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MATLAB Simulation Based Efficiency Study For Two Diode Model Of Photovoltaic Solar Cell

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ABSTRACT

This paper illustrates a detailed explanation about various parameters of two diode equivalent circuit model which is one of the realized models of solar photovoltaic cell. This model is known to have better accuracy at low irradiance levels which allows for more accurate prediction of PV systems performance. The introduction on renewable energy specially focused on solar energy is followed by the modeling and simulation of PV cell. To achieve high efficiency and power, A MATLAB simulation based study of PV cell by varying different model parameters is carried out and presented, which is the main contribution of this paper. Theoretical foundations about Photovoltaic cell and PV electricity generation process are also presented.

Keywords: *PV Cell , Electricity Generation, Two Diode Model, Efficiency,Simulation.*

1. INTRODUCTION

Energy is the driving force for development, economic growth, automation, and modernization [1]. At present, global energy sources are mainly dependent on fossil fuels and the use of fossil fuel is the main reason for global increases of CO_2 density. Global energy demand and environmental concerns are the driving force for use of alternative, sustainable, and clean energy sources [1]. The use of renewable energy provides benefits that reduce emissions of air pollutants as well as greenhouse gases (GHG) [2]. Therefore, alternative sources of energy are needed so that mankind can survive on the Earth without depending on fossil fuels [3]. Solar energy is one of the renewable energy sources that will contribute to the security of future energy supplies without emitting CO_2 [4].

The earth receives an incredible supply of solar energy. The sun, an average star, is a fusion reactor that has been burning over 4 billion years. It provides enough energy in one minute to supply the world's energy needs for one year. A solar cell is an electronic device which directly converts sunlight into electricity. Light shining on the solar cell produces both a current and a voltage to generate electric power [5].

The equivalent circuit model of a PV cell is needed in order to simulate its real behavior. Two Diode model is focused in this paper and to assess the efficiency of this model MATLAB based simulation is done. This study compares I-V, P-V and efficiency curves to describe different cell parameters effect on performance of PV solar cell.

2. PHOTOVOLTAIC SOLAR CELL

PV cell is a chemical composition that takes the energy from the reflected light and turns that energy. It has a semiconductor feature to create voltage and current by providing electron movement between (+) and (-) poles.

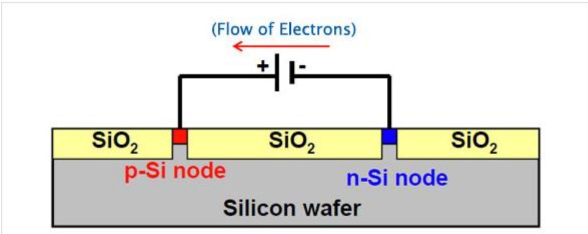

Figure 1: Photovoltaic cell

The operation of a photovoltaic (PV) cell requires 3 basic attributes [5]:

- The absorption of light, generating either electron-hole pairs or excitons.
- The separation of charge carriers of opposite types.
- The separate extraction of those carriers to an external circuit.

2.1 Types of Photovoltaic Solar Cells

There are 4 types of PV cells according to their manufacturing technology.

➢ Single or Mono Crystalline Cells:
Monocrystalline cells, which are made of pure silicon surface and a thin structure, are known to have high efficiency. They have two different manufacturing technologies - Si (Silicon) and Gallium Arsenide (GaAS). The PV cells with the highest efficiency today are those made of Gallium Arsenide.

➢ Polycrystalline:
Has a crystalline structure. It has a manufacturing technology in the form of a thin-film. Cadmium telluride (CdTe) or Copper indium diselenide (CIS) is used in the structure. Efficiency is not more than 10%.

➢ Amorphous silicon:
Has a non-crystalline structure. Rate of efficiency is not very high. It is used in small devices such as calculators and digital dictionaries.

- Hybrid Solar Cell:

It is one of the newest technologies. Organic and chemical substances are used together in its structure. Even though it has quite a high rate of energy efficiency, it is not yet in the industrial manufacturing phase.

