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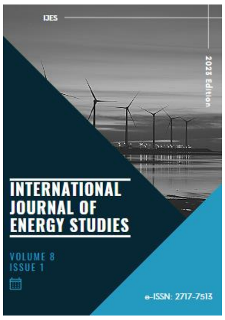

Research Article

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Simulation of a PV module at different set-up and operating conditions to give I-V and P-V curves

Anas Bala[a*], Jamilu Ya'u Muhammad[a], Kadawa Ibrahim Ali[b], Richard Mshellia Balthia[a]

[a]*Department of Mechanical Engineering, Nigerian Army University Biu, Nigeria*

[b]*Department of Electrical and Electronics Engineering, Nigerian Army University Biu, Nigeria*

*(*Corresponding Author: muhdjy87@gmail.com, anasbala1@yahoo.com)*

Highlights

- A solar PV module for power generation is characterized to improve its output using Scilab Xcos software.
- The simulation results show that the voltage across the PV module at open circuit and current produced at short circuit are increased with increasing the solar irradiance.
- The power output for the solar PV modules depend on the solar irradiance harnessed by the solar PV modules.

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ABSTRACT

Solar energy is among the source of energy that is reliable, available and non-harmful to the society. The output of solar photovoltaic system can be improved by means of solar tracking system either mechanically or electrically. The low conversion efficiency of PV modules, which is significantly impacted by operational conditions, is the primary constraint of PV systems. The financial risk of installing a system for maximum power output is increased by improper assessment of PV module at various configurations and operating conditions and the performance of solar modules strongly depends on the temperature of the solar modules. This present work investigates the effect of temperature on PV module using Scilab Xcos™ simulation software at different setups and operating conditions to give I-V and P-V curves in order to evaluate its output performance. The results of the simulations show that the voltage across the PV module at open circuit and current produced at short circuit increased with increasing the solar irradiance harnessed by the solar module from 700W/m^2 to 1000W/m^2 at constant temperature of 25 ^{o}C thereby increasing the maximum output power of the PV module. The results also revealed that using standard test condition (STC) parameters at different operating conditions of PV module the increment of short circuit current is more significant as open circuit voltage than current produced at short circuit.

Keywords: Crystalline silicon, current, insolation, solar PV modules, voltage

1. INTRODUCTION

Increasing of power demand is major challenge in the power sector and non-renewable energy sources cannot overcome this challenge more especially in developing countries. To meet the demand, renewable energy sources are to be alternative sources which are being utilized to reduce pollution and global warming. Hence fossil fuels that causes global warming will not be used for domestic use.

Solar photovoltaic (PV) cells are device that convert solar energy directly into electricity. Electric power can be generated from solar PV cell either direct and indirect from solar radiation [1]. The solar PV cell efficiency varies between 7% and 40% based on semiconductor materials used by the manufacturers [2-4]. In comparison to other PV system installation components, the PV modules typically represent the largest portion of the investment cost. As a result, the PV system's return on investment is largely dependent on the PV modules' ability to produce energy. Unfortunately, the PV modules often had low conversion efficiency because of a few degrading causes. When predicting energy production, PV module temperature is regarded as a crucial factor. For instance, a PV module’s ability to produce electricity may irreparably degrade under prolonged high temperature operating circumstances. The high temperature brought on by waste heat that is produced as a result of solar radiation absorption. Only up to 20% of the solar radiation that strikes a PV modules is converted into electricity [5]. The majority of what is left is transformed into heat. The stored heat energy has the effect of raising the working temperature of the PV modules, which lowers its electrical efficiency. Under standard test condition (STC), each degree of temperature increase results in a 0.40–0.50% reduction in the PV module's conversion efficiency [5]

