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Comparative Analysis between Single Diode and Double Diode Model of PV Cell: Concentrate Different Parameters Effect on Its Efficiency

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Abstract

This research appraises comparative analysis between single diode and double diode model of photovoltaic (PV) solar cells to enhance the conversion efficiency of power engendering PV solar systems. Single diode model is simple and easy to implement, whereas double diode model has better accuracy which acquiesces for more precise forecast of PV systems performance. Exploration is done on the basis of simulation results and MATLAB tool is used to serve this purpose. Simulations are performed by varying distinct model parameters such as solar irradiance, temperature, value of parasitic resistances, ideality factor of diode and number of series and parallel connected solar cells used to assemble PV array. Conspicuous demonstration is executed to analyze effects of these specifications on the efficiency curve and power vs. voltage output characteristics of PV cell for specified models.

Keywords

Photovoltaic Cell, Single Diode Model, Double Diode Model, Efficiency, Simulation

1. Introduction

The globe gains an unbelievable supply of solar energy. The sun is an average star, a fusion reactor. It has been lighting over 4 billion years. It contributes sufficient energy in one minute to supply the world's energy demands

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for one year [1]. Directly sunlight can be converted into electricity using a solar cell, which is an electronic device. Both a current and a voltage are produced from shining light on the solar cell to generate electric power [1].

Global energy requirement and environmental issues are the compelling force for use of sustainable, alternative, and clean energy resources [2]. Solar energy is a promising renewable energy source that will contribute to secure future energy demands without emitting CO_2 [3].

A solar/PV cell is formed by fabricating a p-n junction in a thin wafer of semiconductor. These cells depend on photovoltaic effect for converting solar radiation into electricity [4] [5]. Material property of semiconductor is the reason of photovoltaic phenomena, which enables consumption of distinct type of photons from sunlight and these photons have higher energy than the band-gap energy of the semiconductor [5]. This leads to formation of a few free electron-hole pairs in the cell which are precisely proportional to input solar irradiance. The intramural electric field of p-n junction isolates these electron-hole pairs; as a result photocurrent is generated. Consequently this photocurrent is also proportional to solar radiation. Accordingly, I-V and P-V; the output characteristics of a PV cell are nonlinear and fluctuate with solar radiation, cell temperature [4] as well as other parameters of mathematical model.

Recently a new era for PV cell material has been launched with the study of perovskite, which is a mineral found in the Earth's mantle. Researchers claim that it could be more efficient than conventional cell material by placing it on the top of traditional silicon cells. As well, it presents an economy friendly process. However, stability tests are needed to observe the water and temperature sensitivity of the material. Nevertheless, search for efficient and cost effective material for solar cell is going on [6].

Typically, Silicon is used to assemble solar cells and an inadequate amount of power is produced by the silicon cell, because of low conversion efficiency [7]. Therefore conversion efficiency improvement study is very important for PV based power. Most crucial elements that affect the accuracy of the simulation are the PV cell modelling, which primarily associates the assessment of the efficiency curve and the non-linear I-V, P-V output characteristics curve. This paper presents a comparison between single-diode model and double-diode model of photovoltaic (PV) module to determine cell accuracy for different changing parameters. Henceforth, both models are implemented in MATLAB environment by adjusting model parameters with similar configurations.

2. Electrical Model of PV Cell

For various commercial operations, distinct types of photovoltaic (PV) cell technologies have been used. These cell technologies can be classified as multicrystalline, mono-crystalline and thin film. Single and double diode PV models have been widely used for modelling the output characteristic of a PV module [8].

Single diode model is the simplest as it has a current source in parallel to a diode. This model is upgraded by the inclusion of one series resistance, R_s [9]-[13]. In spite of its simplicity, it exhibits acute deficiencies when suffered from temperature deviations. An accretion of the model which introduces a supplementary shunt resistance R_p [14]-[18] exhibited in **Figure 1**. Although momentous development is attained, this approach claims significant computing exertion. Moreover its precision declines at low irradiance, particularly in the vicinity of open circuit voltage (V_{oc}). Two-diode model (consisting R_p and R_s) shown in **Figure 2** is recommended for improved accuracy [19].

2.1. One Diode Model

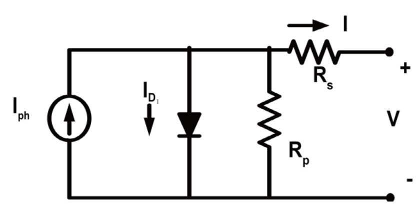


Figure 1. Electrical model of one-diode PV cell [20]-[26].

$$I = I_{ph} - I_o\left[\exp\left(\frac{V + IR_s}{aV_T}\right) - 1\right] - \frac{V + IR_s}{R_p} \quad (1)$$

$$V_T = \frac{N_s kT}{q} \tag{2}$$

$$I_{ph} = \frac{G}{G_n}\left[I_{pvn} + K_1\left(T - T_n\right)\right] \tag{3}$$

$$I_o = I_{on}\left(\frac{Tn}{T}\right)^3 \exp\left[\frac{qE_g}{ak}\left(\frac{1}{T_n} - \frac{1}{T}\right)\right] \tag{4}$$

$$I_{on} = \frac{I_{scn}}{\exp\left(V_{0cn}/aV_{Tn}\right) - 1} \tag{5}$$

2.2. Double Diode Model

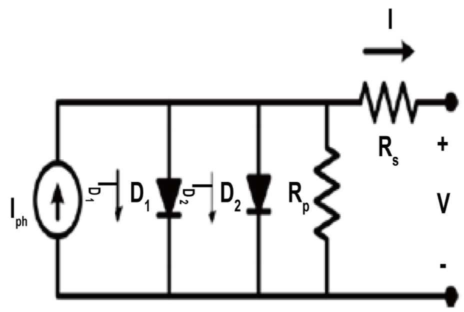


Figure 2. Electrical model of double-diode PV cell [27]-[31].

