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A Comparative Analysis of the Performance of Polycrystalline and Monocrystalline PV Cells Under Different Temperation Conditions: Case Study of Uromi Community, Edo State, Nigeria.

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ABSTRACT

An outdoor experimental study was carried out to investigate and compare the performance of two commercially available photovoltaic modules (polycrystalline and Monocrystalline) under the effect of temperature change in Uromi Community, Edo state for the months of November, 2024 through March, 2025. Maximum power, module efficiency, and fill factor were calculated for each module and comparison was presented. Results show that polycrystalline module perform better at high irradiance and showed poor performance in low irradiance conditions. Monocrystalline solar module show a performance in low light condition and having high fill factor (FF). Polycrystalline photovoltaic module was found to be more efficient, having module efficiency of 13.5 percent higher than that of monocrystalline module. As a result of better performance in low solar irradiance, monocrystalline solar module has shown daily average fill factor of 0.62 which was higher than polycrystalline module under study.

Keywords. Photovoltaic, Polycrystalline, monocrystalline, efficiency, fill factor

1.0 INTRODUCTION

Photovoltaic technology clearly offers tremendous environmental benefits in that it requires no fuel and producing no emissions or other waste beyond that inherent in manufacturing process. The adaptation of thin film solar modules in many applications is growing in last few decades due to their low cost and manufacturing technology. Also, photovoltaic have proven to be economical for a wide range of applications that have traditionally relied on diesel generator. The advantages that photovoltaic have over competing power source options are that they have no moving parts and produce power silently. They are non-polluting with no detectable emissions or odours. They can be stand-alone systems that reliably operate unattended for long periods, and requires no connection to existing power source or fuel supply. It consume no fossil fuel and their fuel is abundant and free.

Unfortunately, solar cells are still far too expensive to produce a significant fraction of the world energy needs. The basic requirement of photovoltaic power generation system in any geological location is to have accurate estimation of its performance at outdoor operating conditions. The information given by the manufactures of a PV module is based on standard test condition (irradiance 1000W/M^2, module temperature 25^{o}c and air mass (AM1.5). Electrical properties of a PV devices comprises of seven parameters: open circuit voltage, short circuit current, maximum voltage, maximum current, maximum power, conversion of efficiency and fill factor. These parameters measured at standard test condition are supplied by the manufacturer. The results may not agree with the actual local operating condition due to variations of environmental parameters (Fuentes et al, 2007).

Carr and Pryor (2004) reported the performance comparison of five different types of PV modules including crystalline silicon(C-Si), C-Si modules with laser grooved buried contact, polycrystalline silicon (P-Si), triple junction amorphous silicon and copper indium diselenide, PV modules for three consecutive days in Malaysia. They found that copper indium diselenide PV module has performance ratioof1.09 which was the highest amongst the four tested, PV modules. Ahmed et al, (1997) investigated the outdoor performance of amorphous silicon and polycrystalline silicon modules and concluded that amorphous silicon has high efficiency and output power during summer time and it was opposite of polycrystalline silicon module.

The performance of PV module is affected by environmental factors including wind speed and direction, dust accumulation, humidity etc. Mani and Pillai (2010) reported the 32 reduction in performance of PV module in KSA during 8-months due to the dust accumulation. Jiang et al, (2011) investigated the effect of dust deposition using a test chamber and solar simulator in laboratory and found a decrease in module efficiency up to 26 for dust accumulation of 22g/m^2. Gossens and Kerschaever (1999) investigated the effect of air borne dust and wind speed on the performance of PV modules. They found that these factors have significant effect on the PV module performance.

In this research an experimental investigations and analysis of results of temperature changes obtained from outdoor testing of polycrystalline and monocrystalline PV modules for the months of November, 2024 through March, 2025 in Uromi Community, Edo State is reported.

2.0 MATERIALS AND METHODS

2.1 MATERIALS

A. The photovoltaic system

Two different modules of PV panels arranged in a series-parallel connection and tested.

- A PV module which has solar cells made of polycrystalline silicon
- A PV module with solar cells made of monocrystalline silicon

Orientation and inclination angle of the solar panel significantly affect efficiency and output. The two tested panel were installed on the same frame to ensure a similar inclination angle for both PV modules. Best orientation of the PV panels is to the south in Uromi to increase total energy incident on the collector surface during day light. The PV panels were placed to face south at tilt angle of 15^o as Uromi has (Latitude 6.59^{o}N, Longitude 5.50^{o}E).

