FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 7 No. 4, August, 2023, pp 36 - 46
DOI: https://doi.org/10.33003/fjs-2023-0704-1928

PERFORMANCE EVALUATION OF THE IMPACTS OF METROLOGICAL PARAMETERS ON CRYSTALLINE AND AMORPHOUS MODULES AT MINNA, NIGERIA

[*1]Ahmed Mohammed, [1]Abubakar Adamu, [2]Ezenwora Joel Aghaegbunam and [1]Moses Ukiri

[1]Department of Physics, School of Secondary Education (Sciences), Federal College of Education (Technical), Gusau-Nigeria.
[2]Department of Physics, Federal University of Technology, Minna-Nigeria

*Corresponding authors' email:

ABSTRACT

Photovoltaic (PV) module performance is rated under standard test conditions (STC) i.e. irradiance of 1000 W/m², solar spectrum of Air Mass 1.5 and module temperature at 25°C. Manufacturers of photovoltaic modules typically provide the ratings at only one operating condition i.e. STC. However, PV module operates over a large range of environmental conditions at the field. So the manufacturer's information is not sufficient to determine the actual performance of the module at field. Optimization of solar energy is affected by so many factors ranging from conversion efficiency of PV module to local metrological conditions. The research work therefore, evaluates the performance of three PV technologies using performance ratio. Metrological parameters such as solar radiation intensity, wind speed, relative humidity, and air temperature were measured simultaneously with the output electrical parameters from the three modules exposed to field test using metrological sensors and a CR1000 software-based data logging system with computer interface attached to the modules. Four years consecutives metrological and modules output data's were collected from the modules and analyzed. The findings indicates that metrological parameters fluctuate non-linear with the modules output, under this conditions the trends as measured by the output power revealed that polycrystalline module has a better performance than amorphous module followed by mono-crystalline module in this experiment. The paper recommends the need to mitigate substandard modules entering our market through appropriate monitoring agencies and the setting of solar module laboratory for locally production of solar modules that would captures our local metrological parameters towards greater efficiency.

Keywords: Electrical and metrological parameters, performance ratio, Photovoltaic module

INTRODUCTION

Conventional fossil fuels such as oil, coal and natural gas are extensively used as the primary energy source (Khaled *et al.*, 2021) in industry, manufacturing company and for cooking especially in developing country. However, they are limited and have an environmental risk associated with extracting, transporting and utilizing them. Approximately 66% of the global carbon dioxide and other greenhouse gases (GHG) emissions are generated from fossil sources (Wang *et al.*, 2017).

In contrast, renewable energy, especially solar, is available everywhere, is non- pollutant and has minimal impact on the environment, making it most suitable for the sustainable energy source (Khaled *et al.*, 2021). The renewable energy resources are becoming the mainstream energy resource (Twidel, J. and Weir, T., 2015). Among these renewable energy resources, the solar PV is the most promising resource (Hill, R., 1999). PV energy now holds an important position in the renewable energy market. PV production has been increasing by an average of 20% each year since 2002, making it a fast-growing energy technology. The global cumulative PV installations have exceeded 21GW (Martinot *et al.*, 2009). Over the past decade, the PV market has experienced unprecedented growth. Particularly in the over the past year, the PV market has reached a cumulative installed capacity of roughly 40 GW world-wide, with an annual added capacity of 16.6 GW (EPIA, 2011). PV installed capacity reached 102.2 GW at the end of year 2012 an addition of 31.1 GW in 2012 (Roney, 2013). PV generation systems have two major problems: the conversion efficiency of electric power generation is very low (9 - 17%) especially under low irradiation conditions, and the amount of electric power generated by solar array changes continuously with weather conditions

Weather parameters such as solar radiation, ambient temperature, relative humidity, wind speed, air pressure and sunshine duration are accepted as dependable and widely variable renewable energy resources (Duby *et al.*, 2013, Ebhota and Tabakov, 2022). These data play a very important role in PV systems (Faranda and Leva, 2008). Varying metrological conditions has impacts on the performance of PV modules, as metrological parameters influences the output of the solar module in the field use. Solar cell degradation is the result of various operating conditions; temperature is one of most important factors controlling outdoor electrical performance of PV module. In a similar work, Olayinka *et al.*, (2018) show that the intensity of the sun has a significant effect on the output of solar panel, but this is been interrupted by meteorological factors interacting with solar radiation from getting to the panel.

The conversion of solar energy to electrical energy through photovoltaic cells is now of great interest not only to developed nations but developing nations (Mekhilef *et al.*, 2012). However, access to solar and other renewable energy technologies is changing the way we create and consume electricity; it seems that not everyone is getting the same level of opportunity. In Malawi, and other places in Africa, the renewable energy markets are flooded with an extraordinarily poor quality of imported solar PV equipment. The financial burden of early product failures on this disadvantaged population has the undesirable effect of constraining the rate of electrification (ESI Africa, 2016).

The success of these PV technologies in a particular environment and major factors it depends on is the reasons for these studies, therefore the main aim of this work is to evaluate the performance the of mono-crystalline, polycrystalline and amorphous modules influenced by metrological parameters, specifically irradiance, humidity, air and module temperature at Minna, Niger state-Nigeria.

