

International Journal of Sustainable Energy and Environmental Research

2020 Vol. 9, No. 1, pp. 34-45.

ISSN(e): 2306-6253

ISSN(p): 2312-5764

DOI: 10.18488/journal.13.2020.91.34.45

© 2020 Conscientia Beam. All Rights Reserved.



SIMULATION AND EXPERIMENTAL VERIFICATION OF ELECTRICAL POWER OUTPUT OF A MICROCONTROLLER BASED SOLAR TRACKING PHOTOVOLTAIC MODULE

Bamiji, Z.

Adewole¹⁺

Babafemi O. Malomo²

Oluwaseun P.

Olatunji³

Abiodun O. Ikobayo⁴

^{1,2,3,4}Department of Mechanical Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria.

Email: badevole@oauife.edu.ng Tel: +2348035026452

ABSTRACT

Article History

Received: 16 January 2020

Revised: 18 February 2020

Accepted: 26 March 2020

Published: 22 April 2020

Keywords

PV module

Microcontroller

Solar tracking

Performance

Matlab

Solar irradiance

Cell temperature

Maximum power output.

The study evaluated the performance of a microcontroller based solar tracking PV system. The system utilized a stepper motor, two light dependent resistors and a worm gear to intelligently control the rotation of the photovoltaic modules such that it automatically provides the best alignment of the solar panel with the sun for maximum power output. The performance of the PV system was evaluated through simulation and experiment. The effect of different levels of solar irradiance and cell temperature was investigated on the power output of the solar tracking PV system. An increase in maximum power output ($P_{max, m}$), actual light generated current (I_{pv}) and actual short circuit current (I_{sc}) has been observed with the increase in solar irradiance. With the decreasing cell temperature, the power produced decreases. The percentage relative error between the optimum simulated and the experimental values for P_{max} and I_{pv} was found below 5%, indicating that the simulation model found good agreement with the experimental values. The results are expected to provide insights into the interaction between weather data (irradiance and temperature) and PV module power output during conversion of solar energy into electricity.

Contribution/Originality: This study contributes in the existing literature to the enhancement of photovoltaic (PV) conversion. This work integrates microcontroller and stepper motor to intelligently control the rotation of the PV module for higher absorption of solar energy. The work incorporates solar position algorithms and MATLAB model to evaluate the performance of the PV system using weather data from the study location and PV module datasets. The paper provides photovoltaic engineers with accurate model for predicting the performance of a microcontroller based solar PV systems at different solar irradiance and cell temperature.

1. INTRODUCTION

Solar photovoltaic system is becoming fast and affordable alternative means of converting solar energy into electrical energy all over the world. Small household photovoltaic systems can sufficiently meet the initial modest electricity demands of most users in terms of standalone PV power station which can be used for solar lighting, street lighting and solar pumps for water distribution and so on.

Solar panel directly converts solar radiation into electrical energy. Performance of solar panels vary with the location of use and actual environmental conditions. Singh (2013) showed that the variation in air mass and other

metrological parameters of the local environment like solar flux, temperature and relative humidity affected the module performance. In practice, solar intensity is usually modulated due to the rapid changing cloud cover and this accounts for major difference between the efficiency of solar panels in the field and the efficiency of the same panel under simulated conditions. One of the ways by which the efficiency of the solar panel could be enhanced is by increasing the intensity of light falling on it. Solar trackers had been tested and proven to increase the efficiency of solar module by tracking the sun position as it rotates.

The sun tracking solar photovoltaic system is an array mounting system that automatically orients the array to the position of the sun. Since the sun's position in the sky changes with the seasons and the time of day, trackers are used to align the collection system to maximize energy production (Abbasoglu & Okoye, 2013). The movement of the tracker is produced by either active or passive means. The active trackers rely on electrically operated positioning drives which involve the use of electric motor, gear drives, coupling or sensor controlled (Alexandru & Pozna, 2010) while the passive trackers are based on the use of thermal expansion materials (Shaifali & Jain, 2014).

Sun trackers can be a single axis tracker that follows the sun from east to west during the day or two axis tracker that follows the sun from east to west during the day and from north to south, during the seasons of the year (azimuth and solar altitude). The sun tracking PV systems is costly because of additional cost of trackers and requires more maintenance due to complexity in its design and operations but have the advantages of higher absorption of solar radiation, higher conversion of solar radiation into electricity from 20 up to 50% (Chang, 2009; Chong et al., 2009; Guo, Curtis, Barendregt, & Surillo, 2009; Kelly & Gibson, 2009; Perpiñán, 2009) and higher power output as compared to the fixed PV systems.

The efficiency of the PV tracking system is satisfied if the condition given in the equation by Alexandru and Pozna (2010) is achieved.

$$\varepsilon = (E_T - E_F) / E_C \gg 0. \quad (1)$$

Here, E_T is the electric energy produced by the PV panel with tracking, E_F is the energy produced by the same panel without tracking and E_C is the energy consumption for orienting the panel. The efficiency (ε) must be within 25-50 percent in order to justify the tracking technically and economically. This however depends on geographical location, day of the year and the site meteorological conditions.

A microcontroller is a small computer (SoC) on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals. They can be considered as a self-contained system with a processor, memory and peripherals and can be used as an embedded system (Heath, 2002). They are used in automatically controlled products and devices, such as automobile engine control systems, implantable medical devices, remote controls, office machines, appliances, power tools, toys and other embedded systems.

