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Comparative Study of Photovoltaic Modules and Their Performance in the Tropics: A Case Study in Nigeria

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ABSTRACT
This field study was carried out in order to analyze and compare the performance of four commercially available photovoltaic (PV) modules (Polycrystalline silicon (P-Si), Triple Junction Amorphous silicon (A-Si), Monocrystalline Silicon (C-Si) and d Copper-Indium-Selenide (CIS)) in Lagos, Nigeria. This research was performed at outdoor conditions and a number of performance related parameters were collected simultaneously using data logger over a period of three consecutive days. Power output, module efficiency and performance ratio were evaluated using appropriate mathematical relations for each module and the effect of solar irradiance and module temperature on these parameters were investigated. Results shows that for a fixed orientation, the C-Si and P-Si PV modules perform better when they are under hot sun with average module efficiency of 11.83% and 9.16% respectively whereas the CIS and A-Si PV modules perform better when it is cloudy and have diffused sunshine with average module efficiency of 7.12% and 3.61% respectively. Furthermore, the efficiency of crystalline silicon PV modules has been found to drop when the temperature rises higher. This phenomenon does not appear in the CIS and a-Si PV modules, which shows that the performance of CIS and A-Si PV cells are better in terms of power efficiency in hot-humid environment. The overall performance ratio of p-Si, a-Si, c-Si and CIS is 0.923, 1.023, 0.900 and 1.065 respectively. It is observed from this study that better performance of a-Si and CIS photovoltaic modules are obtainable in Nigeria.
Keywords: renewable energy, photovoltaic module, efficiency, solar irradiance, performance ratio

1.0 INTRODUCTION

Renewable power generation can help countries meet their sustainable development goals through provision of access to cheap, clean, secure, reliable and affordable energy. Renewable energy has gone mainstream, accounting for the majority of capacity additions in power generation today. Tens of gigawatts of wind, hydropower and solar photovoltaic capacity are installed worldwide every year in a renewable energy (Dolf Gielen, 2012). In renewable energy sources, photovoltaic (PV) cells which are made up of semi-conductors like silicon (Si), selenium (Se), indium (In), cadmium (Cd), germanium (Ge), etc have attracted much attention because of their ability to convert solar energy directly to electrical energy. Individual photovoltaic cells combined together either connected in series or parallel to form a photovoltaic module or a solar panel (Onyenonachi, 2010).

According to Nowshad *et al*., (2009), the Earth receives about 10^{18} watts of power from the sun per year. This amount of power that is about 8.76 x 10^{18} joule/year is enough to cover the Earth's energy demand for over 1000 times. Also, according to Harris *et al*., (2005), to conduct a field study on performance of various PV modules, it is necessary to understand solar energy collection, its conversion into electricity, evaluation of electrical performance and the current efforts being made to improve conversion efficiency.

Extensive research in PV applications and performances in various regions of the globe have been undertaken covering a lot of photovoltaic system. Muhammad *et al*., (2014) conducted an experimental study on the performance measurements of photovoltaic modules during Winter months in Taxila, Pakistan. The results showed that the module parameters such as power output, module efficiency and performance ratio strongly depend on the solar irradiance and module temperature. The world photovoltaic (PV) cell and module technology production comprise mainly Poly-crystalline (p-Si), Mono-crystalline (c-Si) and Amorphous Silicon (a-Si). Amongst these, the use of a-Si PV modules has popularly been claimed to offer better performances than crystalline Modules in the hotter climate regions of the world (Sulaiman *et al*., 2009). Sulaiman *et al*., (2009) recorded that the field study conducted at Malaysia Solar Energy Research Institute found that the normalized power output per PV module operating array temperature for a-Si, p-Si and c-Si modules were 0.0370, 0.0225 and 0.0263 $^oC^{-1}$ with rated power of 62, 225 and 225 watts respectively at a solar irradiance value of 500 W/m^2. Carr and Pryor (2001), recorded that there are four important parameters which must be considered in order to calculate the quality of PV module. They are: the maximum voltage, maximum current and open circuit voltage.