Solar photovoltaic cells are mostly made-up of n-type silicon. When sunlight falls on a cell, the electrons in the atomic orbits of an atoms flows through the material of the solar PV are received as DC electricity. This DC electricity can be converted into AC electricity by connecting inverter to the system and the AC electricity is feeds to home appliances as electric power [6]. Three silicon-based materials for solar PV cells are generally known; monocrystalline silicon, polycrystalline silicon and amorphous silicon. Apart from Silicon-based, cadmium telluride and copper indium gallium selenide are also materials used for manufacturing solar PV cells [7]. One of the limitations of flat plate photovoltaic is that, it cannot converge the solar irradiance, whereas high concentration photovoltaic (HCPV) system is converging solar irradiance by the means of lenses or mirrors [8]. Some modern concentrated solar photovoltaic modules are 31.8% power output efficient over the older modules as stated by the semiconductor materials manufacturer [9]. Solar photovoltaic technologies are always improving for over decades based on the efficiencies of the solar cells. The efficiencies of the crystalline silicon, Cadmium Telluride (CdTe), Copper Indium Gallium Selenide (CIGS) and GaInP/GaAs/Ge solar cells are 24.7%, 16.5%, 18.4% and 39% respectively [10]. The stability and efficiency of an organic solar cells are trending in the world of researchers, but the target values are yet less than the thermodynamic efficiency limits of range between 31-70% [3]. The efficiencies of commercial solar cells rose from 50% to 65% [11].

Chander *et al.* [12] investigated the impact of changing PV cell temperature under constant light intensities. This study found that the output of the parameter is significantly influenced by the temperature of the PV cell. It was determined that the V_{oc}, P_{max}, and fill factor (FF) had negative temperature coefficients while the I_{sc} had positive temperature coefficients. Dash and Gupta [13] have noted how temperature affects the amount of power that may be produced by various types of PV panels. When considering the temperature coefficient of PV panels, monocrystalline had an average output power loss of -0.446%/°C. Other researchers, Temaneh-Nyah and Mukwekwe [14] discovered how high temperatures can result in power losses through PV panels. The outcome suggested that the elevated temperature was to blame for the average energy loss of the 37.8 kW PV system installation over the course of its daily 12-hour operation, which is 14.6 kWh. About 0.31% of power loss per Kelvin was discovered to be the temperature coefficient [14]. Due to their sensitivity to operating temperature, different types of PV panel technologies have played a diverse role in generating output power. When operated at high operating temperatures, amorphous solar panels are more effective than monocrystalline silicon, according to research conducted by Suwapaet and Boonla [15]. For example, with no significant differences in PV panel temperature, monocrystalline silicon produced less power than amorphous silicon at a range solar irradiation of 600 W/m^2 [15]. This study looked into how well PV panels performed at different setups and operating conditions.

2. MATERIALS AND METHOD

Firstly, the analysis of the PV module output performance was simulated using Scilab Xcos™ simulation software. By using this software, the basic data of PV module can be explored as shown in Table 1. All data were obtained from Manufacturer's Datasheet with a rating of 25 °C and maximum of one sun (700W/m^2 to 1000W/m^2). The purpose of the simulation is to model and observe the effect of operating conditions and evaluate the electrical characteristics of PV module in order to get its maximum output performance. To achieve this purpose, there are five equations needed to be solved. Due to complexity in the nature of some of these equations, a software program $Scilab\ Xcos^{TM}$ was used. And after launching $Xcos$ and $Scilab$ instructions to define variables or functions that is used in setting up diagram blocks (i.e. set context) were made in the editing window menu bar.

Table 1. SHARP NU-R240J5 specifications for a PV module

Designation	Rating
Rated power (P_{mp})	240 W
Voltage at maximum power (V_{mp})	30.2 V
Current at maximum power (I_{mp})	7.95 A
Open circuit voltage (V_{oc})	37.3 V
Short circuit current (I_{sc})	8.63 A
Total number of cells in series (N_s)	60

The equations and their block arrangements in the editing window are given below:

2.1. Photovoltaic (PV) Module Equations and Block Arrangements

i. *Photo-current* (I_{ph})

The equation output is I_{ph}, its inputs are $T\ and\ G$ while the constants are $I_{sc}\ and\ k_i$. The photo-current (I_{ph}) is given in the relation below:

$$I_{ph} = [I_{sc} + k_i.(T - 298)].\frac{G}{1000} \quad (1)$$

Where I_{ph} = Photo-current output for the PV Modules (A), T = Temperature (^oC) and G = Solar intensity (W/m^2)

The blocks arrangement for the equation (1) is shown in figure 1.

