Performance Evaluation of Crystalline and Amorphous Photovoltaic Cell: The Case of Usen Community, Edo State

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ABSTRACT

An outdoor experimental study was conducted to investigate and compare the performance of two commercially available photovoltaic modules (polycrystalline and amorphous silicon) under the effect of temperature change in Use community, Edo State for the month of January to April, 2016. Maximum power, module efficiency and fill factor are calculated for each module and comparison is presented. Results have shown that polycrystalline module perform better at high irradiance and show poor performance in low irradiance conditions. Amorphous solar module has shown, better performance in low light condition and having high fill factor (FF). Polycrystalline photovoltaic module is found to be more efficient, having module efficiency of 23.5% higher than that of amorphous modules. As a result of better performance in low solar irradiance, amorphous solar module has shown daily average fill factor of 0.62 which is higher than polycrystalline module under study.

Keywords: Polycrystalline, amorphous, efficiency fill factor, irradiance

INTRODUCTION

The main objective of photovoltaic research industry is to develop high efficiency low cost photovoltaic cells and modules. Photovoltaic technology clearly offers a tremendous environmental benefit that requires no fuel and producing no emissions or other waste beyond that inherent in the manufacturing process. Moreover, photovoltaic have proven to be economically for a wide range of applications that have traditionally relied on diesel generators. The merits that photovoltaic have over competing power option are that they have no moving parts and produce power silently. They are non-polluting with no detectable emission or odours. They can be stand-alone for long period and it requires no connection to an existing power source or fuel supply. They consume no fossils fuels and their fuel in abundant and free.

Consequent upon this, a large number of researchers on photovoltaic cells exist in literature. The performance comparison of five different types of PV modules including crystalline silicon (C-Si), C-Si module with laser grooved buried contact, polycrystalline silicon (P-Si), triple junction amorphous silicon and copper indium diselenide (CIS) in the climate of Perth for a year was reported (Ahmed, Kitamura, Yamamoto, Takakura and Hmakawa, 1997) and the results showed that thin film PV modules have high performance ratio and produce most energy at that site .While the investigation of the performance of monocrystalline, polycrystalline, amorphous silicon and copper indium diselenide PV modules for three consecutive days in Malaysia was carried out by (Amin, Lung and Sopian, 2009) and it was found that CIS module has performance ratio of 1.09 which is the highest amongst four tested PV module. Experimental investigation also shown that monocrystalline PV module performs best in terms of maximum efficiency and overall energy production at that region (Carr and Pryor, 2004). While (Goossens and Kersebaever, 1997) investigated the outdoor performance of amorphous silicon and polycrystalline silicon modules and conducted that amorphous silicon has high efficiency and output power during summertime and it was opposite for polycrystalline silicon module.

The module temperature affects the characteristic parameters of module. It is a well researched fact that at high temperature, the output of PV module decreases (Jiang, Lu and Sun, 2010). Therefore, a cooling, mechanism is required at high solar insulation (Mani and Pillai, 2010) and the performance of PV module is affected by environmental factors including wind speed and direction, dust accumulation, humidity etc. It was also reported that the 32% reduction in performance of PV module in KSA during 8-month due to dust accumulation (Midtgard, Saetre, Yordanov, Imenes and Nge, 2010). While (Rodriguez, Horley, Hermandez, Vorobiev and Gorley, 2005) investigated the effect of dust deposition using a test chamber and solar simulator in lab and found a decrease in module efficiency up to 26% for dust accumulation of 22g/m^2. Singh, Singh, Lai and Hussain (2008) investigated the effect of air borne dust and windspeed on the performance of PV modules and found that these factors have significant effect on the PV module performance.

MATERIALS AND METHODS

In this paper, we used the experimental investigation and analysis of results obtained by outdoor testing under different temperature conditions of polycrystalline and amorphous silicon PV for the month of January to April, 2016 in Usen Community, Edo State. In this study, two commercially available PV modules including polycrystalline and amorphous silicon were used in carryout the investigation. Table 2.0 shows the specifications and characteristic parameters of the modules used in this research. Rated values are given by the manufacturer of PV modules at STC and actual values are measured values at outdoor conditions

Table 1: Modules specification and characteristic parameters

Dimensions	(p-Si)	(a-Si)
Module dimensions (mmxmm)	690x455	1250x640
Cell dimensions (mmxmm)	156x52	1220x610
Number of cells (in series)	4x9	1
Cell area (m^2)	0.292	0.7442
Maximum power, P_{max} (W)	100	100
Maximum current, I_{max} (A)	5.81	2.69
Maximum voltage, V_{max}(V)	17.2	45
Short circuit current, I_{sc} (A)	8.46	3.34
Open circuit voltage, V_{oc} (V)	21.6	59.2