B. Battery Storage

PV systems require energy storage to store the generated electricity during day light which can be used when needed. Most used battery types are lead-calcium and lead-antimony. Nickel-cadmium batteries are also used particularly if battery is subjected to a range of temperatures. The changing nature of solar radiation requires batteries that can undergo charge and discharge cycle without damage. The amount of battery capacity that can be discharged without damaging the battery depends on battery type. Depending on site conditions and presence of backup generator, battery banks are sized to provide a period of system autonomy ranging from a few days to a couple of weeks. Batteries are distinguished by their voltage, which for most applications is a recurrent of 12V. Battery capacity is expressed in Ampere Hour (Ah)

C. Inverter

Inverters are power electronic devices used in various photovoltaic systems to convert direct current to 50H_z alternating current conforming to the grid. The output power of tested photovoltaic panels in the present investigation was measured by calculating output current and voltage using an ohmmeter.

D. Pyranometer

A pyranometer is used to measure broadband solar irradiance on a plane surface and solar irradiance flux density (W/m^2) of an angle view of 180^o.

E. Speedometer

A speedometer is used to collect and record air velocity, temperature, humidity and wet bulb.

2.2 Method (Experimental Approach):

The experiments were performed at the front of Electrical Department in the southern Uromi Community (Latitude 6.59^{o}N, Lognitude 5.50^{o}E) as shown Fig.1 and 2

Fig 1. Experimental setup of the modules

Fig 2. Experimental Readings of the modules

The place of the solar module is chosen such that a shadow will not be cast into solar module at anytime during the test period. Measurement were taken hourly from 7am to 6pm. The two modules under study were mounted on a south facing rack at fixed tilt angle of 15^o with horizontal (at a nearly optimum tilt angle at this site during November,2024 through March, 2025). The plane of array (POA) global solar irradiance was measured using a pyranometer TBQ-2 (sensitivity 11.36V/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 modules was connected to a separate circuit and measurements of all modules were taken at the same time with different temperature levels. I_{max}, V_{max}, and P_{max} were obtained. The other related parameters including maximum power, fill factor, normalized output efficiency, module conversion efficiency and performance ratio were calculated to understand the behavior of the solar module, using the following equations:

Maximum power (P_{max}) = V_{max} x I_{max} (2.1)

Fill factor (FF) = (V_{max}x I_{max})/(V_{oc}x I_{se})$_c$ (2.2)

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

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

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

Direct solar irradiance $(E_D) = E_H / Cos(\sigma)$ (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.

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

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

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

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

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

Where:

T_w = working temperature

dT

3.0 RESULTS AND DISCUSSIONS

During the study, the variation in daily hourly temperature is as shown in Tables 1 and 2, the variation of hourly power output with module temperature was equally shown and the output of polycrystalline silicon module at high temperature showed a higher deviation (decrement) from linear trend than monocrystalline silicon module. This shows that monocrystalline silicon module withstands better performance at high module temperature than polycrystalline silicon module.

For comparison purpose, the module efficiency was used. This is the ratio of the total solar energy incident on a module surface based on its total active areas. The module efficiency was higher at outdoor conditions as compare to their value at standard temperature condition (STC) due to varying environmental conditions. Monocrystalline silicon module showed high decrease in module efficiency at high irradiance and this is due to less variation and stabilization of output at high irradiance level. The lowest modules efficiency was examined at 7am corresponding to peak temperature level.

As shown in Tables 1and2, PV shows a better efficiency at high temperature and it can be seen that polycrystalline module was superior in terms of daily average module efficiency compared to monocrystalline module. The reason is that amorphous silicon has 66.6% less rated power and larger area than polycrystalline module.

This finding is in line with published results of Amin et al, (2009). In comparison with the variation in module and ambient temperature with time, the temperature of the two module stayed above the ambient temperature unless 7am and near the evening and increases with increase in irradiance. The increase in module temperature with irradiance is due to the production of heat during the photovoltaic reaction. In the evening after 4pm, the module temperature reaches close to ambient temperature because of sudden decrease in irradiance which significantly slow down the photovoltaic process and hence decrease the module temperature.