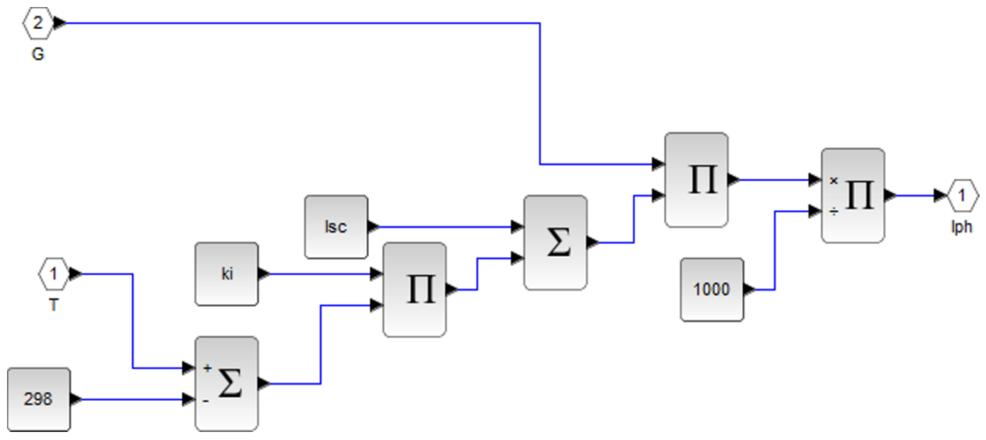

Figure 1. Photo-current (I_{ph}) block diagram

ii. *Saturation current* (I_o)

$$I_o = I_{rs} . \left[\frac{T}{T_n}\right]^3 . exp\left[\frac{q. E_{go}.\left(\frac{1}{T_n} - \frac{1}{T}\right)}{n. K}\right] \quad (2)$$

For equation (2), I_o is the output, $T\ and\ I_{rs}$ are the inputs while $T_n, q, E_{go}, n\ and\ K$ are the equation constants.

The blocks arrangement for the equation (2) is shown in figure 2.

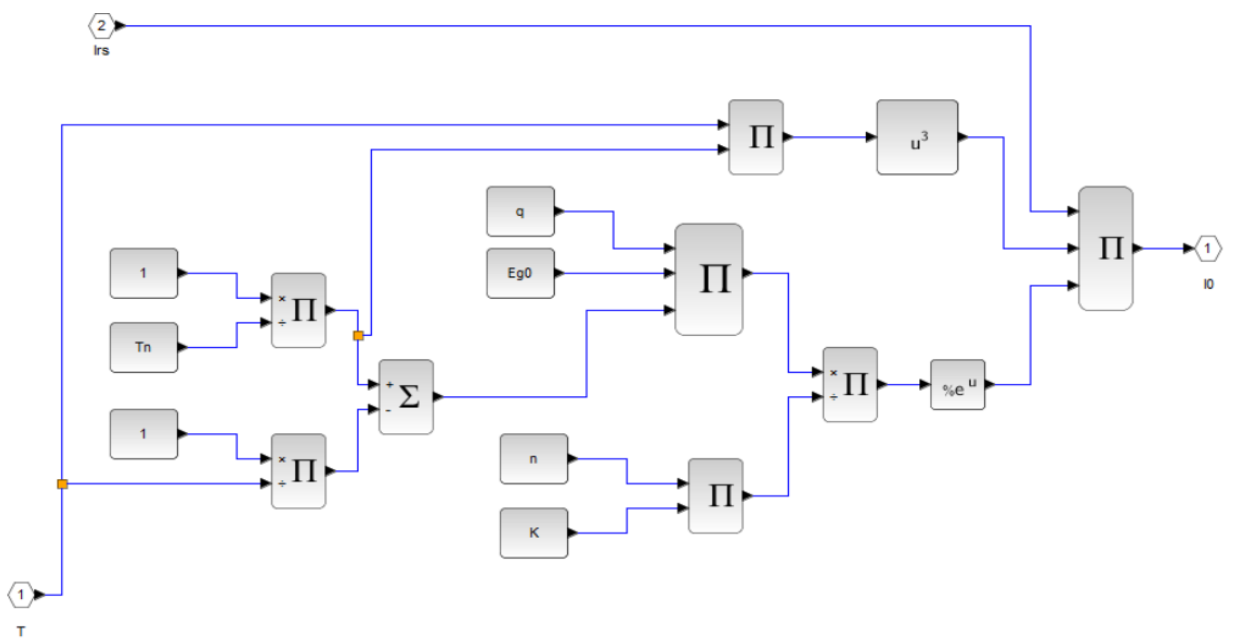

Figure 2. Saturation current (I_o) block diagram

iii. Reverse saturation current (I_{rs})