Experimental setup and approach

In order to carry out the performance test for different PV modules, the experiments were performed at the front of Mechanical Engineering Department of Edo State Institute of Technology and Management, Usen in the southern Usen Community (Latitude 23 18^{o}N, Longitude 38.01^{o}E) as shown in Fig 1(a and b). The place of the solar module was chosen such that a shadow will not be cast into solar module at any time during the test period. Measurement were taken hourly from 7am to 6pm. The two modules under study were mounted on the south facing rack at fixed tilt angle of 45^o with horizontal (at a nearly optimum tilt angle at this site during January to April, 2016. The plane of array (POA) global solar irradiance was measured using a pyranometer TBQ-2 (sensitivity 11.346V/Wm^2). Each PV module was connected to two digital multimeters (Fluke 179, True RMS, accuracy $\pm$ 1% for DC current and $\pm$0.09% for DC volt) for the measurement of voltage and current. A high power multiturn variable resistance (100W) was connected in series in the circuit to vary the output of the modules from zero to maximum. A standard resistance of thermometer detector (RTD-PT100) was used to monitor the surrounding ambient temperature to guarantee high accuracy for critical temperature. Each PV module was connected to separate circuit and measurements of modules were taken at the same time with different temperature levels. The maximum power, fill factor, module conversion efficiency and performance ratio are calculated to understand the bahaviour of the solar module. Using the following equations:

$$\text{Maximum power } (P_{max}) = V_{max} \times I_{max} \quad (2.1)$$

$$\text{Fill factor (FF)} = (V_{max} \times I_{max})/(V_{oc} \times I_{se})_c \quad (2.2)$$

$$\text{Normalized power output efficiency } (\lambda_p) = (P_{mea}/P_{max})(STC) \times 100 \quad (2.3)$$

$$\text{Module efficiency } (\lambda_m) = (P_{mea}/(E \times A/A_a)) \times 100 \quad (2.4)$$

$$\text{Performance ratio (PR)} = P_{mea}/P_{max}(STC)/E \times 100 \quad (2.5)$$

$$\text{Direct solar irradiance } (E_D) = E_H/Cos(\sigma) \quad (2.6)$$

To determine quantitatively the effect of temperature on different electrical parameters, we used the following equations to find out the effects of working temperature (T_w) on these parameters with references to their values at STC.

$$(V_{oc})T_w = (V_{oc})STC + \alpha(T_w - 25^{oc}) \quad (2.7)$$

$$(I_{sc})T_w = (I_{sc})STC + \beta(T_W - 25^{oc}) \quad (2.8)$$

$$(P_{\max})T_w = (P_{\max})STC + y(T_W - 25^{oc}) \quad (2.9)$$

$$(\lambda_m)T_w = (\lambda_m)STC + \partial(T_w - 25^{oc}) \quad (2.10)$$

$$(FF)T_w = (FF)STC + \varepsilon(T_w - 25^{oc}) \quad (2.11)$$

Where:
T_w = working temperature

$$\alpha = \frac{dV_{oc}}{dT}\left(V\,^oC^{-1}\right)$$

$$\beta = \frac{dI_{sc}}{dT}\left(A\,^oC^{-1}\right)$$

$$\gamma = \frac{dP_{\max}}{dT}\left(W\,^oC^{-1}\right)$$

$$\delta = \frac{d\pi}{dT}\left(\%\,^oC^{-1}\right)$$

$$\varepsilon = \frac{dFf}{dT}\left(^oC^{-1}\right)$$

Fig1a. Experimental setup of the modules

Fig1b. Experimental Readings of the modules

Experimental Data and Analysis

In this section, we studied the effect of temperature change on PV panel performance for each technology. In this phase, the panels were pointed to the sun and temperatures were recorded from 7am to 6am daily for the month of January to April, 2016. Table 3a and Table 3b present experimental average data obtained for each panel

Table 2a: Average values readings for polycrystalline silicon (PV) for the month of January to April, 2016.

Time of the day	Temp (^oC)	V_{oc} (V)	I_{sc} (A)	V_{max} (V)	I_{max} (A)	P_{max} (W)	FF	η_m
7.00	13.00	1.66	0.65	1.32	0.46	0.61	0.58	20
8.00	21.00	17.48	6.85	13.92	4.70	65.42	0.56	23
9.00	24.00	20.70	8.11	16.48	5.57	91.79	0.55	32
10.00	24.00	20.70	8.11	16.48	5.57	91.79	0.55	32
11.00	30.00	25.20	9.87	20.07	6.78	136.07	0.53	47
12.00	33.00	26.84	10.51	21.37	7.21	154.08	0.52	53
1.00	37.00	28.61	11.21	22.78	7.70	175.41	0.50	60
2.00	37.00	28.61	11.21	22.78	7.70	175.41	0.50	60
3.00	34.00	27.32	10.70	21.75	7.34	159.65	0.54	55
4.00	30.00	25.20	9.87	20.07	6.78	136.07	0.53	47
5.00	25.00	21.60	8.46	17.20	5.81	99.93	0.54	34
6.00	20.00	16.20	6.35	12.90	4.36	56.24	0.56	23

Table 2b: Average values readings for amorphous silicon (PV) for the month of January to April, 2016.