The tracking of the sun is achieved by coupling a stepper motor to the PV panel to track the sun position as it rotates thereby producing maximum energy. This is achieved by using a programmed microcontroller to deliver stepped pulses in periodical time intervals (Shaifali & Jain, 2014). This causes the stepper motor to rotate the mounted panel as desired. In principle, microcontroller based solar tracker consists of light dependent resistors (LDRs), microcontroller, motor, solar panel, battery and power supply. LDRs are used to sense the light intensity and locate the position of the sun relative to the panel. The microcontroller receives data from LDRs, computes the data and signals the motors to align the panel.

Modelling photovoltaic module requires weather data such as irradiance and temperature as input variables (Habibi, Youcef, & Fatima, 2014). The output variables include current, voltage or power and any changes in the variables influence the output. Therefore, it is important to accurately model PV module in a chosen location in order to understand the behaviour and characteristics of PV module installed in that location so as to obtain more precisely, the electrical power output that is closest to the experimental value.

In the open literature, different authors have used different models to evaluate the performance of solar modules. The models include: Double diode model (Chan & Phang, 1987) circuit based solar PV model

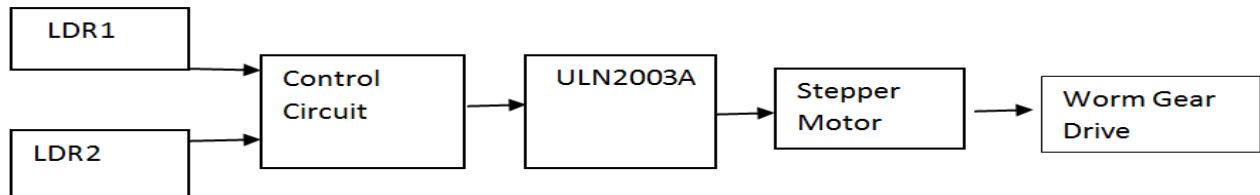
(Krismadinata, Rahim, Ping, & Selvaraj, 2013; Patel & Sharma, 2013) mathematical model (Mohammedi, Rekioua, & Mezzai, 2013; Yatimi & Aroudam, 2015) series-parallel model (Pendem & Mikkili, 2018) single diode equivalent circuit with stepwise simulation (Vinod, Raj, & Singh, 2018) MATLAB model (Abdulkadir, Samosir, & Yatim, 2012; Qi & Ming, 2012) and so on.

MATLAB/Simulink is employed frequently for the simulation of photovoltaic systems due to its effectiveness. Modelling approach requires weather data such as irradiance and temperature as input variables. The output variables include current, voltage and power among others. In this study, the performance of a microcontroller based solar tracking PV system is evaluated through simulation and experiment. Solar position algorithm (SPA) calculator was used in the simulation to determine the specific parameters for the installation of solar tracking PV system under real climatic conditions of Ile-Ife, Nigeria. A MATLAB script (simplest type of MATLAB program) was written and executed on MATLAB to calculate the predicted maximum power output for the study location. The predicted power outputs were compared with the measured values.

2. METHODOLOGY

2.1. The Solar Tracking System

The flow chart for the solar tracking system is shown in [Figure 1](#). The system components include two light dependent resistors (LDRs), a control circuit (control unit) and a geared motor. The system automatically provides the best alignment of the solar panel with the sun to get maximum power output. The Microcontroller allows stepper motor to intelligently control the rotation of the photovoltaic modules according to the direction of the sun rays. It also measures the voltage on the two light sensors at any time of the day and compares the measured voltages. The algorithm to control the rotation of the solar panel is stored and executed by the PIC microcontroller.



[Figure-1.](#) Flow chart of solar tracking system.

Source: Ikobayo and Olatunji (2015).

2.2. Control Circuit Design

The control circuit shown in [Figure 2](#) is used for the experiment. It consists of a PIC microcontroller, capacitors, resistors, oscillator and a voltage regulator. [Figure 3](#) shows the circuit diagram of solar PV tracking system using microcontroller. It consists of two light dependent resistors (LDRs), PIC16F877A microcontroller, stepper motor and ULN2003 stepper motor driver. The two light dependent resistors measure the intensity of light with the help of a microcontroller. The microcontroller then reads the intensity of lights of the two LDRs. Solar panel remains stable and stepper motor remains off when the intensity of light of the two LDRs is same. During the day, light sensor turns and consequently, rotates the solar panel with the help of stepper motor. ULN2003 is used as the stepper motor driver and it amplifies low current signal to high current signal. It also converts electrical pulses into mechanical movement. The algorithm to control the rotation of the solar panel is stored and executed by PIC microcontroller. A solar tracking algorithm is converted to C programming language. The code generated is then compiled and converted to Hex files which is transferred to the PIC microcontroller by using a device called a programmer. The voltage regulator helps to step down the battery voltage to about 5volts needed by the microcontroller while the energy used by the microcontroller is stored by the capacitors. [Figure 4](#) shows the sun tracking PV system and the enlarged view of drive mechanism used for the experiment. It consists of solar panel,

gear drive, stepper motor and panel support. The solar azimuth and zenith angles were used to orientate the PV modules towards the direction of the sun for maximum insolation. The panels were tilted at the optimum tilt angle of 18 degree corresponding to the study location. The rotation of the solar panel is controlled by the microcontroller.

