ARID ZONE JOURNAL OF ENGINEERING, TECHNOLOGY & ENVIRONMENT
AZOJETE March 2022. Vol. 18(1):97-108
Published by the Faculty of Engineering, University of Maiduguri, Maiduguri, Nigeria.
Print ISSN: 1596-2490, Electronic ISSN: 2545-5818
www.azojete.com.ng

ORIGINAL RESEARCH ARTICLE

PERFORMANCE EVALUATION OF 200W SOLAR PHOTOVOLTAIC PANEL CONSIDERING BAUCHI MICROCLIMATIC CONDITIONS

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ARTICLE INFORMATION

Submitted 13 July, 2021
Revised 24 November, 2021
Accepted 2 December, 2021

Keywords:
Characteristic curves
Terrestrial solar radiation
Technologies
Mathematical Modeling
Microclimate Parameters
PV Systems

ABSTRACT

Measurement and modeling of broadband and spectral terrestrial solar radiation is important for the evaluation and deployment of solar renewable energy systems. This paper focuses on optimizing the performance of 200W solar module taking into consideration the local climatic conditions of Bauchi locality. The uncertainty in life cycle savings for solar thermal and photovoltaic (PV) systems as linearly correlated with uncertainty in solar resource data. These uncertainties paved way for the need to conduct a critical assessment of the resource. Assessment of the solar resource for these technologies rely upon measured data, where available. In this paper, we present the development of mathematical model of photovoltaic solar cells based on their detailed single diode equivalent circuit representation. Pertinent simulation models for PV solar module both for an ideal weather situation and for taking into consideration the effects of microclimatic conditions that prevail in Bauchi as evaluated and compared with benchmarks available. The complete model of the PV system was implemented using MATLAB/Simulink platform. The standard characteristic curves for the 200W solar panel are as presented. The simulation of the ideal PV system made use of standard test conditions (STC) to facilitate comparison with the existing benchmark results in the literature. The analysis of the characteristics performance curves returned an average V_{OC} = 42.9v and I_{SC} = 4.21A. The simulation results further revealed that the power delivered by the 200W monocrystalline solar module of 144.3W @620W/m^2, 35°C as recorded for Bauchi under all climatic conditions as evaluated. The benchmark values obtained in the laboratory are V_{OC} = 45.5V, I_{SC} = 5.92A and 200-W under the Standard test condition (STC) conditions of cell temperature 25°C, solar irradiance of 1000W/m^2 and air mass (AM) of 1.5. The average conversion efficiency and fill factor as evaluated are 0.77 and 16% respectively. This result agrees with the benchmark of module efficiency of >15.66% recorded at STC. The results conclusively reveal that the microclimate of a locality essentially affects the performances of solar PV systems deployed to each location on the globe. Therefore, utilization of these parameters is essential for consideration in the design of solar systems in all localities.

1.0 Introduction

The study of frameworks of applied sciences needs a frequent development and utilization of techniques for arithmetic and Computer sciences. When an actual structure is established and carefully investigated, it is habitually valuable to utilize numerical model, appropriate to depict its development in existence. One of the main aims of research in building integrated systems is to improve the performance of installed PV systems (Firth *et al.* 2010), they went on to add that; drive for greater efficiency is necessary to increase the amount of electricity generated per Watt of installed PV capacity and so reduce the unit cost of the electricity. When simulations related to the behavior of system are accessible and reliable (Abdulkadir *et al.* 2012) it reduces time dedicated to discrimination and investigations, therefore, there exists a strong connection between applied sciences and mathematics addressed by numerical models applied to the simulation of systems of real world. Just as the fossil fuel-based energy industry relies on exploration and proven reserves for discovery and economic support of energy markets, the renewable energy sector depends upon the assessment of resources for planning and selling their energy production technology. For solar-based renewable energy technologies such as solar thermal or photovoltaic conversion systems, the basic resource or fuel available is the sunshine. Research have shown that uncertainty in life cycle savings for solar thermal and photovoltaic (PV) systems has linear correlation with uncertainty in solar resource data (Zainab *et al*. 2020). Assessment of the solar resource for these technologies rely upon measured data, where available. However, the sparse distribution in space, and particularly over time, of measured solar data leads to the use of modeled solar radiation as the basis for many engineering and economic decisions. Measured and modeled solar radiation have attendant uncertainties. Most solar radiation models rely on measured data for their development or validation, and often the uncertainty or accuracy of that measured data is unknown. This paper presents the performance of the 200W solar panel using modeling and evaluation of results arising from it.