2.1 MATERIALS AND METHODS

2.2 Materials Used

In this study, the Photovoltaic modules used were Poly-crystalline Silicon (p-Si), Triple Junction Amorphous silicon (a-Si), Mono-crystalline silicon (c-Si) and Copper-indium-Selenide (CIS). Table 1 shows the rated and measured values of Photovoltaic modules used in this study.

Table 1: Summary of rated and measured values of Photovoltaic modules used

Parameters	units	p-Si	**a-Si**	**c-Si**	**CIS**
		Rated Values			
Module model		BP265	USX64	BP275	EX-SOL40W
Maximum Power, P_{max}	W	65	64	75	40
Maximum Current, I_{max}	A	3.69	3.58	4.63	2.40
Maximum Voltage, V_{max}	V	17.60	16.50	17.20	60.60
Short Circuit Current, I_{sc}	A	3.99	4.80	4.87	2.68
Open Circuit Voltage, V_{oc}	V	22.10	23.80	21.60	23.30
		Measured Values			
Ave. Solar Irrad., G	W/m^2	322.66	322.66	322.66	322.66
Ave. Ambient Temp., $T_{a.ave}$	^oC	29.5	29.5	29.5	29.5
Ave. Module Temp., $Tm._{ave}$	^oC	38.91	39.19	40.59	41.47
Ave. Module Voltage, V_{ave}	V	14.340	14.277	13.700	13.880
Ave. Module Current, I_{ave}	A	1.48	1.59	1.35	0.99
Ave. Module Power, P_{ave}	W	19.36	21.13	21.78	13.74
Module Area, A	m^2	0.483	0.938	0.432	0.384
Fill Factor, FF		0.737	0.517	0.757	0.641
Ave. Power Output Efficiency, ή	%	30.78	33.11	30.35	35.88
Ave. Module Efficiency, ή	%	9.16	3.61	11.83	7.12
Performance Ratio		0.923	1.023	0.900	1.065

2.3 Monitoring System

The monitoring system is made up of sets of data loggers and measuring instruments used for measuring and recording of PV module performance related data in the field. It comprised of three sets of units

i. An Environmental Monitoring Station (EMS), unit
ii. Hall Effect (HE) sensors such as DC current/voltage and thermocouple

iii. DC current/voltage data logger unit

A personal computer (PC) for periodic downloading of data was used

2.4 METHODOLOGY

The four different types of photovoltaic module used were installed on one side of a fixed rig in an open field with modules facing south and tilted at an angle of 15 degrees from the horizontal using metal frames with grounding. By affixed the ambient temperature digital thermometer on a metal frame in the field, the ambient temperature was measured and collected hourly. The PV modules were connected to the dc current and voltage data logger, hence its current and voltage output was measured simultaneously. A personal computer (PC) was connected to the data logger and the data were downloaded periodically. The T-type thermocouples were attached to the back of the PV modules and connected to a multi-channel digital thermometer and also the PV module temperatures were measured and collected hourly. The global solar irradiance (GSR) data logger was attached on the PV module horizontally and tilted plane at angle of 15 degrees and the data of the solar irradiance were measured and collected hourly. Wind speed and direction instrument was mounted beside the PV module to monitor the wind speed of the field. The experiment was done at International Energy Academy, Lagos State, Nigeria. Measurements were taken for three consecutive days (from 4^{th} to 6^{th} August) on hourly basis from 7.30 am to 7.30 pm. More parameters related to the performance were evaluated using the following mathematical relations (Onyenonachi, 2010);

Maximum Power, $P_{max} = V_{max} \times I_{max}$

Fill Factor, FF = $\frac{V_{max} \times V_{max}}{V_{oc} \times V_{sc}}$

Module Power Output Efficiency, $\dot{\eta} = \frac{P_{measured}}{P_{max}} \times 100$

Average Module Conversion Efficiency, $\dot{\eta} = \frac{V_{max} I_{max}}{V_{oc} I_{oc}} \times \frac{V_{ave} I_{ave}}{A.G} \times 100$

Performance Ratio = $\frac{P_{measured}}{P_{max}} \times \frac{1000}{G}$

where A is area of the module, $P_{measured}$ is the module measured output power, P_{max} is the module rated power and G is the measured solar irradiance.