3. ELECTRICITY GENERATION

Light striking a silicon semiconductor causes electrons to flow, creating electricity. Solar power generating systems take advantage of this property to convert sunlight directly into electrical energy [6].

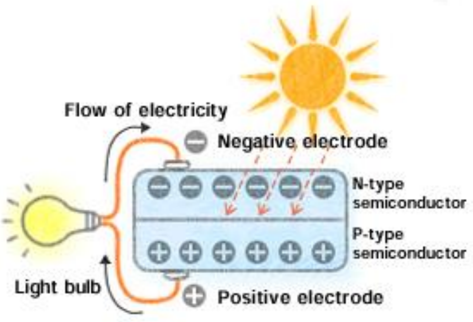

Figure 2: Electricity generation from PV cell

Solar panels (also called "solar modules) produce direct current (DC), which goes through a power inverter to become alternating current (AC) — electricity that we can use in the home or office, like that supplied by a utility power company.

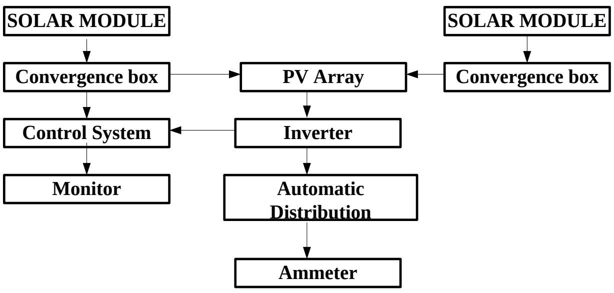

Figure 3: Schematic representation of photovoltaic power generation system [7]

3.1 Types of Solar Electricity

There are two ways we can produce electricity from the sun-

- **Photovoltaic Electricity** :

This method uses photovoltaic cells that absorb the direct sunlight. As light hits the solar panels, the solar radiation is converted into direct current electricity (DC). The direct current flows from the panels and is converted into alternating current (AC) used by local electric utilities. Finally, the electricity travels through transformers, and the voltage is boosted for delivery onto the transmission lines so local electric utilities can distribute the electricity to homes and businesses.

- **Solar-Thermal Electricity**:

This uses a solar collector, it has a mirrored surface that reflects the sunlight onto a receiver that heats up a liquid. This heated liquid is used to make steam that produces electricity [8].

3.2 Types of Solar power generating system

There are two types of solar power generating systems.

- **Grid-connected systems**:

Connected to the commercial power infrastructure [6].

- **Stand-alone systems**:

Feed electricity to a facility for immediate use, or to a battery for storage.

3.3 Solar Module:

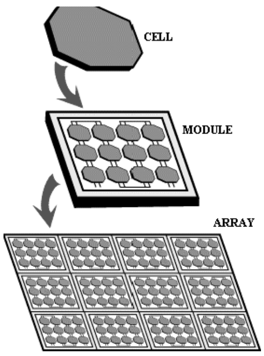

Figure 4: Solar Cell, Module and Array

A number of solar cells electrically connected to each other and mounted in a support structure or frame is called a photovoltaic module. Multiple modules can be wired together to form an array. In general, the larger the area of a module or array, the more electricity that will be produced. Photovoltaic modules and arrays produce direct-current (dc) electricity. [9].

4. ELECTRICAL MODEL OF PV CELL

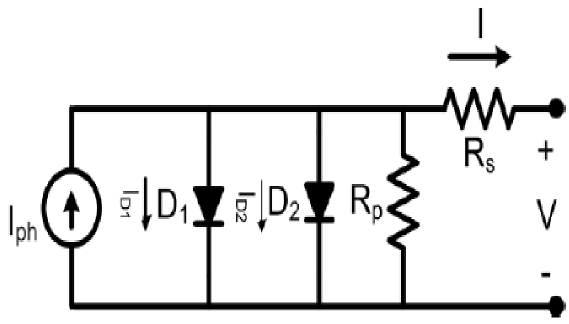

Figure 5: Electrical Model of Two-Diode Photovoltaic Cell [10-14].