The modeling of PV cell for the most part involves the approximation of the non-linear I-V curve. Many researchers utilized circuit-based approach to characterize the PV cell of which the simplest model is the current source in corresponding to a diode. Investigation of the improvement of a technique for the mathematical modeling of the PV cell is important to satisfy the numerical I-V equation with the experimental remarkable points of the I-V curve of the practical solar cell (Guda, 2012). To describe a specific photovoltaic cell, it is appropriate to decide the current-voltage (I-V) and power-voltage (P-V) characteristic curves of the array for all operating field conditions. This is significant because the performance characteristic of the PV cell's building block regularly published in the manufacturer's datasheet depends on ideal Standard Test Condition (STC) that may not be achievable anywhere on the planet (Guda, 2012; Jayashri and Harish, 2013). Subsequently, the need to conduct the mathematical modeling to characterize the system and restrict the model to track down the optimal performance of the PV cell/module at prevailing conditions found in a specific area.

Tarak *et al.* (2012) introduced MATLAB/Simulink model to mimic the solar cell at different boundary conditions while (Gupta *et al.* 2017) introduced the advancement of a MATLAB/Simulink model for the solar PV cell, module and array. (Guda and Aliyu, 2015; Jayashri and Harish 2013) additionally recreated the attributes of PV module for acquiring the exhibition of a reference PV array. Mansur and Richard (1989) reported that knowledge of the characteristic of photovoltaic (PV) panel is a prerequisite for designing and dimensioning a PV electricity power supply system. These were the reason for the development of PV panel models useful for electrical applications. (Abdulwahab, 2014; Rahim and Mehrdad, 2018) presented modeling and simulation for the PV cells, modules, and array, and building of blocks based on MATLAB / Simulink programming package. The aim of this paper is to develop a model based on the equivalent single diode circuit using MATLAB/Simulink resources to generate the characteristic curves of the solar PV system under investigation, extract the computed key output parameters such as Vpv, Ipv and Ppv. Other objectives include evaluation of performance of the PV electricity generator by comparing the output power when the operating temperature is calculated and measured respectively, determination of the module conversion efficiency, the fill factor (FF) and compare the results with the benchmark values (efficiency >15.66% and 0.7 – 0.8 FF) of the module technology under investigation.

2. Materials and Method

In this section, the materials deployed, and methods used in achieving the objectives of this work are presented. It guides the paper in the proper sequence into its logical conclusion.

2.1 Description of the Experimental Test Rig

The ground data used was from the archives of the experimental test rig and CAR database all in the Department of Electrical and Electronics Engineering, ATBU, Bauchi, Nigeria. The key data measuring equipment installed at the stations are; Kipp & Zonen Pyranometer, Wind Monitor (05103-L) (Medugu and Ogbaka, 2017), Data Logger (CR 1000), are all found at Campbellsci, (2021). The data parameters for the study are as presented in Table 1. Bauchi is located at Lat. N10° 16' 48.1", Lon. E 9° 47' 23" and Alt. 627m. The Electrical Characteristics of the installed 200W solar module are as presented in Table 2 to serve as part of the inputs parameters to the PV model for simulation to determine the power output for the microclimate in consideration. Data measured for the year 2019 from the experimental test bed installed at the research hut of the Faculty of Engineering, Abubakar Tafawa Balewa University (ATBU) Bauchi and that obtained from the meteorological station installed by Center for Atmospheric Research (CAR) at the Department of Electrical and Electronics Engineering, ATBU Bauchi described above for the comparative performance analysis.

Table 1: Meteorological Data Description

S/N.	Parameter	Unit
1.	Solar Irradiance	W/m^2
2.	Ambient Temperature	(^{0}C)
3.	Air Temperature	(^{0}C)
4.	Relative Humidity	%
5.	Wind Speed	m/s
6.	Wind Direction	Degrees
7.	Barometric Pressure	Bars
8.	Cell Temperature	(^{0}C)

Table 2: Electrical Characteristics of 200W Solar Module @STC (African Energy, 2014)

Module Technology (Si- mono)	Values
Nominal Output (P_{max}) [W_{Pk}]	200
Voltage at P_{max} (V_{MP}) [V]	37.77
Current at P_{max} (I_{MP}) [A]	5.29
Open Circuit Voltage (V_{OC}) [V]	45.25
Short Circuit Current (I_{SC}) [A]	5.92
Power Tolerance	+/- 3%
Maximum System Voltage	DC 1000V
Cell Efficiency	>18.3% -165
Module Efficiency	>15.66%

2.2 Methods

2.2.1 *Temperature dependent electrical efficiency of PV module*

The most common model for calculating cell temperature (T_C) is given by Eqn. (1), (De Rosa *et al.* 2015; Mboumbow and Njomo 2013; Xue Gui *et al.* 2011).

$$T_C = T_{ref} + (NOCT - 20^O C)\frac{\phi}{800} \quad (1)$$

Where; T_{ref} is the reference ambient Temperature, NOCT is the nominal operating cell temperature, ϕ solar irradiance at that Instance.