$$I = I_{ph} - I_{D1} - I_{D2} \tag{6}$$

$$I_{D1} = I_{o1}\left[\exp\left(\frac{V + IR_s}{a_1 * V_T}\right) - 1\right] \tag{7}$$

$$I_{D2} = I_{o2}\left[\exp\left(\frac{V + IR_s}{a_2 * V_T}\right) - 1\right] \tag{8}$$

$$I = I_{ph} - I_{o1}\left[\exp\left(\frac{V + IR_s}{a_1 * V_T}\right) - 1\right] - I_{o2}\left[\exp\left(\frac{V + IR_s}{a_2 * V_T}\right) - 1\right] - \frac{V + IR_s}{R_p} \tag{9}$$

$$I_{ph} = \frac{G}{G_n}\left[I_{ph,n} + K_I \Delta T\right] \tag{10}$$

$$I_{01} = I_{02} = \frac{I_{sc,n} + K_I \Delta T}{\exp\left(\frac{V_{oc,n} + K_V \Delta T}{\left(\left(a_1 + a_2\right)/p\right) * V_T}\right) - 1} \tag{11}$$

2.3. Different Parameters

- I_{ph} **is** the current generated by the incident light.
- I_{D1} **is** the Shockley diode equation due to diffusion.
- I_{D2} **is** the Shockley diode equation due to charge recombination mechanisms.
- I **is** the output Current of PV cell.

- I_{01}, I_{02} **[A] are** the reverse saturation current of the diodes D_1 and D_2 respectively.
- q **is** the electron charge [1.60217646*10^{-19} C].
- k **is** the Boltzmann constant [1.3806503*10^{-23} J/K].
- T **[K] is** the temperature of the p-n junction.
- a_1 and a_2 **are** ideality factor of the diodes D_1 and D_2 respectively for two diode model.
- a **is** ideality factor of diode for one diode model.
- V_T **is** the thermal voltage of the module.

2.4. Efficiency

Proportion of output energy of the solar cell to input energy from the sun is described as efficiency. Simultaneously reflecting the capability of the solar cell itself, the efficiency relies upon the spectrum and intensity of the incident sunlight and the temperature of the solar cell [32]. Therefore, conditions, which are used to measure efficiency, must be regulated cautiously in order to correlate the performance of one apparatus to another. Form factor (FF) is delineated as the ratio of the maximum power output from the solar cell to the product of open circuit voltage (V_{oc}) and short circuit current (I_{sc}).

$$FF = \frac{V_m I_m}{V_{oc} I_{sc}} \tag{12}$$

$$\eta = \frac{V_{oc} I_{sc} FF}{P_{in}} \tag{13}$$

$$\Delta T = T - T_n \tag{14}$$

- V_{OC} is open circuit voltage & I_{SC} is the short circuit current and
- G_n is the irradiance, T_n is the temperature, all at standard test conditions.
- K_V is the open circuit voltage temperature coefficient & K_I is the short circuit current temperature coefficient. η is efficiency.

The dominant phenomena that confine cell efficiency are [33]:

- Reflection from the cell's exterior.
- Light that is not enough dynamic to isolate electrons from their atomic bonds.
- Light that has excess energy beyond that required to isolate electrons from bonds.
- Light-produced electrons and holes (empty bonds) that casually collide with each other and recombine before they can promote to cell performance.
- Light-produced electrons and holes that are brought together by exterior and material blemishes in the cell.
- Resistance to current movement.
- Self-shading ensuing from upper-surface electric contacts.
- Performance degradation at non optimal (high or low) conducting temperatures.

3. Simulation and Observation

In order to analyze the behavior of both PV model, simulation is operated in MATLAB environment [5] [8] [34]-[36]. To compare PV models & to inspect the effect of various parameters, same specifications are used. These specifications are summarized in **Table 1**.

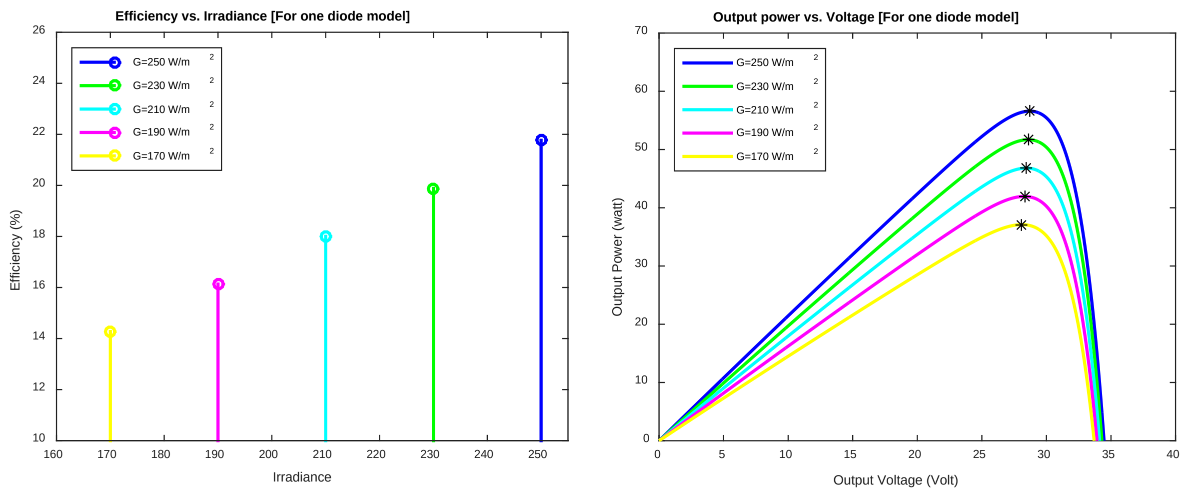
Table 1. Specifications for PV cell.

Input Power	260 W
Open Circuit Voltage (V_{oc})	37.92 V
Short Circuit Current (I_{sc})	8.67 A
Temperature Coefficient of V_{oc}	−0.33%/˚C
Temperature Coefficient of I_{sc}	0.06%/˚C
Reference Temperature	25˚C