$$I = I_{ph} - I_{D1} - I_{D2} \qquad (1)$$

- Iph 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.

$$I_{D1} = I_{o1}\left[exp\left(\frac{V+IR_S}{a1*V_T}\right) - 1\right] \qquad (2)$$

$$I_{D1} = I_{o2}\left[exp\left(\frac{V+IR_s}{a2*V_T}\right) - 1\right] \quad (3)$$

$$I = I_{ph} - I_{o1}\left[exp\left(\frac{V+IR_s}{a1*V_T}\right) - 1\right] - I_{o2}\left[exp\left(\frac{V+IR_s}{a2*V_T}\right) - 1\right] - \frac{V+IR_s}{R_{sh}} \quad (4)$$

$$I_{ph} = \frac{G}{G_n}\left[I_{ph,n} + K_I \Delta T\right] \quad (5)$$

$$I_{01} = I_{02} = \frac{I_{sc,n} + K_I \Delta T}{exp\left(\frac{V_{oc,n} + K_V \Delta T}{((a1+a2)/p)*V_T}\right) - 1} \quad (6)$$

- ❖ 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.
- ❖ a1 and a2 are ideality factor of the diodes D_1 and D_2 respectively
- ❖ V_T is the thermal voltage of the module

$$V_T = N_s[(k*T)/q] \quad (7)$$

$$P_{max} = V_{oc} I_{sc} FF \quad (8)$$

$$\eta = \frac{V_{oc} I_{sc} FF}{P_{in}} \quad (9)$$

$$\Delta T = T - T_n \quad (10)$$

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

5. SIMULATION RESULTS

Table 1: Simulation Parameters for PV cell

Input power	260W
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	33°C

5.1 Vary Irradiance

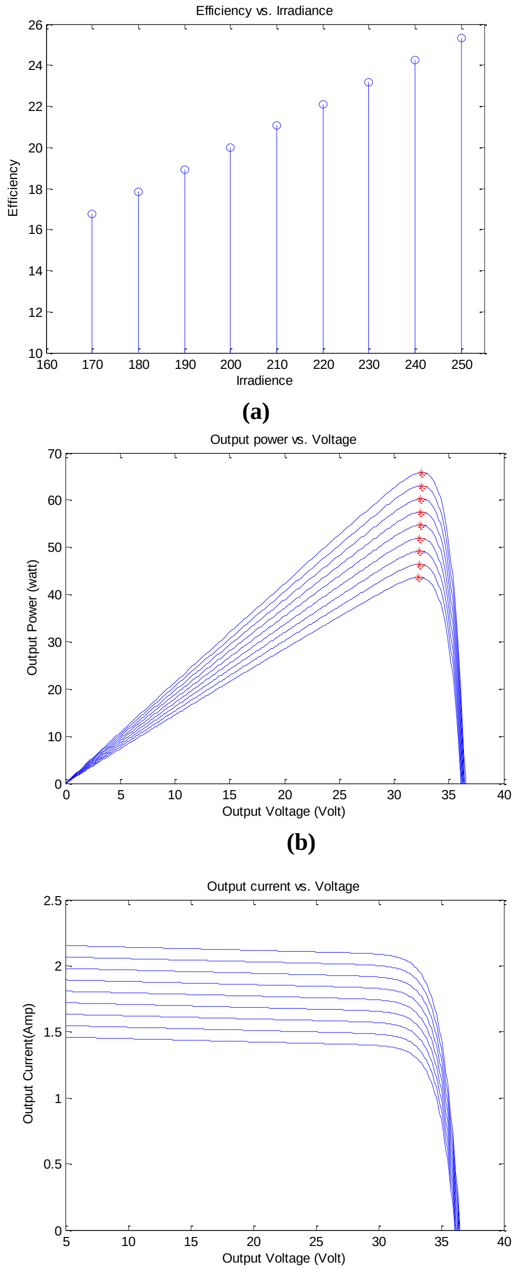

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Figure 6: For different values of Irradiance (G) (a) Efficiency vs. Irradiance (b) Output Power vs. Output voltage (c) Output Current vs. Output voltage

The efficiency of a PV device depends on the spectral distribution of the solar radiation. The Sun is a light source whose radiation spectrum may be compared to the spectrum of a blackbody near 6000 K. A black body absorbs and emits electro magnet radiation in all wavelengths [15].