MATERIALS AND METHODS

Area of Study

The study area is located in the latitude 09°37N′ and longitude 06°32′E, at altitude 249 meters above level and is one of the Northern states of Nigeria that lies partially, within the semi Sahel belt of West Africa. The climate of this zone is characterized by two distinct well defined seasons, namely wet (or rainy) and dry seasons (also as Hamattern). These seasons correspond to northern hemisphere summer and winter respectively (Ezenwora *et al.,* 2011).

Materials

The materials used for this study are solar panel with the following specifications:

Table 1: Specifications for solar panel

Electrical parameters	Mono-crystalline silicon	Polycrystalline silicon	Amorphous
Model	SPL 10 - 12	SPL 10 - 12	SPL 10 - 12
Maximum rated power P_{max} (Watts)	10.0	10.0	10.0
Maximum rated Voltage V_{max} (Volts)	17.4	17.4	17.4
Maximum rated current I_{max} (Amps)	0.59	0.57	0.55
Open circuit voltage V_{oc} (Voltage)	21.6	21.6	21.2
Short circuit current I_{sc} (Amperes)	0.65	0.67	0.62
Fill factor	0.73	0.69	0.73

Monitoring stage: The performance response of the silicon PV modules to ambient weather parameters, such as solar irradiance, temperature, wind speed and relative humidity, was monitored in environment of Minna, Niger State, Nigeria, using a CR1000 software-based data logging system with computer interface.

Procedure: The PV modules under test, and meteorological sensors, were installed on support structure at the same test plane, at surface level, to ensure adequate exposure to insolation and enough wind speed since wind speed is proportional to height. The elevation will also ensure that the system is free from any shading and protected from damage or interference by any person. The modules were tilted at latitude of Minna, Niger State, Nigeria to horizontal and south- facing to ensure maximum insolation. The global solar radiations, ambient temperature, relative humidity, wind speed and module temperature were monitored using their respective sensors incorporated in the CR1000 Campbell Scientific data logger with measurement and control module. Also data points that represent low irradiance conditions associated with late evening time from 6pm down and night measurements that might not contribute significant value to the overall data of interest were filtered out.

Data collection: The experiment was performed for four years and data measurements were taken from 8.00am to 6.00pm each day continuously for a period of four years. The sensor was connected directly to the CR1000 Campbell Scientific data logger, while the modules were connected to the logger via a voltage divider. Instantaneous data collections were performed by the logger at an interval of 5 minutes. Data download at the data acquisition site was performed every seven days to ensure effective and close monitoring of the data acquisition system (DAS). At the end of each month, hourly, daily and monthly averages of each of the parameters-solar radiation, wind speed, ambient and module temperatures, and the output response variables (open-circuit voltage, V_{OC}, short-circuit current, I_{SC}, voltage at maximum power, V_{max}, current at maximum power, I_{max}, efficiency, Eff and fill factor, FF) of the PV modules were obtained.

RESULTS AND DISCUSSION

The four years metrological data's collected and measured output electrical parameters of the three modules in a field test outside physics department of FUT, Minna, are displayed below:

1ST Year of module exposure uu

Table 2: Monthly average of ambient parameters and electrical performance responses for mono-crystalline silicon module

Month	Wind speed (ms^{-1})	Air temperature (ºC)	Module temperature (ºC)	Relative Humidity %	Irradiance ($W m^{-2}$)	P(W)	P_{max} (W)	I_{SC} (A)	V_{OC} (Volt)	I_{max} (A)	V_{max} (Volt)
January	2.4950	26.1980	32.9633	0.6441	536.0070	0.5023	0.3681	1.6893	9.2996	0.0925	4.7572
February	1.4585	33.7852	42.4327	29.9863	549.2464	0.4192	0.3345	1.6379	8.3931	0.0895	4.4766
March	2.0693	34.1434	41.7248	22.1725	557.6410	0.3678	0.3217	1.5710	7.9828	0.0856	4.4568
April	9.6900	33.5586	41.6429	34.8324	518.8353	0.4449	0.3356	1.6398	8.5611	0.0897	4.5826
May	1.8865	32.4723	40.0033	52.7410	539.6129	0.4754	0.3415	1.6755	8.7506	0.0918	4.5140
June	1.7107	28.4986	33.3939	71.3828	401.7963	0.2042	0.2239	1.1947	5.5261	0.0646	3.4670
July	1.5576	29.0915	36.1904	69.1475	470.2297	0.3370	0.2741	1.4016	6.9285	0.0763	3.8377
August	1.4830	26.7596	31.7792	81.1056	318.3472	0.1866	0.1870	1.0852	4.7367	0.0587	2.9233
September	1.4403	27.6574	34.6387	74.7902	384.2647	0.3123	0.2483	1.3177	6.3252	0.0721	3.6039
October	1.4136	29.1799	37.8225	73.5642	465.1116	0.5536	0.3395	1.6849	8.8538	0.0932	4.4181
November	1.3617	32.0261	41.6169	43.2111	540.9504	0.7850	0.4317	2.0510	11.3631	0.1140	4.9865
December	1.9984	29.5782	37.6729	21.2254	513.3893	0.5231	0.3642	1.7534	9.4502	0.0962	4.7948