3.1. Irradiance

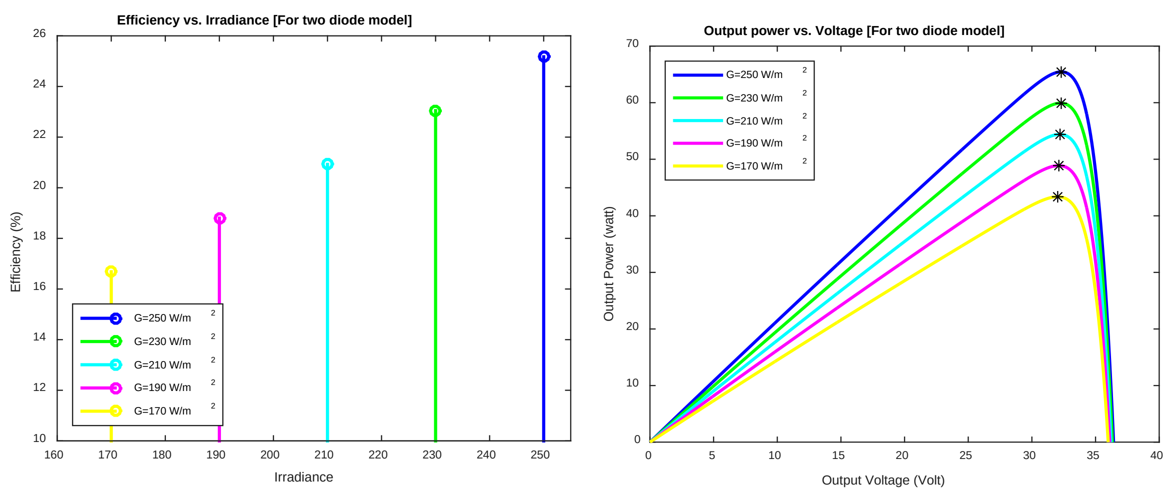
The efficiency of a PV appliance is contingent on the spectral distribution of the solar radiation. The Sun is a source of light and its radiation spectrum may be examined with the spectrum of a blackbody near 6000 K. Radiation of electro magnet in all wavelengths are absorbed and emitted by a black body [37].

The study of the effect of the solar radiation on PV devices is difficult because the spectrum of the sunlight on the Earth's outward is affected by components such as the variation of temperature on the solar disc and the impact of the ambient [38].



(a) (b)

Figure 3. Different values of irradiance (G) for one diode model. (a) Efficiency vs. irradiance; (b) Output power vs. output voltage.



(a) (b)

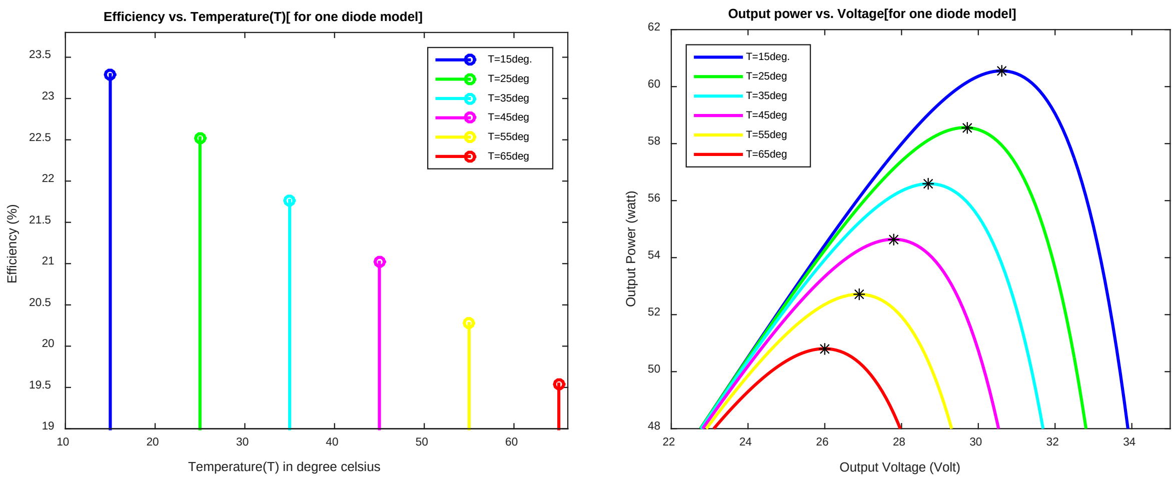
Figure 4. Different values of irradiance (G) for two diode models. (a) Efficiency vs. irradiance; (b) Output power vs. output voltage.

As demonstrate in **Figure 3(b)** and **Figure 4(b)**, an increase in solar irradiance causes the power curves to move upward. Along with this, **Table 2** demonstrates that maximum power and efficiency are increased at a significant amount with increasing value of solar irradiance for both models of PV cell. When irradiance is 170 watt/m^2, efficiency of two diode models is 2.4% higher than one diode model. Consequently when irradiance is 250 watt/m^2, efficiency of two diode models is 3.4% higher than one diode model. Hence **Table 2** clearly shows that two diode models provide better efficiency.

Table 2. Efficiency & P_{max} for different values of irradiance (G).

Changing Parameter	Two Diode Model		One Diode Model	
Irradiance (watt/m^2)	P_{max} (watt)	Efficiency (%)	P_{max} (watt)	Efficiency (%)
250	65.45	25.1733	56.59	21.7667
230	59.92	23.0467	51.69	19.8822
210	54.39	20.9229	46.81	18.0038
190	48.88	18.8008	41.94	16.1340
170	43.37	16.6818	37.11	14.2731

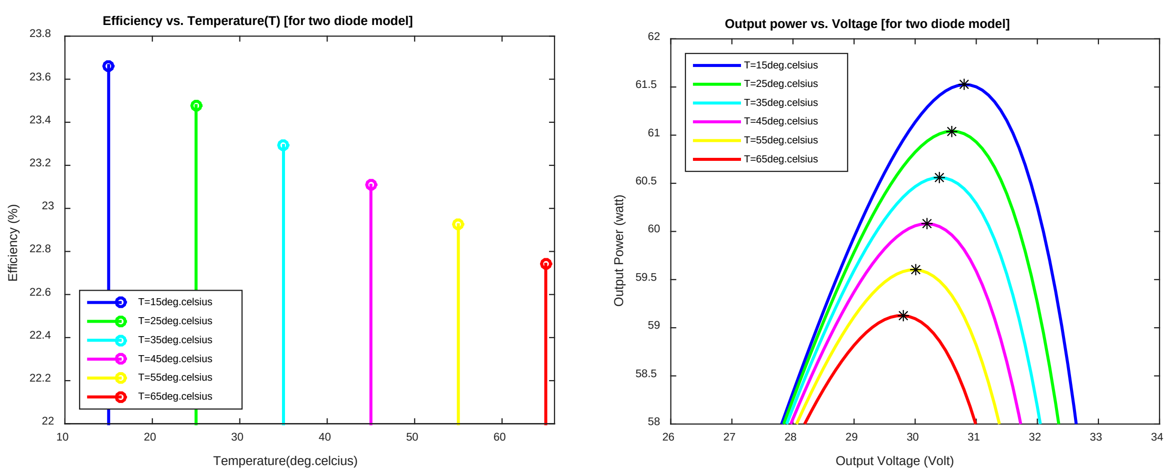
3.2. Temperature



(a) (b)

Figure 5. Different values of temperature (T) for one diode model. (a) Efficiency vs. temperature (T); (b) Output power vs. output voltage.

