Performance Improvement of Photovoltaic Module Using Plane Mirror

Aliyu Abubakar, M.H Ali

Department of physics ,Bayero University Kano, Nigeria

Abstract- This work presents the quantitative advantage of using a plane mirror as reflector for photovoltaic application. Shade, intermittent nature of solar radiation and dust reduce the total amount of the incident radiation on PV panel and thus reduce its efficiency. Plane mirror is used to increase the incident radiation and thus minimized the effect of the above problems. Experimental measurements are conducted on the performance of a 15 W silicon polycrystalline PV module with mirror reflector and compared with its performance without the mirror. The results obtained show that the plane mirror increased the output power of the PV panel to 20.4W.Thus the use of plane mirror as reflector is recommended to overcome the problem of poor performance due to these problems.

Index Terms- intermittent solar radiation, plane mirror,PV module, quantitative advantage

I. Introduction

Solar energy is the most abundance form of energy available with the permanent source whose magnitude is a function of earth surface topography. Sun is the main source of all solar energies on the earth's surface [1]. This energy resource is free from contamination because it does not emit toxic substances to pollute the environment as some resources possess [2]. The scenario of solar energy will address global warming issues when serious attention is focused to its use [3]. There is a fervent need for private and public to revamp the sector considering its huge potential for improving social and economic development in both rural and urban areas through the different range of applications [1]. The depletion of non-renewable resources have shown good evidences that even with conservative assumption of future increase rates, solar energy will be the mainstream electricity providing industries within the coming decade where large percentage of energy need will be covered by renewable energy resources from ecological and economical point of view. It has been recognised that sunlight striking the surface of earth is more than adequate to supply all the energy that human activities require [4]. The great challenge is the way to harvest this dilute and intermittent solar energy to a form that will be convenient for use by the inhabitant [5]. Solar energy can be harvested in four different ways: (i) direct photo-induced and endothermic reaction (photosynthesis). (ii) Direct production of electrical power (photoelectric effect). (iii) Direct conversion of sunlight to thermal energy such as solar heater and solar cookers. (iv)Conversion of thermal energy into electricity(thermoelectric effect) [6].

Photovoltaic (PV) cells are specialised semiconductor diodes that convert visible light into direct current based on photoelectric effect (the generation of potential difference at the junction of two different materials in response to visible light or other radiation). PV cells are an integral part of solar electrical energy system which is becoming increasingly important as alternative source of utility power [6].

There are many problems associated with the use of photovoltaic technologies. Shadow exercises a tremendous effect on the performance of the solar cell by casting on the whole or some portion of the module, e.g. blockage from a nearby building, trees and cloud. Therefore, casting shadow on a portion of a single cell reduce the performance of the cell, and subsequently reduce the entire performance of the module because of the number of cells in the module connected in series [7]. The low absorption of solar radiation by the solar cell is a function of overall efficiency of the panel. As a result, the module build up from the manufacturer is inherently of low efficiency; maximum ranging from 10-20% and this lowers the absorption capacity of the cell (Abd-Elhady, Fouad & Khalil, 2016). Dirt accumulation like dust, water and sand on the surface of the panel obstruct or distract light energy from reaching the solar cells. These light obstructing materials build external resistances in the cell which reduce the performance of solar module. Overheating rises the temperature and warmed up cells and Consequently, lower the overall efficiency of the panel [9]. Intermittency of solar radiation is an hourly fluctuation of solar insolation which reduces the overall efficiency of the module [10].