Table 3: Monthly average of ambient parameters and electrical performance responses for polycrystalline silicon module

Month	Wind speed (ms^{-1})	Air temperature (ºC)	Module temperature (ºC)	Relative Humidity %	Irradiance ($W m^{-2}$)	P(W)	P_{max} (W)	I_{SC} (A)	V_{OC} (Volt)	I_{max} (A)	V_{max} (Volt)
January	2.4950	26.1980	30.1542	0.6441	536.0070	2.1090	0.7328	2.5603	18.7636	0.1469	6.0064
February	1.4585	33.7852	39.3944	29.9863	549.2464	2.0751	0.7032	2.5667	18.3368	0.1472	5.7776
March	2.0693	34.1434	39.6828	22.1725	557.6410	1.8578	0.6684	2.4454	17.2376	0.1393	5.8446
April	9.6900	33.5586	39.2369	34.8324	518.8353	2.1794	0.7387	2.6073	19.0108	0.1497	6.1696
May	1.8865	32.4723	38.7181	52.7410	539.6129	2.4346	0.7856	2.7529	20.2481	0.1588	6.3042
June	1.7107	28.4986	32.7979	71.3828	401.7963	1.4728	0.5518	2.0905	14.1178	0.1180	5.4861
July	1.5576	29.0915	34.2069	69.1475	470.2297	1.8894	0.6467	2.3911	16.4882	0.1366	5.8270
August	1.4830	26.7596	30.3634	81.1056	318.3472	1.1043	0.4477	1.8343	11.3436	0.1026	5.1221
September	1.4403	27.6574	32.6869	74.7902	384.2647	0.0031	0.0023	0.0722	0.1681	0.0038	0.0492
October	1.4136	29.1799	34.8193	73.5642	465.1116	2.3834	0.7391	2.5635	18.9324	0.1480	5.9474
November	1.3617	32.0261	37.3396	43.2111	540.9504	3.0176	0.8816	2.9892	22.8164	0.1746	6.1265
December	1.9984	29.5782	34.5265	21.2254	513.3893	1.9332	0.6953	2.4625	17.7071	0.1399	5.8446

Table 4: Monthly average of ambient parameters and electrical performance responses for amorphous module

uMonth	Wind speed (ms^{-1})	Air temperature (ºC)	Module temperature (ºC)	Relative Humidity %	Irradiance (W m^{-2})	P(W)	P_{max} (W)	I_{SC} (A)	V_{OC} (Volt)	I_{max} (A)	V_{max} (Volt)
January	2.4950	26.1980	30.1542	0.6441	536.0070	0.2621	0.2253	0.8534	18.7636	0.0453	4.3611
February	1.4585	33.7852	39.3944	29.9863	549.2464	0.2476	0.2108	0.8494	18.3368	0.0451	4.0829
March	2.0693	34.1434	39.6828	22.1725	557.6410	0.1758	0.1458	0.7769	17.2376	0.0412	2.8183
April	9.69	33.5u586	39.2369	34.8324	518.8353	0.1467	0.1198	07307	19.0107	0.0387	2.3213
May	1.8865	32.4723	38.7181	52.7410	539.6129	0.1848	0.1525	0.7910	20.2481	0.0419	2.9545
June	1.7107	28.4986	32.7979	71.3828	401.7963	0.0834	0.0644	0.5840	14.1178	0.0309	1.2521
July	1.5576	29.0915	34.2069	69.1475	470.2297	0.1317	0.1073	0.6709	16.4782	0.0356	2.0788
August	1.4830	26.7596	30.3634	81.1056	318.3472	0.0590	0.0434	0.5180	11.3436	0.0274	0.8451
September	1.4403	27.6574	32.6869	74.7902	384.2647	0.1088	0.0840	0.6254	0.1681	0.0332	1.6272
October	1.4136	29.1799	34.8193	73.5642	465.1116	0.2140	0.1727	0.8211	18.9324	0.0438	3.3419
November	1.3617	32.0261	37.3396	43.2111	540.9504	0.3618	0.3086	1.0137	22.8164	0.0541	5.9734
December	1.9984	29.5782	34.5265	21.2254	513.3893	0.2130	0.1781	0.8278	17.7071	0.0439	3.4454

2ND Year of module exposure

Table 5: Monthly average of ambient parameters and electrical performance responses for mono-crystalline silicon module