3.1 RESULTS AND DISCUSSION

The data of the three consecutive days in the month of August was recorded and comparison was made. Most of the data points lie in the bottom left of the graph as the weather condition for all the three days were cloudy. The hourly average output power of photovoltaic modules for the three consecutive days is shown in Figure 3.1. The PV modules show increment in output power with time and peak at 1.30 pm. The installation capacity of c-Si PV module is higher than any other kind, and that is why the output power shows the highest value before comparison with normalized values. CIS module, in contrast, has the lowest output power value. Figure 3.2 shows the hourly average solar irradiance during the study with peak of 933 W/m^2 at 12.30 pm.

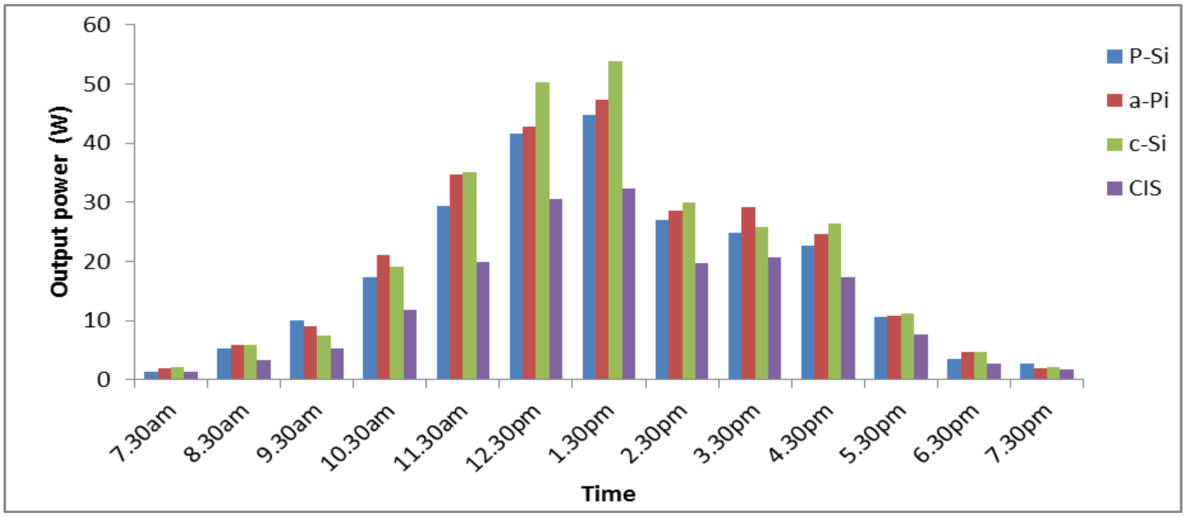

Fig. 3.1: Bar chart plot of hourly average output power versus time for all the PV modules.

