Advanced Journal of Graduate Research
ISSN:2456-7108
Volume 13, Issue 1, pp. 8-17, January 2023
DOI: https://doi.org/10.21467/ajgr.13.1.8-17

GRADUATE RESEARCH ARTICLE

Evaluation of Power Performance of Solar Module Using Two Diode Model with MATLAB Simulation

Md. Hafizur Rahman, Shahena Akter, Suman Chowdhury*

Department of Electrical and Electronic Engineering, International University of Business Agriculture and Technology, Dhaka-1230, Bangladesh

*Corresponding Author email: suman@iubat.edu

Article History

Received: 20 May 2021
Revised: 30 March 2022
Accepted: 09 December 2022
Published: 20 January 2023

Student(s)

- Md. Hafizur Rahman
- Shahena Akter

Academic Year: 2019-2020
Course Level: Bachelor
Course Name: B.Sc.
Course year: 2019

Mentor(s)

- Suman Chowdhury

ABSTRACT

This paper tries to represent the difference between single diode and two diode photovoltaic models in terms of efficiency simulated by MATLAB. The research activities done earlier had shown a clear preview that the solar cell can act as concentrated solar cell for increasing the conversion efficiency to a great extant so that output power can be improved to a large scale. Here for showing the manner of concentrated solar action double diode model has been calculated for observing the power difference in comparison with the solar cell of single diode as a convenient one. It has been observed that the photovoltaic module with two diode model is observed as highly efficient in comparison with single diode model. And this two diode model can be treated as highly efficient to convert the solar energy in the electric energy. Also, the behavior of power performance is observed practically which is included in this paper. And finally, a comparison has been drawn out to exhibit the verification of power performance for two diode model using MATLAB simulation. The mostly impact factors considered in this paper are solar irradiance and temperature affecting the power output from PV module.

Keywords: Photovoltaic, module, power.

1 Introduction

Day by day, fossil fuels utilization is increasing. Fossil fuel is extremely used in power plants responsible to generate electricity by fossil fuels such as coal, oil, gas. The steam produced by boilers of generators drives big turbines that generate electricity. These power plants are largely dependent on fossil fuels for the long run power generation process. However, by burning these fossil fuels they generate large amounts of carbon dioxide, which causes world weather change. It also pollutes our environment, and this pollution increases malign disease. Renewable energy is that type of energy which is coming from renewable resources, such as wind, sunlight, tides, waves, and geothermal heat. Renewable energy does not pollute our environment. Now a day, many researchers are taking their researches on the photovoltaic (PV) cell technology and its efficiency. The electricity produced by utilization of the PV module relies on important factors like solar irradiance and temperature. The photovoltaic (PV) cell is the root device that produces electricity from sunlight. Cells are connected in series combination to increase voltage or in parallel combination to increase current level. Modules and arrays are created by the connection of cells in a demand based manner. The PV cell is represented by an electrical equivalent circuit according to the principal of semi-conductors [1]. In this model, the equivalent circuit has two resistances R_p and R_s. R_p is connected in parallel and R_s is connected in series with current source. Here we represented two models, one is single diode model, and another is two diode model and we also compared between these models which is more accurate model for more efficiency. In these model, there have inputs, outputs and other parameters. Sunlight (light and heat) is considering as input and there have some variable data, assumption data, and constant data. After building the PV module, we have got optimist power and here we measure accurate data with the equivalent model. Here I_p is the reverse saturation currents of both models and I_{s1} and I_{s2} are diode current and here ideal factors respectively A_1 and A_2. The purpose of the paper is to determine the power and simulate these modules by MATLAB Simulation [1]. Here diodes are connected parallel with source in this module. A solar cell is directly affected by sunlight and the other two parameters are irradiance and temperature. In this module load is connected with series resistance. It is necessary to operate the photovoltaic (PV) systems and find out the peak power point and current of these systems. However, there is a different equation current and power curve, and which depends on the photovoltaic (PV) array terminal voltage of these photovoltaic systems. The maximum power point varies because the sunlight (temperature and irradiation level) are variable. When temperature increases, current and power also increases. When temperature decreases, current and power also decreases [2]. Normally the available voltage and current of a PV device can meet the demand of the small load but in case of bigger complicated applications some electronic converters are required to fulfill the demand [3]. The photovoltaic cell fabricated in thin wafer of semiconductor is capable of showing slightly different electrical property than a diode characterized by the Shockley equation[4]. The commercially produced PV panels are mainly produced by Silicon (Si), although Si is not the only possible material for the PV panel. The main reason behind the utilization of the Si material is its feasibility of fabrication process in the large scale even though low conversion efficiency [5]. The modeling of the PV module is involved with the non-linearity of the I-V curves [6]–[8]. The early period researchers developed the circuit for characterizing the PV cell in terms of environment parameters like irradiance and temperature whereas at present time researchers try to represent the circuit models in terms of single and double diode or two model characterized by the modified Shockley equation [9]. The research shows that the single diode model is less efficient than two diode model to describe the cell characteristics at low illuminations [10]. Here we try to justify which module is perfect for maximum power. In the two-diode model power is higher more than one diode model. This PV system has some leakage current. Here I_{s1} and I_{s2} are leakage current. Solar panel consists of series connected photovoltaic cells. The Russian researchers are interested to work in photovoltaic system, because solar power generation has large growth potential voltage. In this work to solve the complex equation we used MATLAB Simulation [11]. In addition, it is said that the two different doped layers of semiconductor materials are responsible for absorbing the irradiance from the solar energy [12]. And the equivalent models of photovoltaic are very important to execute the performance of the PV module so that further improvement can be investigated [13]. And the tilt angle is one influencing factor to affect the power performance of the PV module [14]–[16]. On top of this the power output can be maximized using several MPPT techniques [17], [18]. But to control the duty cycle of the MPPT the DC-DC converter plays a vital role [19], [20].