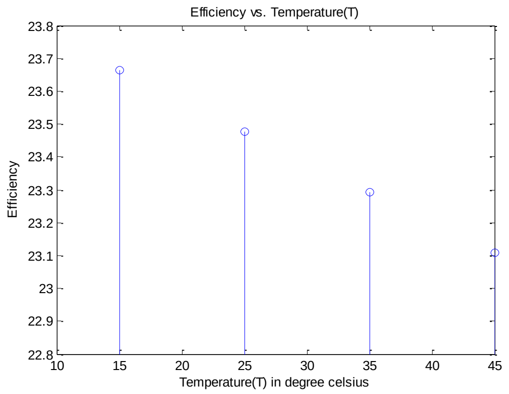
The study of the effect of the solar radiation on PV devices is difficult because the spectrum of the sunlight on the Earth's surface is influenced by factors such as the variation of the temperature on the solar disc and the influence of the atmosphere [16].

Table 2: Efficiency, Pmax & Imax for different values of Irradiance (G)

Irradiance(w att/m^2)	*Pmax (watt)*	*Efficiency (%)*	*Imax(amp)*
250	65.8154	25.3136	2.0251
240	63.0375	24.2452	1.9396
230	60.2591	23.1766	1.8598
220	57.4852	22.1097	1.7742
210	54.7108	21.0426	1.6886
200	51.9358	19.9753	1.6079
190	49.1660	18.9100	1.5222
180	46.3957	17.8445	1.4364
170	43.6284	16.7802	1.3549

As demonstrate in Fig-6(c), an increase in solar irradiance causes the output current to increase and the horizotal part of the curve moves upward.Along with this, Table 2 demonstrate that maximum power is increased at a signaficant amount with increasing value of solar irradiance. Hence Fig-6(a) clearly shows that efficiency increased proportionally with solar irradiance.

5.2 Vary Temperature



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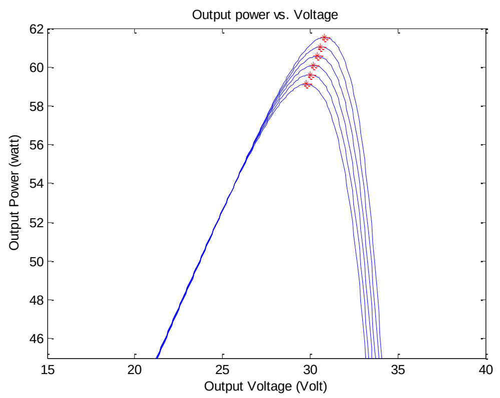

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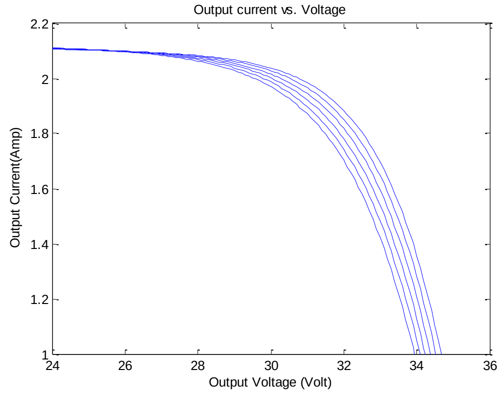

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Figure 7: For different values of Temperature (T) (G=250 w/m^2) (a) Efficiency vs. Temperature (b) Output Power vs. Output voltage (c) Output Current vs. Output voltage

Table 3: Efficiency, Pmax & Imax for different values of Temperature (T)