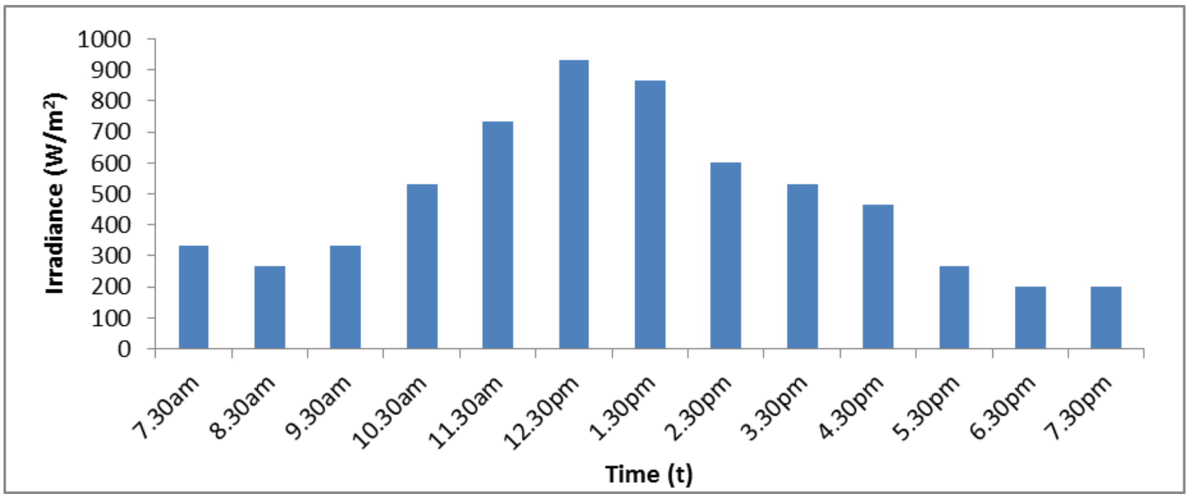

Figure 3.2: Bar chart plot of hourly average solar irradiance versus time

Figure 3.3 shows the hourly average output power of the four photovoltaic (PV) modules with the change of solar irradiance level. It can be seen that the output power increases with solar irradiance. But the various photovoltaic modules have their peaks at different solar irradiance points. The temperature of the PV module increases with irradiance level. As the sun's irradiance increases, more energy is absorbed by the module and more heat will be generated.

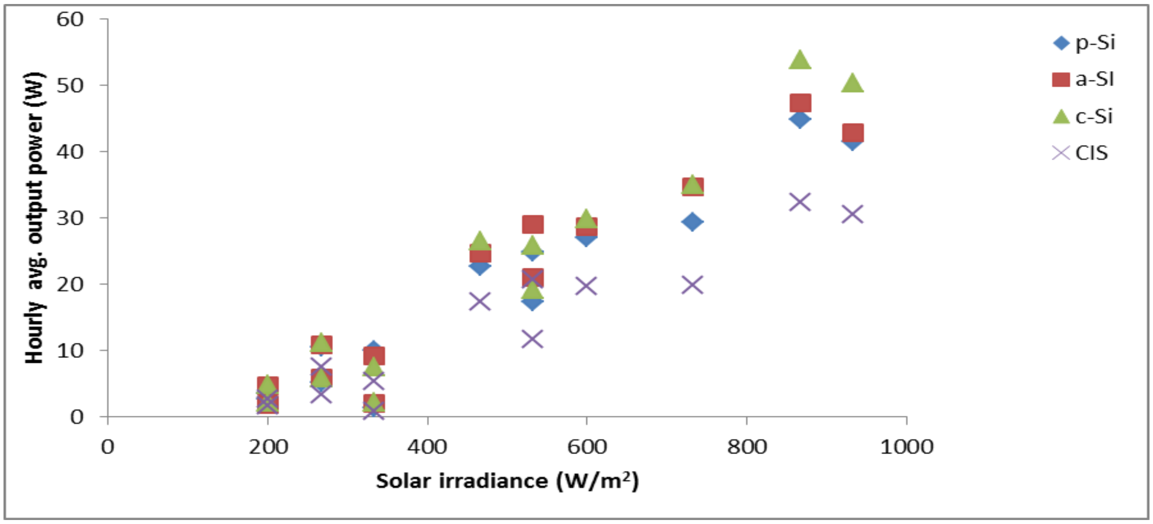

Fig. 3.3: Scatter plot of hourly average output power versus solar irradiance for all the PV modules

