Determination of Yearly Performance and Degradation Rate of Electrical Parameters of a Monocrystalline Photovoltaic Modules in Minna, Central Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

Outdoor degradation analysis was carried out on a monocrystalline PV module rated 10 W using the CR1000 software-based Data Acquisition System (DAS). The PV module under test and meteorological Sensors were installed on a metal support structure on the same test plane. The data obtained was monitored from 09:00 to 18:00 hours each day continuously for a period of four years, from December 2014 to November 2018.The experiment was carried out near the Physics Department, Federal University of Technology, Minna (latitude $09^o37'N$, longitude $06^o32'E$, and 249 meters above sea level). The sensors were connected directly to the CR1000 Campbell Scientific data logger, while the module is connected to the logger via electronic loads. The logger was programmed to scan the load current from 0 to 1 A at intervals of 50mA every 5 minutes, and average values of short-circuit current, $(I_{sc},)$ open-circuit voltage, (V_{oc}), current at maximum power, (I_{max}), the voltage at maximum power,(V_{max}), power and maximum power obtained from the modules together with the ambient parameters are recorded and logged. Data download at the data acquisition site was performed every 7 days to ensure effective and close monitoring of the data acquisition system (DAS). At the end of each month and where necessary, hourly, daily and monthly averages of each of the parameters-solar irradiance, solar insolation, wind speed, ambient and

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module temperatures, and the output response variables (open-circuit voltage, V_{oc}, short-circuit current, I_{sc}, the voltage at maximum power, V_{max}, current at maximum power, I_{max}, efficiency, Eff, and fill factor, FF) of the photovoltaic modules were obtained.Yearly averages of the performance variables were obtained to ascertain the performance, degradation rate, and lifespan of the module. The module performance for the four years of study was compared with Standard Test Condition (STC) specifications. The maximum power achieved at 1000W/m^2 for the four years of study are 0.711W, 1.82W, 0.50W, and 0.22W representing 7.11%, 18.39%, 5.0% and 2.25% of the manufacturer's 10W specification. Module efficiency at 1000W/m^2 for the four years of study is 3.30%, 10.12%, 3.98%, and 2.82% respectively as against the manufacturer's STC specification of 46%. Accordingly, Module Performance Ratios for the PV module investigated were 0.072, 0.22, 0.087, and 0.061respectively. For the Rate of Degradation (RoD), it was observed that Open-Circuit voltage (V_{oc}), Short-Circuit Current (I_{sc}), Power-Output (P), and Maximum Power (P_{max}), has an average yearly degradation rate of 1.06V, 0.002A, 0.082W and 0.142W representing 4.9%,0.30%,0.56%, and 1.4%respectively for the four years of study.