2 Methodology

At first the two and single diode model of solar cell have been taken for analyzing the MATLAB simulation. The single diode model and the two diode model for the solar cell is shown in figure 4 and figure 5. And the process of analyzing the simulation is shown in figure 1 as a flow chart diagram. This photovoltaic (PV) module estimates the non-linear I–V and P-V curves. Figure 2 exhibits the single diode model arrangement for expressing the equivalent circuit of the PV module. Again figure 3 represents the double diode model or two diode model accordingly. Out of these two models only double diode model is considered as the better diode model since it is capable to generate the more power under the same operating condition [2].

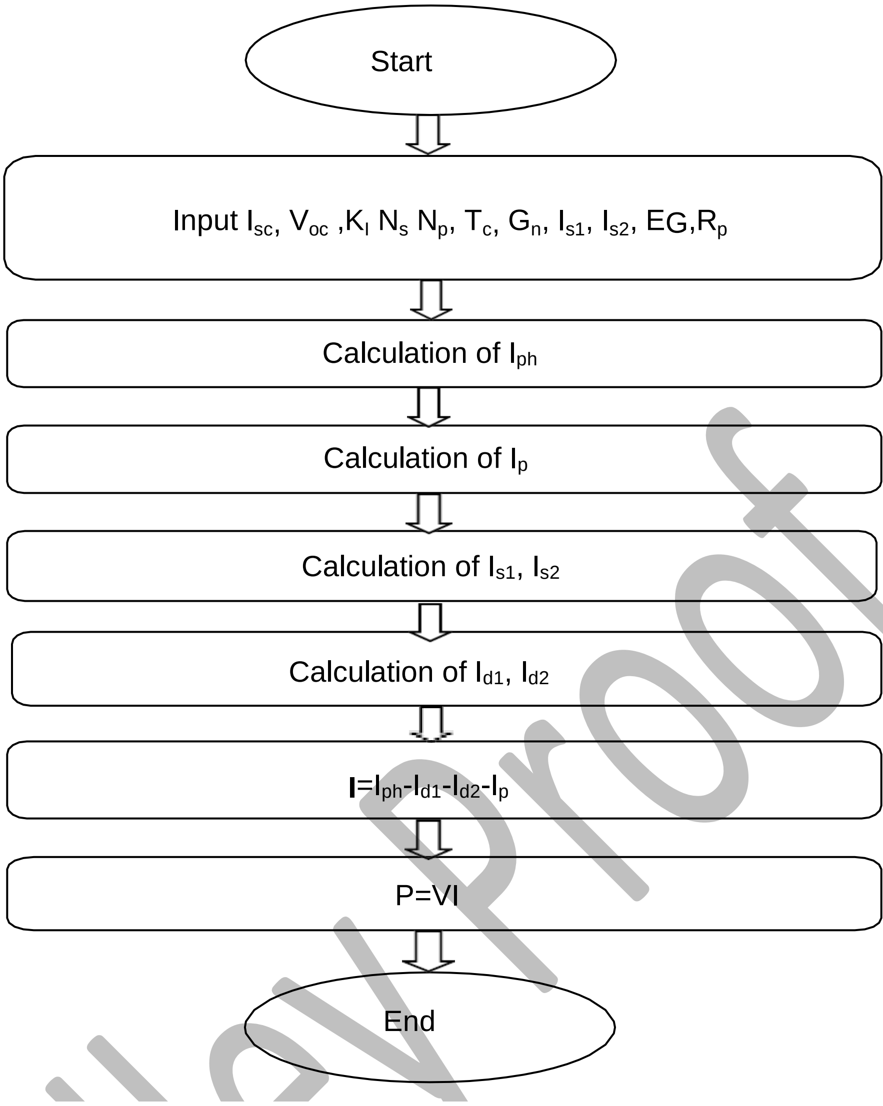

Figure 1: *Flow chart of power estimation process for the double diode model.*

The photocurrent (I_{ph}) is taken from the provided parameters of data sheet. Here the ideality factor (A_1 and A_2) are taken as unity, leaving shunt resistance (R_{sh}) and series resistance (R_s) values to be measured. Initial estimates of series and parallel resistances are taken considering respective derivations utilizing equation (1) and (6) [21].

Finally, an experiment set up has been initiated for investigating the power performance of the PV module to get the output characteristics of the PV module. The experiment is done in the IUBAT campus located in Dhaka in Bangladesh.

3 Analysis of PV Characteristic using Experiment