3.2 Module Efficiency and Performance Ratio Analysis

Figure 3.4 shows the average value of PV module normalized output power efficiencies with time. The performance of each PV module cannot be obtained by just looking at the power output of the modules. Therefore the power output efficiency which has been normalized by dividing the output power with the rated power of each module and multiplied by 100 is used to compare them. The output power efficiency of each PV module shows how much power is actually generated at a specific time over installed capacity of the module. The module efficiency as shown in Figure 3.5 is calculated from the data obtained from the field study the values are much lower if compared to the expected value under the standard test conditions (STC). This is because the module efficiency value given under STC is the maximum efficiency of the module and is being calculated for only one data. Under the field condition, the varying solar irradiance and temperature affect the performance and efficiency of PV cells.

The values shown in Figure 3.4 are the average value of the three days which includes low-light and high-light conditions. As expected, the c-Si PV module's efficiency is the highest, followed by the p-Si type. Crystalline silicon PV cells are well known for their high cell efficiency; therefore they are expected to have higher efficiency if compared to thin film PV cells. CIS module used in the field study has shown higher module efficiency compared to the a-Si module. This is also expected since both PV cells are categorized under the thin film technology with CIS PV cells, having higher efficiency under standard Test Conditions. Therefore, under the field conditions, CIS PV module is expected to have higher efficiency value compared to a-Si PV module.

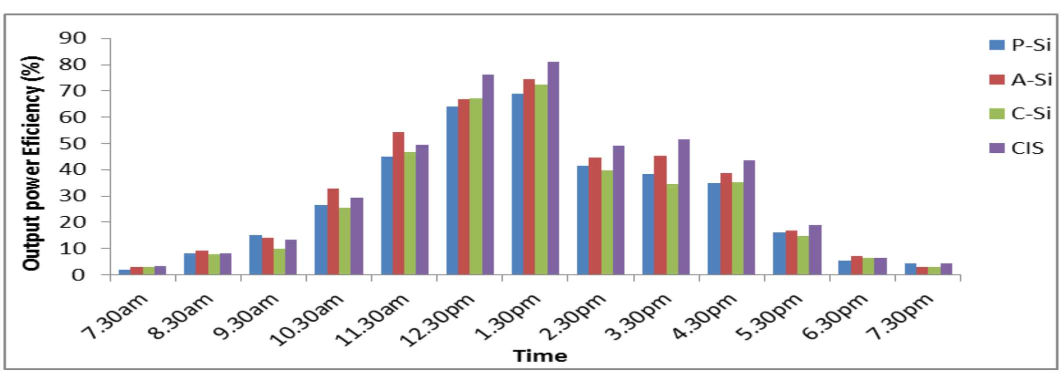

Figure 3.4: Bar chart plot of hourly average of normalized output power efficiency vs time for all the PV modules

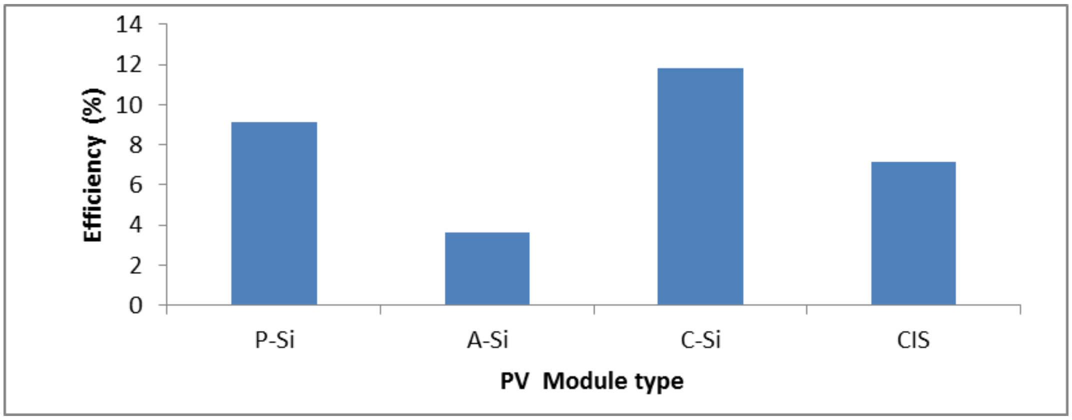

Figure 3.4: Average module efficiency of each PV module type used in the field study