$$I_{rs} = \frac{I_{sc}}{e^{\left(\frac{q.V_{OC}}{n.N_S.K.T}\right)} - 1} \quad (3)$$

The equation (3) output and input are I_{rs} *and* T respectively while$I_{sc}, V_{oc}, q, n, N_s$ *and* K are the constants.

The blocks arrangement for this equation is shown in figure 3.

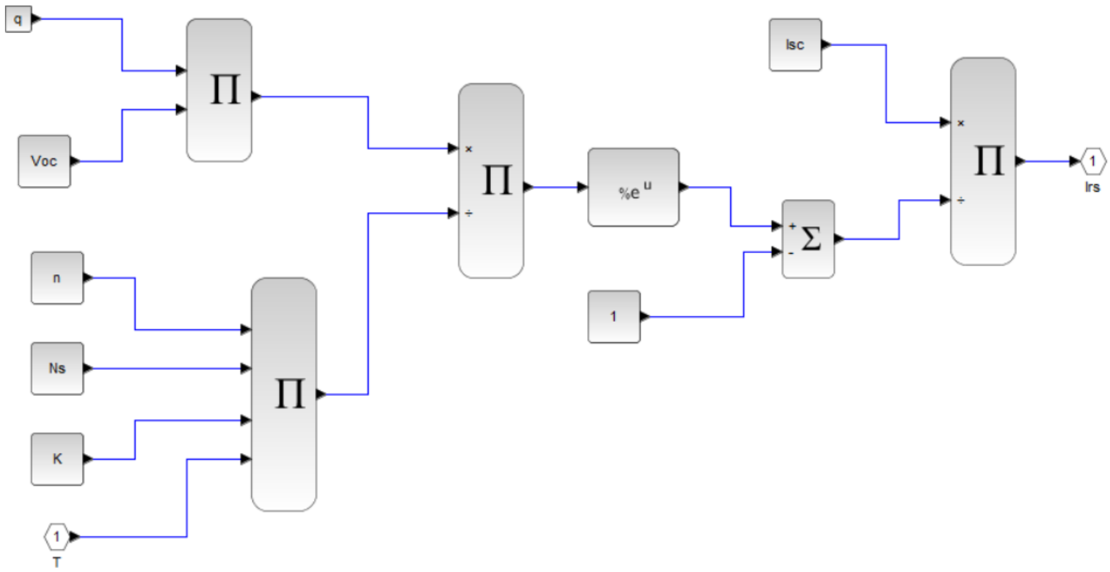

Figure 3. Reverse saturation current (I_{rs}) block diagram

iv. Current through shunt resistor (I_{sh})

$$I_{sh} = \left(\frac{V + I.R_s}{R_{sh}}\right) \quad (4)$$

The output for the equation (4) is I_{sh}, the inputs are I *and* V while both R_s *and* R_{sh} are the constants.

The blocks arrangement for this equation is shown in figure 4.

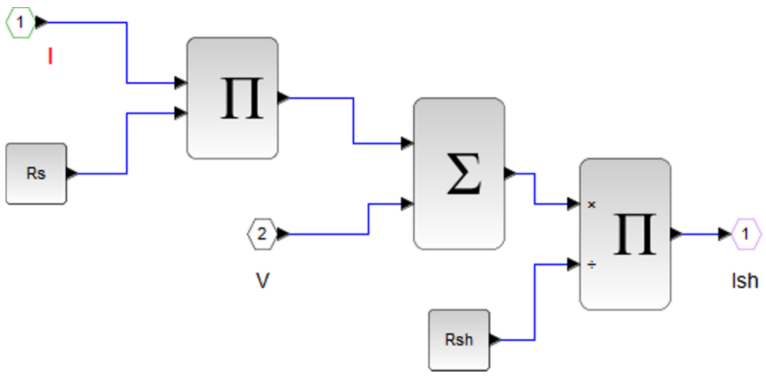

Figure 4. Current through shunt resistor (I_{sh}) block diagram

v. Output current (I)

$$I = I_{ph} - I_o . \left[exp\left(\frac{q.(V + I.R_s)}{n.K.N_s.T}\right) - 1\right] - I_{sh} \tag{5}$$