The highest efficiency of solar cell at commercial rate still remains around 20%. Abd-Elhady, Fouad and Khalil (2016) reported increase of 20% in the cell efficiency by smearing oil on the surface of the panel to increase the amount of light transmitted to the panel. Decrease in cell efficiency due to overheating was tackled in Popovici, Hudişteanu, Mateescu and Chereches(2016) work by the use of air cooled heat sink method. While the use of the water cooling was recommended for the improvement of efficiency by Odeh and Behnia (2009). The effect of dust particles staining on the panel adversely affect cell efficiency as revealed in the work of Rao, Pillai, Mani and Ramamurthy (2014) and suggested the use of daily routine maintenance operation as the best approach to clean up dust particles on the panel and mitigate the effect of dust. Narasimman and Selvarasan (2016) worked on the effect of intermittent solar radiation on cell efficiency and recommended the use of glass reflector to boost the efficiency. The investigation of cell efficiency was performed by Hossain, Muhida and Ali (2008) and suggested the use of compound parabolic concentrator and sun tracking system to

ISSN 2250-3153
improve the low efficiency. Rizk andNagrial (2009) reported in the work the effect of intermittent solar insolation on the efficiency of the panel and recommend the use of Aluminium foil as concentrator and sun tracking system to boost the reflection of light on the panel and improve cell efficiency.

In this research work, we quantitatively determined the effect of plane mirror on the overall performance of photovoltaic module .The results obtained from these characteristics curves of the experimental work conducted depicted the increase in the output power and efficiency.

II. Background Theory

Introduction

Atmosphere compose of substances that intercept, scattered, absorb and reflect some solar radiation coming to the earth as a consequence reduce the total radiation reaching the earth surface. These compositions of the atmosphere are vapour molecule, dust particles, cloud and air pollution. Besides, the solar radiations striking the surface of the panel or collector are grouped into three components namely direct beam, diffuse and reflected component. The components diffuse and reflected solar radiationarecumbersome because their values cannot beeasily estimated by virtues of their nature. Therefore, in computing the solar irradiance in this research work only direct beam value is considered because of certainties attached its nature.

Clear sky direct beam solar radiation

The clear sky direct beam solar radiation describes the transmission of solar radiation from the sun down to the earth surface without interception of the cloud cover. The expression of clear sky solar radiation reaching the earth's surface (normal to the collector surface) is given by [17]

$$I_B = Ae^{-km} \quad (1)$$

where I_B= solar beam insolation at the earth's surface, A=Apparent extra- terrestrial solar insolation. m=air mass ratio.

$$A=1160+75 \sin [\frac{360}{365}(n-100)] \quad (2)$$

where n=number of days

$$k= 0.174+0.035\, sin[\frac{360}{365}(n-100)] \quad (3)$$

where k=atmospheric optical depth

$$m=\frac{1}{sin\beta} \quad (4)$$

where m=mass air ratio, $\beta = solar\ latitude$

Total clear sky solar radiation on the collector surface

The clear sky solar radiation on the collecting surface can be reasonably estimated on the surface as accurate, direct solar radiation are easy to work out and the geometry involved to determine how much energy striking a collector surface is clear and explicit but it not easy to account for the diffuse and reflected solar radiation.

Direct beam solar radiation

The direct beam solar radiation is a definite pattern of solar radiation that describes how the rays of light travelled on a straight line from the sun down to the surface of the earth. In these modes of transitions, the rays are travelling in the same direction and object can block them at the same time [17].

$$I_{BC} = I_B cos\theta \quad (5)$$

Where $\theta = incidence\ angle, I_{BC} = solar\ insolation\ striking\ the\ collector$

The expression of incidence angle θ is given by [17].

$$cos\theta = cos\beta cos(\emptyset_s - \emptyset_c)sin\varphi + sin\beta cos\varphi \quad (6)$$

where$\emptyset_s = solar\ azimuth\ angle, \emptyset_c = collector\ azimuth\ angle, \varphi collector\ tilt\ angle, \beta = solar\ latitude,$
$\varphi =$