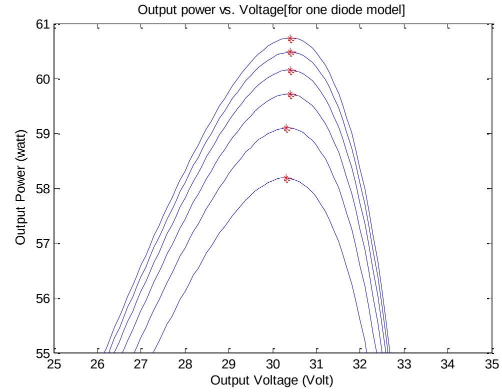
Temperature (Deg. Celsius)	*Efficiency (%)*	*Pmax (watt)*	*Imax (amp)*
15	23.6634	61.5249	1.9976
25	23.4774	61.0413	1.9948
35	23.2922	60.5597	1.9921
45	23.1077	60.0800	1.9894
55	22.9239	59.6021	1.9867
65	22.7407	59.1259	1.9841

Increasing temperature increases the intrinsic carrier concentration. This pushes the fermi level closer to the intrinsic fermi level (the middle of the band gap). The built-in potential of a diode is determined by the difference in fermi-levels in the p-type and n-type regions. Due to temperature increase, the fermi level in each region moves closer to the middle of the gap, and the built-in potential is decreased.

The operating voltage of a solar cell is related to the diode's built-in potential. 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.Fig-7 clearly illustrates this fact [17].

5.3 Varying Shunt Resistance (Rp)

(a)



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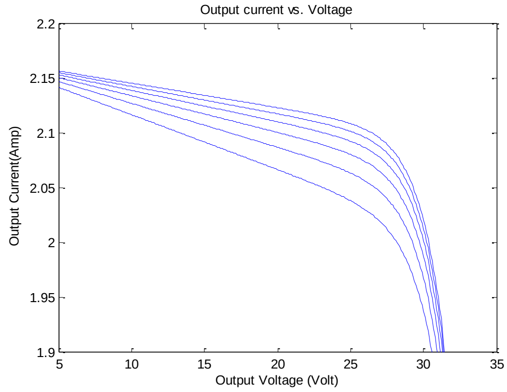

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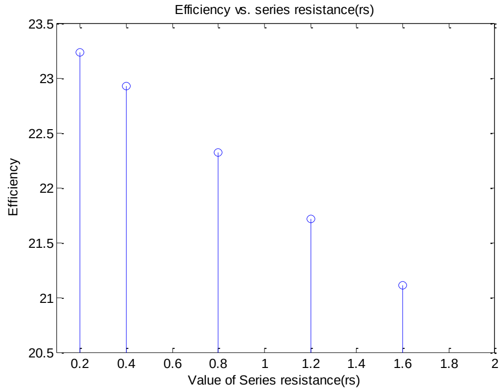
Figure 8: For different values of Parallel Resistance (Rp) (a) Efficiency vs. Parallel Resistance (b) Output Power vs. Output voltage (c) Output Current vs. Output voltage

Table 4: Efficiency, Pmax & Imax for different values of Parallel Resistance (Rp)

Shunt resistance (Rp)	*Efficiency(%)*	*Pmax (watt)*	*Imax (amp)*
200	22.3772	58.1806	1.9202
250	22.7291	59.0957	1.9504
300	22.9642	59.7070	1.9640
350	23.1329	60.1455	1.9785
400	23.2594	60.4744	1.9893
450	23.3578	60.7302	1.9977

As shunt resistance decreases, the current diverted through the shunt resistor increases for a given level of junction voltage. The result is that the voltage-controlled portion of the I-V curve begins to sag far from the origin, producing a significant decrease in the terminal current I and a slight reduction in V_{OC}. Very low values of R_{SH} will produce a significant reduction in V_{OC}. Fig-8 and Table 4 clearly express that, Pmax and efficiency are increased along with increasing value of shunt resistance.

