| 6:00 pm| 9.16  | 0.34  | 3.1134 | 50.1  |
| 6:30 pm| 7.34  | 0.20  | 1.4680 | 48.7  |
| 7:00 pm| 6.21  | 0.18  | 1.1178 | 45.5  |
| 7:30 pm| 5.55  | 0.15  | 0.8325 | 40.8  |

Table 1 presents the outputs from stationary solar panel, Table 2 presents the outputs from dual axis solar tracker without mirror reflection and Table 3 presents the outputs from dual axis solar tracker with mirror reflection. All the power parameters are recorded from the sunrise, 7.30am until the sunset 7.30pm with an interval of 30 minutes.

According to the experimental result, the dual axis solar tracking system without mirror reflection generates more energy than stationary solar panel. But, the dual axis tracking system with mirror reflection generates more energy compare to dual axis tracking system without mirror reflection and stationary solar panel. It proves that, the solar panels can generate more energy when facing the sun directly and also when more sunlight directed into it. These methods also improve the efficiency of solar panel.

![Output Power vs Time](image-url)
The recorded output power data is then illustrated graphically in figure 5 above for a better view on the differences in output powers from all three experiment setups. As a conclusion, dual axis tracker with mirror reflection is a good method for solar panels to draw more energy from the sun.

4. Conclusion

This paper gives a brief overview on designing and implementation of a dual axis solar tracking system with mirror reflection. The advantages of dual axis solar tracking system with mirror reflection lies in its better efficiency and sustainability to generate better output compared to stationary panel. A simple working dual axis solar tracker with mirror reflection has been developed to trap the solar energy in all possible directions. Hence, maximum possible sun energy can trap and converted into electrical power throughout the day as well as throughout the year. Based on the results, the working prototype efficiency is 108.36 % more than the stationary panel. The work concludes that the dual axis solar tracker with mirror reflection provides better efficiency and improves the performance of the solar panel.

Acknowledgments

The author would like to acknowledge School of Electrical System Engineering, Universiti Malaysia Perlis for the funding of this work.

References

[1] Alam S M S and Rahman A N M M 2016 4th International Conference on the Development in the in Renewable Energy Technology (ICDRET), Dhaka. pp. 1-4
[2] Al-Mohamad A 2004 Applied Energy 79(3) pp 345-354
[3] Yousef H A 1999 IEEE International Symposium on Industrial Electronics 3 pp 1030-1034
[4] Ismail M A, Aziz M J, Idris M H, Fadzail N F, Ahmad M S, Amirruddin M, Abdullah F S and Mukhtar N M 2017 MATEC Web Of Conferences 97 01011.
[5] Clifford M J and Eastwood D 2004 Solar Energy 77 pp 269-280 2004
[6] Huang Y J, Member I, Kuo T C, Chen C Y, Chang C H, Wu P C and Wu T H 2009 Engineering Letters 17(4) pp 252-256
[7] Ismail M A and Fadzail N F 2015 Applied Mechanics and Materials 793 pp. 216-221.
[8] Sefa I, Demirtas M and Colak I 2009 Energy Conversion and Management 50 pp 2709-2718