Figure 3.5 shows the average value of the performance ratio of the PV modules used in the study. The performance ratio is calculated to determine which type of PV cells is actually performing the best in average under Nigeria's climate. This calculation took account of output power and solar irradiance level which are to be compared with the Standard Test Condition. Although the value of performance ratio is small, it is possible since that the data for calculation are obtained under low-light condition and not as specified 1000 W/m^2 in Standard Test Condition. In Figure 3.5, A-Si and CIS PV module had shown a better performance ratio compared to other PV module. This is expected in Nigeria's climate weather as researches conducted in oversea founded that thin film PV cells perform best both in hot and humid environment. The solar irradiance level during the study was much lower than the yearly average value. This may be due to the unstable weather with much of cloudy and rainy days during the study period. This confirms that CIS and A-Si PV cells perform better under low-light condition.

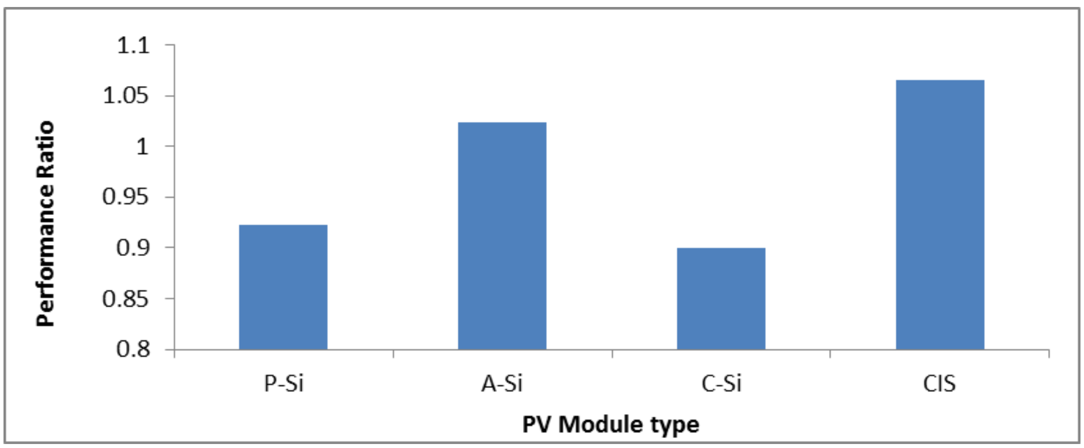

Figure 3.5: Average performance ratio of each PV module type used in the field study

3.3 Temperature Analysis

Figure 3.6 shows the hourly average of output power versus module temperature of the four PV modules used in this study. The output power of PV modules increased with module temperature but shows a decrement from linear trend at high temperature in some of the PV modules as shown in Figure 3.6. For p-Si module it can be seen that the output power is less when the module temperature is high. The a-Si PV module does not shown any drop in output power although the module temperature is high. This shows that a-Si PV cells can withstand the heat better compared to the c-Si PV cells. The CIS PV module followed a similar trend like the a-Si module. In fact, the output power is at the peak when the module temperature is at the highest.