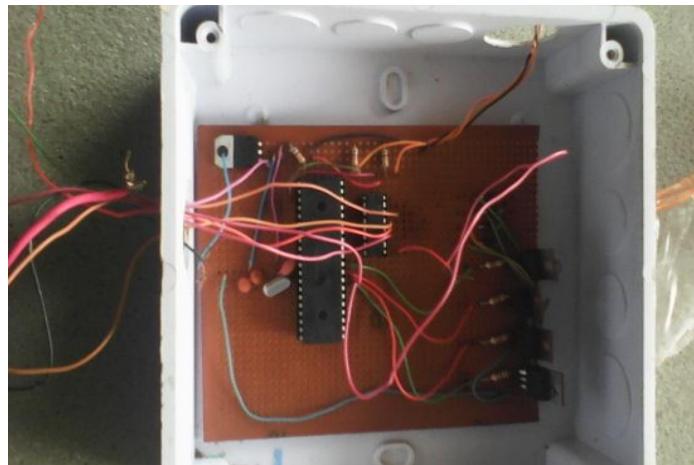


Figure-2. Control circuit.

Source: Ikobayo and Olatunji (2015).

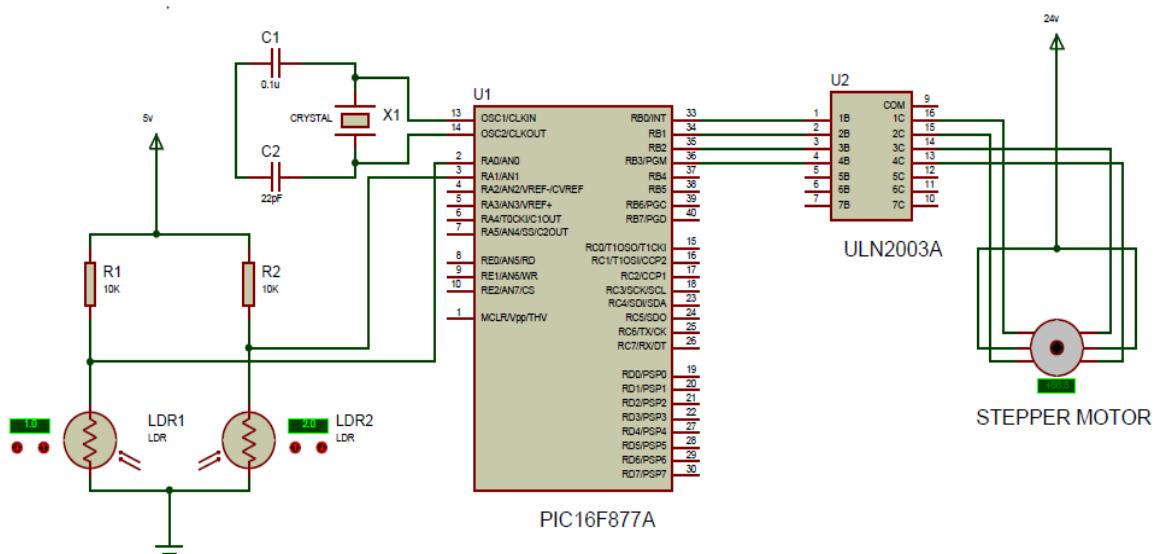


Figure-3. Circuit diagram of microcontroller solar PV tracking system.

Source: MicrocontrollerLab.com (2020).

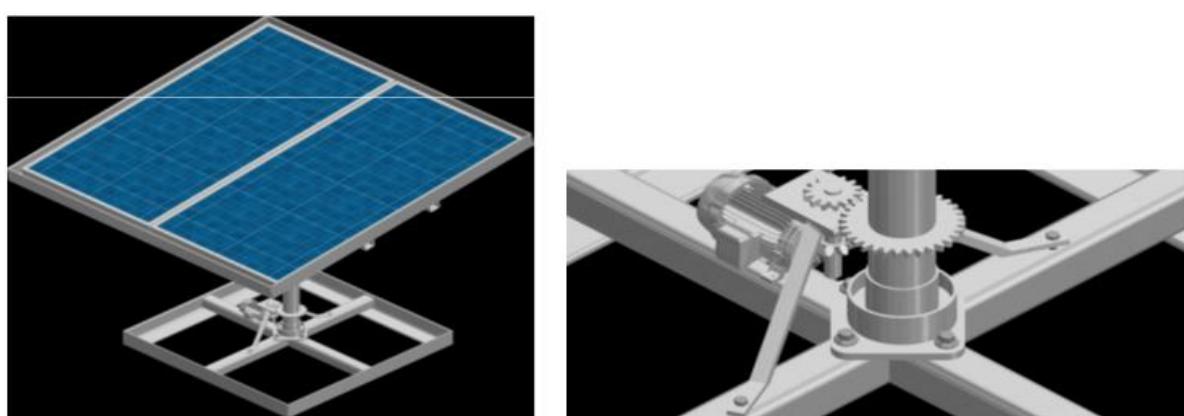


Figure-4. Sun tracking PV system and enlarged view of the drive mechanism.

Source: Ikobayo and Olatunji (2015).

2.3. Simulation

2.3.1. Solar Position Algorithm (SPA) Calculator

The solar position algorithm (SPA) calculator was used in the simulation to determine the specific parameters for the installation of solar tracking PV system in the study location. The required parameters include: time zone, latitude, longitude, average annual pressure, average annual temperature, elevation, surface slope and the surface azimuth rotation. The outputs obtained from the simulation are the solar zenith angles, the solar azimuth angles and the incidence angles of the sun rays. These parameters were used to orient the PV modules towards the direction of the sun for maximum insolation.