Month	Wind speed (ms^{-1})	Air temperature (ºC)	Module temperature (ºC)	Relative Humidity %	Irradiance (W m^{-2})	P(W)	P_{max} (W)	I_{SC} (A)	V_{OC} (Volt)	I_{max} (A)	V_{max} (Volt)
January	1.9948	31.4005	38.8291	15.5826	522.6807	0.6885	0.3477	1.6868	8.8461	0.0923	4.6922
February	1.7418	32.2667	40.4086	12.3984	552.9501	0.6760	0.3468	1.6915	8.7588	0.0925	4.6651
March	1.7718	33.5649	41.2108	45.7708	493.067	0.4752	0.2636	1.3913	6.6218	0.0757	3.8522
April	1.8257	33.4082	42.8387	53.8328	573.0570	0.8492	0.3755	1.8768	9.9012	0.1038	4.7623
May	1.6333	32.3620	40.5435	59.2942	518.9635	0.6395	0.3151	1.6320	8.1795	0.0893	4.4267
June	1.7303	29.5716	34.6457	70.9246	443.5784	0.4609	0.2587	1.3810	6.5219	0.0748	3.9689
July	1.5624	28.5575	32.5590	73.8882	413.1334	0.4261	0.2383	1.3140	6.0555	0.0710	3.7720
August	1.6136	27.1533	30.7639	79.1410	336.3725	0.3312	0.1866	1.1273	4.7822	0.0610	3.0161
September	1.2606	28.4023	33.5346	75.0007	420.1251	0.5837	0.2784	1.4684	7.2395	0.0803	3.9164
uOctober	1.3637	29.6715	37.5273	73.1799	497.7644	0.8295	0.3609	1.8149	9.5584	0.1003	4.7293
November	0.8718	32.7361	41.7204	41.2770	531.2346	0.9578	0.4010	2.0391	10.8389	0.1130	4.9804
December	0.7643	33.7588	42.1233	24.3867	472.1558	0.6715	0.3243	1.7320	8.5406	0.0949	4.4835

Table 6: Monthly average of ambient parameters and electrical performance responses for polycrystalline silicon module

Month	Wind speed (ms^{-1})	Air temperature (ºC)	Module temperature (ºC)	Relative Humidity %	Irradiance ($W\ m^{-2}$)	P(W)	P_{max} (W)	I_{SC} (A)	V_{OC} (Volt)	I_{max} (A)	V_{max} (Volt)
January	1.9948	31.4005	35.8012	15.5826	522.6807	1.7284	0.6463	2.3598	16.4375	0.1334	5.7117
February	1.7418	3u2.2667	38.2415	12.3984	552.9501	1.6982	0.6381	2.3602	16.3488	0.1332	5.7014
March	1.7718	33.56u49	38.7533	45.7708	493.067	1.2170	0.4973	1.9680	12.6487	0.1102	5.1077
April	1.8257	33.4082	40.2097	53.8328	573.0570	2.6432	0.8193	2.8740	21.0712	0.1670	6.1355
May	1.6333	32.3620	37.8648	59.2942	518.9635	2.0324	0.7087	2.5336	18.0185	0.1445	6.1538
June	1.7303	29.5716	33.6686	70.9246	443.5784	1.5761	0.6101	2.2423	15.3968	0.1264	6.1678
July	1.5624	28.5575	33.0503	73.8882	413.1334	1.3804	0.5540	2.1189	13.9106	0.1193	5.8462
August	1.6136	27.1533	30.5610	79.1410	336.3725	1.0743	0.4574	1.8045	11.4546	0.1006	5.2076
September	1.2606	28.4023	32.7675	75.0007	420.1251	0.0021	0.0016	0.0731	0.1581	0.0039	0.0375
October	1.3637	29.6715	35.4434	73.1799	497.7644	2.5211	0.7926	2.6732	20.1792	0.1545	6.0666
November	0.8718	32.7361	37.1384	41.2770	53LU1.2346	2.7338	0.8579	2.9098	21.9015	0.1684	6.2435
December	0.7643	33.7588	36.9407	24.3867	472.1558	1.8878	0.6802	2.4504	17.2877	0.1392	5.7123

Table 7: Monthly average of ambient parameters and electrical performance responses for amorphous module

Month	Wind speed (ms^{-1})	Air temperature (ºC)	Module temperature (ºC)	Relative Humidity %	Irradiance ($W\ m^{-2}$)	P(W)	P_{max} (W)	I_{SC} (A)	V_{OC} (Volt)	I_{max} (A)	V_{max} (Volt)
January	1.9948	31.4005	34.7601	15.5826	522.6807	0.1529	0.1237	0.7601	2.9970	0.0402	2.3934
February	1.7418	32.2667	37.4161	12.3984	552.9501	0.0858	0.0613	0.7031	1.7499	0.0371	1.1880
March	1.7718	33.5649	37.5631	45.7708	493.067	0.0073	0.0191	-0.7296	0.6951	0.0300	0.2737
April	1.8257	33.4082	38.4905	53.8328	573.0570	0.3957	0.3979	-0.1047	4.6890	0.0533	4.0165
May	1.6333	32.3620	36.5132	59.2942	518.9635	0.0487	0.0496	-0.0351	2.6970	0.0102	2.1426
June	1.7303	29.5716	33.2059	70.9246	443.5784	0.0530	0.0431	0.3737	1.6462	0.0309	1.1284
July	1.5624	28.5575	31.9518	73.8882	413.1334	0.0397	0.0328	0.2892	1.4842	0.0242	0.9854
August	1.6136	27.1533	29.6161	79.1410	336.3725	0.0353	0.0315	0.1808	1.0693	0.0149	0.6370
September	1.2606	28.4023	31.1012	75.0007	420.1251	0.1259	0.1168	0.2789	2.2338	0.0250	1.7160
October	1.3637	29.6715	33.3611	73.1799	497.7644	0.4293	0.3909	1.0408	3.6697	0.0720	3.0371
Nuovember	0.8718	32.7361	36.3387	41.2770	531.2346	0.7505	0.6667	2.1764	4.5454	0.1523	3.8572
December	0.7643	33.7588	38.0003	24.3867	472.1558	0.2131	0.1604	1.6767	1.7934	0.1282	1.2276