The correlation between temperature rise and the decline of PV efficiency (η) as presented in Eqn. (2) (Adeel *et al.* 2019; Tao *et al.* 2018).

$$\eta = \eta_{ref}\left[1 - \beta_{ref}\left(T_C - T_{ref}\right) + \gamma Log_{10}\phi(t)\right] \quad (2)$$

Where; η_{ref}, is the reference PV efficiency, β_{ref} is the temperature coefficient of PV efficiency (0.5%/°C); T_C and T_{ref} represents the real PV temperature and the reference temperature at the standard test condition respectively (STC) in °C and γ is the solar radiation coefficient. ϕ is a material property, having values of about 0.004/K and 0.12/K respectively, for crystalline silicon modules, the latter part, however, is usually taken as zero and Eqn. (2) reduces to Eqn. (3) (Adeel *et al.* 2019; Tao *et al.* 2018).

$$\eta = \eta_{ref}\left[1 - \beta_{ref}\left(T_C - T_{ref}\right)\right] \quad (3)$$

The effect of temperature on the electrical efficiency of a PV cell/module is determined by using the fundamental equation of power (P_m) as in Eqn (4) (Adeel *et al.* 2019).

$$P_m = I_m V_m = (FF) I_{SC} V_{OC} \quad (4)$$

where; *FF* is fill factor, I_{sc} is short circuit current, V_{oc} is open circuit voltage and subscript m refers to the maximum power point in the modules I-V curve. Both the open circuit voltage and the fill factor decrease substantially with temperature (as the thermally excited electrons begin to dominate the electrical properties of the semi-conductor), while short-circuit current increases, but only slightly.

2.2.2 Characteristic of solar cell

The analysis of the characteristics of the solar cell is resolved by using the equivalent electrical circuit model of the PV cell depicted in Figure 1. It is a one-diode model, also known as the 5-parameter circuit. The most commonly used one diode model of Figure 1 can model the cell. The parameters in the circuit are; Diode Current (I_D), Photo Generated Current (I_{SC}), Shunt Current (I_{SH}), Shunt Resistance (R_{SH}), Series Resistance (R_S), Output Current (I) and Output Voltage (V). The ideal photovoltaic module consists of a single diode connected in parallel with a light generated current source (I_{SC}) (Abdulkadir *et al.* 2012).

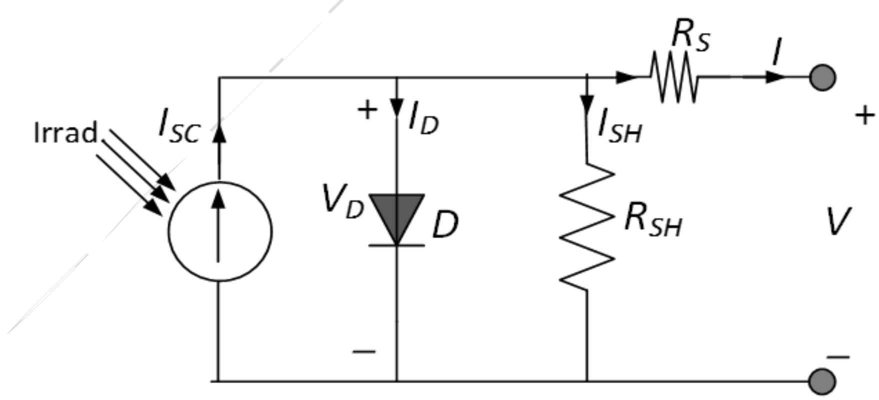


Figure 1: Equivalent One Diode Model of Solar Cell

Applying Kirchhoff's current law, the output current (I) is given by eqn. (5), (Harrag and Messalt, 2017)

$$I = I_{SC} - I_D - I_{SH} \quad (5)$$

I_{SC} (photo-generated current) is also called I_L (light current) which refers to direct current generated by photovoltaic effect, whereas I is the output current of the cell. The light current depends on both irradiance and temperature and measured at some reference conditions Eqn. (6), Adeel *et al.* (2019).

$$I_{SC} = \left[I_{SCref} + K_i\left(T_k + T_{ref}\right)\right] = {}^{\sigma}/_{1000} \tag{6}$$

From Shockley's diode equation Eqn. (7) (Santiago, 2018).

$$I_D = I_O\left[exp\left\{\frac{(V+I_{RS})}{nV_1}\right\} - 1\right] \tag{7}$$

Where; $V_1 = \frac{kT}{q}$ (Nguyen and Nguyen, 2015) (8)

Applying Ohm's Law the shunt current;

$$I_{SH} = \frac{V+IR_S}{R_{SH}} \tag{9}$$

Substitute eqn. (6), (7), and (8) in eqn. (5) and re-arranging them gives the output current in Eqn. (9) in the form of Eqn. (10).

$$I = I_{SC} - I_O\left[exp\left\{\frac{q(V_{PV}+I_{PH}R_S)}{N_SAkT}\right\} - V_{PV} + \left\{\frac{I_{PH}R_S}{R_{SH}}\right\}\right] \tag{10}$$

Where *I(A)* is PV cell current, I_{SC} is the photo-generated current in (A) or Short Circuit Current, I_O is the diode saturation current (A), q is the electron charge (1.602×10^{-19} C.), V_{PV} Photovoltaic open circuit voltage in (volts), I_{PH} is the photo current (A), R_S is the series resistance in ohms, N_S is the number of series cells, *A* is the diode ideality factor, k is Boltzmanns constant (1.38×10^{-23} Joules per Kelvin, T is the cell temperature in Kelvin and R_{SH} is the shunt resistance in ohms.