Table 1 shows the experimental data that has been collected from the experiment set up in IUBAT campus. This experiment set up includes a solar module, an ammeter, a voltmeter and a variable resistor as the load. Then changing the load, the corresponding voltage and current have been noted which is shown in the data table. In the data table resistance, voltage, current and power data are shown. From the data table it is shown that the voltage level is increased with the increment of load resistance. Again, the current level is almost constant throughput the variation of load resistance. And finally, the table exhibits the power data which is very important parameter in the investigation.

Rahman *et al.*, *Adv. J. Grad. Res.;* Vol. 13, Issue 1, pp: 8-17, January 2023

Table 1: *Obtained Experimental data for investigation of PV characteristics*

Resistance (kΩ)	Voltage (volt)	Current(mA)	Power(watt)
1.8	0.199	50.10	0.010149
3.7	1.2	50.3	0.06036
4.5	1.89	48.65	0.091949
5.01	2.38	48.01	0.114264
7.6	4.25	47.74	0.202895
9.00	5.01	47.1	0.235971
10.15	5.25	46.06	0.241815
12.00	5.34	19	0.10146
13.00	5.4	3.58	0.03294
13.9	5.5	1.5	0.00825

Figure 2 expresses the I-V curve of the PV module taking practical data from experiment set up. The figure shows that the current is almost constant throughout the change of voltage. These are the important characteristics obtained from the PV module which is responsible for producing the significant power from the PV module.

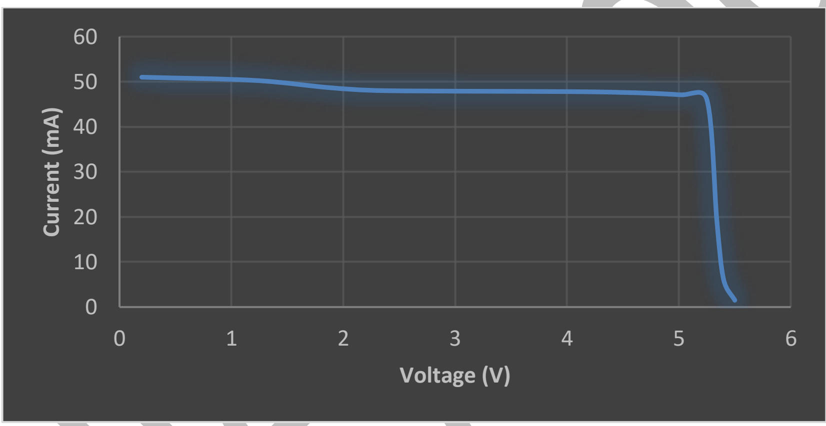

Figure 2: *I-V Curve obtained from experimental data (Current and voltage)*

Figure 3 expresses the P-V curve of the PV module taking practical data from experiment set up. The figure shows that the power is increasing rapidly with the increment of the voltage level. These are the important characteristics obtained from the PV module which is responsible for tracking the significant power from the PV module.