3RD Year of module exposure

Table 8: Monthly average of ambient parameters and electrical performance responses for mono-crystalline silicon module

Month	Wind speed (ms^{-1})	Air temperature (°C)	Module temperature (°C)	Relative Humidity %	Irradiance ($W m^{-2}$)	P(W)	P_{max} (W)	I_{SC} (A)	V_{OC} (Volt)	I_{max} (A)	V_{max} (Volt)
January	1.3750	30.609u9	37.7563	19.7318	447.115	0.5036	0.2751	1.4802	7.0297	0.0895	4.1013
February	1.9161	33.3204	38.9826	12.2438	501.754	0.4967	0.2680	1.4655	6.9367	0.0795	4.0568
March	1.5468	35.6907	42.5130	20.2008	582.774	0.5544	0.2976	1.6132	7.5911	0.0795	4.3336
April	1.7404	34.3794	41.1771	42.5847	493.627	0.4461	0.2454	1.3963	6.3220	0.0758	3.8493
May	1.7245	3u2.5396	38.9754	58.7398	503.208	0.5791	0.2842	1.5712	77.5348	0.0858	4.2289
June	1.3065	30.6924	38.6134	69.4635	470.795	0.4793	0.2586	1.4475	6.6782	0.0788	4.0583
July	1.4914	28.4018	35.4659	75.4718	404.115	0.4163	0.2203	1.2834	5.7608	0.0697	3.4874
August	1.1745	27.4128	34.3436	81.3037	342.325	0.3713	0.1930	1.1725	5.0631	0.0637	2.9937
September	1.2754	28.3957	37.9551	75.9694	453.146	0.6149	0.2793	1.5587	7.4621	0.0858	3.9843
October	1.0887	29.9467	39.8125	73.0639	469.633	0.7058	0.3062	1.6955	8.3249	0.0936	4.2368
November	0.6759	34.9916	46.5185	28.4889	527.346	0.5836	0.2474	1.7962	7.2262	0.0985	3.7802
December	1.0123	32.7269	42.9228	21.1274	443.511	0.4059	0.1952	1.4470	5.5296	0.0787	3.1939

Table 9: Monthly average of ambient parameters and electrical performance responses for polycrystalline silicon module

Month	Wind speed (ms^{-1})	Air temperature (°C)	Module temperature (°C)	Relative Humidity %	Irradiance ($W m^{-2}$)	P(W)	P_{max} (W)	I_{SC} (A)	V_{OC} (Volt)	I_{max} (A)	V_{max} (Volt)
January	1.3750	30.6099	34.7181	19.7318	447.115	1.4295	0.5713	2.1495	14.4709	0.1205	5.4789
February	1.9161	33.3204	37.3478	12.2438	501.754	1.0498	0.4712	1.8954	11.9457	0.1050	5.0944
March	1.5468	35.6907	41.2625	20.2008	582.774	1.0794	0.4853	1.9790	12.2279	0.1100	5.1993
April	1.7404	34.3794	39.9552	42.5847	493.627	0.9952	0.4466	1.8082	11.2129	0.1003	5.1142
May	1.7245	32.5396	37.0974	58.7398	503.208	1.7855	0.6548	2.3821	16.5713	0.1351	6.1704
June	1.3065	30.6924	35.4225	69.4635	470.795	1.5470	0.6025	2.2516	15.1914	0.1271	6.0971
July	1.4914	28.4018	32.6155	75.4718	404.115	1.2278	0.4850	1.8975	12.2606	0.1063	5.2080
August	1.1745	27.4128	31.3936	81.3037	342.325	1.2336	0.4732	1.8296	11.9345	0.1026	4.8431
September	1.2754	28.3957	34.2054	75.9694	453.146	1.9915	0.6679	2.3527	16.8631	0.1346	5.8431
October	1.0887	29.9467	35.4532	73.0639	469.633	2.2105	0.7142	2.4913	18.1632	0.1432	5.8366
Nouvember	0.6759	34.9916	40.2078	28.4889	527.346	2.2307	0.7519	2.6577	19.2523	0.1522	5.9762
December	1.0123	32.7269	38.0233	21.1274	443.511	1.3272	0.5380	2.0318	13.5242	0.1138	5.2080

Table 10: Monthly average of ambient parameters and electrical performance responses for amorphous module