In order to determine the operating behavior of the different PV modules, hourly fill factor (FF) of module was examined in the study. Table 1 and 2 shown the hourly (FF) of the two modules under test. In general, the fill factor with temperature was significant in the case of monocrystalline silicon. Monocrystalline silicon module shows better operating condition at high temperature of 0.62 which is 7% higher than polycrystalline silicon module. It can be seen that monocrystalline module has much higher fill factor (FF) at high temperature which decreases with decrease in temperature. This is due to the fact that the output power of monocrystalline module do not much vary with increase in module temperature.

Table 1: Average measured values for polycrystalline silicon for the month of November,2024 through March, 2025.

Daily hourly	Temp ^oC	Voc (V)	I_{sc} (A)	V_{max}(A)	I_{max}	P_{max} (W)	FF	Efficiency
7.00	1400	4.63	1.82	3.68	1.25	4.60	0.55	19.00
8.00	20.00	16.20	6.35	12.90	4.36	56.24	0.55	23.00
9.00	21.00	17.48	6.85	13.92	4.70	65.42	0.55	23.00
10.00	24.00	20.70	8.11	16.48	5.57	91.79	0.55	32.00
11.00	24.00	20.70	8.11	16.48	5.57	91.79	0.55	32.00
12.00	32.00	26.33	10.31	20.97	7.08	148.47	0.55	51.00
1.00	31.00	25.78	10.10	20.53	6.93	142.27	0.55	49.00
2.00	32.00	26.33	10.31	20.97	7.08	148.47	0.55	51.00
3.00	32.00	26.33	10.31	20.97	7.08	148.47	0.55	51.00
4.00	31.00	25.78	10.11	20.53	6.93	142.27	0.55	49.00
5.00	30.00	25.20	9.87	20.07	6.68	136.07	0.55	47.00
6.00	25.00	21.60	8.46	17.20	5.81	99.93	0.55	34.00

Table 2: Average measured values for Monocrystalline silicon for the month of November,2024 through March, 2025.

Daily hourly	Temp ºC	Voc (V)	I_{sc} (A)	V_{max}(A)	I_{max}	P_{max} (W)	FF	Efficiency
7.00	1400	12.68	0.71	9.69	0.60	5.81	0.64	0.70
8.00	20.00	44.40	2.51	33.75	2.04	08.85	0.62	9.20
9.00	21.00	47.32	2.70	36.44	2.17	79.07	0.62	10.60
10.00	24.00	56.73	3.20	43.12	2.58	111.25	0.61	14.90
11.00	24.00	56.73	3.20	43.12	2.58	111.25	0.61	14.90
12.00	32.00	72.16	4.07	54.87	3.25	178.33	0.61	24.00
1.00	31.00	70.66	3.99	53.70	3.23	173.45	0.61	23.00
2.00	32.00	72.16	4.07	54.87	3.25	178.33	0.61	24.00
3.00	32.00	72.16	4.07	54.87	3.25	178.33	0.61	24.00
4.00	31.00	70.66	3.99	53.70	3.23	173.45	0.61	23.00
5.00	30.00	69.07	3.90	52.50	3.14	164.85	0.61	22.00
6.00	25.00	59.20	3.34	45.00	2.69	121.05	0.61	16.00

4.0 CONCLUSION AND RECOMMENDATION

4.1 Conclusion

Two different commercially available modules have been tested at outdoor conditions in Uromi, Community, Edo State during the month of November,2024 through March, 2025. A custom made setup was used to determine the characteristic parameters of the PV under study. The result reveals that output power of module varies linearly with temperature. Monocrystalline module has shown 7% higher daily average fill factor than polycrystalline module due to low irradiance condition, although having much lower installed capacity than polycrystalline module.

The average efficiency of polycrystalline module was 25.4% which was higher than monocrystalline module under study. Furthermore, result depicts that the module efficiency increase with increase in module temperature. Monocrystalline module has shown the highest fill factor (FF) ratio 0.61 when compared with polycrystalline module of 0.55.

4.2 Recommendation:

Uromi community, has a favourable climate for implementation of photovoltaic technology with long sunshine hour at high isolation level. With the capability of being better in low light condition and having high fill factor (FF) monocrystalline module was found to be the most suitable solar energy system in Uromi and its surrounding regions. It is thus hereby recommended to that effect.

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