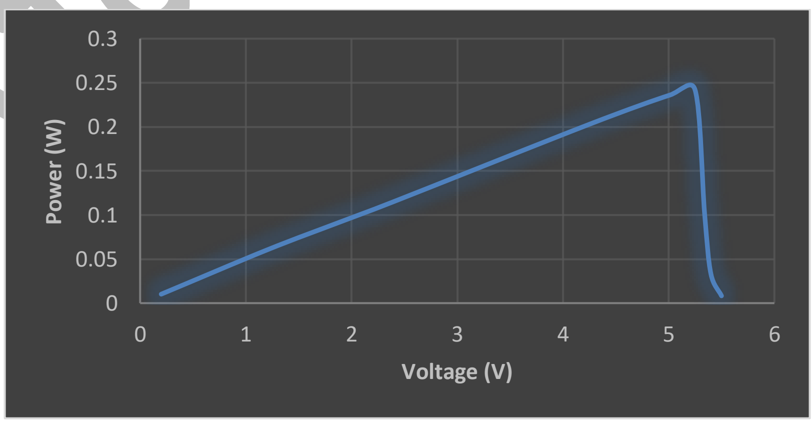

Figure 3: *P-V Curve obtained from experimental data (Power and voltage)*

4 Working Principle of Solar Cell Model

Solar cell works on light energy, and it converts the solar energy into electric energy through electron hole pair generation process. Again, the generated electron hole pair are separated by an electric field produced internally in the cell. Through the accumulation of the electron and hole in opposite polarity makes a voltage across the two terminals by which power is transmitted to the load. Now this solar cell can be manufactured in various materials with various techniques performing improved efficiency. The main problem in solar cell is its conversion efficiency. Almost maximum portion of the absorbed radiation is converted into heat energy which is totally lost criterion. So, researchers are trying to absorb maximum radiation as well as conversion to electric energy by producing the more electron hole pairs. From this concept two diode model has been come out for achieving the maximum power from the solar cell. In construction one diode and one resistance are connected in parallel with the current source. And one resistance and one the load are series connected with the current source. On top of this in two diode model, two diodes and one resistance are parallel connected with the current source and rest part of connection is same. Many researchers tried to decrease the number of unknown parameters. Since the two-diode model involves with large unknown parameters, most of the researchers prefer single diode model for involving reduced number of unknown parameters which make them easier to find the unknown parameters in the respective analysis [21], [22]. Alternatively, the single diode model cannot withstand with the climate change because it provides unusual data which is expected in real life implementation of PV module [2]. The construction of equivalent circuit for one diode model is shown in figure 4 and the construction of equivalent circuit for two diode model is shown in figure 5.

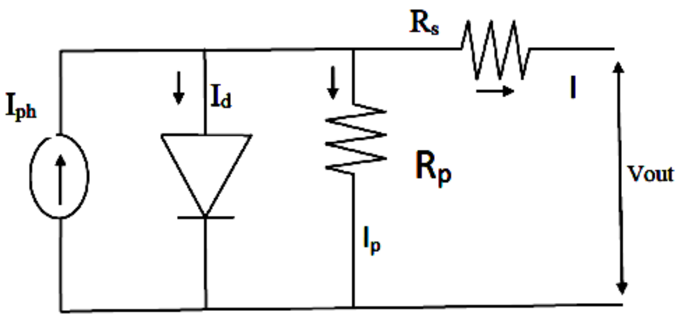

Figure 4: *Single diode model*

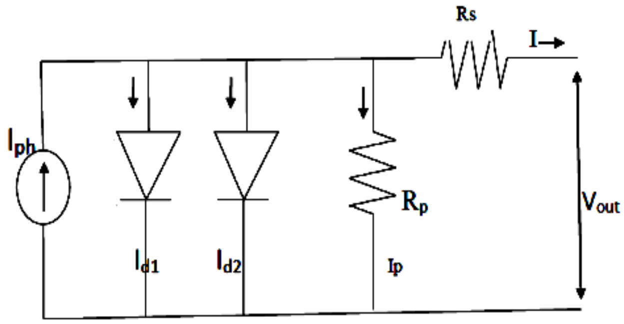

Figure 5: *Two diode model*

From figure 4, it is shown that only one diode is connected in the circuit diagram. In this figure, it is observed that a current source is connected in parallel with the diode. Also, a high resistance is connected in parallel with the diode and a low resistance is connected in series in the circuit. From figure 5, it is shown that two diodes are connected in the circuit diagram. A current source is connected in parallel with the diodes in the circuit diagram. Also, a high resistance is connected in parallel with the diode and a low resistance is connected in series in the same circuit.

Where I_{ph} is the current source that is produced by the sunlight, and it is directly proportional to the solar radiation. Here for single diode model I_d reverse saturation current, for two diode model I_{d1} and I_{d2} are the reverse saturation diode currents of diode 1 and 2 respectively. Here I is the load current (I). R_p is the shunt resistance and R_s is the series resistance. V_{out} is the load of this these circuit. R_s is variable to compute R_p in which is implemented in Matlab Simulink environment. On the other hand, there is given another module which is consist by two diode that shows the PV cell more accurate while it needs extra unknown variables in the two-diode model. The proposed two-diode model is more accurate that one diode model.