2.2.3 Performance of photovoltaic panel (AFR 200)

The performance of the PV cell is determined at three (3) key points on the characteristic curve. Five (5) Eqns. are required to find the five unknown parameters in Eqn. (13). Manufacturer's data sheet provides cell voltage and current at three (3) key points at M, A and S depicted in Figure 2.

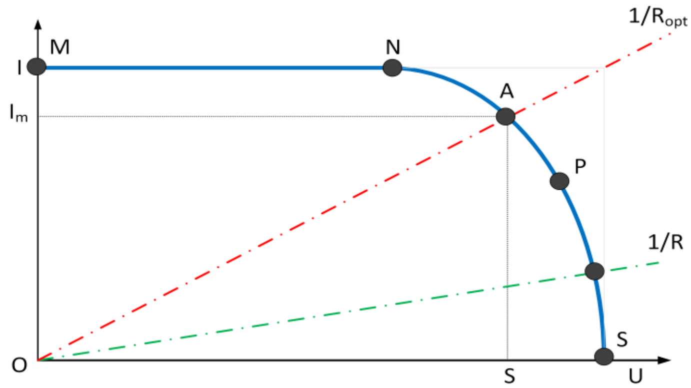


Figure 2: PV Characteristics Curve illustrating key Points of Performance

$$I_{SC} = I_D - \frac{V_D}{R_{SH}} - I_{PV} = 0 \tag{11}$$

$$I_{RS} = I_{SCref}\left[exp\left(\frac{qV_{OC}}{N_SkAT}\right) - 1\right] \tag{12}$$

$$I_O = I_{PV}\left[\left(\frac{T}{T_{ref}}\right)^3 e^{{qC_g}/{Ak}} \times \left(\frac{1}{T_{ref}} - \frac{1}{T}\right)\right] \tag{13}$$

$$I_{PV} = N_PI_{SC} - N_SI_O\left[exp\left\{\frac{q(V_{PV}+I_{PH}R_S)}{N_SAkT}\right\} - 1\right] - V_{PV} + \left\{\frac{I_{PH}R_S}{R_{SH}}\right\} \tag{14}$$

The parameters that need to be defined before solving Eqn. (14) are R_{SH}, R_S, A, I_{PH} and I_O. These parameters are specific to every different commercial PV module and calculated from the product data sheet values tested at standard test condition (STC) or reference point, 1kW/m^2 solar irradiation, 25^{o}C cell temperatures and air mass (AM)1.5 (IEC, 2008). Knowing the parameters, solar radiation data and the cell temperature, the electricity generated by the solar cell can be determined.

To solve the four non-linear equations with four unknowns, MATLAB codes as written and Simulink blocks constructed to calculate the I_{PV}, V_{PV} and P_{PV} using Figure 3. The solar irradiance and the calculated cell temperature (T_C) and or measured cell temperature as imputed to the Simulink model for the *P-V* characteristic curves and *I-V* characteristic curves; upon appropriate MATLAB, command is given. Eqns. (6), (7), (11), (12), (13) and (14) imbedded in sub blocks within the Simulink model solves for the required unknowns. This method eliminates the long iteration associated in the Newton Raphson method used by (Guda and Aliyu, 2015) for solving the unknown equations derived, represented here in equations (11), (12), (13) and (14). Data filter pro, Origin 50, and MATLAB computing software as utilized to process the data. The algorithmic flowchart for the implementation of the simulation is as in Figure 4.