2.3.2. The Solar PV Module Model

The solar system configuration consists of a required number of solar photovoltaic cells **Figure 5** commonly referred to as PV modules, connected in series or in parallel to attain the required voltage output. The basic equation (**Sumothei, Kumar, & Surekha, 2015**) that mathematically describes the I-V characteristic of the ideal PV cell is:

$$I = I_{pv,cell} - I_{o,cell} [\exp(qV/\alpha kT) - 1] \quad (2)$$

This equation does not represent the I-V characteristic of a practical PV array but can predict the required I-V characteristics for practical use. Cells are connected either in parallel or in series. Cells connected in parallel increase the current and cells connected in series provide greater output voltages.

Solarworld AG - Sunmodule SW 140 poly R6A

Main parameters		Mechanical characteristics		Charts	
PV Module					
Length	1508.0 mm	Width	680.0 mm	Thickness	34.0 mm
Weight	11.8 Kg	Area	1.03 m ²		
Cells					
Number of cells connected in series	36	Number of cells connected in parallel	1	Total	36

Source: SolarworldAG (2020).

Figure-5. PV module specification sheet.

2.3.3. The MATLAB Model

MATLAB model was used to simulate the solar PV module (model SW 140 poly R6A). The model predicted the maximum output power at different solar intensity and sunlight temperatures. A MATLAB script (simplest type of MATLAB program) was written and executed on MATLAB to calculate the predicted output peak power using information from the sun module SW 140 poly R6A solar array dataset in **Table 1**.

Table-1. Sun module SW 140 Poly R6A solar array dataset.

S/N	Variables	Description	Value	Unit
1	Iscn	Nominal short circuit current	8.21	A
2	Vocn	Nominal array open circuit voltage	32.9	V
3	Imp	Array current at maximum power point	7.85	A
4	Vmp	Array voltage at maximum power point	18.0	V
5	kv	Voltage/temperature coefficients	0.34	V/K
6	ki	Current/temperature coefficients	0.034	A/K
7	Ns	Number of cells connected in series	36	
8	k	Boltzmann constants	1.3806503 e ⁻²³	J/K
9	q	Electron charge	1.60217646 e ⁻¹⁹	C
10	a	Diode constants	1.3	
11	Gn	Nominal irradiance @25°C	1000	W/m ²
12	Tn	Nominal operating temperatures	25 + 273.15	K

Source: SolarworldAG (2020).

2.3.4. Determination of Parameters

The number of parameters varied depending on the chosen model. In this work, parameters in **Table 2** were calculated from the model equations using manufacturing data in **Table 1**. The model equation determines: Nominal thermal junction voltage **Equation 1**, Thermal junction voltage-current temperature **Equation 2**; Nominal diode saturation current **Equation 3** and so on. Iterative process was done for R_s and R_p until P_{max} , model = P_{max} , experiment. Effect of temperature and radiation on the current, nominal light-generated current, actual light-generated current and actual short-circuit current were calculated using **Equation 6, 7, 8** and **9** respectively. Parallel and series resistance model were calculated using **Equation 4, 5** and **11** respectively. The characteristics I-V equation **Equation 12** was solved for several (V, I) pairs to obtain power ($P=P_{max}$). Graphs of solar intensity and temperature against maximum output peak power were plotted for evaluating the performance of the PV module.

Table-2. PV module equations.

S/N	PV Module Characteristics	PV Module Equations
1	Nominal thermal junction voltage	$V_{tn} = (K*T_n)/q;$
2	Thermal junction voltage-current temperature	$V_t = (K*T)/q;$
3	Nominal diode saturation current	$I_{on} = I_{scn}/(\exp(V_{ocn}/a/N_s/V_{tn}) - 1)$
4	Maximum series resistance	$R_{s,max} = V_{ocn}/I_{mp}$
5	Minimum parallel resistance	$R_{p,min} = V_{mp}/(I_{scn} - I_{mp}) - R_{s,max};$
6	Temperature and radiation effect on current	$dT = T - T_n$
7	Nominal light generated current	$I_{pvn} = (R_s + R_p)/R_p * I_{scn}$
8	Actual light-generated current (I_{pv})	$I_{pv} = (I_{pvn} + K_i * d_T) * G/G_n$
9	Actual short-circuit current (I_{sc})	$I_{sc} = (I_{scn} + K_i * d_T) * G/G_n$
10	Maximum output peak power	$P_{max} = V_{mp} * I_{mp}$
11	Parallel resistance	$R_p = V_{mp} * (V_{mp} + I_{mp} * R_s) / (V_{mp} * I_{pv} - V_{mp} * I_o * \exp((V_{mp} + I_{mp} * R_s) / V_t / N_s / a) + V_{mp} * I_o * P_{max})$
12	Power (I-V equation)	$P = (I_{pv} - I_o) * (\exp((V + I * R_s) / V_t / N_s / a) - 1) / (V + I * R_s) / R_p * V.$

Note: Constants: Boltzmann $[K] = 1.3806503e-23$ J/K; Electron charge $[q] = 1.60217646e-19$ C; Diode constant $[a] = 1.3$;

Source: Sumothei, Kumar, and Surekha (2015)

2.4. Experimentation

2.4.1. The Study location

The experiment was carried out under the climatic conditions of Obafemi Awolowo University, Ile-Ife, Nigeria (Latitude 7.517722° N, Longitude: 4.526348° E). The weather condition varies, depending on the period of the year. The dry season starts in November and ends in March. The rainy season begins in the month of April and ends at the end of October. The rainfall is heavy reaching an average of between 45 and 60 inches. The Months of July and August have the most remarkable rainfall. It is possible to observe three different segments in the solar energy profile: hot/dry, hot and wet, corresponding to November/December, February/March, and July/August.