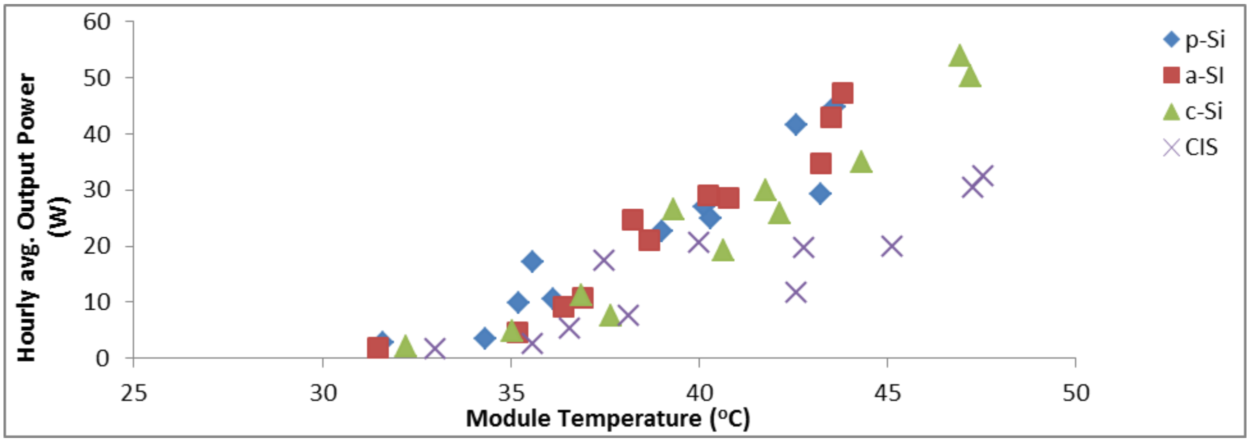

Figure 3.6: Scatter plot of hourly average output power vs module temperature for all the PV modules.

The temperature of the photovoltaic module depends upon solar irradiance and ambient temperature. As the sun's irradiance increases, more energy is absorbed by the module and more heat will be generated. The plot of hourly average ambient and modules temperature against time is shown in Figure 3.7; it shows that all module temperature stays above the ambient temperature for all the three days under study. This is because of heat which is converted from sunlight in the PV module when photovoltaic effect process occurs. The a-Si module has shown lowest average module temperature. This is due to its large surface area which causes more heat convection between the module surface and surrounding air resulting in the cooling of module. The temperature of the modules changes unexpectedly in the afternoon (4.30 pm) and gone down below the ambient temperature. The phenomenon may be because of the blowing wind, which creates a cooling effect to the modules. The cooling effect is also dependent on the wind speed.

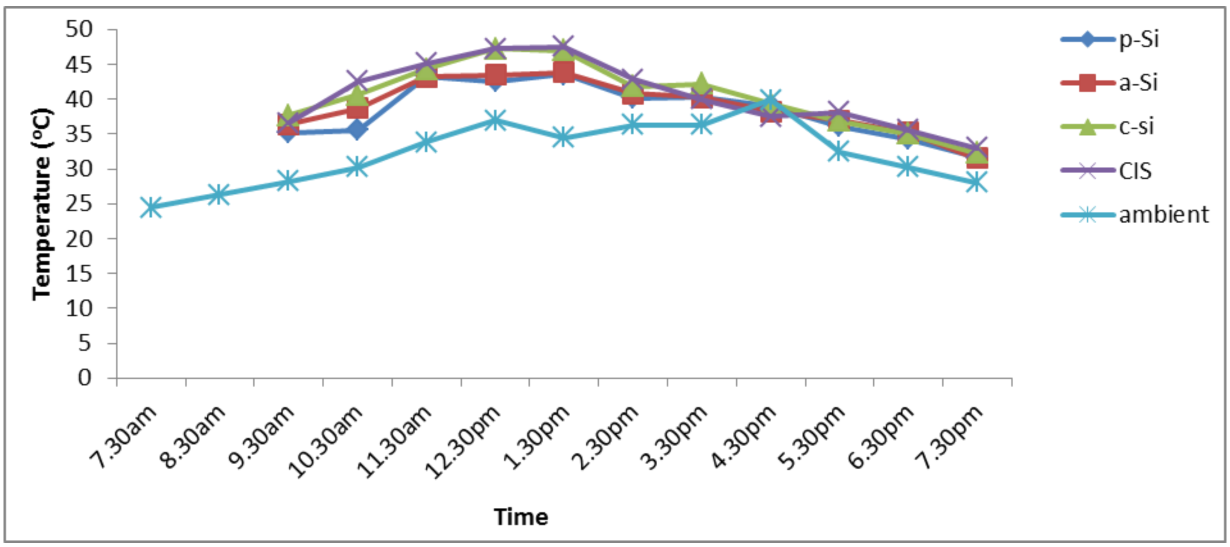

Figure 3.7: Line plot of hourly average ambient temperature versus all the PV module temperatures.