5 Comparison of One Diode and Two Diode Model

In the field we used variable resistance so that we may get variable voltage current and power. Some researchers tried to evaluate I_{d1} and I_{d2} the diode currents using the iteration process in the two diode model.

But due to impact of anonymous initial values the computational time has been increased in the iteration process. The total process is done in MATLAB simulation taking the initials from the data sheet. The experiment set up is done for the observation of current and power characteristics against of voltage across the load. It is noted that this experimental data is not directly associated with the simulation process.

Mathematical Model of Solar Cells

In figure (1), according to Kirchhoff current law we can write

$$I = I_{ph} - I_d - I_p \tag{1}$$

Where I_{ph} is the photovoltaic current and I_d is the diode current. I_p is the leakage current of parallel resistance R_p.

$$I_{ph} = N_p(I_{sc} + K_i)(T_c - T_{ref})(\frac{G}{G_n}) \tag{2}$$

At 25 °C where I_{sc} is the short circuit current of PV cell and that short circuit current coefficient is K_i, T_{ref} is the temperature coefficient, T_c is the reference temperature and G is the solar radiation in kW/m² and G_n is nominal solar irradiation at STC in kW/m². To measure the parameters of single–diode and a two-diode models, the analysis has been executed based on an analytical method. Although, the Newton-Raphson method is offered the merits of fast convergence, when it can only be executed if the first-order derivative can be done [4].

$$I_d = N_p I_s \left[e^{\frac{q\left(\frac{V}{N_S} + \frac{I.R_S}{N_P}\right)}{k.T_C.A}} - 1 \right] \tag{3}$$

Here the diode voltage is V, T_c is the cell temperature in Kelvin (K), k is the Boltzmann constant that value is $1{,}381.10^{-23}$ J/K, also here q is electron charge, and the amount of charge is $1.602.10^{-19}$ C, N_s is the number of cell connected in series, N_p is the assumption value, the ideality factor is A and I_s is the reverse saturation current [15].

$$I_p = \frac{\frac{N_p.V}{N_s} + I.R_s}{R_p} \tag{4}$$

Finally, we can write that for single diode model

$$I = I_{ph} - N_p I_s \left[e^{\frac{q\left(\frac{V}{N_S} + \frac{I.R_S}{N_P}\right)}{k.T_C.A}} - 1 \right] - \frac{\frac{N_P.V}{N_S} + I.R_S}{R_P} \tag{5}$$

For two diode model:

In figure (2), according to Kirchhoff current law we can write,

$$I = I_{ph} - I_{d1} - I_{d2} - I_p \tag{6}$$

Where $I_{d1} and I_{d2}$ are diodes current.

$$I_{d1} = N_p I_{s1} \left[e^{\frac{q\left(\frac{V}{N_S} + \frac{I.R_S}{N_P}\right)}{k.T_C.A_1}} - 1 \right] \tag{7}$$

And

$$I_{d2} = N_p I_{s1}\left[e^{\frac{q\left(\frac{V}{N_S}+\frac{I.R_S}{N_P}\right)}{k.T_C.A_2}} - 1\right] \quad (8)$$

Finally, we can write that for two diode model

$$I = I_{ph} - N_p I_{s1}\left[e^{\frac{q\left(\frac{V}{N_S}+\frac{I.R_S}{N_P}\right)}{k.T_C.A_1}} - 1\right] - N_p I_{s2}\left[e^{\frac{q\left(\frac{V}{N_S}+\frac{I.R_S}{N_P}\right)}{k.T_C.A_2}} - 1\right] - \frac{\frac{N_p.V}{N_s} + I.R_s}{R_p} \quad (9)$$

Where I_{ph} is the current source which generated from the sunlight, and it is directly proportional tothe solar irradiation. In this model diode current I_{s1} and I_{s2} are the reverse saturation current. Here A_1 and A_2 are the ideality factors of single diode and double diode respectively, the charge on electron is q, k is the Boltzmann constant, and that value is given in single diode method, R_s and R_p are resistance respectively. The series resistance and the shunt resistance, V_{out} is the output voltage, and I is the output current of the solar cell. Here assuming ideality factor $A_1=1$ and $A_2=1.2$. Also here, $I_{s1}=1.782*10^{-10}$ and $I_{s2}=9.075*10^{-9}$ [22].

6 MATLAB Simulation

In these simulation models, from the equivalent circuits, we can establish the R_s and R_p value by MATLAB Simulation. Here we use controlled current source to simulate photocurrent I_{ph} and the constant current is obtained at certain sunlight intensity [23].

The specification as provided by the manufacturer is given in table 2. From the data table it is shown that the parameters are shown for both of the single and double diode models. These data are used as parametric value for the MATLAB simulation. From the data table it is shown that all parameters are same for both models except A_1, A_2, I_{s1}, I_{s2}.