1. INTRODUCTION

Photovoltaic is a system of renewable energy based on the availability of sunlight all year round and has come to stay as part of the electrical energy mix in Europe, the United States, Japan, China, Australia, Nigeria, and many more countries. A solar cell is a device that converts energy from sunlight to electricity using the photovoltaic (PV) effect, this technology is one of the promising ways to achieve the rapidly increasing global electricity demanding with a pollution-free environment. The reliability and durability of PV modules are of extreme importance for the reliability of the entire PV system, the solar-powered grid, promote the credibility of PV, and increase the investment in the PV industry. Besides, improving PV reliability contributes to reducing the leveled cost of electricity (LCOE) for PV-generated electricity. The science regarding the reliability of PV modules is still immature [1]. There is not yet a complete understanding of what qualification test or test sequence is required to guarantee that a particular PV module would survive 25 years in a particular climate. It is well understood that the degradation rate or the lifetime of PV modules and systems are greatly influenced by the climatic conditions [2], but the exact understanding of the influence of temperature, thermal cycling, UV exposure, relative humidity, or a combination of these is far from being completed. It is, therefore, necessary to build a database of real-world performance and reliability for estimating the leveled cost of electricity in different climatic conditions. Most degradation studies have so far been based on temperature and hot-dry climates due to the abundance of data in this type of climate. It is important to know that the sun is the nearest star to the earth and therefore the source of all renewable energy on earth which provides sustenance for both plants, animals and also serves as the source for the solar system. Indeed, solar energy is used for industry, communities as well as individual needs. Over the past decade, the photovoltaic (PV) market has experienced unprecedented growth and besides these, the photovoltaic market has reached a cumulative installed capacity of roughly 40 GW worldwide, with an annual added capacity of 16.6 GW [3]. However, there is little information on PV module degradation in terms of frequency, speed of evolution, and degree of impact on module lifetime and reliability. Research on photovoltaic modules is rather focused on the race to develop new technologies to provide sufficient experience feedback on already operational technologies [4,5,6]. For economic development in a society, the rate at which the demands for electricity will keep increasing as the population keeps increasing. Let us consider the present situation whereby primary energy account for 40% of the global energy used for power generation, and solar or renewable energy only account for 3.6% (Nasiror, 2018). It implies that the renewable energy demands that work needed to be done on it to be able to withstand higher population. The investigation of the performance evaluation and degradation rate of the monocrystalline photovoltaic module in the local environment will establish a degradation rate comparison between the locally available modules and the laboratory projection and a database will be generated where necessary. The result of these investigations will assist the designers, scientists, and Energy Research centers to get first-hand information on the performance of the module in

the local environment before they proceed on design and installation for power supply.

2. MATERIALS AND METHODS

2.1 Method of Data Acquisition

This work involves characterisation and evaluation of the yearly performance of the monocrystalline photovoltaic module in other to estimate the degradation rate of the various electrical parameters of the monocrystalline module type in Minna local environment using four years of data acquired. The research process involved two processes which include data acquisition by continuous monitoring and data analysis.

2.2 Monitoring State

The degradation rate of electrical parameters of the monocrystalline PV modules to ambient weather parameters: solar irradiance, temperature, wind speed, and relative humidity, was monitored in Minna local environment, using a CR1000 software-based data logging system with a computer interface. The PV modules under test, and meteorological sensors, were installed on a support structure at the same test plane, at about three meters of height, to ensure adequate exposure to insolation and enough wind speed, since wind speed is proportional to height. The elevation equally ensures that the system is free from any shading from shrubs and also protected from damage or interference by intruders. Also, the whole experimental setup was secured in an area of about 16 square meters. The module was tilted at approximately 10° (since Minna is on latitude 09° 37' N) to horizontal and south facing to ensure maximum insolation [2] (Scheller and Strong,1991). The data monitoring was from 9.00 am to 6.00 pm local time each day continuously for a period of four years, starting from December 2014 to November 2018. The experiment was carried out in the experimental garden at Bosso campus of the Federal University of Technology, Minna (latitude 09° 37' N, longitude 06° 32' E and 249 meters above sea level). The sensors were connected directly to the CR1000 Campbell Scientific data logger, while the module was connected to the logger via electronic load. The logger was programmed to scan the load current from 0 to 1 A at an interval of 50 mA every 5 minutes, and average values of short-circuit current,(I_{sc}), open-circuit voltage, (Voc), current

at maximum power,(I_{max}), the voltage at maximum power(Vmax,) power and maximum power obtained from the modules together with the ambient parameters are recorded and logged. Data download at the data acquisition site was performed every 7 days to ensure effective and close monitoring of the data acquisition system. The global solar radiation was monitored using Li-200SA M200 Pyranometer, manufactured by LI-COR Inc. USA, with the calibration of 94.62 microamperes per 1000 W/ m^2 . The ambient temperature and relative humidity were monitored using HC2S3-L Rotronic Hy-groClip2 Temperature/Relative Humidity probe, manufactured in Switzerland. Wind speed was monitored using 03002-L RM Young Wind Sentry Set. And module temperature was monitored using a110PV-L Surface-Mount Temperature probe. All sensors were installed in the CR1000 Campbell Scientific data logger with the measurement and control module. The experimental set up is shown in plate I.