2.4.2. Experimental Set Up and Procedure

The set up for the experiment consists of two solar panels, worm and spur gears, mounting stand, a charge controller, battery and the control circuit. The solar panel have a capacity of 150W, 12V each and were connected together to double the capacity. The PV modules were tilted at an optimum angle of 17.5 degrees to the horizontal. Charge controller was used to control the charging and discharging of the battery to produce 5 volts needed to power the microcontroller and the stepper motor. Experiment was conducted by connecting the control circuit to the battery and the stepper motor to rotate the PV module. The output current and voltage were then measured using a multimeter. The peak current and voltage were also measured by connecting the positive and negative terminals of the multimeter to the positive and negative wires of the PV modules respectively. When the PV modules rotated to another direction according to the direction of the sun rays, the same procedure was repeated to get new readings. The DC electricity generated by the PV modules was stored by the battery. A GRM

100 Global radiation meter was used to measure solar intensity while Type k thermocouple was used to measure the temperature of the day at different time interval.

3. RESULTS AND DISCUSSIONS

3.1. Solar Position Data for the Study Location

Table 3 shows the computed specific parameters for the installation of solar tracking PV system for 15th, 16th and 17th June between 10 am and 4 pm at the study location. The azimuth angle for the eastern and western hemispheres of south pole seems to be higher for higher solar intensities. The maximum azimuth angle was recorded at 1 pm where solar intensity was higher for both eastern and western hemispheres. The solar azimuth and zenith angles of the sun are used to orient the PV modules towards the direction of the sun for maximum insolation.

3.2. Performance of PV Module under Simulated Conditions

Results of MATLAB script at different cell temperatures and solar intensities are presented in Table 4 and Table 5. The model I-V curve was determined at three levels of cell temperature and three levels of solar intensities. Calculated specifications for SW140 Poly R6A under the outdoor conditions of G=222 W/m² and T = 33.85 °C, G=788.92 W/m² and T = 31.77 °C and G=736.69 W/m² and T = 32.77 °C are presented in Table 4.

Table-3. Specific parameters for the installation of solar tracking PV system in the study location.

Time	Zenith angle	Azimuth angle (N/E)	Azimuth angle (S/W)	Solar Intensity (W/m ²)	Temperature (°C)
10 am	41.44	63.98	-116.98	330	26
11 am	28.56	55.10	-124.89	574	25
12 am	18.06	31.64	-148.36	1110	31
1 pm	15.89	343.50	163.50	1160	34
2 pm	24.39	310.73	130.72	804	34
3 pm	36.75	298.33	118.32	864	35
4 pm	50.16	293.42	113.42	720	38

Table-4. Predicted performance parameters for a Single PV module at different solar intensity and cell temperature.

Operating condition	Specification	Calculated value
222 W/m ² 33.85 °C	Resistance in parallel (min)	3.085674
	Resistance in series	1.300000
	Maximum output peak power (P _{max,m})	43.967569
	Actual light generated current (I _{pv})	4.2389420
	Actual short circuit current (I _{sc})	4.2389420
736.69 W/m 32.77 °C	Resistance in parallel	11.443898
	Resistance in series	1.300000
	Maximum output peak power (P _{max,m})	79.592350
	Actual light generated current (I _{pv})	8.252844
	Actual short circuit current (I _{sc})	8.252844
	Resistance in parallel	15.43763
788.92 W/m ² 31.77 °C	Resistance in series	1.300000
	Maximum output peak power (P _{max,m})	89.521319
	Actual light generated current (I _{pv})	9.058627
	Actual short circuit current (I _{sc})	9.058627

Parameters shown in Table 4 predicts the performance of solar module at different operating irradiance and cell temperatures. Parallel resistance increases with increasing solar irradiance and the maximum value is obtained at the highest solar irradiance of 788.92 W/m². This result is in accordance with the mathematical equation of Desoto, Klein, and Beckman (2006) expressing direct relationship between parallel resistance and solar irradiance. The series resistance (R_s) according to Desoto et al. (2006) is independent of cell temperature and solar irradiance. For all operating cell temperature and solar irradiance, series resistance is constant at 1.30000. Table 4 further reveals

that the maximum output peak power ($P_{max, m}$), actual light generated current (I_{pv}) and actual short circuit current (I_{sc}) increase as the solar irradiance increases. Results here also agree with the work of [Mancilla-David, Tian, Ellis, Muljadi, and Jenkins \(2012\)](#).

In [Table 5](#), results of the predicted values of P_{max} , I_{pv} and V_{max} for double solar PV modules are presented. The modules are connected in series at different cell temperature and solar intensity. The maximum power output, the actual light generated current and the short circuit current generated by MATLAB script at different cell temperatures and solar intensities also showed that they all increased with increasing solar irradiance. Maximum output peak power ($P_{max, m}$) of 179 W, actual light generated current (I_{pv}) of 9.06 A and maximum voltage of 19.764 V could be obtained at the maximum solar irradiance of 788.92 W/m^2 at the study location.