Month	Wind speed (ms^{-1})	Air temperature (ºC)	Module temperature (ºC)	Relative Humidity %	Irradiance ($W\ m^{-2}$)	P(W)	$P_{m\ ax}$(W)	I_{SC} (A)	V_{OC} (Volt)	I_{max} (A)	V_{max} (Volt)
January	1.3750	30.6099u	34.8178	19.7318	447.115	0.0172	0.0032	0.5432	0.4976	0.0643	0.0449
February	1.9161	33.3204	37.3028	12.2438	501.754	0.0045	0.0016	0.0555	0.4149	0.0401	0.0222
March	1.5468	35.6907	40.4790	20.2008	582.774	-0.0084	0.0011	-0.5837	0.4361	0.0084	0.0232
April	1.7404	34.3794	38.5344	42.5847	493.627	-0.0606	0.0027	-2.4048	0.7423	-0.0845	0.3234
May	1.7245	32.5396	35.7046	58.7398	503.208	-0.0088	0.1022	-2.0518	3.2761	-0.0697	2.6704
June	1.3065	30.6924	34.1105	69.4635	470.795	0.2874	0.2672	0.5993	2.4224	0.0490	1.8606
July	1.4914	28.4018	30.9654	75.4718	404.115	0.2983	0.2617	1.2190	1.9396	0.0758	1.4322
August	1.1745	27.4128	29.9307	81.3037	342.325	0.1987	0.1733	0.8887	1.6267	0.0537	1.1627
September	1.2754	28.3957	32.1039	75.9694	453.146	0.3023	0.2709	0.8276	3.1933	0.0481	2.5765
October	1.0887	u29.9467	33.5576	73.0639	469.633	0.3763	0.3380	1.0179	3.9082	0.0620	3.2669
November	0.6759	34.9916	39.5359	28.4889	527.346	0.6066	0.5372	1.8645	4.5490	0.1290	3.8709
December	1.0123	32.7269	37.4512	21.1274	443.511	0.2467	0.2033	1.5077	2.0474	0.1115	1.5307

4^TH^ Year of module exposure

Table 11: Monthly average of ambient parameters and electrical performance responses for mono-crystalline silicon module

Month	Wind speed (ms^{-1})	Air temperature (ºC)	Module temperature (ºC)	Relative Humidity %	Irradiance ($W\ m^{-2}$)	P(W)	P_{max} (W)	I_{SC} (A)	V_{OC} (Volt)	I_{max} (A)	V_{max} (Volt)
January	0.7882	30.2346	40.4336	13.8481	482.7817	0.2832	0.1265	1.4354	4.0960	0.0778	2.5108
February	0.7406	34.5469	45.1531	19.5346	511.2109	0.0962	0.0379	0.7764	1.4936	0.0416	0.7339
March	1.1391	35.5716	47.6885	40.8809	594.2938	0.0265	0.0056	0.7261	0.5989	0.0384	0.1112
April	0.8856	35.2542	44.3796	47.2861	479.0825	0.0338	0.0103	0.7836	0.7210	0.0415	0.2049
May	1.8178	32.7688	40.6502	62.4699	465.0931	0.0804	0.0364	0.9559	1.4043	0.0508	0.7156
June	1.3410	32.2825	37.1677	68.1345	457.7439	0.1324	0.0781	1.0969	2.3063	0.0506	1.5381
July	1.2096	30.4673	33.6783	80.3988	403.6963	0.2861	0.1609	1.2048	4.4096	0.0651	2.9067
August	0.9372	28.9060	31.7903	83.1904	352.796	0.1897	0.1024	1.0670	3.0260	0.0575	1.9961
September	0.7438	28.8211	34.3291	80.3326	396.0436	0.2044	0.1149	1.1868	3.3120	0.0640	2.2554
October	0.6681	31.4008	39.6802	75.1541	489.6732	0.0994	0.0508	0.9842	1.6971	0.0525	0.9819
November	0.8100	35.4728	43.3583	52.5751	495.3418	0.0097	0.0017	0.4381	0.3268	0.0231	0.0385
Decuember	NO DATA RECORDED										

Table 12: Monthly average of ambient parameters and electrical performance responses for polycrystalline silicon module

Month	Wind speed (ms^{-1})	Air temperature (ºC)u	Module temperature (ºC)	Relative Humidity %	Irradiance ($W\ m^{-2}$)	P(W)	P_{max} (W)	I_{SC} (A)	V_{OC} (Volt)	I_{max} (A)	V_{max} (Volt)
January	0.7882	30.2346	35.3124	13.8481	482.7817	1.0228	0.4749	1.8616	11.8778	0.1030	5.2333
February	0.7406	34.5469	40.4174	19.5346	511.2109	1.2990	0.5393	2.1224	13.7206	0.1186	5.3927
March	1.1391	35.5716	41.9184	40.8809	594.2938	2.6317	0.8318	2.8954	21.2392	0.1675	6.1978
April	0.8856	35.2542	40.1033	47.2861	479.0825	1.5449	0.5962	2.2262	15.0912	0.1254	5.7121
May	1.8178	32.7688	36.9328	62.4699	465.0931	1.7277	0.6271	2.2758	15.8535	0.1291	5.7427
June	1.3410	32.2825	36.1251	68.1345	457.7439	1.5185	0.5802	2.1920	14.6156	0.1236	5.8704
July	1.2096	30.4673	33.1963	80.3988	403.6963	1.0151	0.4046	1.5290	10.1267	0.0858	4.2081
August	0.9372	28.9060	31.4026	83.1904	352.796	1.1920	0.4750	1.8426	11.9185	0.1031	5.3188
September	0.7438	28.8211	33.4641	80.3326	396.0436	1.4788	0.5505	2.1116	13.8318	0.1194	5.4218
October	0.6681	31.4008	35.2017	75.1541	489.6732	2.3524	0.7525	2.6350	19.1263	0.1522	6.0161
November	0.8100	35.4728	38.7592	52.5751	495.3418	2.2893	0.7572	2.6860	19.2594	0.1522	5.9522
December	NO DATA RECORDED										