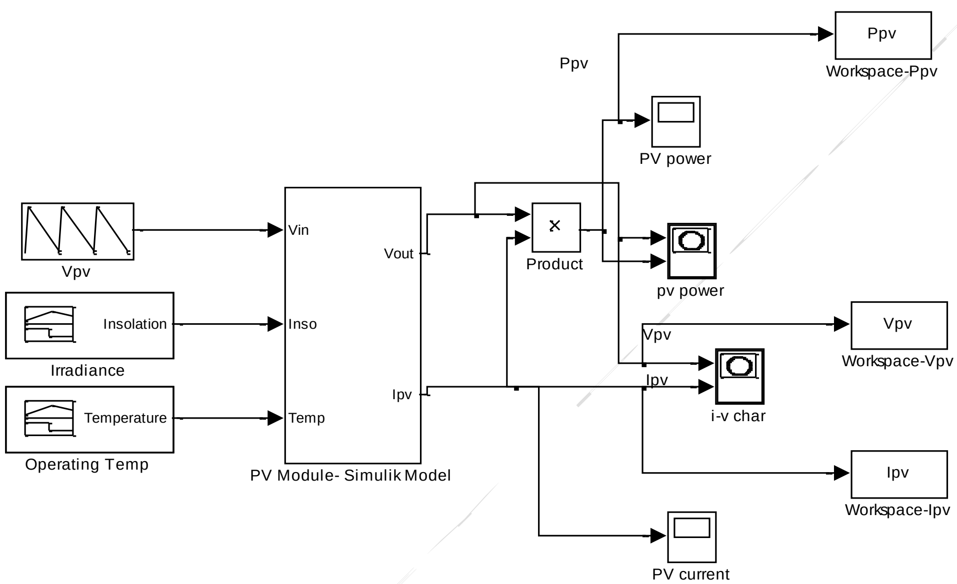


Figure 3: PV Model Simulator

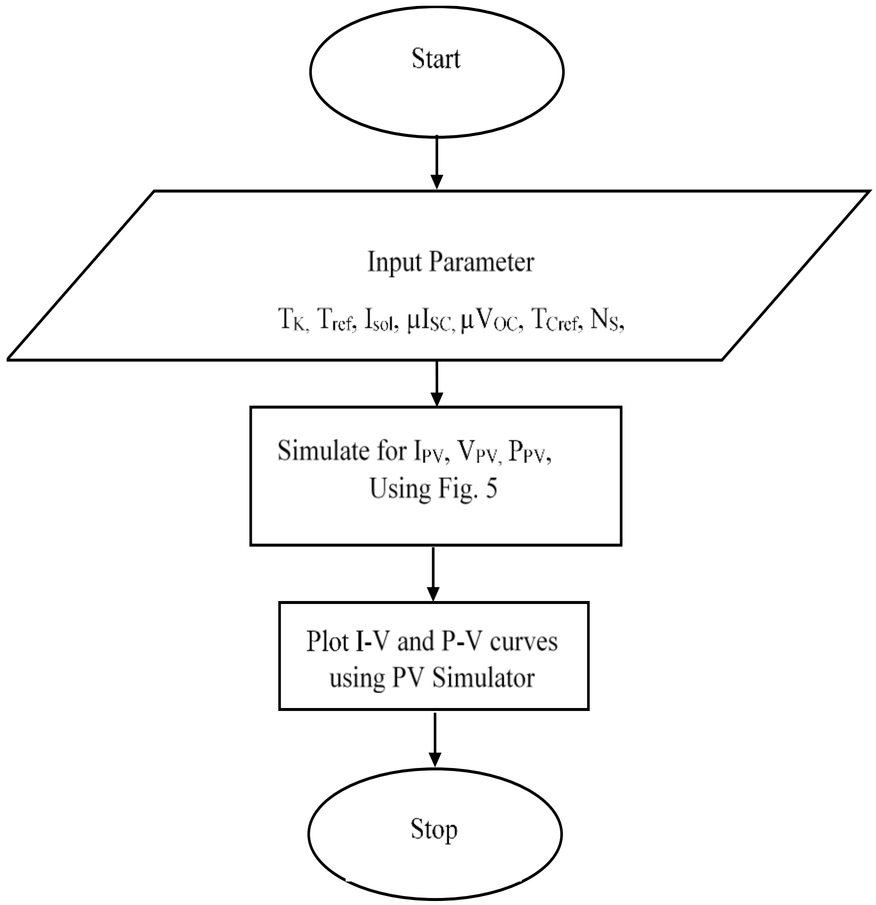


Figure 4: Algorithmic Flowchart for PV Model Simulation

3.0 Results and Discussion

3.1 Characterization of Measured Data

The various results for the performance evaluation of the 200W solar PV panel obtained in this paper are as presented and subsequently discussed. Firstly, is the determination of the power output of the 200W panel at prevailing weather conditions of Bauchi. Secondly, the Fill Factor and Module Efficiency are determined.

The characterized seasonal average test bed data presented in Table 3 and that for Center for atmospheric research (CAR) data obtained from the archives of Electrical and Electronics Engineering department in Table 4. The seasons comprised of Harmattan spanning through October, November, December and January; Clear Sky spanning through February, March, April and May while Cloudy spans through June, July, August and September for the year 2019

These seasonal average solar irradiance and Cell Temperature are the inputs to the MATLAB Simulink model to generate the characteristic curves to determine the performance parameters comprising of Open circuit voltage (V_{OC}), Short Circuit Current (I_{SC}), and Power output of the 200W solar module using the characterized data presented in Tables 3 and 4. Secondly, Open circuit voltage (V_{OC}), Short Circuit Current (I_{SC}), Voltage at maximum power point (V_{MMP}), Current at maximum power point (I_{MPP}) and power at maximum power point (P_{MPP}) using data characterized in Table 3 for varying temperature between 25^{O}C and 75^{O}C keeping solar irradiance constant for the respective seasons.