Increasing temperature increases the intrinsic carrier concentration. This urges the Fermi level adjacent to the intrinsic Fermi level (the middle of the band gap). Inequality between Fermi-levels of the p-type and n-type regions determines the built-in potential of a diode. As temperature increases, the Fermi level in each region shifts closer to the center of the gap, hence the built-in potential is decreased [39] [40].



(a) (b)

Figure 6. Different values of temperature (T) for two diode model. (a) Efficiency vs. temperature (T); (b) Output power vs. output voltage.

Table 3. Efficiency & P_{max} for different values of temperature (T).

Changing Parameter	Two Diode Model		One Diode Model	
Temperature (deg. Celsius)	P_{max} (watt)	Efficiency (%)	P_{max} (watt)	Efficiency (%)
15	61.52	23.6634	60.55	23.2895
25	61.04	23.4774	58.56	19.8822
35	60.55	23.2922	56.59	21.7667
45	60.08	23.1077	54.64	21.0170
55	59.60	22.9239	52.71	20.2749
65	59.12	22.7407	50.80	19.5407

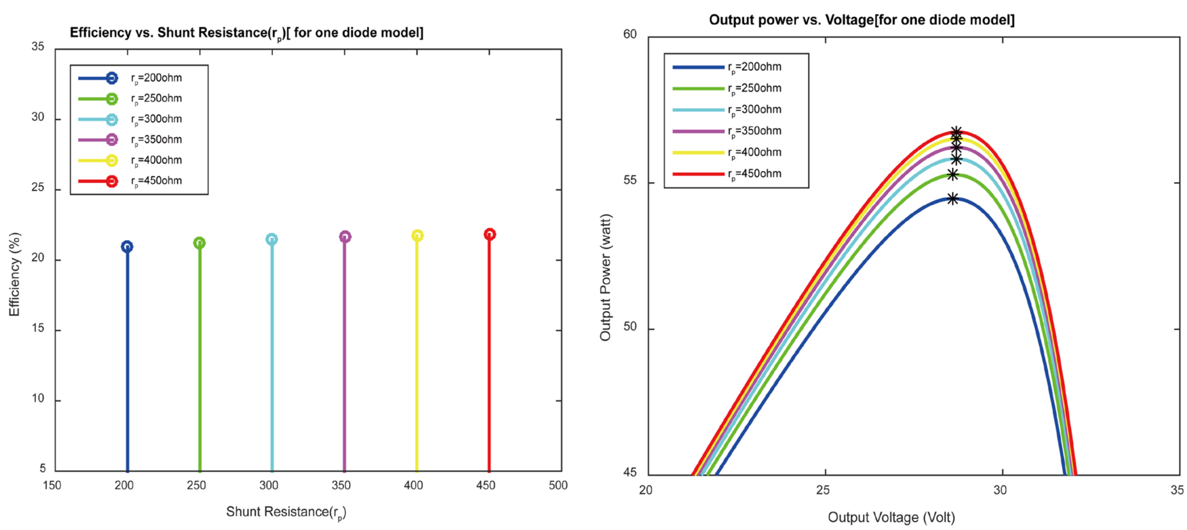
Diode's built-in potential is relevant with the conducting voltage of a solar cell. As a solar cell gets hot, the voltage is reduced, and therefore the output power and efficiency both are reduced. Thus the performance of solar cells decreases at high temperatures. **Figure 5(b)** and **Figure 6(b)** clearly illustrate this fact for simulated mathematical models [41].

Table 3 pageants that, at low temperature both model provide approximately same efficiency whereas at high temperature, double diode model provide better efficiency.

3.3. Shunt Resistance (R_p)

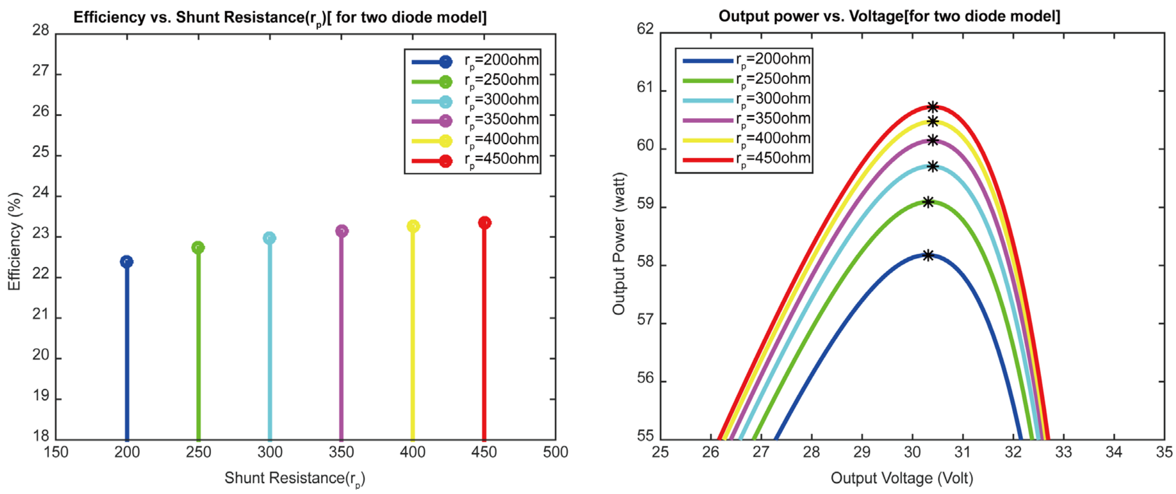
Power dissipation across internal resistances affects efficiency as well as maximum output power of solar cells. These parasitic resistances can be modelled as a parallel shunt resistance (R_p) and series resistance (R_S) [42] [43]. For an ideal cell, R_p would be infinite and would not provide an alternate path for current to flow, while R_S would be zero, resulting in no further voltage drop before the load.