Table 13: Monthly average of ambient parameters and electrical performance responses for amorphous module

Month	Wind speed (ms^{-1})	Air temperature (ºC)	Module temperature (ºC)	Relative Humidity %	Irradiance ($W\ m^{-2}$)	P(W)	P_{max}(W)	I_{SC} (A)	V_{OC} (Volt)	I_{max} (A)	V_{max} (Volt)
January	0.7882	30.2346	34.86	13.8481	482.7817	0.0136	0.0046	0.2934	0.5173	0.4473	0.0696
February	0.7406	34.5469	39.1714	19.5346	511.2109	0.0085	0.0045	0.0209	0.5286	0.0328	0.0641
March	1.1391	35.5716	39.2850	40.8809	594.2938	0.3230	0.3486	-0.6570	4.4782	0.0015	3.8193
April	0.8856	35.2542	37.5812	47.2861	479.0825	-0.0429	0.0232	-1.8454	1.7257	-0.0593	1.2132
May	1.8178	32.7688	35.2288	62.4699	465.0931	-0.0058	0.0818	-2.1075	2.5622	-0.0794	2.0035
June	1.3410	32.2825	34.6979	68.1345	457.7439	0.1418	0.1344	0.2304	2.3013	0.0235	1.7692
July	1.2096	30.4673	31.5383	80.3988	403.6963	0.0946	0.0789	0.5464	1.4726	0.0318	0.9819
August	0.9372	28.9060	29.8332	83.1904	352.796	0.1142	0.1007	0.5188	1.4559	0.0320	0.9962
September	0.7438	28.8211	31.9523	80.3326	396.0436	0.0155	0.0124	0.6713	0.2449	0.0392	0.1073
October	0.6681	31.4008	34.7489	75.1541	489.6732	0.2695	0.2461	0.5668	4.3190	0.0446	3.6302
November	0.8100	35.4728	38.8966	52.5751	495.3418	0.3145	0.2798	0.8422	4.7625	0.0696	4.0676
December	NO DATA RECORDED										

Results of the first year of modules field exposure is presented in tables above it indicates monthly average variation of air temperature, wind speed, relative humidity and irradiance for the period of January to December of each year respectively. According to Skoplaki and Palyvos (2009) several factors determine the performance of a PV system and can be categorized into two: meteorological and PV system configuration parameters. The PV system configuration parameters are PV cell, PV panel orientation, storage, and self-consumption. Other configuration parameters include interconnections, inverter, and controller.

For the first year of modules exposure, the wind speed peak in April recording 9.6900ms^{-1} having lowest value in November as 1.3617ms^{-1}, in the second year of modules exposure, wind speed was recorded high in the month of January (1.9948ms^{-1}) and least in the month of December (0.7643ms^{-1}), during the third year of modules exposure, wind speed has maximum and minimum values in February (1.9161ms^{-1}) and November (0.6759ms^{-1}) while in the fourth year of modules exposure, wind speed has minimum and maximum values in February and November with an amounts 0.7406ms^{-1} and 0.8100ms^{-1} respectively. Generally, the wind speed varies throughout the year except in the first year where the wind speed shows linear decreases from April to November. Literature study according to Olayinka, (2018) revealed that wind speed was inversely related to the ambient temperature, in this work the wind speed fluctuate throughout the days as ambient temperature fluctuates which confirmed Tanima *et al.*, (2014) reports where the wind speed fluctuates across the year. Conclusively, the PV modules, overall performance varied with the wind speed and fluctuates with the output electrical characteristics.

Humidity is a function of temperature as assumed by Xueyan *et al.,* (2013). Nigeria being solar region, humidity is expected to be high however, in this research work and in the first year of the module field test, relative humidity peak in August and has lowest value in January. In the second year, of field test, relative humidity recorded highest reading in the month of August and lowest reading in the month of February. For the third year, relative humidity increase from 12.2438% in February to 81.3037% in August while in fourth year, relative humidity varied from 13.8481% as measured in January to 83.1904% measured in August. Within the four years data collection, humidity in this locality shows nearly the same pattern with two minimum values corresponding to January, February and maximum values recorded in August respectively. The performance of PV technologies in connection with humidity indicates that output electrical parameters varied with the varying humidity.

Irradiance is the energy that strikes a unit horizontal area per unit wavelength interval per unit time (Wang *et al.*, 2008 and Liu L., 2009). The PV panel output significantly depends on solar power or solar irradiance as the solar resource is highly variable (Wang *et al.*, 2008 and Shah *et ual.*, 2015). In this data collection, irradiance peaked in March with lowest value in August during the first year of modules test. During the second year of modules test, irradiance was measured high in the month of April and less in the month of August. Third year record shows irradiance range from a minimum of 342.325 in August to a maximum of 582.774Wm^{-2} in March. Data collected in fourth year indicates irradiance raised from 352.7960Wm^{-2} measured in August to 594.2938Wm^{-2} measured in March. Irradiance displayed fairly regular pattern throughout the years recording minimum values in unique month, August and maximum values in the months of March and April respectively. Analyzing the behavior of irradiance with the module output shows that irradiance fluctuate throughout the year contrary to the report of Zogou, (2011) and Fouad *et al.,* (2017) where the output of the PV module increases as the irradiation does, furthermore, studies conducted by Mondol, (2017) and Khaled *et al.,* (2021) indicate solar irradiance have direct relationship with module current. Evaluating the performance of PV technologies due to impact of irradiance, shows that outputs electrical parameters are non-linear with the fluctuating irradiance. The main cause of the fluctuating irradiance values is cloudy situations (Wang *et al.,* 2020) which obstruct the incidence irradiance on the PV panels.