This is the level where it all becomes complex. This equation (5) has I as the output and at the same time as one of the inputs. The other inputs are $V, T, I_o, I_{ph} and\ I_{sh}$ while the constants are$q, R_s, n, K, and\ N_s$.

The blocks arrangement for this equation is shown in figure 5.

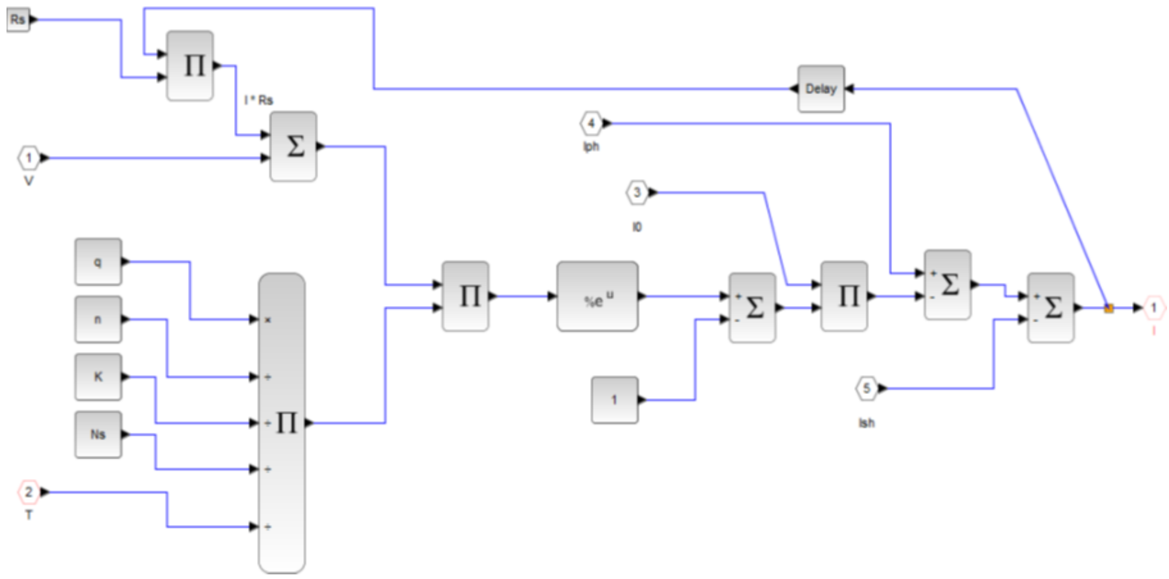

Figure 5. Output current (I) block diagram

Figure 6 shows the interconnectivity of these block diagrams in superblocks with one another.