As shunt resistance declines, current passed through it increases for a given level of junction voltage. Consequence is that the voltage-controlled portion of the I-V curve begins to sag far from the origin, producing a remarkable devaluation in the terminal current *I* and a minor reduction in V_{OC}. Hence output power is reduced. Very inferior amount of R_p will attain a significant deflation in V_{OC}. Much as in the case of a large value of series resistance, a poorly shunted solar cell will take on operating attributes analogous to those of a resistor [44].



(a) (b)

Figure 7. Different values of shunt resistance (R_p) for one diode model. (a) Efficiency vs. shunt resistance (R_p); (b) Output power vs. output voltage.



(a) (b)

Figure 8. Different values of shunt resistance (R_p) for two diode model. (a) Efficiency vs. shunt resistance (R_p); (b) Output power vs. output voltage.

Table 4. Efficiency & P_{max} for different values of shunt resistance (R_p).

Changing Parameter	Two Diode Model		One Diode Model	
Shunt Resistance (R_p)	P_{max} (watt)	Efficiency (%)	P_{max} (watt)	Efficiency (%)
200	58.18	22.3772	54.47	20.9507
250	59.09	22.7291	55.28	21.2642
300	59.70	22.9642	55.83	21.4744
350	60.14	23.1329	56.22	21.6247
400	60.47	23.2594	56.51	21.7374
450	60.73	23.3578	56.74	21.8251

PV cell efficiency as well as maximum power is increased with increasing value of shunt resistance. **Figure 7** and **Figure 8** expose this fact. Scrutinizing **Table 4**, it is examined that, PV cell efficiency will become almost constant after a certain value of shunt résistance. And this constant point occurs earlier (considering value of shunt resistance) for one diode model comparing with double diode model.

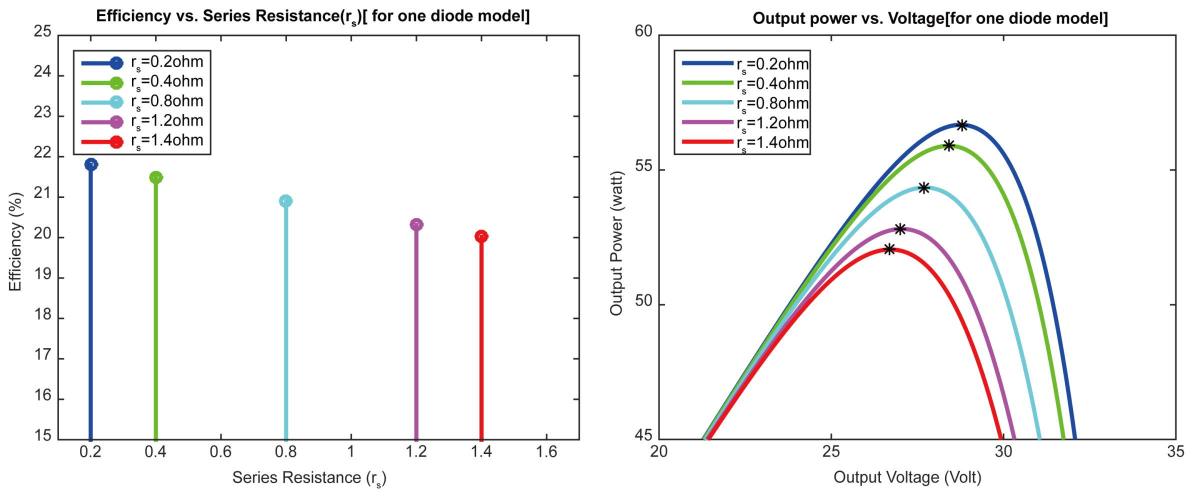
3.4. Series Resistance (R_S)

For the same amount of current, the voltage drop between the junction voltage and the terminal voltage becomes greater as series resistance increases [44]. As a result, current-controlled segment of the I-V curve initiates to sag toward the origin, causing a remarkable decrease in the terminal voltage and a minor contraction in I_{SC}, the short-circuit current. Tremendous values of R_S will also generate a significant reduction in I_{SC}; in these regimes, series resistance governs and the behavior of the solar cell resembles that of a resistor [44].

Inspecting **Figure 9** and **Figure 10**, it is detected that maximum Power as well as cell efficiency reduced with increasing value of series resistance for both models. Therefore, **Table 5** presents that, double diode model furnish better performance for changing values of series resistance.

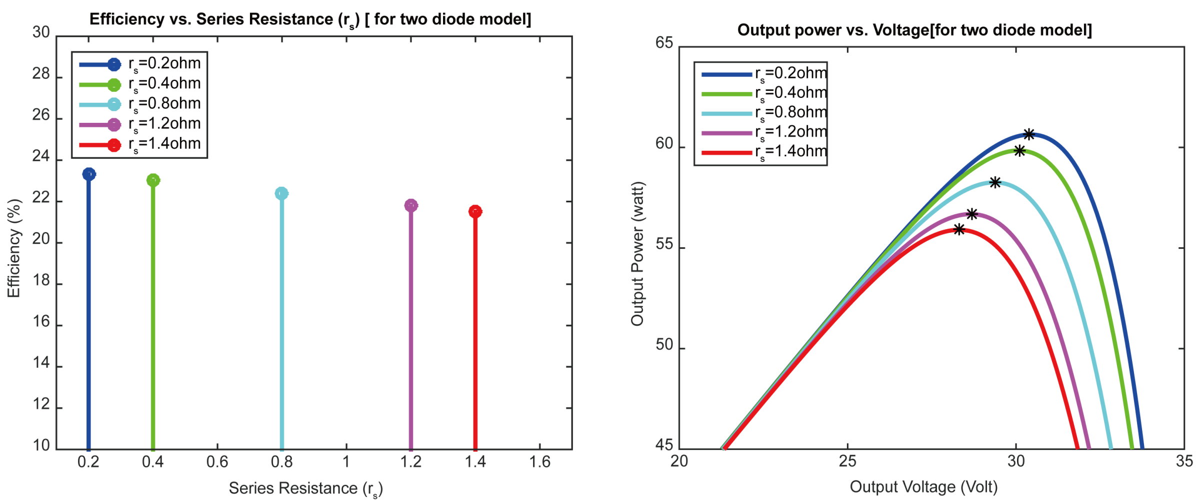
3.5. Number of Series Connected Cells (N_S)

Multiple numbers of solar cells are connected to form panels. Therefore panels can be connected in series string



(a) (b)

Figure 9. Different values of series resistance (R_s) for one diode model. (a) Efficiency vs. series resistance (R_s); (b) Output power vs. output voltage.