$slope\ of\ panel$

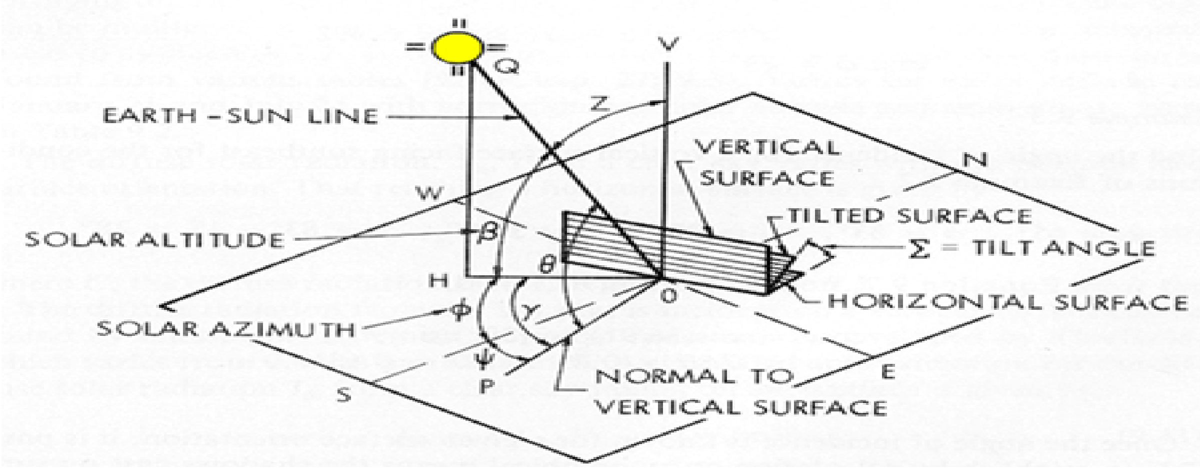


Figure.1 Solar angles

Solar declination angle

The angle formed between the plane of the equator and a line drawn from the centre of the Sun to the centre of the earth is the declination angle. It varies between the extremes of $\pm 23.45°$; and is a simple sinusoidal relationship that assumes a 365-day year which puts the spring equinox on a day n=284 provides good approximation [17]

$$\delta = 23.45 \sin\left[\frac{360}{365.25}(284+n)\right] \quad (7)$$

Where $\delta = declination\ angle$, n=number of days

Solar azimuth angle

The position of the sun at any time of the day can be describes in term of its latitude angle β and its azimuth angle$\emptyset_s$. By convention, the azimuth angle is positive in the morning with the sun in the east and negative in the afternoon with the sun at west[17]

$$sin\emptyset_s = \frac{cos\delta * sinH}{cos\beta} \quad (8)$$

Where H = hour angle, $\beta = solar\ altitude, \delta = solar\ declination\ angle$

The expression for solar altitude at solar noon is given by [17]

$$\beta_N = 90 - L - \delta \quad (9)$$

Where $\beta_N = solar\ altitude\ angle\ at\ noon, L = latitude, \delta = declination\ angle$

The expression for calculating solar altitude angle is given by[17]

$$sin\beta = cosLcosH + sinLsin\delta \quad (10)$$

Where L=latitude, H=hour angle,$\delta = declination\ angle$,$\beta = solar\ altitude$ angle

The hour angle H is the number of degree that earth must rotate before the sun will be directly over your local meridian given by [17]

$$H = \frac{15° * hour\ before\ noon}{hour} \quad or\ H = \frac{-15°}{hour} * hourbefore\ noon \quad (11)$$

Single diode PV cell model

The simplest empirical model of a PV cell is an equivalent circuit consisting of photocurrent sourceI_{ph} and diode current I_D in parallel with the resistor $R_s$in series[18]

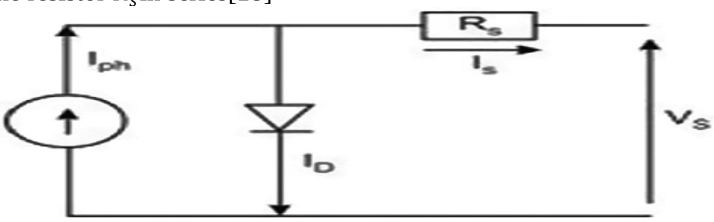


Figure. 2 Equivalent circuit of PV cell [18]