5.4 Vary Series resistance (Rs)



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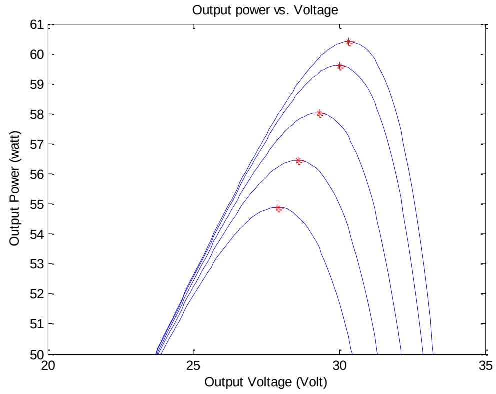

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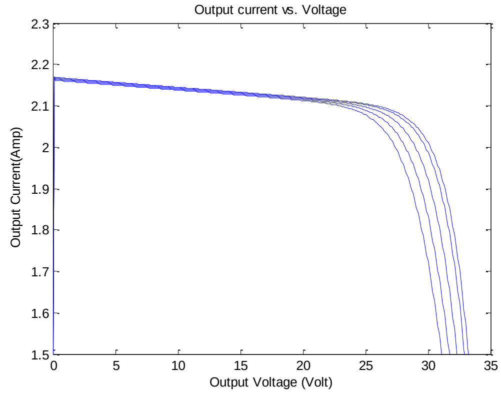

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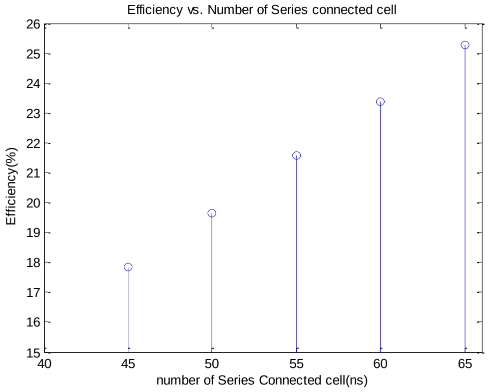
Figure 9: For different values of Series Resistance (Rs) (G=250 w/m^2) (a) Efficiency vs. Series Resistance (b) Output Power vs. Output voltage (c) Output Current vs. Output voltage

Fig-9 and Table 5 illustrate that, Pmax and efficiency are reduced with increasing value of series resistance (Rs). It is also observed that maximum output current is not affected significantly with changing value of Rs and being remain almost constant.

Table 5: Efficiency, Pmax & Imax for different values of Series Resistance (Rs)

Series resistance (Rs)	*Efficiency (%)*	*Pmax (watt)*	*Imax (amp)*
.2	23.2318	60.4027	1.9935
.4	22.9261	59.6079	1.9869
.8	22.3172	58.0246	1.9804
1.2	21.7120	56.4512	1.9738
1.6	21.1110	54.8886	1.9673

5.5 Vary Number of Series cells (Ns)



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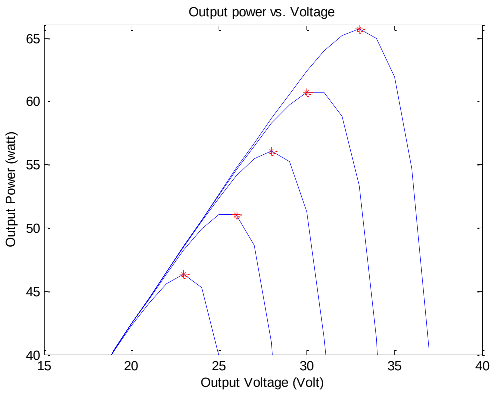

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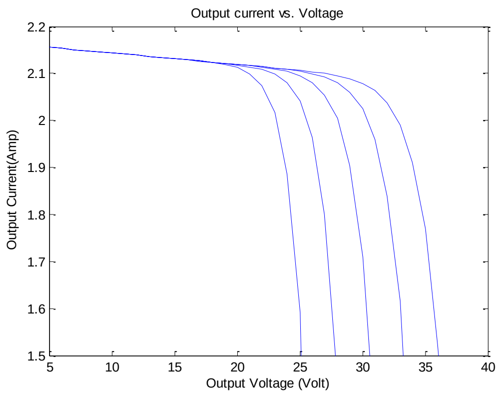