Table-5. Predicted values of P_{max} , I_{pv} and V_{max} for double solar pv module

Temp (°C)	Solar Intensity (G) w/m^2	Output Parameters	Simulated Value
33.85	222	P_{max} (W)	87.935
		I_{pv} (A)	4.239
		V_{max} (V)	20.744
32.27	736.69	P_{max} (W)	159.185
		I_{pv} (A)	8.253
		V_{max} (V)	19.288
31.77	788.92	P_{max} (W)	179.043
		I_{pv} (A)	9.059
		V_{max} (V)	19.764

3.3. Experimental Results

Experiments were conducted to validate the results of MATLAB scripts. [Table 6](#) shows values of P_{max} , I_{pv} and V_{max} for double solar PV module under the same outdoor conditions of solar intensity and cell temperatures.

Table-6. Experimental values of P_{max} , I_{pv} and V_{max} for double solar PV module.

Temp (°C)	Solar Intensity (G) w/m^2	Output Parameters	Measured value
33.85	222	P_{max} (W)	78.69
		I_{pv} (A)	4.09
		V_{max} (V)	19.24
32.27	736.69	P_{max} (W)	156.56
		I_{pv} (A)	8.10
		V_{max} (V)	19.33
31.77	788.92	P_{max} (W)	171.20
		I_{pv} (A)	8.88
		V_{max} (V)	19.28

The double panel module yielded results very close to the simulation values. Experimental results for maximum power output (P_{max}), actual light generated current (I_{pv}) and maximum voltage (V_{max}) are shown to be 78.69 W, 4.09A and 19.24V respectively, for solar irradiance of 222 W/m^2 and cell temperature of 33.85°C . It is also observed that measured values of maximum power output (P_{max}), actual light generated current (I_{pv}) and maximum voltage (V_{max}) increase with increasing solar irradiation. Maximum power output (P_{max}) of 171.20 W could be obtained from the double solar module at solar intensity of 788 W/m^2 and cell temperature of 31.77°C for the study location.

3.4. Model Validation

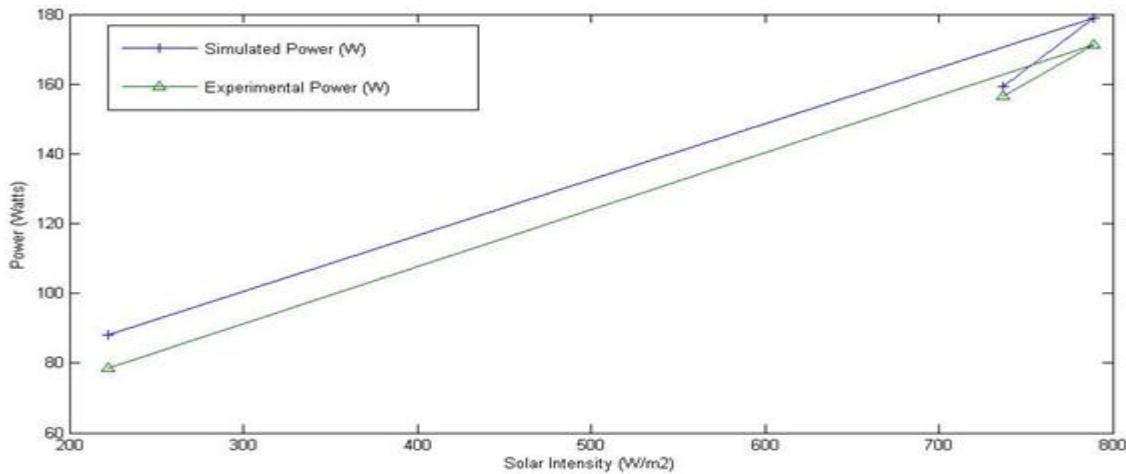
To check the model ability to predict maximum power (P_{max}), values of maximum voltage (V_{max}) and the actual light generated current (I_{sc}), comparison between the outdoor experimental values and the predicted values of Matlab scripts were performed for the three outdoor conditions as presented in [Table 7](#).

Table-7. Predicted versus experimental values.

Temperature (°C)	Solar Intensity (W/m²)	Output Parameters	Simulated Value	Experimental Value	Relative error (%)
33.85	222	P_{\max} (W)	87.935	78.690	10.513
		I_{pv} (A)	4.239	4.090	3.515
		V_{\max} (V)	20.744	19.240	7.250
32.27	736.69	P_{\max} (W)	159.185	156.560	1.649
		I_{pv} (A)	8.253	8.100	1.854
		V_{\max} (V)	19.288	19.328	0.206
31.77	788.92	P_{\max} (W)	179.043	171.200	4.381
		I_{pv} (A)	9.059	8.880	1.976
		V_{\max} (V)	19.764	19.279	2.454

It is clear from [Table 7](#) that power generated by PV module during simulation and experimentation increased with increasing solar irradiance. Accuracy of the model was investigated by determining the percentage relative error between the simulated and the experimental values. The relative error for the power output between the simulated value (159.185 W) and the experimental value (156.56 W) for the outdoor conditions of 32.27 °C and 736.69 W/m² is found below 2% indicating that the simulation model found good agreement with the experimental values. [Abdullahi, Saha, and Jinks \(2017\)](#) found that the error among the modelling PV results and PV panel datasheets was less than 10, hence concluded that the simulation results can be used to predict the performance of the PV solar module. The relative error between the optimum simulated and experimental values for all the parameters (P_{\max} , I_{pv} and V_{\max}) at cell temperature of 31.77 °C and solar irradiance of 788.92 W/m² is found below 5%. Hence, results from the MATLAB scripts can be used to predict maximum power output from PV modules.