The equation describing the V-I and P-V characteristics curve of the PV cell is derived using Kirchhoff's current law as follows[19]

$$I_s = I_{Ph} - I_D \quad (12)$$

Where $$I_D = I_O\left[e^{\left(\frac{q(v_S + R_S I_S)}{mkT}\right)} - 1\right] \quad (13)$$

And q=1.6 $\times 10^{-19}$C , k=1.38$\times 10^{-23}$J/K, m is ideality factor of PV panel and I_0 is diode saturation current

And thus $I_s \; = \; I_{ph} - I_O \left[e^{\left(\frac{(q(v_S+R_S I_S)}{mkT}\right)} - 1\right]$ (14)

$$I_{ph} = [I_{sc} + K_t \Delta T] \times \frac{G}{G_{stc}} \quad (15)$$

Where ΔT is change in temperature, G is solar irradiance,G_{stc} is irradiance at standard condition, K_t Temperature coefficient. ofI_{sc}

The expression of input power is given by (Abdelhady,Foud& Khalil,2016)

$$P_{in} = G \times A_S \quad (17)$$

WhereG is solar irradiance,A_s surface area of panel.
The expression of efficiency is given by(Abdelhady,Foud& Khalil,2016)

$$Efficiency = \frac{P_{max}}{P_{in}} \times 100\% \quad (18)$$

The above equation (18) was used in the evaluation of efficiency of PV module at a particular point.

III. Method

The experimental method was adopted for this work. The experiment took place at M block hostel in the Bayero university old campus. The photovoltaic module used is a 15W Panel with model number as (YL 015P-17b) which is silicon polycrystalline panel. Two intelligent digital multimeter with model number (MS 345) were used for the panel current and voltage measurement. Additional Rheostat (SR 451) was used for varying the resistance in step. The panel was aligned to the direction facing north south and used latitude of the location as inclination angle of the panel. The open circuit and short circuit values of currents and voltages were obtained by opening and shortening the circuit terminal[19] these instruments were connected as shown in Fig 3.The experimental connection in fig3 was used to obtain the characteristics currents and voltages of PV module by varying Rheostat in step. The circuit connection was repeated with the used of plane mirror placed at an angle of 60°between the panel and then measured the characteristics currents and voltages of PV module with mirror also by varying the resistance in step.Experiment was repeated five times in three days. Simulation for panel with mirror and without mirror was carried out. The I-V and P-V characteristics curves of PV module with and without mirrorwere plotted for the five times values of the three days

3.1DIAGRAM OF THE EXPERIMENTAL SETUP

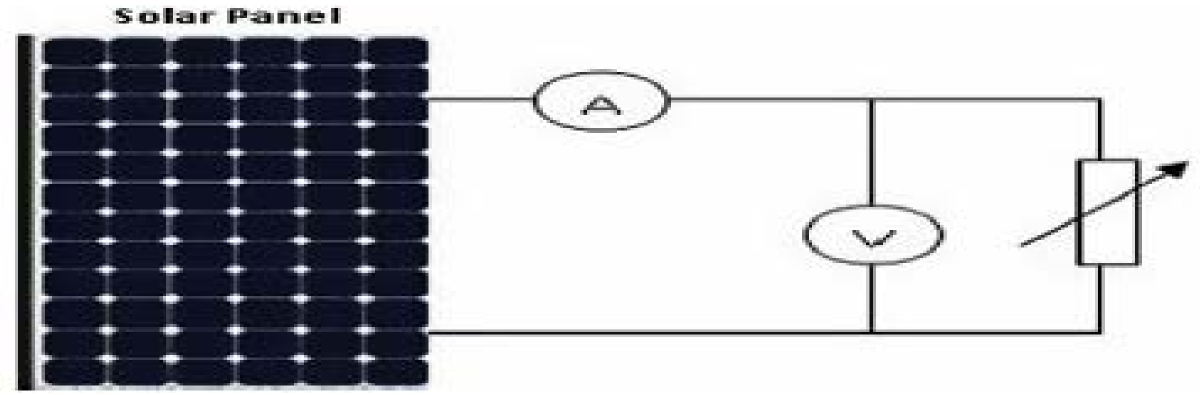
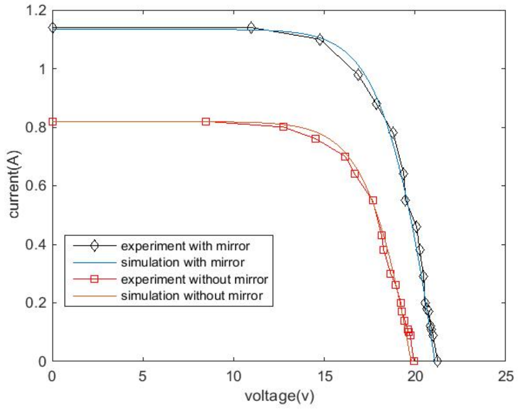