2.3 Method Data Analysis

Analysis of the yearly degradation rate of the monocrystalline module was investigated in terms of open-circuit voltage (Voc),Short-circuit current (Isc), Voltage at Maximum power (Pmax),current at maximum power(Imax),Efficiency(Eff), Fill factor(FF) and module performance Ratio (MPR) was also evaluated using the following expressions:

$$\text{Fill factor (FF)} = I_{max}V_{Max}/I_{SC}\,V_{oc} \qquad (1)$$

$$\text{Efficiency (Eff)} = {}^{I_{Max}V_{max}}/_{P_{in}} = I_{sc}VocFF/$$
$$P_{in} = {}^{I_{sc}V_{OC}}/_{AE_e} \qquad (2)$$

Module performance Ratio, MPR = Effective Efficiency/Efficiency at STC (2.3)

The maximum power (P max) which is the operating point of the module, was recorded by the logger which is expected to corresponds to the largest area of a rectangle that fit inside the I-V curve. The highest current and voltage at this point are Maximum Current ($I_{\max}$) and voltage maximum ($V_{\max}$) respectively. Microsoft Excel was used to analyse the data and the hourly averages monthly averages, and annual averages of the performance variables as against their ambient parameters were calculated and recorded. In the case of the hourly averages,
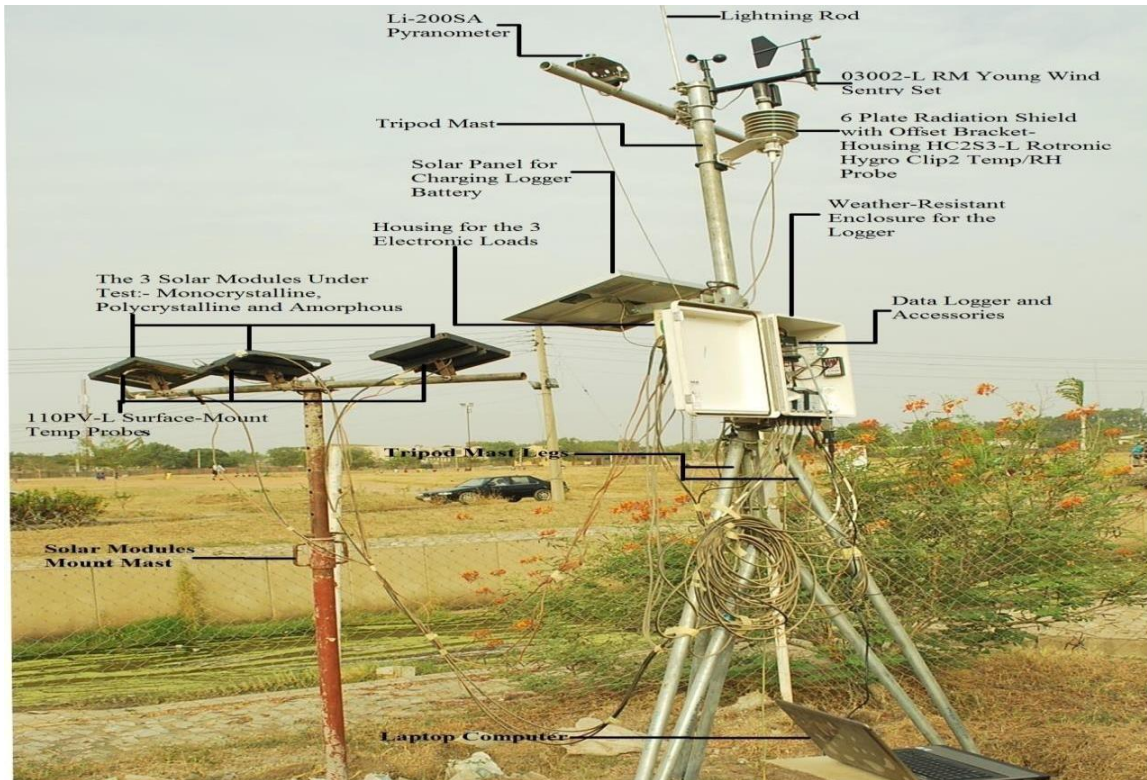
Plate 1. The Experimental set Up (Near Physics Department, FUT Minna)