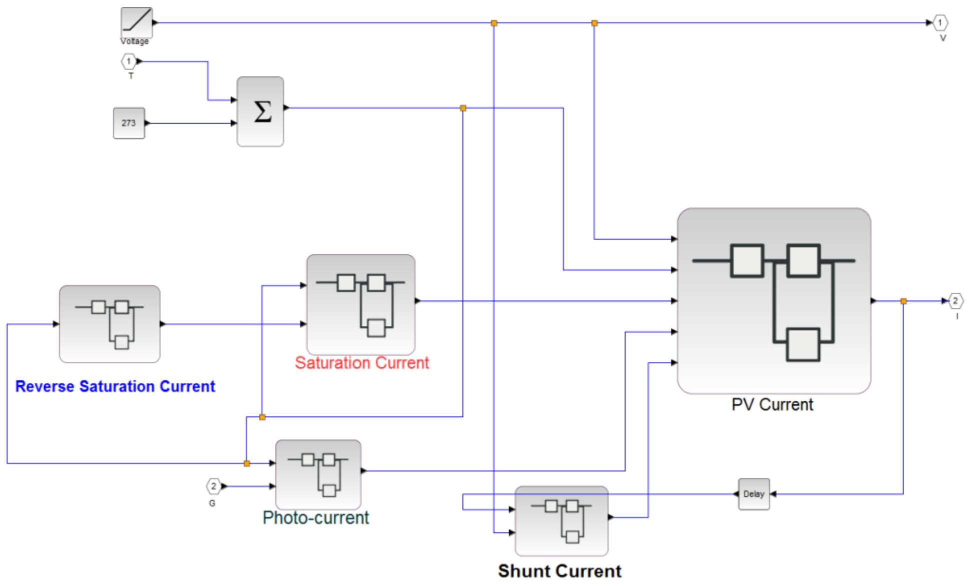

Figure 6. Photovoltaic (PV) module sub-superblocks

Figure 7 shows that for the system to give the necessary outputs (i.e. current and voltage) the module will need a particular value of T and G as inputs into the system.

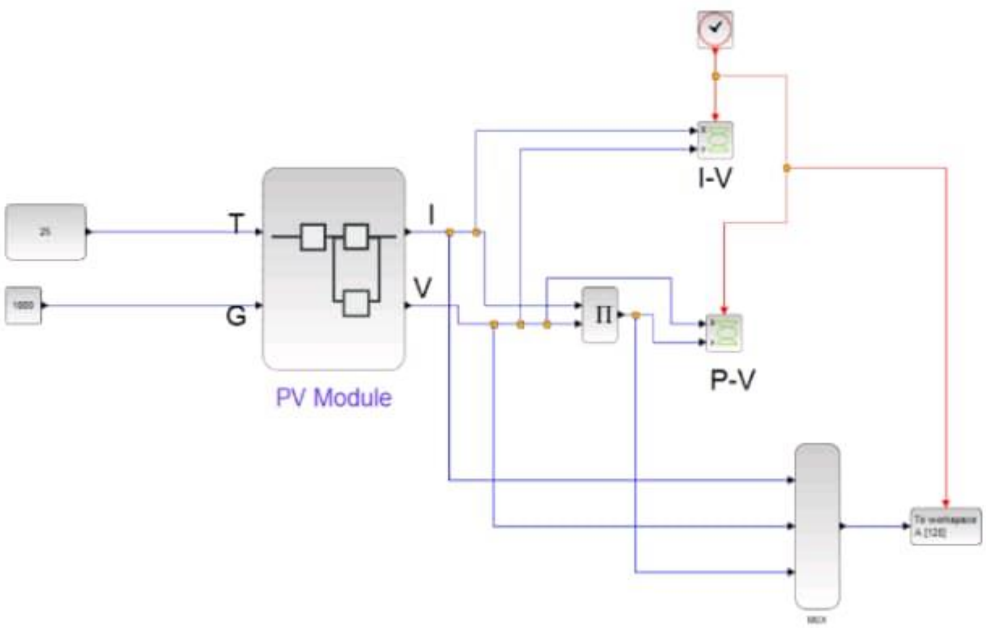

Figure 7. Photovoltaic (PV) module visualization

3. RESULTS AND DISCUSSION

The data obtained from modeling and simulations in Scilab Xcos™ were exported to the Excel Worksheet. The table 2 shows the data at different solar irradiance.