Figure.3. Experimental setup for the field measurement[19]

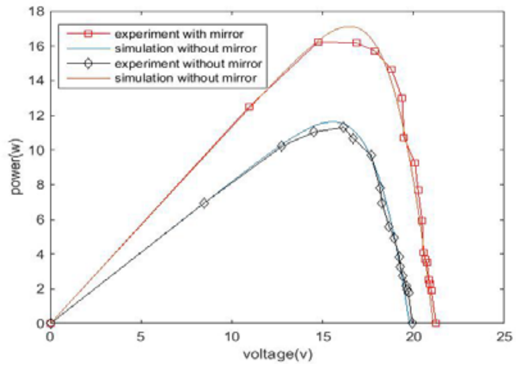
IV. Results and Discussion

The experimental and simulated results of the Photovoltaic module performances with mirror and without the mirror as concentrator are compared graphically.



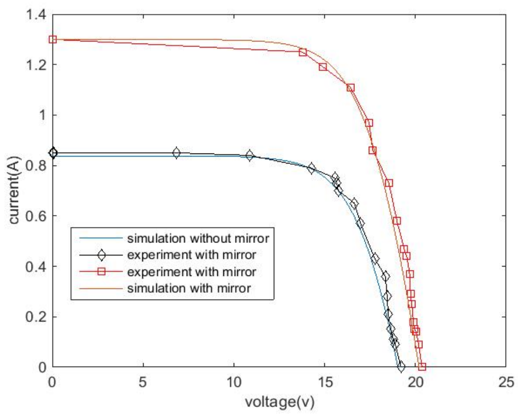
(a)

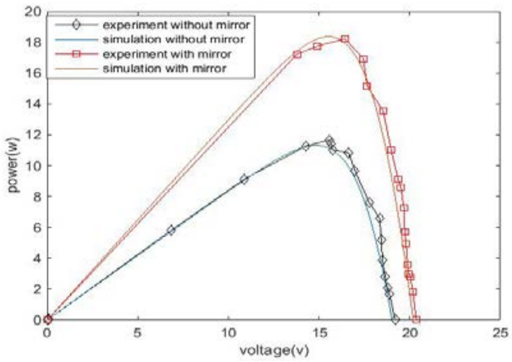
Figure.4 (a) I-V characteristics curve obtained from the simulation and experimental study on the day of 30th August, 2016 at 3.30 pm with the ambient temperature of 33℃.



(b)

Figure.4 (b) P-V characteristics curve obtained from the simulation and experimental study on the day of 30th August, 2016 at 3.30pm with the ambient temperature of 33℃.

