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EFFECT OF PARASITIC PARAMETERS AND ENVIRONMENTAL CONDITIONS ON I-V AND P-V CHARACTERISTICS OF 1D5P MODEL SOLAR PV CELL USING LTSPICE-IV[†]

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In this research work, the electrical simulation of 1D5P model solar cell is done using LTSpice-IV simulation software. In this work effect of environmental conditions i.e temperature, solar irradiance, and parasitic parameters i.e series as well as shunt resistances was carried out. It has been discovered that as temperature increases the performance of solar cell decrease because temperature causes to increase the recombination phenomenon and hence lower the performance. However, when the temperature rises from 0^0C to 50^0C, the I-V and P-V curves move to the origin showing the negative effect of increasing temperature on the solar cell. Solar irradiance has major role on the performance of solar cell. As solar irradiance increases from 250 Wm^{-2} to 1000 Wm^{-2}, the performance of solar cell increases accordingly and I-V as well as P-V curve moves away from the origin. It is concluded that for different series resistances, I-V along with P-V characteristic of 1D5P model solar cell varies, as at 0.02Ω series resistance, a maximum short circuit current and maximum power is obtained. But when series resistance increased up 2 ohm only, the I-V and P-V curves moves to origin drastically. Shunt Resistance is the path of reverse current of the cell. As the shunt resistance increases, the path for reverse current decreased, hence all current goes to load, hence maximum power is obtained. Similarly when the value of shunt resistance decreased, the voltage-controlled section of I-V characteristics curve is moved closer to the origin hence reduced the solar cell performance. It's critical to understand how different factors affect the I-V and P-V characteristics curves of solar cells. The open circuit voltage, short circuit current and maximum power is all variable. The influence of these factors may be extremely beneficial when tracking highest power point of a solar cell applying various methods.
Keywords: Solar Cell, 1D5P, Simulation, Temperature, Irradiance, LTSpice
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Because of the catastrophic situation with conventional fuels, renewable energy sources have grown increasingly appealing. Solar energy consumption has grown by 20 percent to 25 percent in the last 20 years [1]. PV cells are devices that use solar energy to turn it directly into electricity. However, energy generation has a significant impact on the environment and solar cell manufacture. The short circuit current increases somewhat as temperature rise, whereas open circuit voltage of PV cell drops significantly [2].

A short circuit current decreases as sun irradiation decreased [3]. The open circuit voltage, on the other hand, does not fluctuate substantially. It is substantially diminished after a certain point [4]. Voltage drop between junction and terminal increases as the series resistance of the PV cell increases, as well as current-controlled section of I-V characteristics curve moves closer to the origin [5]. Current flowing through the shunt resistance improves when the shunt resistance is reduced, and the voltage regulated part of I-V characteristics curve moves closer to an origin [6].

The characteristics curves of PV cells are affected by changes in many factors. This document includes a brief explanation of the PV cell as well as LTSpice IV modeling [7]. LTSpice IV is a strong, high-performance, and a quick sufficient program that makes it simple to build and simulate various circuit models while also providing accurate simulation results. LTSpice's capabilities include the ability to do simulations based on transient, AC, noise, and DC analyses [8]. Because of its advantages, LTSpice IV is utilized to run the simulations. This simulation tool is entirely free and is easily downloaded from the LTC website [9]. It is compatible with a wide range of operating systems, including Windows NT4.0, Me, XP, Vista, Windows 7, Windows 8, Windows 8.1, and Windows 10. LTSpice-IV program is available for Linux users also [10].

PV CELL MODELING

Mathematical expressions representing current-voltage (I-V) curves describe the electric performance of solar modules. Typically, seven mathematical models are employed, split into three categories as shown in Table 1 [11]. The

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single diode variant is the most common. Because these equations are non-linear, the right procedures for extracting their parameters are required. Several writers have reviewed the approaches for extracting module parameters in the literature [12,13,14].

Despite the fact that these many approaches are strong, the majority of them, particularly iterative methods like the Levenberg-Marquardt (LM) algorithm, need beginning data. In most cases, the user enters these initial settings instinctively. Algorithm's computation will take a long time or, at the very least, a convergence problem will arise if input values are distant from true beginning values. Because incorrect starting values might influence algorithm accuracy, convergence, and computation time, it would be beneficial to have a way to get these initial values [15].

Table. 1. Classification of photovoltaic cell comparable models [16].