Table 2: *Data sheet for initials of parameters* [22]

Parameters	Single diode value	Two diode value
I_{sc}	3.11	3.11
V_{oc}	21.8	21.8
R_s	0.55	0.55
R_p	1000	1000
A_1	-	1
A_2	-	1.2
N_s	36	36
N_p	1	1
T_c	300	300
T_{ref}	298	298
I_{s1}	-	$1.782*10^{-10}$
I_{s2}	-	$9.075*10^{-9}$
G	800	800
G_n	1000	1000
V_{oc}	21.8	21.8

Table 2 shows the blank cell for the single diode model because the single diode model only does not need these factors.

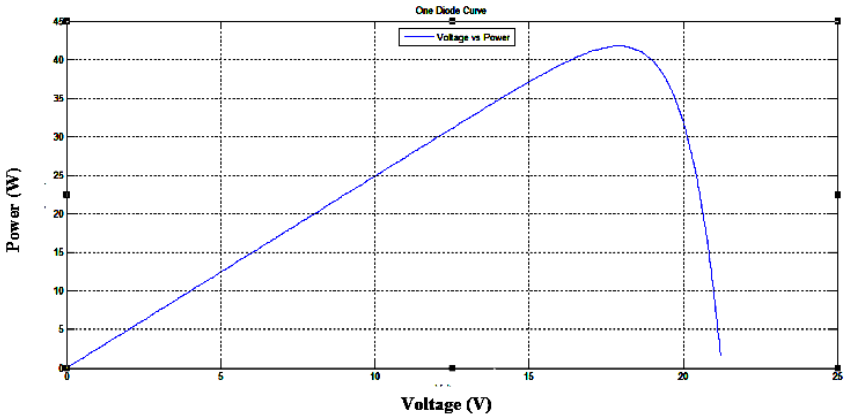

Figure 6: *P-V curve for one diode model using Matlab*

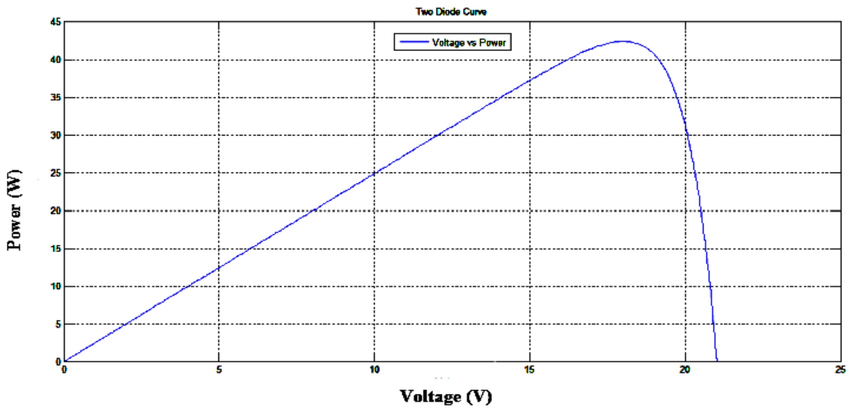

Figure 7: *P-V curve for two diode model using Matlab*

It is clear, which one is the better model from figure 6 and figure 7, that the two-diode model gives a better power more than the single-diode model under the same condition. Here x axis reference is voltage and Y axis reference is power. The solar energy is directly relying on solar radiation (temperature and illumination). In general, under same conditions, in photovoltaic system, the big area solar arrays will generate more power than the smaller solar arrays because big area solar arrays absorb large [2].To verify PV model, the PV module is simulated by MATLAB simulation.

Figure 6 is standing for observation of power performance in case of the single diode model and figure 7 is standing for the observation of power performance in case of the two diode model. These figures are obtained from the MATLAB simulation. Though these two figures are showing almost same manner, there is a little bit maximum power difference which is manipulated in table 3. Though the power difference is little in the small PV panel but for a large PV panel this power difference will reach a significant level. The power data obtained from two different models are provided in the data table 3. From the data table it is seen that the voltage and current are slightly in better position in case of two diode model. Also, power is better in the two diode model.

Table 3: *Data table for comparison between one diode and two diode model using MATLAB (Power, current)*

Parameters	**One diode value**	**Two diode value**
Maximum Voltage (Vm)	17.8 (V)	18 (V)
Maximum current (Im)	2.3442(A)	2.3550 (A)
Maximum power (Pm)	41.7275 (w)	42.3903 (w)

From this comparison table we have seen that two diode model is better than single diode model.