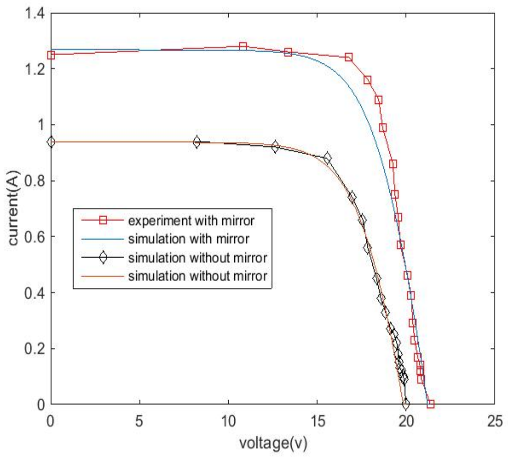




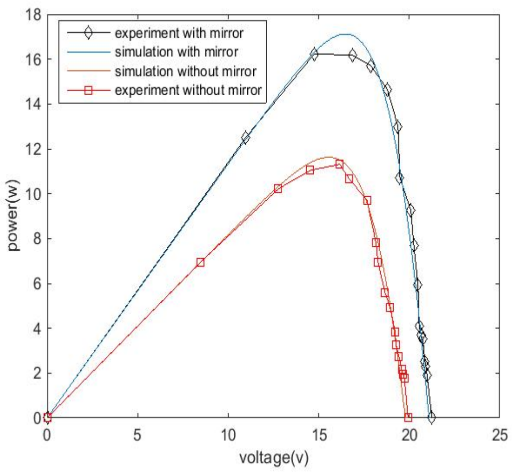
(a)

Figure5 (a) I-V characteristics curve obtained from the simulation and experimental study on the day of 30th August, 2016 at 1.30 pm with the ambient temperature of 33℃

Figure.5 (b) P-V characteristics curve obtained from the simulation and experimental study on the day of 30th August, 2016 at 1.30pm with the ambient temperature of 33℃.



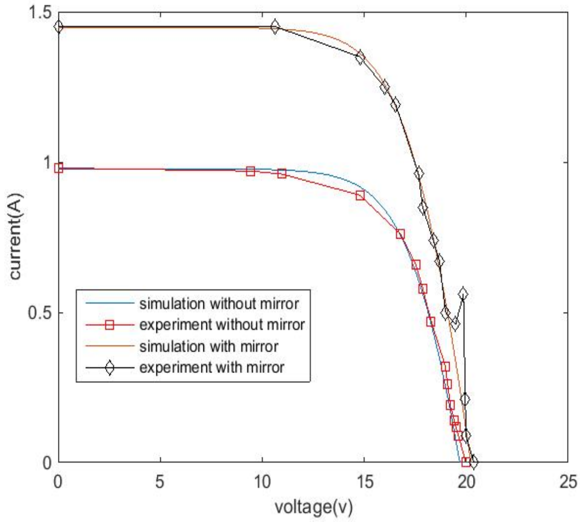
(a)

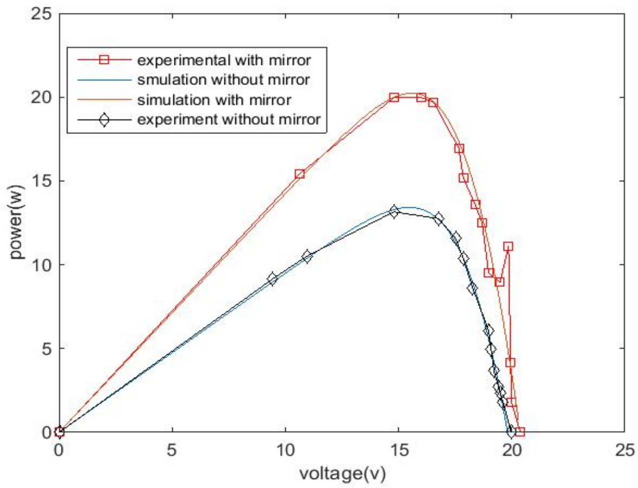


(b)

Figure.6 (a) I-V characteristics curve obtained from the simulation and experimental study on the day of 1st September, 2016 at 9.30 am with the ambient temperature of 33℃.Figure.6 (b) P-V characteristics curve

obtained from the simulation and experimental study on the day of 1st September, 2016 at 9.30am with the ambient temperature of 33℃