Table 3: Summary of Statistical Characterizations of Measured test rig data for Bauchi

Measured Parameters	Statistical Information	Micro-climatic Seasons		
		Harmattan	Cloudy	Clear Sunny
Solar Irradiance (W/m^2)	Maximum	761	723	758
	Average	653	563	646
	Minimum	348	341	347
Temperature (^oC)	Maximum	41	35	48
	Average	38	33	44
	Minimum	30	31	35

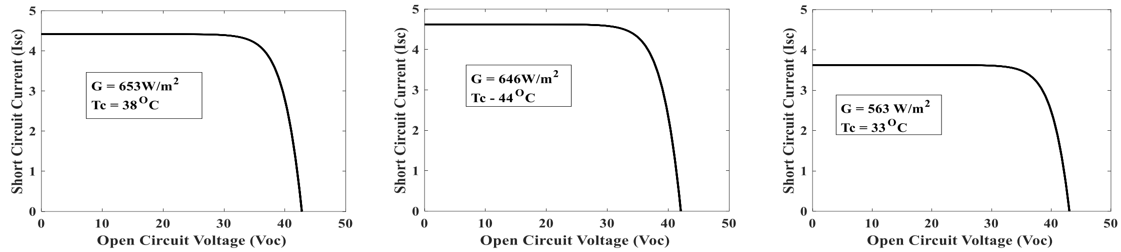
Table 4: Summary of Statistical Characterizations of Measured CAR Met data for Bauchi

Measured Parameters	Statistical Information	Micro-climatic Seasons		
		Harmattan	Cloudy	Clear Sunny
Solar Irradiance (W/m^2)	Maximum	484	628	724.5
	Average	448	412	608
	Minimum	425.4	120	381
Temperature (°C)	Maximum	30	27	35
	Average	27	26	33
	Minimum	24	24.9	30

3.2 Analysis of Characteristic Curves

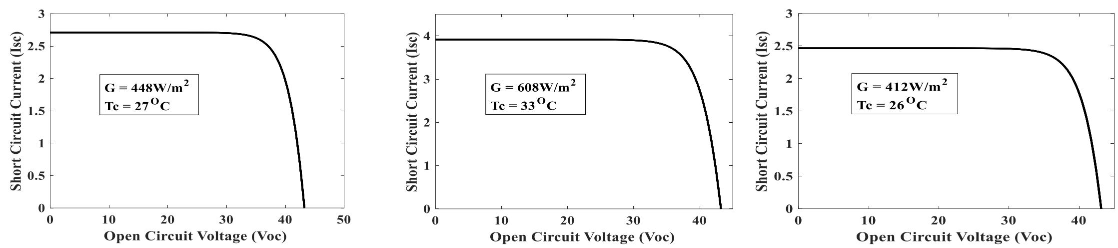
The family of seasonal characteristic *I-V* curves of the 200W solar module installed at the test rig for the three seasons are as presented in Figures. 5 (a, b, & c) and 6 (a, b, & c) when the cell temperature was measured directly from the underside of the module and when the cell temperature was calculated using Eqn. (1) respectively. Figures. 7 (a, b & c) presents the corresponding family of *P-V* curves when the cell temperature was measured and similarly, Figures. 8 (a, b & c) are P-V curves when the cell temperature was calculated using eqn. (1). The characteristics in the Figures clearly depicts the variations in the respective seasons; during each season the power output is dependent both on solar irradiance and temperature changes. The effect is noticeable during the cloudy season because of cloud cover at that period. During the Harmattan however, the variation is small due to hazy conditions. The clear sunny period shows a remarkable performance due to the clearness of the sky during that period.

The current and voltage deduced from them are I_{SC} = 4.4A, V_{OC} = 43.5V during Harmattan season; I_{SC} = 4.6A, V_{OC} = 42V during the clear sunny season and I_{SC} = 3.64A, V_{OC} = 43.2V during the cloudy season. The average power generated for the year was 144.3W. Similarly, when the data obtained from CAR station was used, the cell temperature was calculated using Eqn. (1), the corresponding values of the current and voltage deduced from this family of curves are I_{SC} = 2.72A, V_{OC} = 43.4V during Harmattan season; I_{SC} = 3.93A, V_{OC} = 43.3V during the clear sunny season and I_{SC} = 2.47A, V_{OC} = 43.3V. The average power generated for the year was 104.2W. These results showed correlating values when compared to the benchmark values of I_{SC} = 5.9A, V_{OC} = 45.5V, and 200W obtained at STC (25^{o}C, 1000W/m^2 and AM of 1.5).