12 x 20 columns per performance variable was recorded by the logger per hour since the logger scanned the load current from 0 to 1 A at an interval of 50mA every five minutes from the hour of 9:00am to 6:00pm daily. A mini syntax programme was developed to calculate the hourly, daily, and yearly averages given the enormity of data involved. The percentage degradation rates of the various electrical parameters like output power,short-circuit current (Isc),open-circuit voltage (Voc), and fill factor (FF) are therefore calculated for the nameplate rating of the module provided by the manufacturer using the following formula [1]

$$\text{Rate of degradation (RoD)} = \frac{Initial\ data - Final\ data}{Final\ data} \times 100 \qquad (3)$$

3. RESULTS AND DISCUSSIONS

The ambient parameters are responsible for the degradation of the variable electrical parameters and as such, there is a need to ascertain the annual yearly averages of the performance variables to know the effect and rate of degradations of the electrical parameters. From Table1, it was observed that the module temperature increases $from\ 38.9^o$, $39.8^o 40.8^o$ and 41.0^o for 2015,2016, 2017, and 2018 respectively, and also short circuit current increased from 0.038 A,0.039 A,0.045Afrom 2015,2016 and 2017 but decreases to 0.034 A in 2018.In the same vein, the output power decreases steadily to 0.342 W, 0.282 W, 0.274 W, and 0.094 W for the years 2015,2016,2017 and 2018 respectively. The maximum power also was observed to decreases from 0.543 W to 0.439,2015 to 2016 but slightly increased to 0.455 W in 2017 and decreased to 0.154 W in 2018.

From Table 2, it was observed that Voc and Isc has a yearly degradation rate of 0.71 V and 0.001 A from 2015 to 2016, slightly increased to 0.11V and 0.006A from 2016 to 2017 and further increased to 2.38V and 0.011A from 2017 to 2018. The increases noticed in short circuit current is believed to have been as a result of the continuous increases in module temperature from 38.9^o in the first year up to 41° in the fourth year as indicated in Table 4.6. Meanwhile, the power (W) has a yearly decrease of 0.06W for the year 2015 to 2016, 0.008W for the year 2016 to 2017 and 0.18Wfor the year 2017 to 2018, while the maximum power has a slight decrease from0.104W to0.016W in 2016 to 2017 and finally increased to 0.301 Win 2017 to 2018.The

Annual Average Rate of Degradation (RoD) for the four years was calculated on the performance variables which indicates that open-circuit voltage (Voc),short circuit current (Isc),power (P) and maximum power (P_{max}) has an annual average(RoD) of 1.06V,0.002A,0.082W and 0.140 W respectively for the four years of study as seen in Table 1.