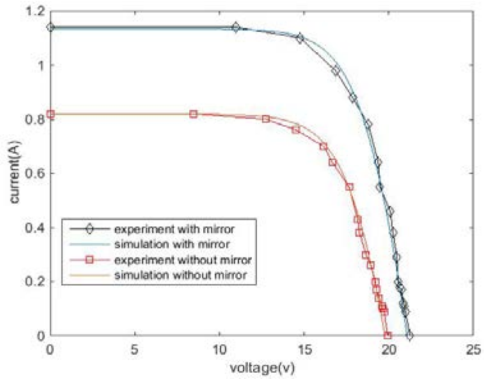




(b)

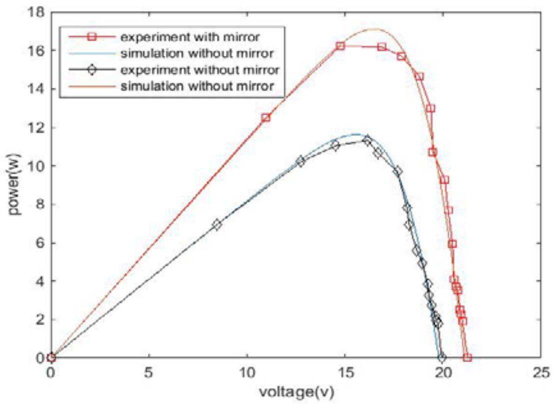
(a)

Figure.7 (a) I-V characteristics curve obtained from the simulation and experimental study on the day of 29th August, 2016 at 3.30 pm with the ambient temperature of 31℃.Figure.7 (b) P-V characteristics curve obtained from the simulation and experimental study on the day of 29th August, 2016 at 3.30pm with the ambient temperature of 31℃



(a)

Figure.8 (a) I-V characteristics curve obtained from the simulation and experimental study on the day of 30th August, 2016 at 2.30 pm with the ambient temperature of 33℃.



(b)

Figure.8 (b) P-V characteristics curve obtained from the simulation and experimental study on the day of 30th August, 2016 at 2.30pm with ambient temperature of 33℃

It can be seen that in all the graphs that the curve with mirror is always above the one without mirror. In the above figures (1-8) simulation curves closely matched the experimental curves indicating minimal errors in the experimental measurement.

Table 4.1 Values obtained from experiment at M-Block Hostel (Latitude11.9832N, Long8.4768E)

Date	Experiment	Time of the day	Efficiency (without mirror)%	Efficiency (with mirror)%	*change in* efficiency%
30/08/2016	I	3.30pm	14.44	17.68	3.24
30/08/2016	II	1.30pm	13.33	18.41	5.08
29/08/2016	III	3.30pm	14.95	18.83	3.88
30/08/2016	IV	2.30pm	15.87	19...85	4.18
01/09/2016	V	9.30am	14.92	18.46	3.54

V. Conclusion

We found the use of plane mirror as concentrator improved the performance of photovoltaic module. The increase in performance recorded with mirror as the Reflector for the five experiment was 20.4W. In all the above figures, the simulated curves are found to closely fit the experimental ones indicating minimal errors in the experiment. The addition of the mirror can be seen to bring additional solar radiation of about 305.6 Wm^{-2}. Since the performance of PV module increase with increase in the solar insolation, the use of plane mirror can also bring increase in the PV module performance .Thus the effect of dust, snow, shade and irradiance fluctuation could be reduced with the use of plane mirror as reflector.

References

[1] O. S. Ohunakin, M. S. Adaramola, O. M. Oyewola, and R. O. Fagbenle, “Solar energy applications and development in Nigeria: Drivers and barriers,” Renew. Sustain. Energy Rev., vol. 32, pp. 294–301, 2014.