Table 2. Voltage, current and power at different solar irradiance

Time [s]	V [volt]	I [amps] @ 700 W/m²	P [watt] @ 700 W/m²	I [amps] @ 800 W/m²	P [watt] @ 800 W/m²	I [amps] @ 900 W/m²	P [watt] @ 900 W/m²	I [amps] @ 1000 W/m²	P [watt] @ 1000 W/m²
0.1	1	6.038593	6.038593	6.901593	6.901593	7.764593	7.764593	8.627593	8.627593
0.3	3	6.033778	18.10133	6.896778	20.69033	7.759778	23.27933	8.622778	25.86833
0.5	5	6.028963	30.14481	6.891963	34.45981	7.754963	38.77481	8.617963	43.08981
0.7	7	6.024147	42.16903	6.887147	48.21003	7.750147	54.25103	8.613147	60.29203
0.9	9	6.019328	54.17395	6.882328	61.94095	7.745328	69.70795	8.608328	77.47495
1.1	11	6.011274	66.12401	6.873811	75.61192	7.736348	85.09983	8.598885	94.58774
1.3	13	6.006404	78.08325	6.868936	89.29616	7.731467	100.5091	8.593996	111.722
1.5	15	6.001434	90.02151	6.86395	102.9593	7.726464	115.897	8.588975	128.8346
1.7	17	5.996199	101.9354	6.858672	116.5974	7.72114	131.2594	8.583599	145.9212
1.9	19	5.990238	113.8145	6.852597	130.1994	7.714939	146.5838	8.57726	162.9679
2.1	21	5.982316	125.6286	6.844364	143.7317	7.706364	161.8336	8.56831	179.9345
2.3	23	5.969073	137.2887	6.830281	157.0965	7.691356	176.9012	8.552285	196.7026
2.5	25	5.941406	148.5351	6.800334	170.0084	7.658902	191.4726	8.517074	212.9268
2.7	27	5.874651	158.6156	6.727401	181.6398	7.579175	204.6377	8.429874	227.6066
2.9	29	5.70197	165.3571	6.537979	189.6014	7.371341	213.7689	8.201794	237.852
3.1	31	5.242306	162.5115	6.032965	187.0219	6.81646	211.3103	7.592076	235.3544
3.3	33	4.005636	132.186	4.673583	154.2282	5.322159	175.6313	5.949441	196.3316
3.5	35	0.669047	23.41664	1.005863	35.20521	1.290532	45.16862	1.517914	53.12698