ISSN: 2456-7108
Available online at Journals.aijr.org

7 View of Practical Work and Simulation

A practical work has been investigated for the basic I-V and P-V characteristics of the PV module so that power performance of the PV module can be realized properly. This experiment is essentially needed to improve the power performance from the PV module. Because all the related parameters are directly involved in the power characteristic such as solar irradiance, temperature, fill factor, ideality factor, and clearness index and the current versus voltage curve is also a matter of fact to analyze. From the experiment it is shown that the current is almost constant for the wide variation of the terminal voltage of the PV module which brings excellent benefit of obtaining a maximum power at a certain voltage level. Besides a simulation work is investigated for showing the power performance variation with two and single diode models. And from the simulation process it has been perceived that the power is highly dependent on the number of connected diodes in the equivalent models. This investigation is focusing the important potentiality of the PV module to produce more efficient power with concentrated technique of the semiconductor layers with optimization of the power potentiality.

8 Conclusion

In this paper, an accurate module of photovoltaic (PV) system is represented in detail under MATLAB Simulation. The simulation directly shows the power performance of the PV module for the both case of models. The single diode model shows the obtained maximum power is 41.7275 W whereas the double diode model shows 42.3903 W which is expressing the improved gain of the power. This improved power output is possible only for consideration of the diode action in excess. From the simulation result it has been observed that around 1.6 % more power can be developed in case two diode model for the consideration of 36 cells integrated module. It has been concluded that the two diode model can be treated as more efficient model to get optimum power from the solar cell.

9 Declarations

9.1 Study Limitations

No external fund to execute the biogas power plant. For this reason, we need to rely on online data to execute the research.

9.2 Acknowledgements

We are heartily grateful to EEE department for its valuable support.

9.3 Competing Interests

We the authors declare that no conflict of interest exists in this work.

9.4 Publisher's Note

AIJR remains neutral with regard to jurisdictional claims in published institutional affiliations.

How to Cite this Article:

Will be updated in the final version.

References

[1] H. B. Assia and M. Fatima, "Detailed modeling of two diode photovoltaic module using MATLAB simulik," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 10, no. 3, pp. 1603–1612, Sep. 2019, doi: 10.11591/IJPEDS.V10.I3.PP1603-1612.

[2] N. M. A. Alrahim Shannan, N. Z. Yahaya, and B. Singh, "Single-diode model and two-diode model of PV modules: A comparison," in *2013 IEEE International Conference on Control System, Computing and Engineering*, Nov. 2013, pp. 210–214. doi: 10.1109/ICCSCE.2013.6719960.

[3] K. Ishaque, Z. Salam, and H. Taheri, "Accurate MATLAB Simulink PV System Simulator Based on a Two-Diode Model," *Journal of Power Electronics*, vol. 11, no. 2, pp. 179–187, 2011, doi: 10.6113/JPE.2011.11.2.179.

[4] M. Hadjab, S. Berrah, and H. Abid, "Neural Network for Modeling Solar Panel," *International Journal of Energy*, vol. 6, no. 1, pp. 9–16, 2012, Accessed: Dec. 13, 2022. [Online]. Available: https://www.naun.org/main/NAUN/energy/17-072.pdf

[5] K. Ishaque, Z. Salam, and H. Taheri, "Simple, fast and accurate two-diode model for photovoltaic modules," *Solar Energy Materials and Solar Cells*, vol. 95, no. 2, pp. 586–594, Feb. 2011, doi: 10.1016/j.solmat.2010.09.023.

[6] J. A. Gow and C. D. Manning, "Development of a photovoltaic array model for use in power-electronics simulation studies," *IEE Proceedings - Electric Power Applications*, vol. 146, no. 2, p. 193, 1999, doi: 10.1049/ip-epa:19990116.

[7] J. C. H. Phang, D. S. H. Chan, and J. R. Phillips, "Accurate analytical method for the extraction of solar cell model parameters," *Electron Lett*, vol. 10, no. 20, pp. 406–408, May 1984, doi: 10.1049/EL:19840281.

[8] C. Sah, R. N. Noyce, and W. Shockley, "Carrier Generation and Recombination in P-N Junctions and P-N Junction Characteristics," *Proceedings of the IRE*, vol. 45, no. 9, pp. 1228–1243, Sep. 1957, doi: 10.1109/JRPROC.1957.278528.

[9] K. L. Kennerud, "Analysis of Performance Degradation in CdS Solar Cells," *IEEE Trans Aerosp Electron Syst*, vol. AES-5, no. 6, pp. 912–917, Nov. 1969, doi: 10.1109/TAES.1969.309966.

[10] D. S. H. Chan, J. R. Phillips, and J. C. H. Phang, "A comparative study of extraction methods for solar cell model parameters," *Solid State Electron*, vol. 29, no. 3, pp. 329–337, Mar. 1986, doi: 10.1016/0038-1101(86)90212-1.