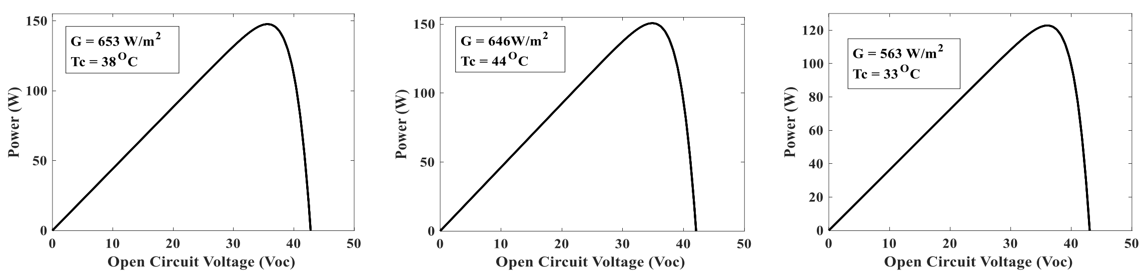
(a) Harmattan Season (b) Clear Sunny Season (c) Cloudy Season

Figure 5: Seasonal Average I-V Characteristics curve using Test Rig Data for Bauchi



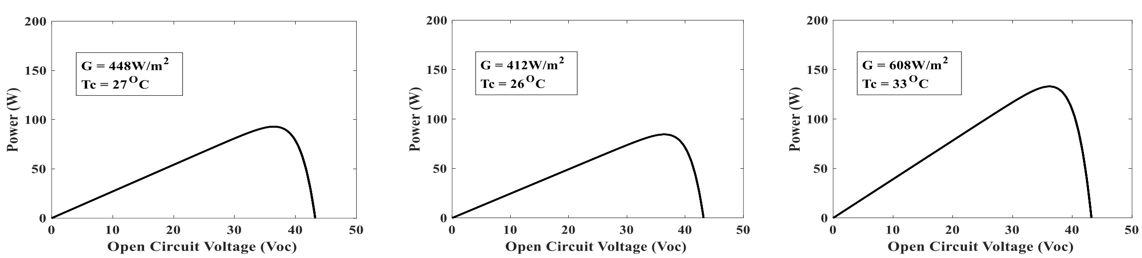
(a) Harmatttan Season (b) Clear Sunny Season (c) Cloudy Season

Figure 6: Seasonal Average I-V Characteristics curve using CAR Data for Bauchi



(a) Harmatttan Season (b) Clear Sunny Season (c) Cloudy Season

Figure 7: Seasonal Average P-V Characteristic curve using Test Bed Data for Bauchi



(a) Harmatttan Season (b) Clear Sunny Season (c) Cloudy Season

Figure 8: Seasonal Average P-V Characteristic curve using CAR Data for Bauchi

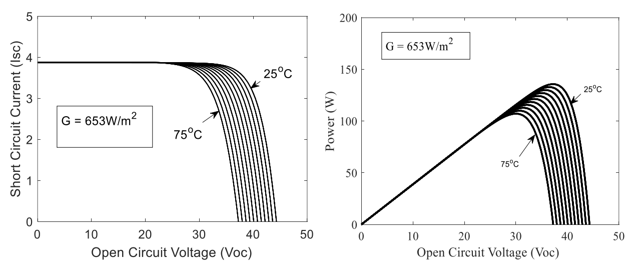
Table 5 summarizes the performance indices of the 200W solar panel investigated. It can be seen that the average values of short circuit current (I_{SC}), open circuit voltages (V_{OC}) and power at maximum power point (P_{MPP}) for the three scenarios are correlating and within the benchmark of the manufacturers results.

Table 5: Performance analysis of the 200W Solar Module

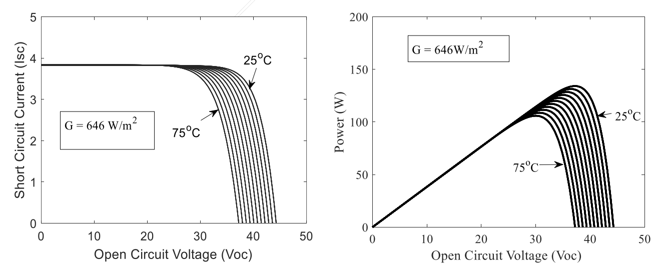
Performance Indicator	Measured Temperature	Calculated Temperature	Laboratory obtained Values (@STC)
Short circuit current (A)	4.2	3.04	5.9
Open circuit voltage (V)	42.9	43.3	45.5
Power at max. Power Point (W)	144.3	104.2	200

Where; Test Rig or experimental rig in column 1; refers to the results computed when the cell temperature of the solar panel was measured directly at the underside of the surface of the panel on the other hand CAR column 2; refers to the results computed when the cell temperature was calculated at prevailing Bauchi microclimate conditions using Eqn. (1). These results are now compared and tallied with the values obtained by the manufacturer at standard test condition (STC) defined in the methods as obtained in the laboratory presented in column three and it is the benchmark to which the performance is validated.