Group	Model	Parameters
One Diode Model	3 Parameters Model	I_{ph}, I_o, n
	4 Parameters Model	I_{ph}, I_o, n, R_s
	5 Parameters Model	$I_{ph}, I_o, n, R_s, R_{sh}$
One Diode Model	6 Parameters Model	$I_{ph}, I_{o1}, n_1, I_{o2}, n_2, R_s$
	7 Parameters Model	$I_{ph}, I_{o1}, n_1, I_{o2}, n_2, R_s, R_{sh}$
Model with recombination in intrinsic layer	1 Diode Model with Recombination	$I_{ph}, I_o, n, R_s, R_{sh}, \mu\tau$
	2 Diode Model with Recombination	$I_{ph}, I_{o1}, n_1, I_{o2}, n_2, R_s, R_{sh}, \mu\tau$

Equation of the diode current is

$$I_d = I_0(e^{\frac{qVd}{kT}} - 1) \tag{1}$$

Equation of load current is

$$I_L = I_{ph} - I_d \tag{2}$$

$$I_L = I_{ph} - I_0(e^{\frac{qV_d}{kT}} - 1) \tag{3}$$

When terminals are short circuited ($V_d = 0$);

$$I_{sc} = I_{ph} - I_0(e^{\frac{q0}{kT}} - 1) \tag{4}$$

$$I_{sc} = I_{ph} \tag{5}$$

When terminals are open circuited ($I_{sc} = 0$);

$$V_d = V_L = V_{oc} \tag{6}$$

$$V_{oc} = \left(\frac{kT}{q}\right)\ln\left\{\left(\frac{I_{ph}}{I_0}\right) + 1\right\} \tag{7}$$

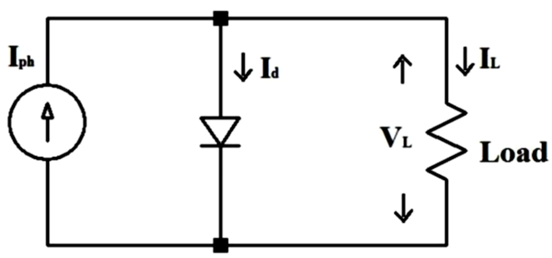


Figure 1. Ideal Equivalent Circuit of a Solar Cell [17].

A current source, a diode, and a shunt resistance R_P parallel to it make up the realistic equivalent circuit of a solar cell as given in Figure 2. Between a connection and load there lies a series resistance Rs [5].
Equation of load current is,

$$I_L = I_{ph} - I_d - I_P \tag{8}$$

$$I_L = I_{ph} - I_0(e^{\frac{qI_{ph}R_S}{kT}} - 1) - (I_{ph}\frac{R_S}{R_P}) \tag{9}$$

Open circuit voltage (Voc) equation:

$$V_{oc} = \left(\frac{kT}{q}\right)\ln\left\{\left(\frac{I_{ph}}{I_0}\right) + 1\right\} \tag{10}$$

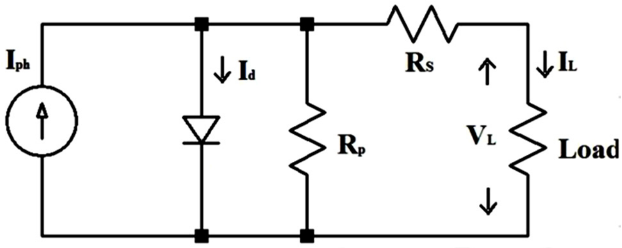


Figure 2. Practical Equivalent Circuit of a Solar Cell [18].

I-V and P-V characteristics of solar cell

The following Figure 3 describes I-V as well as P-V characteristics of solar cell.