From Fig. 1. It was observed that open-circuit voltage decreased drastically from the first year to the last year of study while the short circuit current experience a slight rise in the second year but degrade from the third year downwards. The slight rise in the short circuit current in the second year (2016) does not imply degradation were not taking place but further confirmed a decreased in the band-gap of silicon as the temperature increases and the saturation current (I_o) of the silicon material also increased leading to an increased in the short circuit current.
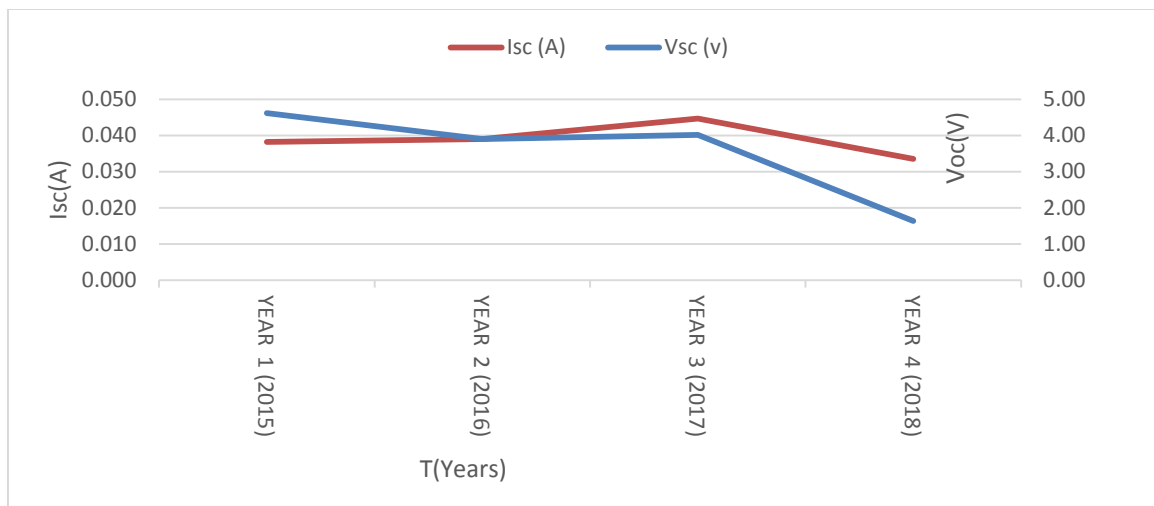

Fig. 1. Yearly Variation of Short Circuit Current and Open-Circuit Voltage
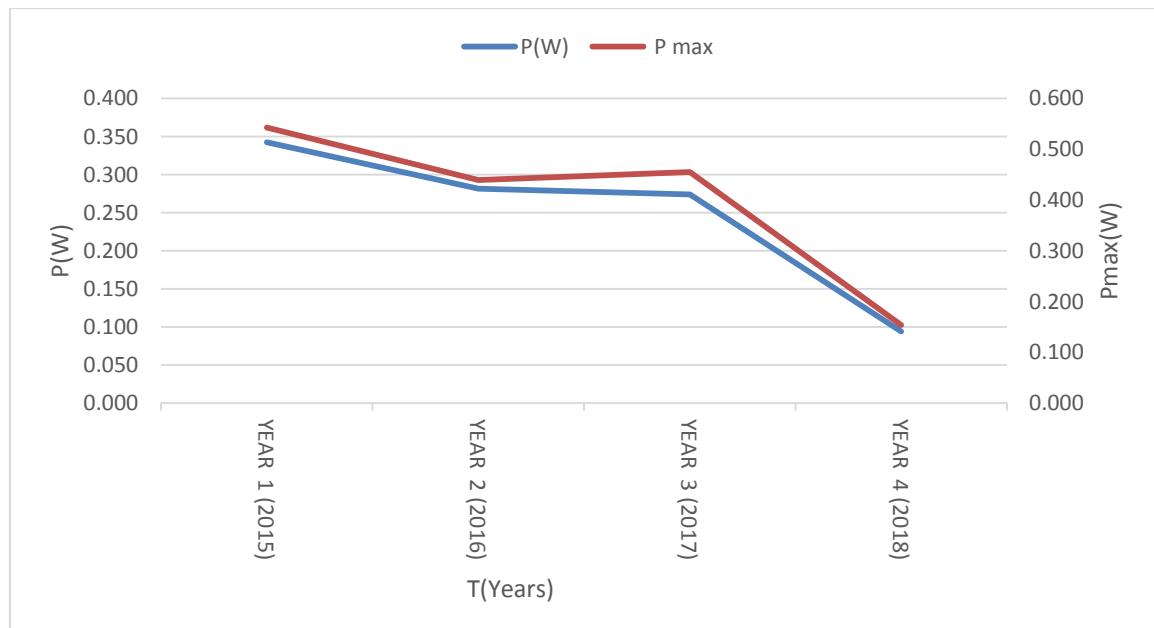

Fig. 2. Yearly variation of Power (W) and Maximum Power (W)