In [Figures 6 and 7](#), effects of solar irradiance and cell temperature on the power output from the solar PV module is well presented in graphical form. In [Figure 6](#), power produced during simulation and experimentation shows increasing trends with the solar irradiance. A minor gap is observed between the simulated and the experimental values for different irradiation levels. In [Figure 7](#), power produced by solar PV module shows decreasing trends with increase in cell temperature. Results obtained here are similar to the work of [Vinod et al. \(2018\)](#). Thus, Peak power of 179 W and 171.2 W could be produced from the simulation and experimentation respectively, at the study location.

**Figure-6.** Effect of solar irradiance on the output power of solar PV module during simulation and experimentation.

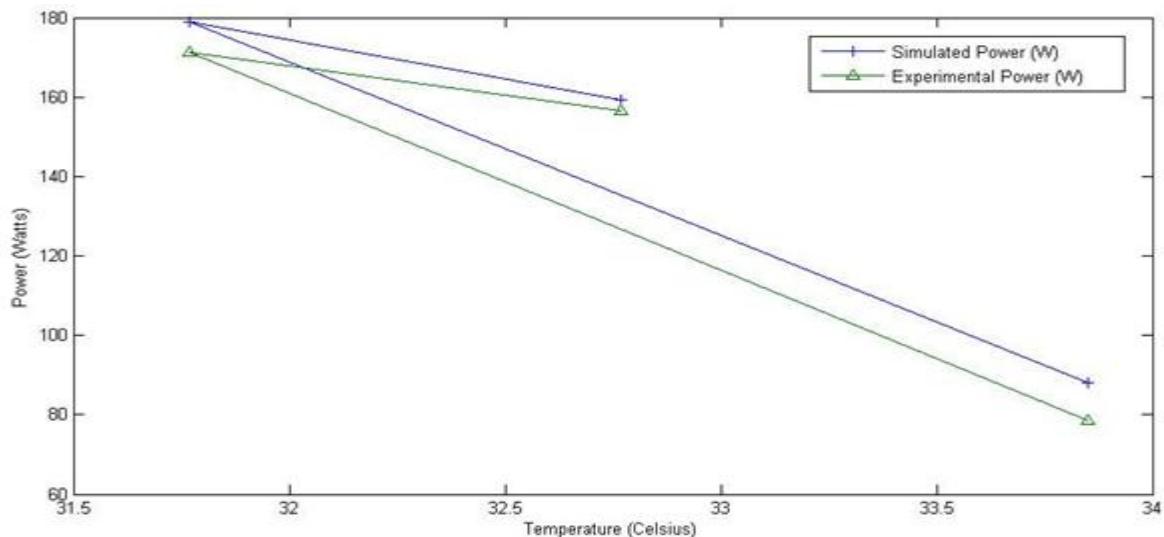


Figure-7. Effect of cell temperature on the output power of solar PV module during simulation and experimentation.

4. CONCLUSION

Simulation of PV module for power generation provides photovoltaic engineers with accurate models for predicting the performance of PV arrays of any size under different metrological conditions. In this study, maximum azimuth angle, maximum output peak power ($P_{max,m}$), actual light generated current (I_{pv}) and actual short circuit current (I_{sc}) were all predicted accurately for different solar irradiance and cell temperatures. The maximum azimuth angle obtained could be used to orient the PV modules towards the direction of the sun for maximum insolation. Performance of the PV solar module for June metrological data indicated that the maximum power output (P_{max}) of 171.20 W could be obtained at the study location. The relative error between the optimum simulated and experimental values for all parameters (P_{max} , I_{pv} and V_{max}) was found below 5%. This indicates that the simulation model found good agreement with the experimental data. Results here further reveal that MATLAB model can be used as a useful tool for validating the performance of a solar tracking PV system.

Funding: This study received no specific financial support.

Competing Interests: The authors declare that they have no competing interests.

Acknowledgement: Authors sincerely appreciate the Central Technology Laboratory Workshop (CTLW), Obafemi Awolowo University, Ile-Ife, Nigeria, for providing equipment and technical support.

REFERENCES

- Abbasoglu, S., & Okoye, C. S. (2013). Empirical investigation of fixed and dual axis sun tracking photovoltaic system installations in Turkish Republic of Northern Cyprus. *Journal of Asian Scientific Research*, 3(5), 440-453.
- Abdulkadir, M., Samosir, A. S., & Yatim, A. H. M. (2012). Modelling and simulation based approach of photovoltaic system in simulink model. *Journal of Engineering and Applied Sciences (ARPN)*, 7(5), 616–623.
- Abdullahi, N., Saha, C., & Jinks, R. (2017). Modeling and performance analysis of a silicon PV module. *Journal of Renewable and Sustainable Energy*, 9(3), 1–11. Available at: <http://dx.doi.org/10.1063/14982744>.
- Alexandru, C., & Pozna, C. (2010). Simulation of a dual-axis solar tracker for improving the performance of a photovoltaic panel. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, 224(6), 797-811. Available at: <https://doi.org/10.1243/09576509jpe871>.
- Chan, D. S., & Phang, J. C. (1987). Analytical methods for the extraction of solar-cell single-and double-diode model parameters from IV characteristics. *IEEE Transactions on Electron devices*, 34(2), 286-293. Available at: <https://doi.org/10.1109/t-ed.1987.22920>.