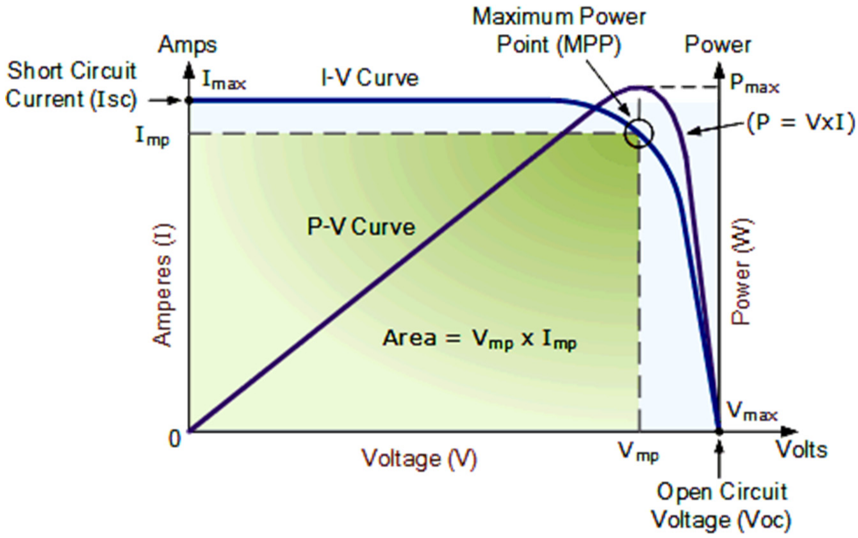


Figure 3. I-V and P-V Characteristics Curve of Solar Cell [19].

For a single operating point, maximum power is gained at output of a solar cell. When the given quantity of load is applied, the resulting power at load is P_L for load current I_L as well as load voltage V_L. However, for a given load value, the load current ($I_L = I_{mpp}$) and load voltage ($V_L = V_{mpp}$) are maximum, and the power obtained is maximum, P_{max}. Ratio of maximum power to product of V_{oc} and I_{sc} is known as the fill factor that reflects quality of solar cell [20]. Changes in parameters have an impact on I-V characteristics curve and maximum power value. As a result, it's critical to understand the impact of changing these factors [21].

Simulation of Solar Cell Model using LTSpice-IV

Schematic diagram of solar cell model 1D5P (one diode, five parameters) is shown in Figure 4. This model is used to simulate the effects of temperature, sun irradiation, series resistance, and shunt resistance of the solar cell.

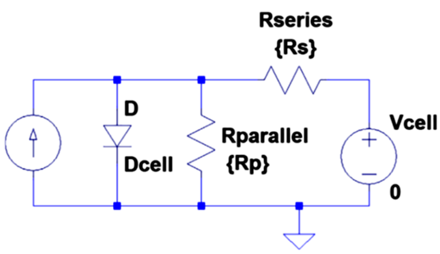


Figure 4. Single-diode solar cell 1D5P-model simulated in LTSpice IV.

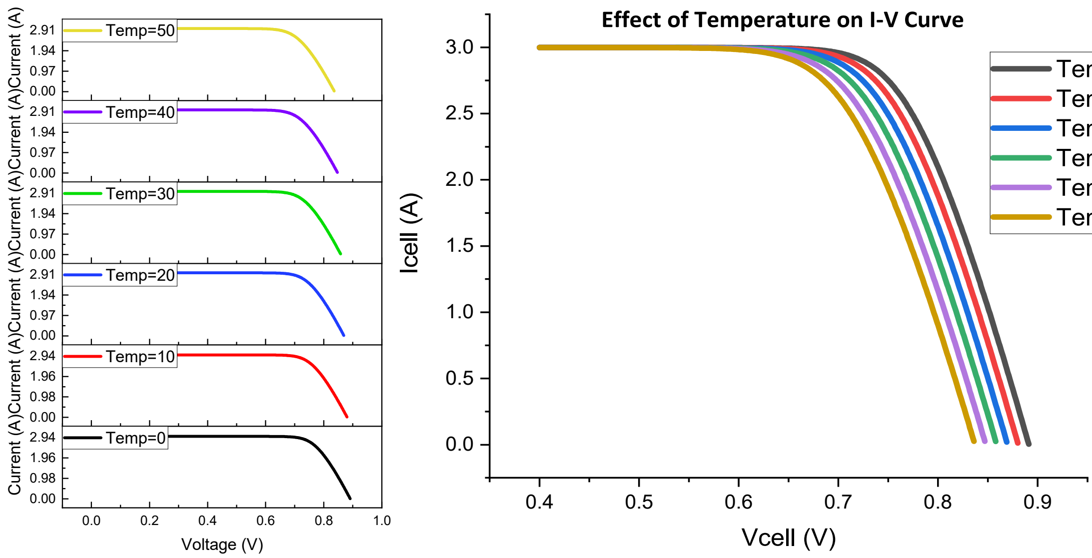
As illustrated in Figure 5, the model accepts as input the cell characteristics in reference circumstances as well as environmental data (cell temperature, irradiation). The characteristics of solar cells change as a result of climatic factors (irradiation, temperature).