(c)

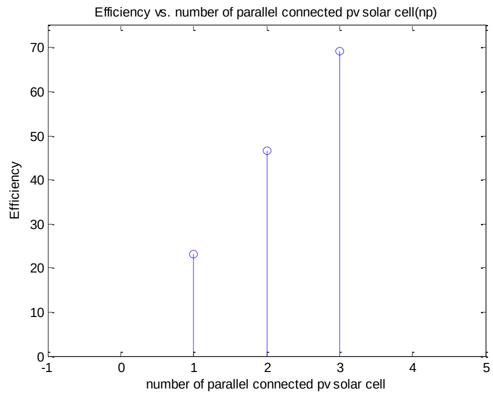
Figure 10: For different values of Number of Series connected cells (Ns) (G=250 w/m^2) (a) Efficiency vs. Number of Series connected cells (b) Output Power vs. Output voltage (c) Output Current vs. Output voltage

Table 6: Efficiency, Pmax & Imax for different values of Number of Series connected solar cell (Ns)

Number of series cells(Ns)	Efficiency (%)	Pmax (watt)	Imax (amp)
45	17.8366	46.3753	2.0163
50	19.6374	51.0571	1.9637
55	21.5768	56.0997	2.0036
60	23.3656	60.7506	2.0250
65	25.2705	65.7032	1.9910

Solar modules can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination. Series connections increase voltage output whereas output current remains almost constant.Fig-10 and Table 6, clearly justify this fact. Therefore, Fig-10(a) shows that efficiency of solar panel is increased with increasing number of series connected cells.

5.6 Vary Number of Parallel cells (Np)



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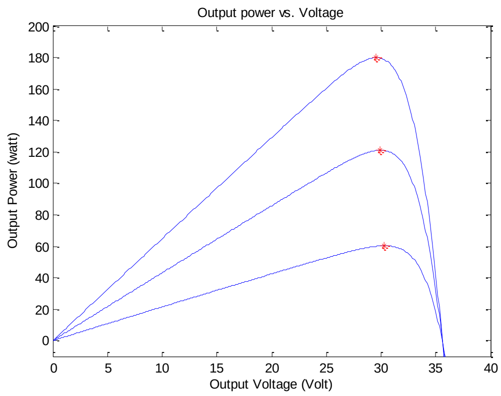

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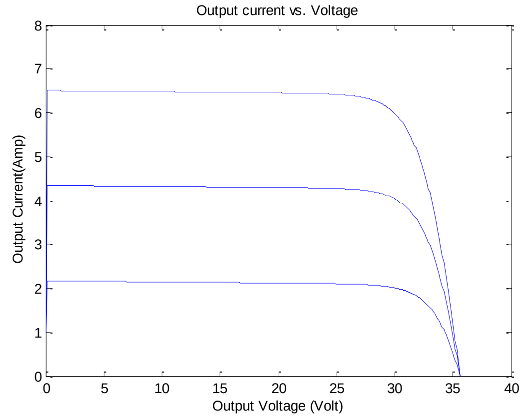

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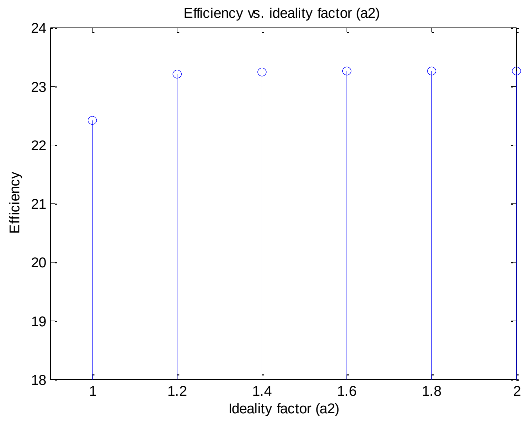
Figure 11: For different values of Number of Parallel connected cells (Np) (G=250 w/m²) (a) Efficiency vs. Number of Parallel connected cells (b) Output Power vs. Output voltage (c) Output Current vs. Output voltage