[2] K. H. Solangi, T. N. W. Lwin, N. A. Rahim, M. S. Hossain, R. Saidur, and H. Fayaz, “Development of solar energy and present policies in Malaysia,” in 2011 IEEE 1st Conference on Clean Energy and Technology, CET 2011, 2011, pp. 115–120.

[3] V. Kumar, R. L. Shrivastava, and S. P. Untawale, “Solar Energy: Review of Potential Green & Clean Energy for Coastal and Offshore Applications,” Aquat. Procedia, vol. 4, no. Icwrcoe, pp. 473–480, 2015.

[4] K. Kalyanasundaram, “Photochemical energy conversion,” in Photochemistry: Volume 39, vol. 39, 2011, pp. 112–190.

[5] K. M. Gangotri and M. K. Bhimwal, “The photochemical conversion of solar energy into electrical energy: Eosin-fructose system,” Environ. Prog. Sustain. Energy, vol. 30, no. 3, pp. 493–499, 2011.

[6] A. Malviya and P. P. Solanki, “Photogalvanics: A sustainable and promising device for solar energy conversion and storage,” Renewable and Sustainable Energy Reviews, vol. 59. pp. 662–691, 2016.

[7] M. Jamal, “Shading Effect in Solar Energy and Solar Cell,” Int. Adv. Res. J. Sci. Eng. Technol., vol. 3, no. 2, 2016.

[8] M. S. Abd-Elhady, M. M. Fouad, and T. Khalil, “Improving the efficiency of photovoltaic (PV) panels by oil coating,” Energy Convers. Manag., vol. 115, pp. 1–7, 2016.

[9] M. J. Adinoyi and S. A. M. Said, “Effect of dust accumulation on the power outputs of solar photovoltaic modules,” Renew. Energy, vol. 60, pp. 633–636, 2013.

[10] D. Bechki, H. Bouguettaia, J. Blanco-Galvez, S. Babay, B. Bouchekima, S. Boughali, and H. Mahcene, “Effect of partial intermittent shading on the performance of a simple basin solar still in south Algeria,” Desalination, vol. 260, no. 1–3, pp. 65–69, 2010.

[11] C. G. Popovici, S. V. Hudişteanu, T. D. Mateescu, and N.-C. Cherecheş, “Efficiency Improvement of Photovoltaic Panels by Using Air Cooled Heat Sinks,” Energy Procedia, vol. 85, pp. 425–432, 2016.

[12] S. Odeh and M. Behnia, “Improving Photovoltaic Module Efficiency Using Water Cooling,” Heat Transf. Eng., vol. 30, no. 6, pp. 499–505, 2009.

[13] A. Rao, R. Pillai, M. Mani, and P. Ramamurthy, “Influence of dust deposition on photovoltaic panel performance,” in Energy Procedia, 2014, vol. 54, pp. 690–700.

[14] K. Narasimman and I. Selvarasan, “Design construction and analysis of solar ridge concentrator photovoltaic (PV) system to improve battery charging performance,” Ecotoxicol. Environ. Saf., vol. 127, pp. 187–192, 2016.

[15] E. Hossain, R. Muhida, and A. Ali, “Efficiency improvement of solar cell using compound parabolic concentrator and sun tracking system,” in 2008 IEEE Electrical Power and Energy Conference - Energy Innovation, 2008.

[16] J. Rizk and M. Nagrial, “Impact of Reflectors on Solar Energy Systems,” Technology, pp. 563–567, 2009.

[17] G. M. Masters, Renewable and Efficient Electric Power Systems. 2004.

[18] R. P. Vengatesh and S. E. Rajan, “Investigation of cloudless solar radiation with PV module employing Matlab-Simulink,” Sol. Energy, vol. 85, no. 9, pp. 1727–1734, 2011.

Authors

First Author – ALIYU ABUBAKAR, Department of physics ,Bayero University Kano, Nigeria, babandubu@gmail.com
Second Author – M.H ALI, Department of physics ,Bayero University Kano, Nigeria, alim@buk.edu.ng