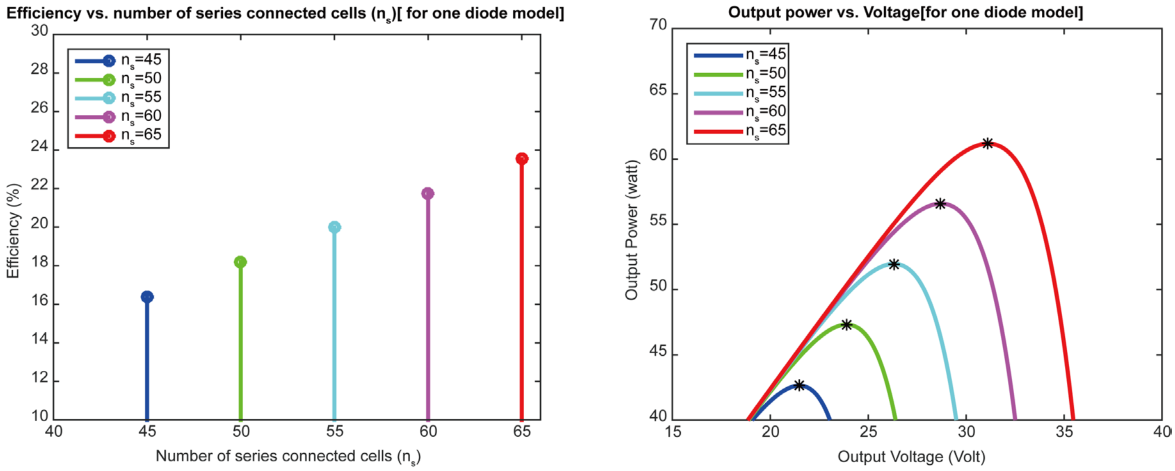


(a) (b)

Figure 10. Different values of series resistance (R_s) for two diode model. (a) Efficiency vs. series resistance (R_s); (b) Output power vs. output voltage.

Table 5. Efficiency & P_{max} for different values of series resistance (R_s).

Changing Parameter	Two Diode Model		One Diode Model	
Series Resistance (R_s)	P_{max} (watt)	Efficiency (%)	P_{max} (watt)	Efficiency (%)
0.2	60.64	23.3241	56.67	21.7978
0.4	59.84	23.0182	55.89	21.4989
0.8	58.26	22.4085	54.34	20.9034
1.2	56.68	21.8026	52.81	20.3122
1.4	55.90	21.5015	52.04	20.0189



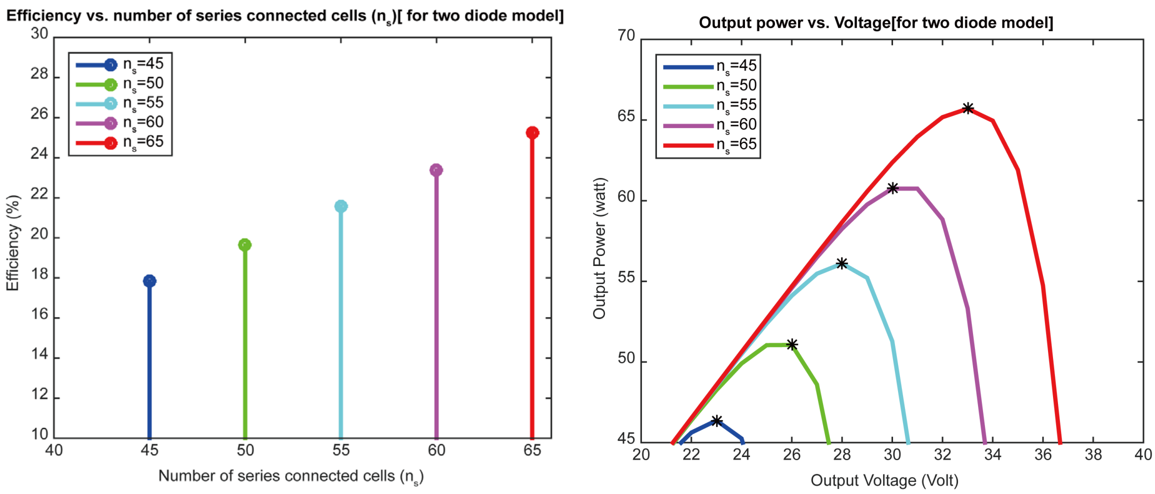
(a) (b)

Figure 11. Different values of number of series connected cells (N_s) for one diode model. (a) Efficiency vs. number of series connected cells (N_s); (b) Output power vs. output voltage.

to increase the voltage level and in parallel to increase the current level or in a consolidation of the two. The accurate configuration depends on the current and voltage load prerequisites. Efficiency of the array can be maximized by coordinating interconnected panels in respect of their outputs [45].

Imbalance in the short-circuit current of series connected solar cells can, contingent upon the conducting point of the module and the degree of conflict, have a severe repercussion on the PV module.

Series connections increase output power because voltage output is increased whereas output current remains almost constant. **Figure 11** and **Figure 12** clearly justify this fact. Efficiency of solar panel is increased with increasing number of series connected cells. For different values of series connected cell, double diode model serve with higher efficiency than single diode model. This evaluation is clearly exhibited in **Table 6**.