Time of the day	Temp (^oC)	V_{oc} (V)	I_{sc} (A)	V_{max} (V)	I_{max} (A)	P_{max} (W)	FF	η_m
7.00	13.00	4.55	0.26	3.48	0.17	0.59	0.59	2
8.00	21.00	47.32	2.70	36.44	2.17	79.07	0.62	11
9.00	24.00	56.73	3.20	43.12	2.58	111.25	0.61	15
10.00	24.00	56.73	3.20	43.12	2.58	111.25	0.61	15
11.00	30.00	69.07	3.90	52.50	3.14	164.85	0.61	22
12.00	33.00	73.55	4.15	55.88	3.33	186.08	0.61	25
1.00	37.00	78.40	4.42	59.64	3.53	210.53	0.61	28
2.00	37.00	78.40	4.42	59.64	3.53	210.53	0.61	28
3.00	34.00	74.87	4.22	56.88	3.41	193.96	0.61	26
4.00	30.00	69.07	3.90	52.50	3.41	164.85	0.61	22
5.00	25.00	59.20	3.34	45.00	2.69	121.05	0.61	16
6.00	20.00	44.40	2.51	33.75	2.04	68.85	0.62	9

RESULTS AND DISCUSSION

During the research, the variation in average daily hourly temperature is shown in Table 3a and Table 2b. The output power of polycrystalline silicon module at high module temperature shows a higher deviation (decrement) from linear trend than amorphous silicon module. This shows that amorphous silicon module withstands better performance at high module temperature than polycrystalline module. For comparison purpose, we have used the module efficiency which is the ratio of the total solar energy incident on a module surface based on its active area. That is:

$$\text{Module efficiency } (\lambda_m) = \left(P_{mea} / \left(E \times A/A_a\right)\right) \times 100$$

The module efficiency is higher is higher at outdoor conditions as compared to their values at STC due to varying environmental conditions. Amorphous silicon module shows high decrease in module efficiency at high temperature while polycrystalline module shows better efficiency at high superior in term of daily average module efficiency than amorphous silicon. The reason is that amorphous silicon has 66.6% less rated power and larger area than polycrystalline module.

In order to determine the operating behaviour of the two PV modules, hourly fill-factor (FF) of modules has been examined it the research. In general, the fill factor increases with increase in temperature and however, the rate of increase in fill factor with temperature is significant in the case of amorphous silicon. Amorphous silicon module shows better operating condition at high temperature of 0.62% which is 10% higher than polycrystalline silicon module. It can be seen that amorphous module has much higher fill factor (FF) at higher temperature and a decrease with decrease in temperature. This is due to the fact that output power of amorphous module does not vary much with increase of module temperature.

CONCLUSION

Two different commercially available modules have been tested at outdoor conditions in Edo State Institute of Technology and management, Usen during the month of January to April, 2016. A custom made setup was used to determine the characteristic parameters of the PV under study the results reveals that output power of module varies linearly with temperature.

Amorphous module has shown 10% higher daily average fill factor than polycrystalline efficiency of polycrystalline was 25.5% which was higher than amorphous module under study. Furthermore, result depict that the module efficiency increases with increase in module temperature. Amorphous module has shown the higher fill factor (FF) ratio 0.62 when compared with polycrystalline module of 0.55.

Usen community has a favourable climate for implementation of photovoltaic technology with long sunshine hour at high isolation level. Due to the capability of better in low light condition and having high fill factor (FF), amorphous module is found to be the most suitable solar energy system in Usen community and its surrounding regions.

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NOMENCLATURE

Am	-	air mass	I_{max}	-	Maximum current [A]
Aa	-	active area of module [m^2]	I_{sc}	-	Short circuit current [A]
a-Si	-	amorphous silicon module	PoA	-	Plane of array
p-Si	-	polycrystalline silicon module	P_{max}	-	Maximum power
E	-	solar irradiance [W/m^2]	E_D	-	direct solar irradiance [W/m^2]
STC	-	Standard test condition	V_{max}	-	Maximum voltage [V]
δ	-	angle of tilt with horizontal	η_m	-	module efficiency
V_{oc}	-	open circuit voltage [V]	Pv	-	photovoltaic
E_H	-	solar irradiance at horizontal surface [W/m^2]			