4.1 CONCLUSION

In tropical areas like Nigeria which is known to be hot and humid climate region, is very suitable for photovoltaic module implementation. This is because the weather condition is almost predictable and availability of sunlight for more than ten hours daily. As it is possible to have about six hours of direct sunlight with solar irradiance of between 800 W/m^2 and 1000 W/m^2, which is already very good to consider for usage of photovoltaic module. Within the scope of this study, the hourly output power, efficiency and performance ratio of four modules were measured and variation of these parameters with solar irradiance and temperature of the modules were investigated. The average solar irradiance for the three days of study is 322.66 W/m^2. The average ambient temperature in the field for the three days of study is about 29.5^{o}C against the Standard Test Condition (STC) that specified the ambient temperature to be 25^{0}C and this will change the characteristics of the output power.

The study summarized that output power of the modules increases linearly with increase of solar irradiance. The c-Si module has shown high average output power but CIS has shown higher normalized output power efficiency due to its better performance in low irradiance condition. Also results show that for a fixed orientation, c-Si and p-Si PV modules perform better when they are under hot sun with average module efficiency of 11.83% and 9.16% respectively. Whereas the CIS and a-Si PV modules perform better when it is cloudy and have diffused sunshine with average module efficiency of 7.12% and 3.61% respectively. Furthermore, the efficiency of crystalline silicon PV modules has been found to drop when the temperature rises higher. This phenomenon does not appear in the CIS and a-Si PV modules, which shows that the performance of CIS and a-Si PV cells are better in terms of power conversion efficiency in hot-humid environment. The overall performance ratio of p-Si, a-Si, c-Si and CIS is 0.923, 1.023, 0.900 and 1.065 respectively. Better performances of thin film PV cells like a-Si and CIS are observed in Nigeria.

REFERENCES

Carr, A.J. and Pryor, T.L. (2001): A comparison of the performance of different PV module types in high ambient temperature. ISES, Solar World Congress.

Dolf Gielen (2012): Cost Analysis of Solar Photovoltaic. International Renewable Energy Agency. 1(4/5). Pp 52.

Haris, A.H., Shaari, S. and Sopian, K. (2005): Building integrated photovoltaic in Malaysia Systems, applications and the way forward proceeding of the National Seminar on Energy in Buildings. Malaysian Institute of Energy, Malaysia, pp 150-156

Muhammad Anser Bashir, Hafiz Muhammad Ali, Shahid Khalil, Muzaffar Ali and Aysha Maryann Siddiqui (2014): Comparison of Performance Measurements of Photovoltaic Modules during Winter Months in Taxila, Pakistan. International Journal of Photoenergy. Vol 2014. Article 1D898414, 8 pages.

Nowshad, A., Chin, W.L and Kamaruzzaman, S. (2009): A Practical field study of various Solar cells on their performance in Malaysia. Eleseviier Ltd., Bangi Selangor, Malaysia. 34: 1939 – 1946.

Onyenonachi, F.C. (2010): A Comparative Study of Various Photovoltaic Modules and Their Performance in The Tropics: A Case Study in Nigeria. B.Sc Project (Unpublished), Department of Physics, Michael Okpara University of Agriculture, Umudike.

Sulaiman, S., Kamaruzzaman, S., Nowshad, A. and Mohd, N.K (2009): The Temperature Dependence Coefficients of Amorphous Silicon and Crystalline Photovoltaic Modules using Malaysian Field Test Investigation. American Journal of Applied Sciences. 6(4): 586 – 593.