(a) (b)

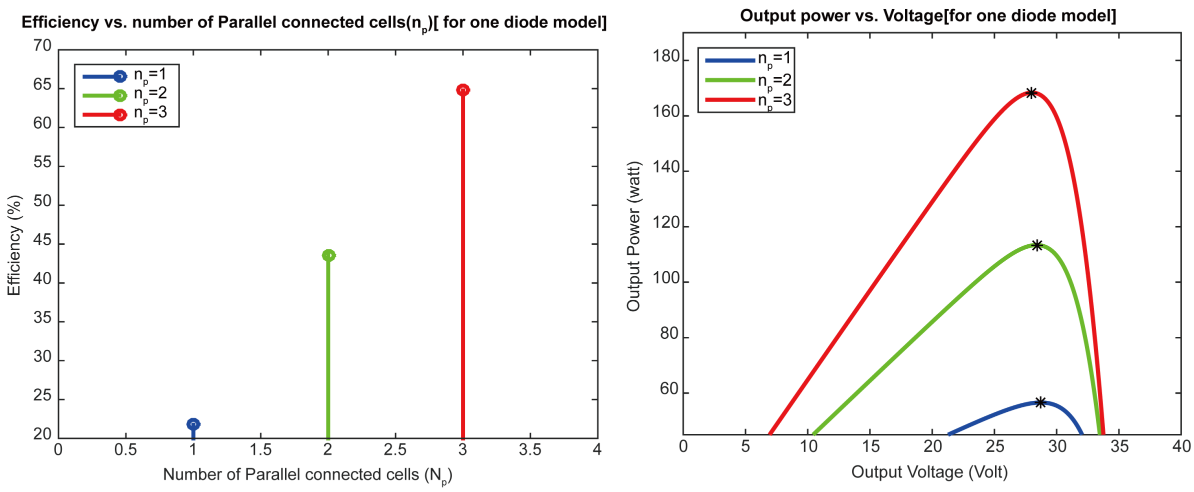
Figure 12. Different values of number of series connected cells (N_s) for two diode model. (a) Efficiency vs. number of series connected cells (N_s); (b) Output power vs. output voltage.

3.6. Parallel Connected Cells (N_p)

Parallel mismatch is not an issue for small modules, because in these cases cells are connected in series. Large arrays are generated by combining modules in parallel. So conflict mostly contributes at a module level rather than at a cell level.

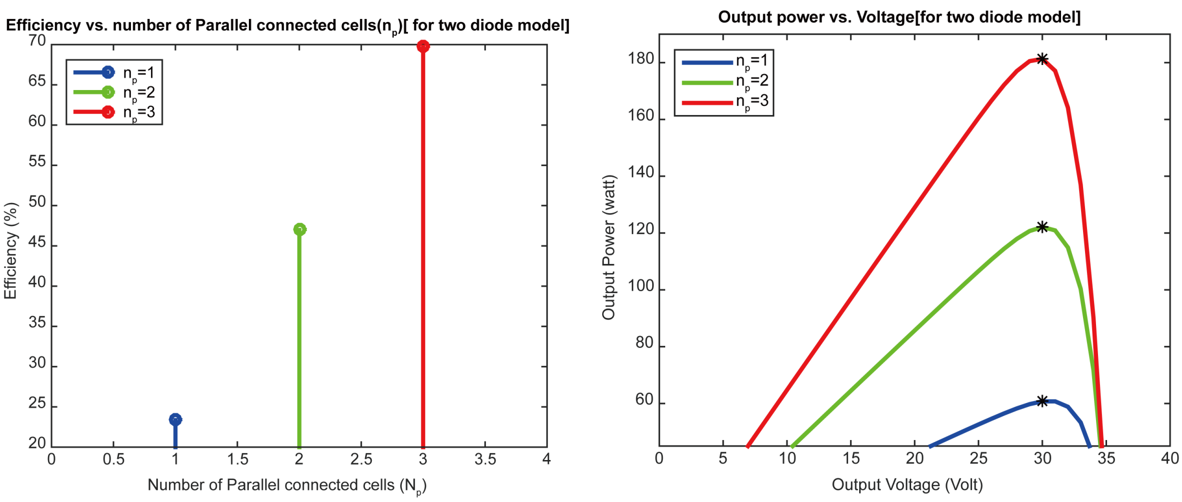
Table 6. Efficiency & P_{max} for different values of number of series connected cells (N_s).

Changing Parameter	Two Diode Model		One Diode Model	
Number of Series Connected Cells (N_s)	P_{max} (watt)	Efficiency (%)	P_{max} (watt)	Efficiency (%)
45	46.37	17.8366	42.64	16.4025
50	51.05	19.6374	47.32	18.2015
55	56.09	21.5768	51.97	19.9895
60	60.75	23.3656	56.59	21.7667
65	65.70	25.2705	61.18	23.5331



(a) (b)

Figure 13. Different values of number of parallel connected cells (N_p) for one diode model. (a) Efficiency vs. parallel connected cells (N_p); (b) Output power vs. output voltage.



(a) (b)

Figure 14. Different values of parallel connected cells (N_p) for two diode model. (a) Efficiency vs. number of series connected cells (N_s); (b) Output power vs. output voltage.

Expanded number of parallel connected cells causes the output current to increase and the horizontal part of the I-V curve moves upward. Along with this, **Figure 13(b)** and **Figure 14(b)** show that maximum power moves upward with respective changing parameter. Also **Figure 13(a)** and **Figure 14(a)** clearly show that efficiency increased proportionally with increasing number of parallel connected cells. Similar with other parameters, two diode models contribute improved performance than either model. With percentage values of efficiency for both models shown in **Table 7** confirms authenticity of this finding.

Table 7. Efficiency & P_{max} for different values of parallel connected cells (N_p).

Changing Parameter	Two Diode Model		One Diode Model	
Parallel Connected Cells (N_p)	P_{max} (watt)	Efficiency (%)	P_{max} (watt)	Efficiency (%)
1	60.75	23.3656	56.59	21.7667
2	122.12	46.9694	113.39	43.6139
3	181.30	69.7340	168.38	64.7632

3.7. Diode Ideality Factor

Ideality factor of a diode is an assessment of how intimately the diode pursues the conceptual diode equation. It is also evaluate the junction feature and the type of recombination in a solar cell [46].

A constant value for the ideality factor is assumed for single diode equation. Practically, ideality factor is a function of voltage across the device. At high voltage, when surfaces and the bulk provinces command the recombination in the device, the ideality factor (a_1) is approximately one. However the ideality factor (a_2) approaches two when recombination in the junction dominates at lower voltages. The junction recombination is designed by including a second diode in parallel with the first and locating the ideality factor typically to two [47].

A superior value of diode ideality factor degrades the FF and efficiency for a single diode model. However it usually signals high recombination and gives low open-circuit voltages [48]. **Figure 15** justifies this theoretical assumption properly.