- Chang, T. P. (2009). Output energy of a photovoltaic module mounted on a single-axis tracking system. *Applied Energy*, 86(10), 2071-2078. Available at: <https://doi.org/10.1016/j.apenergy.2009.02.006>.
- Chong, K. K., Wong, C. W., Siaw, F. L., Yew, T. K., Ng, S. S., Liang, M. S., & Lau, S. L. (2009). Integration of an on-axis general sun-tracking formula in the algorithm of an open-loop sun-tracking system. *Sensors*, 9(10), 7849-7865. Available at: <https://doi.org/10.3390/s91007849>.
- Desoto, W., Klein, S. A., & Beckman, W. A. (2006). Improvement and validation of a model for photovoltaic array performance. *Solar Energy*, 80(1), 78-88. Available at: <https://doi.org/10.1016/j.solener.2005.06.010>.
- Guo, L., Curtis, P., Barendregt, A., & Surillo, A. (2009). *Design and implementation of a sun tracking solar power system*. Paper presented at the Proceedings of the American Society for Engineering Education, ASEE Annual Conference & Exposition, Washington, Paper ID 10308.
- Habbati, B., Youcef, R., & Fatima, M. (2014). A detailed modeling of photovoltaic module using MATLAB. *NRIAG Journal of Astronomy and Geophysics*, 3(1), 53-61. Available at: <https://doi.org/10.1016/j.nrjag.2014.04.001>.
- Heath, S. (2002). Embedded systems design. EDN series for design engineers (2nd ed., pp. 8-25). Jordan Hill, Oxford, Burlington, United State: Newness, Liancre House.
- Ikobayo, A. O., & Olatunji, O. P. (2015). *Modification and performance evaluation of a solar tracking photovoltaic system*. Unpublished B.Sc. Dissertation, Obafemi Awolowo University, Ile-Ife, Nigeria.
- Kelly, N. A., & Gibson, T. L. (2009). Improved photovoltaic energy output for cloudy conditions with a solar tracking system. *Solar Energy*, 83(11), 2092-2102. Available at: <https://doi.org/10.1016/j.solener.2009.08.009>.
- Krismadinata, Rahim, N. A., Ping, H. W., & Selvaraj, J. (2013). Photovoltaic module modelling using Simulink/Matlab. *Procedia Environmental Sciences*, 17, 537-546. Available at: <http://dx.doi.org/10.1016/j.proenv.2013.02.069>.
- Mancilla-David, F., Tian, H., Ellis, K., Muljadi, E., & Jenkins, P. (2012). *A detailed performance model for photovoltaic systems*. National Renewable Energy Laboratory, Preprint.
- MicrocontrollerLab.com. (2020). Sun tracking system using PIC Microcontroller. Retrieved from: <http://io.wp.com/microcontrollerlab.com>. [Accessed April 2, 2020].
- Mohammedi, A., Rekioua, D., & Mezzai, N. (2013). Experimental study of a PV water pumping system. *Journal of Electrical Systems*, 9(2), 212-222.
- Patel, J., & Sharma, G. (2013). Modeling and simulation of solar photovoltaic module using matlab/simulink. *International Journal of Research in Engineering and Technology*, 2(3), 225-228. Available at: <https://doi.org/10.15623/ijret.2013.0203003>.
- Pendem, S. R., & Mikkili, S. (2018). Modeling, simulation and performance analysis of solar PV array configurations (Series, Series-Parallel and Honey-Comb) to extract maximum power under Partial Shading Conditions. *Energy Reports*, 4, 274-287. Available at: <https://doi.org/10.1016/j.egyr.2018.03.003>.
- Perpiñán, O. (2009). Statistical analysis of the performance and simulation of a two-axis tracking PV system. *Solar Energy*, 83(11), 2074-2085. Available at: <https://doi.org/10.1016/j.solener.2009.08.008>.
- Qi, C., & Ming, Z. (2012). Photovoltaic module Simulink model for a stand-alone PV system. *Physics Procedia*, 24, 94-100. Available at: <https://doi.org/10.1016/j.phpro.2012.02.015>.
- Shaifali, J., & Jain, R. (2014). Microcontroller based solar tracking system for enhancing efficiency of a photovoltaic system. *Journal of Engineering Research and Applications*, 4(9), 73-78.
- Singh, G. K. (2013). Solar power generation by photovoltaic technology: A review. *Energy*, 58(1), 1-13. Available at: <https://doi.org/10.1016/j.energy.2013.02.057>.
- SolarworldAG. (2020). Sunmodule SW 130/135/140 Poly R6A. Retrieved from: <https://www.yumpu.com/en/document/read/34015930/sunmodule-sw-130-135-140-poly-r6a-data-sheet-solarworld>. [Accessed, April 2, 2020].

- Sumothi, S., Kumar, L. A., & Surekha, P. (2015). Solar PV and wind energy conversion systems. An introduction to theory, modelling with MATLAB/SIMULINK and the role of soft computing technologies. Green energy and technology series (pp. 71-78). Switzerland: Springer International Publishing.
- Vinod, Raj, K., & Singh, S. K. (2018). Solar photovoltaic modeling and simulation as a renewable energy solution. *Energy Reports*, 4, 701–712. Available at: <https://doi.org/10.1016/j.egyr.2018.09.008>.
- Yatimi, H., & Aroudam, E. H. (2015). A detailed study and modeling of photovoltaic module under real climatic conditions. *International Journal of Electronics and Electrical Engineering*, 3(3), 171-176. Available at: <https://doi.org/10.12720/ijeee.3.3.171-176>.

Views and opinions expressed in this article are the views and opinions of the author(s), International Journal of Sustainable Energy and Environmental Research shall not be responsible or answerable for any loss, damage or liability etc. caused in relation to/arising out of the use of the content.