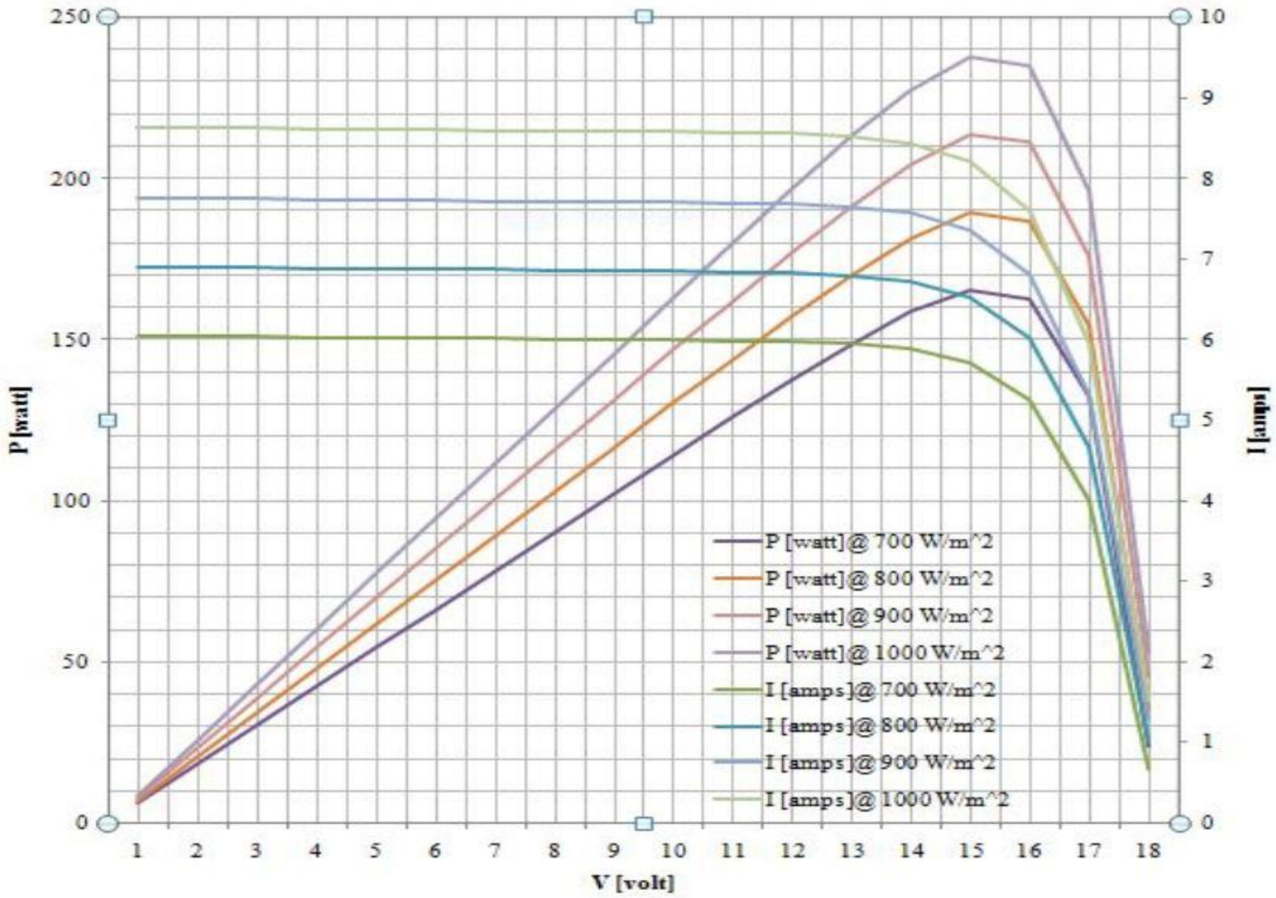

Figure 8. Power againsts voltage (P-V) and current versus voltage (I-V) curves at different solar irradiance

Table 2 shows open circuit voltage, short circuit current and power output at different solar irradiance. The power output in the solar PV modules increases as the short circuit current increases at constant voltage across the open circuit of the solar PV. Whereas, the current decreases with the increase in time intervals and the power output in the solar PV modules increases as the time interval and voltage across the circuit of the solar PV modules increases. This result is concurring with the result obtained by Shukla *et al.*, [16].

Figure 8 present solar photovoltaic (PV) module that was modeled and simulated using Scilab Xcos^{TM} for different solar irradiance and constant temperature of 25^{o}C. The irradiance ranges from 700W/m^2 to 1000W/m^2 i.e. maximum of one sun, this increase in irradiance therefore lead to increase in current with the voltage is kept constant for different solar irradiance. As the solar insolation is increasing throughout the day similarly I-V and P-V characteristics changes. When the solar irradiance increase, the power output increases with the increase in voltage and the current. The result obtained is agreed to the one obtained by Kumar Mahanta *et al.,* [17], Pradhan, *et al.,* [18], Mustapha *et al.,* [19] and Shaari, *et al.,* [20] under Bangladesh, India, Nigeria and Malaysian conditions.

4. CONCLUSION

A solar photovoltaic module for power generation is characterized to improve its output using Scilab Xcos software under standard solar radiation data for Ilorin of Kwara State Nigeria. Each components and subsystems of the photovoltaic modules have been analyzed to get their block diagrams and equations. The simulation results show that the voltage across the PV module at open circuit and current produced at short circuit are increased with increasing the solar irradiance ranges from 700W/m^2 to 1000 W/m^2. Since the relationship between the voltage across the open circuit, short circuit current and solar irradiance of the solar photovoltaic module is direct proportion, then the increment is linear function of the solar irradiance. And the power output for the solar photovoltaic (PV) modules depend on the solar irradiance harnessed by the solar photovoltaic (PV) modules. The power output of the module is also directly proportional to the amount of solar irradiance extracted by the solar PV modules.

It can be said that this research will serve as a good simulation model to test the performance of any PV module/array under the variation of temperature and irradiance condition and of course to pave a way in designing the PV module/array that will give the maximum power output.

Effect of shading or dirty on the solar PV array and different configurations of the algorithms for better MPPT are recommended as future work.

DECLARATION OF ETHICAL STANDARDS

The authors of the paper submitted declare that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

CONTRIBUTION OF THE AUTHORS

Anas Bala: Brought the Idea and Planned the method.

Jamilu Ya'u Muhammad and Kadawa Ibrahim Ali: Conducted the literature review and found the research gap.

Anas Bala, Kadawa Ibrahim Ali and Richard Balthia Mshelia: Performed the experiments and analyse the results.

Jamilu Ya'u Muhammad: Wrote the manuscript.

Jamilu Ya'u Muhammad and Richard Balthia Mshelia: Re-examined the spelling and grammar of the article.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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