Diode ideality factors a_1 and a_2 respectively represent the diffusion and recombination current components for a double diode model. In accordance with Shockley's diffusion theory, the diffusion current, a1 must be unity [49]. Nevertheless, the value of a_2 is malleable. **Figure 16** describes that, P_{max} and efficiency are almost constant after a_2 reaches the value of (1.2). Hence this will be the appropriate ideality actor for diode (D_2) to have maximum cell efficiency. **Table 8** validates theoretical recognitions for both models regarding diode ideality factor.

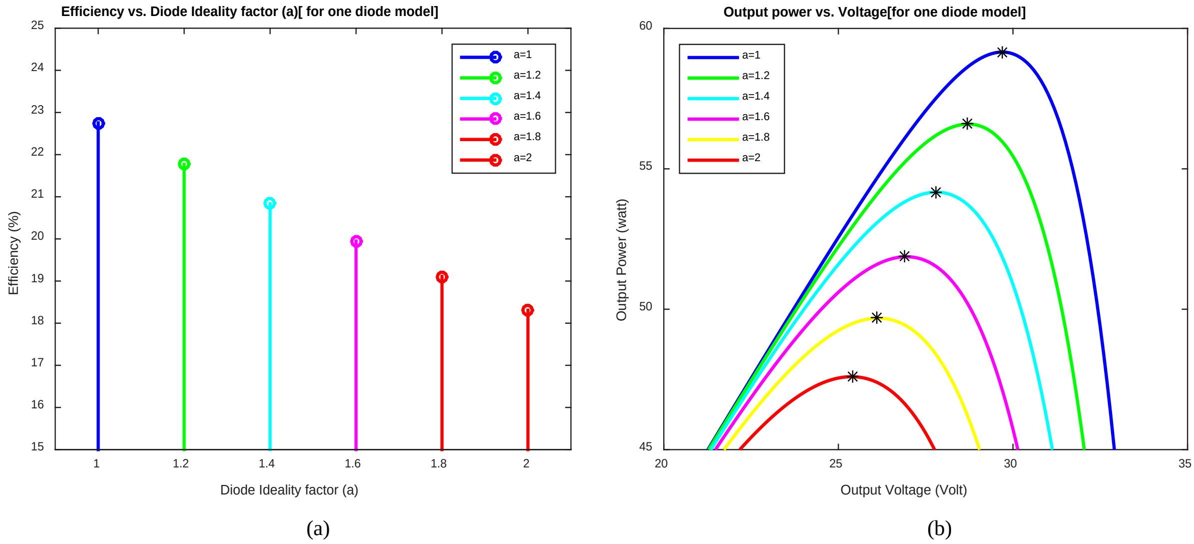
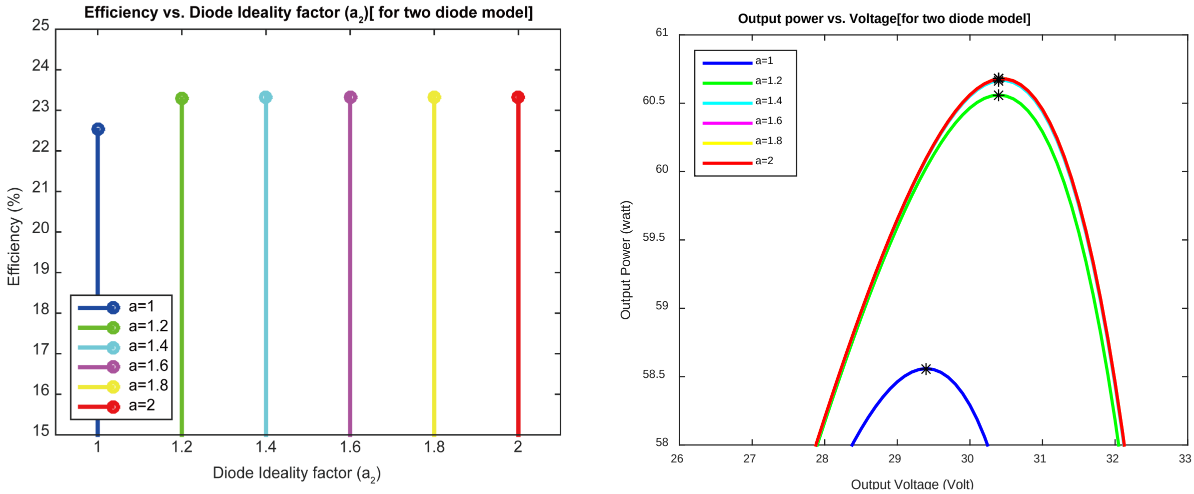


Figure 15. Different values of diode ideality factor (a) for one diode model. (a) Efficiency vs. diode ideality factor; (b) Output power vs. output voltage.



(a) (b)

Figure 16. Different values of diode ideality factor (a_2) for two diode model. (a) Efficiency vs. diode ideality factor (a_2); (b) Output power vs. output voltage.

Table 8. Efficiency & P_{max} for different values of diode ideality factor.

Changing Parameter	Two Diode Model		One Diode Model	
Diode Ideality factor (“a” for one diode model and “a_2” for two diode model	P_{max} (watt)	Efficiency (%)	P_{max} (watt)	Efficiency (%)
1	58.55	22.5226	59.15	22.7537
1.2	60.55	23.2922	56.59	21.7667
1.4	60.66	23.3333	54.16	20.8342
1.6	60.67	23.3371	51.86	19.9493
1.8	60.67	23.3377	49.68	19.1082
2	60.67	23.3379	47.59	18.3066

4. Concluding Remarks

Because of the large expenditure of PV modules, optimal utilization of the accessible solar energy has to be assured in PV power generation. This desires an authentic, detailed, dependable and extensive investigation of the designed scheme prior to initiation. Inclusion of the additional diode for double diode model increases model parameters. To achieve desired performance, prime challenge is to compute the values of all the model specifications. Using this MATLAB simulation-based comparative analysis, double diode model is found to contribute superior performance compared to single diode model. Accordingly selected model could be effective for professionals who require easy, understandable and accurate PV models with most desired performance to design their system. Influence of air pollutants, dirt and many other climate factors are not considered in this research. It will be appealing to investigate how these components will affect the entire energy delivered from the Sun. Additional approach specifies two-diode model by inspecting its physical attributes such as the electron diffusion coefficient, minority carrier’s lifetime, intrinsic carrier density and other semiconductor properties.

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