Table 7: Efficiency, Pmax & Imax for different values of Number of parallel connected solar cell (Np)

Number of parallel connected solar cell (Np)	Imax(amp)	Pmax(watt)	Efficiency (%)
1	1.9907	60.3196	23.1999
2	4.0478	121.0280	46.5492
3	6.0974	179.8721	69.1816

Parallel connections increase current output. Fig-11(c) indicates that, an increase in number of parallel connected cells causes the output current to increase and the horizotal part of the curve moves upward.Along with this, Fig-11(b) shows that maximum power moves upward with respective changing parameter. Also Fig-11(a) clearly shows that efficiency increased proportionally with increasing number of parallel connected cells.

5.7 Vary Ideality Factor



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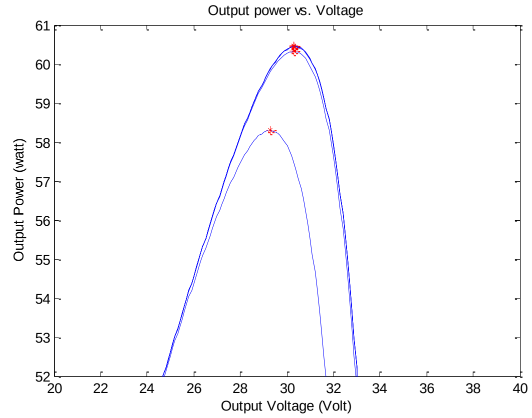

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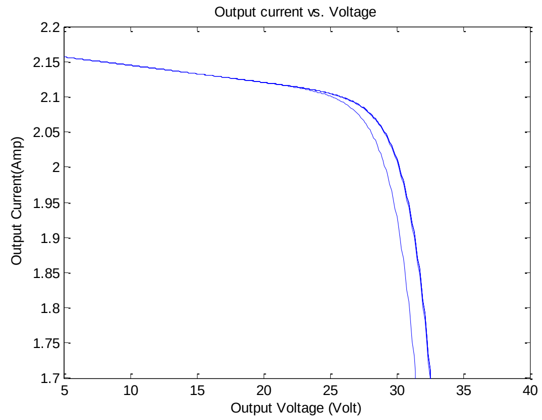

(c)

Figure 12: For different values of Ideality Factor (for diode D_2) G=250 w/m²) (a) Efficiency vs. Ideality Factor (b) Output Power vs. Output voltage (c) Output Current vs. Output voltage

Table 8: Efficiency, Pmax & Imax for different values of Ideality Factor (a_2)

Ideality factor(a_2)	*Efficiency(%)*	*Pmax (watt)*	*Imax(amp)*
1	22.42	58.2946	1.9896
1.2	23.20	60.3196	1.9907
1.4	23.24	60.4348	1.9945
1.6	23.24	60.4458	1.9949
1.8	23.24	60.4476	1.9950
2.0	23.24	60.4480	1.9950

The diode ideal factors a1 and a2 represent the diffusion and recombination current components, respectively. In accordance with Shockley's diffusion theory, the diffusion current, a1 must be unity [18]. The value of a2, however, is flexible.Table-8 describe that, Pmax, Imax and efficiency almost constant after a2 reaches the value of 1.2.Hence this will be the appropriate ideality actor for diode(D_2) to have maximum cell efficiency.

6. CONCLUDING REMARKS

To achieve better performance of solar cell, it is essential to design the model with appropriate value of parameters. In this work MATLAB based simulation is done to determine values of different parameters to attain optimum efficiency of the PV cell .We conclude that, efficiency increases with increasing irradiance and number of parallel connected cells, decreasing temperature, series resistance, number of parallel connected cells and value of shunt resistance. Also determine most advantageous value of ideality factor of diode having recombination current component. Accurateness of the simulated determination can be verified by hardware implementation

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