[11] T. R. Teregulov, B. Sharifov, and A. R. Valeev, "Simplified solar panel modeling in MATLAB/Simulink considering Bashkortostan Republic (Russia) environment characteristics," in *2016 2nd International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM)*, 2016, pp. 1–4. doi: 10.1109/ICIEAM.2016.7911448.

[12] A. S. Bayoumi, R. A. El-Sehiemy, K. Mahmoud, M. Lehtonen, and M. M. F. Darwish, "Assessment of an Improved Three-Diode against Modified Two-Diode Patterns of MCS Solar Cells Associated with Soft Parameter Estimation Paradigms," *Applied Sciences*, vol. 11, no. 3, p. 1055, Jan. 2021, doi: 10.3390/app11031055.

[13] X. Ma, S. Bader, and B. Oelmann, "On the Performance of the Two-Diode Model for Photovoltaic Cells Under Indoor Artificial Lighting," *IEEE Access*, vol. 9, pp. 1350–1361, 2021, doi: 10.1109/ACCESS.2020.3047158.

[14] Md. F. Faysal, Md. S. Hossain, and S. Chowdhury, "Power Potentiality Analysis of Photovoltaic Module with variation of tilt angle in Bangladesh," *International Journal of Renewable Energy Resources*, vol. 11, no. 1, pp. 27–33, Dec. 2021, Accessed: Dec. 10, 2022. [Online]. Available: https://ejournal.um.edu.my/index.php/IJRER/article/view/28987

[15] S. Chowdhury, M. Al-Amin, S. Sanjari, S. Tasnim, and M. Ahmad, "Performance parameter analysis of grid connected building integrated photovoltaic application in Bangladesh," *2012 International Conference on Informatics, Electronics and Vision, ICIEV 2012*, pp. 870–875, 2012, doi: 10.1109/ICIEV.2012.6317438.

[16] S. Chowdhury, M. Al-Amin, and M. Ahmad, "Performance variation of Building integrated photovoltaic application with tilt and azimuth angle in Bangladesh," *2012 7th International Conference on Electrical and Computer Engineering, ICECE 2012*, pp. 896–899, 2012, doi: 10.1109/ICECE.2012.6471695.

[17] M. T. Hossain, M. A. Rahman, and S. Chowdhury, "Evaluation of Power Performance of a PV Module with MPPT Solution Using MATLAB Simulation," *Journal of Renewable Energy and Environment*, vol. 8, no. 4, pp. 101–107, Oct. 2021, doi: 10.30501/JREE.2021.274901.1193.

[18] S. Chowdhury, D. K. Das, and Md. S. Hossain, "Power Performance Evaluation of a PV Module Using MPPT with Fuzzy Logic Control," *Journal of Engineering Advancements*, vol. 2, no. 01, pp. 07–12, Jan. 2021, doi: 10.38032/JEA.2021.01.002.

[19] J. Hasan, S. Ferjana, and S. Chowdhury, "INVESTIGATION OF POWER PERFORMANCE OF A PV MODULE WITH BOOST CONVERTER USING MATLAB SIMULATION," *American International Journal of Sciences and Engineering Research* , vol. 4, no. 1, pp. 1–13, Jun. 2021, doi: 10.46545/aijser.v4i1.322.

[20] N. Murshed, Md. S. K. Tushar, and S. Chowdhury, "Power Performance Analysis of PV Module with DC to DC Buck Converter," *Advanced Journal of Graduate Research*, vol. 8, no. 1, pp. 27–39, Apr. 2020, doi: 10.21467/ajgr.8.1.27-39.

[21] F. Abdulal, N. Anani, and N. Bowring, "Comparative modelling and parameter extraction of a single- and two-diode model of a solar cell," *2014 9th International Symposium on Communication Systems, Networks and Digital Signal Processing, CSNDSP 2014*, pp. 856–860, Oct. 2014, doi: 10.1109/CSNDSP.2014.6923947.

[22] S. Gupta, H. Tiwari, M. Fozdar, and V. Chandna, "Development of a two diode model for photovoltaic modules suitable for use in simulation studies," *Asia-Pacific Power and Energy Engineering Conference, APPEEC*, 2012, doi: 10.1109/APPEEC.2012.6307201.

[23] W. Zhu, S. Yang, L. Wang, and L. Luo, "Modeling and analysis of output features of the solar cells based on MATLAB/Simulink," *ICMREE2011 - Proceedings 2011 International Conference on Materials for Renewable Energy and Environment*, vol. 1, pp. 730–734, 2011, doi: 10.1109/ICMREE.2011.5930912.