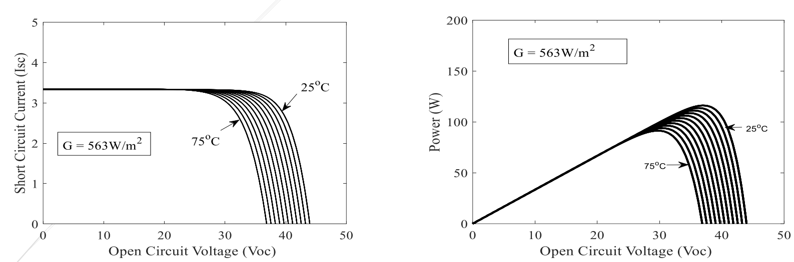
Figure. 9. (a, b & c) are family of Characteristic curves generated at an interval of 5°C rise in cell temperature starting from 25°C to 75°C. The curves as generated facilitates to investigate the temperature effects on the performance efficiency and the fill factor of the solar module at the prevailing weather conditions of Bauchi. The determined key performance indicators as compared to the benchmark values from manufacturer's data sheet. Fill factor and conversion efficiency are performance parameters of PV cells that are dependent on the cell temperature and irradiation prevailing at a location. The fill factor is dependent on the thermally excited electrons, as the temperature begin to rise it dominates the electrical properties of the semi-conductor. The correlation between temperature rise and the decline of PV efficiency as presented in Eqn. (3) was the basis for this evaluation, hence, the use of the curves to extract key evaluation parameters.



(a) Harmattan Season



(b) Clear Sunny Season



(c) Cloudy Season

Figure 9: Family of I-V & P-V Characteristic Curves as a Function of Temperature for Bauchi

Tables 6 presents the conversion efficiency and the fill factor for the 200W solar module under investigation. The trend revealed that; as the temperature begins to rises, the value of the conversion efficiency drops progressively to 13.6% across all the season. Similarly, the fill factor follows in the same trends to about 0.77 as the temperature rises to 75°C. The overall result gives an average efficiency of 16% and fill factor of 0.77. The performance of the 200W module investigated for the whole year is satisfactory. This result is in the neighborhood of the benchmark of >15.66% presented by the manufacturers data sheet at STC. It can as well be seen that as the fill factor approaches unity the conversion efficiency improves and hence, the performance of the PV module.

Table 6: Temperature Effects on the Conversion Efficiency and Fill Factor for the 200W Solar Module in the three Climatic Seasons

Temperature (°C)	Micro-Climatic Variant					
	Harmattan		Cloudy		Clear Sunny	
	Fill Factor	Conversion Efficiency (%)	Fill Factor	Conversion Efficiency (%)	Fill Factor	Conversion Efficiency (%)
25	0.800	16.9	0.744	16.9	0.886	16.9
30	0.767	16.7	0.797	16.7	0.859	16.7
35	0.756	16.3	0.805	16.3	0.817	16.3
40	0.747	16.0	0.812	16.0	0.718	16.0
45	0.794	15.7	0.801	15.7	0.757	15.7
50	0.779	15.3	0.773	15.3	0.779	15.3
55	0.765	15.0	0.749	15.0	0.747	15.0
60	0.744	14.6	0.727	14.6	0.732	14.6
65	0.730	14.3	0.725	14.3	0.769	14.3
70	0.724	13.9	0.768	13.9	0.777	13.9
75	0.744	13.6	0.784	13.6	0.787	13.6

4. Conclusion

The Mathematical model of the solar PV system for the determination of performance parameters as implemented in this paper was successful. The 200W module I-V and P-V characteristics performance curves analysis conducted returned an average open circuit voltage of 42.9V and short circuit current of 4.21A, under all climatic conditions in Bauchi. This result is in agreement with the benchmark values obtained in the laboratory of V_{OC} = 45.5V, I_{SC}. = 5.9A and 200W at STP conditions (25°C, 1000W/m^2 and AM of 1.5). The simulation results further revealed that the power delivered by the 200W monocrystalline solar module of 144.3W @620.6W/m^2, 35°C is within the benchmark obtained at STP in the manufacturer's data sheet. The evaluated conversion efficiency of 16% and fill factor of 0.77 are within the benchmark values of >15.66% efficiency and 50% to 82% fill factor range for silicon solar cells respectively. Finally, the key results presented here have conclusively exhibited the performance of the solar module investigated.

Acknowledgement

The results presented in this paper rely on TRODAN data collected and managed by the Centre for Atmospheric Research, National Space Research and Development Agency, Federal Ministry of Science and Technology, Anyigba, Nigeria. We thank the Centre for Atmospheric Research and their partners for promoting high standards of atmospheric observatory practice as well as the Federal Government of Nigeria for continuous funding of the Nigerian Space program (www.carnasrda.com).

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