Table 1. Annual average ambient parameters and performance variables for the mono-crystalline module

T (YEAR)	WS (m/s)	T_a (o_C)	RH (%)	T_{mod} (0_c)	H_g (w/m^2)	V_{oc} (v)	I_{sc} (A)	P (w)	V_{max} (v)	I_{max} (A)	P_{max} (w)	FF	Eff (%)
YEAR 1 (2015)	1.65	25.4	48.3	38.9	477	4.62	0.038	0.342	4.62	0.095	0.543	2.477	0.03
YEAR 2 (2016)	1.57	31.4	49.7	39.3	520	3.91	0.039	0.282	3.91	0.087	0.439	2.235	0.02
YEAR 3 (2017)	1.34	32.3	47.1	40.8	502	4.02	0.045	0.274	4.03	0.094	0.455	2.112	0.03
YEAR 4 (2018)	1.03	32.7	53.1	41.0	485	1.64	0.034	0.094	1.64	0.057	0.154	1.701	0.01
AVERAGE	1.40	30.5	49.6	40.0	496	3.55	0.039	0.248	3.55	0.083	0.398	2.131	0.02

Table 2. Annual average rate of degradation (RoD)

T(YEAR)	V_{oc} (V)	I_{sc} (A)	P(A)	P_{max} (W)
2015 to 2016	0.71	0.001	0.060	0.104
2016 to 2017	0.11	0.006	0.008	0.016
2017 to 2018	2.38	0.011	0.180	0.301
ROD	1.06	0.002	0.082	0.140

In Fig. 2. It was observed that the power (W) and maximum power(W) decreased steadily from 2015 down to 2018 which correspond to the investigation and performance evaluation of monocrystalline photovoltaic panels in Funaab, Alabata, Ogun State by Kifilideen et al. [7] and that of the result from three different types of commercially available silicon PV module of monocrystalline that were simultaneously characterised with their performance evaluation by Ugwuoke and Okeke [8] at Energy Research Center, University of Nigeria, Nsukka, Southeast Nigeria.

3. CONCLUSION

The determination of yearly performance and degradation rate of electrical parameters of the monocrystalline photovoltaic module in Minna local environment for the four years of study indicated that the electrical parameters degrade accordingly. The maximum power achieved at 1000W/m^2 for the four years of study are 0.711W, 1.839 W, 0.503 W and 0.225 W representing 7.11%, 18.39%, 5.03% and 2.25% of the initial value of 10 W for 2015,2016 2017 and 2018. Modules efficiency at 1000W/m^2 for the four years of study degrades to 3.30%, 10.0%, 3.99%, and 2.82% for the years 2015, 2016, 2017, and 2018 respectively from the initial value of 46%. All the temperature recorded by the module for the four years of study were all beyond 25^0 C at 1000W/ m^2 irradiance.This further proves that there is a degradation in the values of the electrical parameters.

The yearly Rate of Degradation (RoD) of monocrystalline photovoltaic modules in Minna local environment shows that all the electrical performance variables of the module degraded significantly from year to year for the four years of study. It was discovered that Voc, Isc, P and Pmax has an annual average RoD of 1.06 V, 0.002 A, 0.082W and 0.142W respectively for the four years of study. Similarly, it was observed that Voc and Isc reduced to 0.71 V and 0.001A from 2015 to 2016, decreased by 0.11V and 0.006A from 2016 to 2017 and further decreased with 2.38V and 0.011A from 2017 to 2018. Meanwhile, power and power at maximum have a yearly decrease of 0.06W and 0.104W from the year 2015 to 2016, 0.008W 2016 to 2017 for power (W) but power at maximum has a slight increase of 0.016W and finally,0.18W and 0.301W of P(W) and P(max) decreased from 2017 to 2018.

The Annual Average Rate of Degradation (RoD) for the four years was calculated only for the performance variables which indicates that Voc, Isc, P and Pmax has an annual average (RoD) of 1.06V,0.002A,0.082 W and 0.142 W respectively for the four years of study

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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