In the first year air and module temperature varies across the table during this period; air temperature record it highest value in March and lowest value in January with average temperature of 31^{o}C while module temperature has it highest value in February and list value in August with average temperature of 37^{o}C. For the second year air temperature was measured high in December and lowest in August with average temperature of 32^{o}C. Modules temperature peak high in the month of April and has the lowest value in the month of August with average temperature of 35^{o}C. In the third year, air temperature ranges from 27.4128 in August – 35.6907^{o}C in March having average temperature of 30^{o}C, modules temperature varies from 34.3436 in August – 46.5185^{o}C in November with average temperature of 32^{o}C, while in the fourth year air temperature shows highest value in March (35.5716^{o}C) has average temperature of 31^{o}C. Module temperature has peak value of 39^{o}C having average temperature of 38^{o}C. The results of the modules electrical output shows non-linear corresponding to fluctuating air and module temperature being dependent variables. The module output behavior in this research contradict the findings of Feroz *et al.,* (2023) and Narendra *et al.,* (2014) where temperature and voltage are inversely related and opposed to linear increase current due to decrease band gap, udecrease open circuit voltage due to increase reverse saturation current and decreases power with increase module temperature. On the performance of PV technologies influenced by air and module temperatures and considering the view of Feroz *et al.,* (2023) that temperature is crucial for the usage of PV modules in power generation, when module temperature rises, their performance suffers in addition, Griffith *et al.,* (1981) reports that efficiency drops by 0.03–0.05% for every 1 °C increase in temperature without cooling. The haphazard research outcome of these PVs influenced by temperatures did not support the above findings and opposed the work of Zouine *et al.,* (2018) where PV module output performance decreases with increasing temperature with the electrical power depend linearly on the operating temperature.

Performance ratio (PR) analysis of the three technologies

Considering tables in the first year field test, comparative performance studies of the three technologies shows that polycrystalline (Poly-cr) is more effective follow by mono-crystalline (mono-cr) and then amorphous crystalline (a-cr) modules with 63%, 31% and 15% for $P_{max,}$ in relation to $V_{oc,}$ (a-cr) displayed high effectiveness follow by (Poly-cr) and then (mono-cr) panel with their PR as 77, 75 and 37%, where V_{max} recorded 31, 24 and 17% PR for (Poly-cr), (mono-cr) and (a-cr) and I_{max} have 23, 15 and 7% PR for (Poly-cr), (mono-cr) and (a-cr) respectively.

In the case of second year performance studies of the three modules, indicates Poly-cr has higher PR follow by mono-cr and then a-cr with 61%, 31% and 17% for $P_{max,}$ in relation to $V_{oc,}$ Poly-cr displayed high effectiveness follow by mono-cr

and then a-cr panel with of 71, 37 and 12%, where V_{max} recorded 31, 25 and 11% for Poly-cr, mono-cr and a-cr and I_{max} have 22, 15 and 9% for Poly-cr, mono-cr and a-cr respectively.
Comparative performance studies of the three modules in the third year shows that Poly-cr is more effective follow by mono-cr and then a-cr modules with 57%, 26% and 18% for $P_{max,}$ in respect to $V_{oc,}$ Poly-ci recorded high effectiveness follow by mono-cr and then a-cr panel with their PR as 67, 58 and 10%, where for V_{max} 32, 22 and 9% PR was recorded for Poly-cr, mono-cr and a-cr and I_{max} have 21, 14 and 7% PR for Poly-cr, mono-cr and a-cr respectively.
Conversely PR studies of the three modules in the fourth year revealed that Poly-cr has better effectiveness follow by a-cr and then mono-cr modules with 60%, 12% and 7% for $P_{max,}$ in relation to $V_{oc,}$ Poly-ci recorded high effectiveness follow by a-cr and then mono-cr with their PR as 15, 11 and 10%, V_{max} measured 10, 7 and 3% PR for a-cr, mono-cr and then Poly-cr, wuhereas I_{max} have 10, 9 and 2% PR for a-cr, mono-cr and then Poly-cr, respectively.

CONCLUSION

In this research work, the impact of metrological condition on the three module technologies were investigated and the findings indicates that metrological parameters fluctuate non-linearly with the three modules output throughout the period of the module field exposure and under this conditions the trends as measured by the output electrical characteristics generally revealed that polycrystalline module in term of its performance ratio shows better performance than amorphous module then followed by mono-crystalline module in the locality. In order to produce module that function properly with local environmental conditions there is need to start production module in Nigeria. To achieve this, government funding in area of renewable energy and specifically solar electrification, solar laboratory station need put in place.

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