Figure 5. Illustrative diagrams of the inputs and outputs of the LTSpice model.

RESULTS AND DISCUSSION

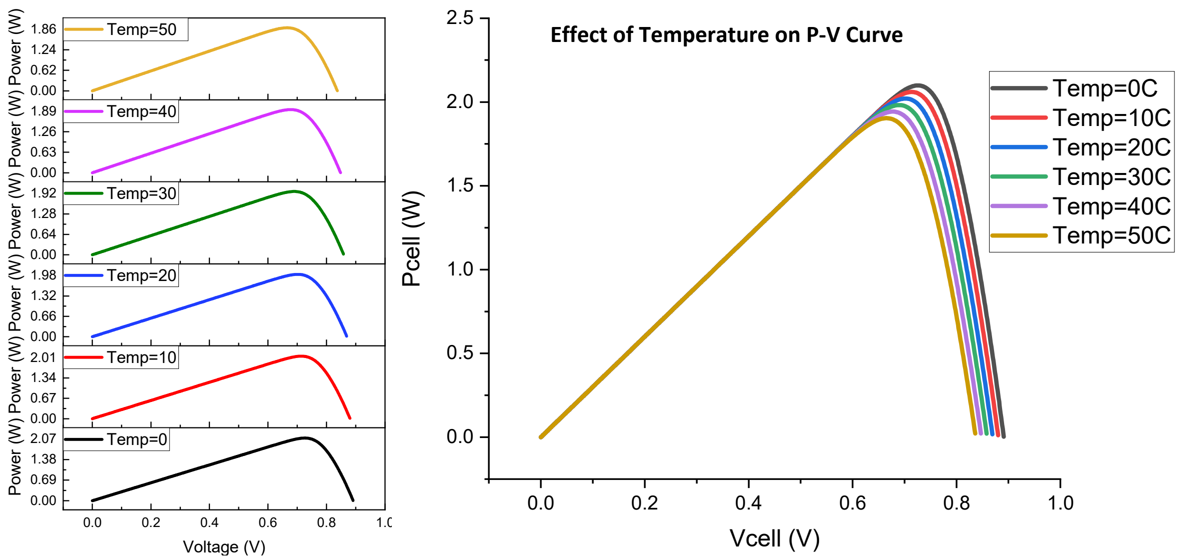
Temperature Effect on 1D5P Model Solar Cell

PV system-1 (1D5P) is used to demonstrate the effect of temperature variation. The command used in LTSpice IV to run the simulation is (step temp 0 50 10). The beginning temperature is 0 degree, with 10 degrees as the step size and 50 degrees as the end temperature. The series and shunt resistances are 0.03 Ohms and 500 Ohms, respectively, in 1D5P solar cell model. The current source is assumed to be 3A since the irradiance is 1000 Wm^{-2}. The simulation for the temperature impact is illustrated in Figures 6 and 7. The curve on the right represents 0 degrees celsius, while the curves on the left represent 10, 20, 30, 40, and 50 degrees celsius, respectively.



(a) **(b)**

Figure 6. Temperature effect on I-V curve (a) Stack (b) Batch



(a) **(b)**

Figure 7. Temperature effect on P-V curve (a) Stacked (b) Batch

Solar cells, like all other semiconductor devices, are temperature sensitive. Increasing temperature, lowers the bandgap of a semiconductor, affecting the majority of its material characteristics. A reduction in a semiconductor's band gap as temperature rises might be interpreted as an increase in the energy of the material's electrons. As a result, less energy is required to break a connection. A decrease in bond energy decreases a bandgap in the bond model of a semiconductor bandgap. Open-circuit voltage is characteristic in a solar cell that is most impacted by temperature changes. The observed variations in parameters owing to rise in temperature are reported in table 2 based on the temperature impact simulations (Figure 6 and 7).

Table. 2. Effect of temperature

Temperature (degree)	**Open circuit voltage, V_{oc} (V)**	**Short circuit current, I_{sc} (A)**	**Maximum Power, P_{max} (W)**
0	0.891136	2.99998	2.09897
10	0.880491	2. 99997	2.05999
20	0.869756	2. 99997	2.02095
30	0.858932	2. 99996	1.98187
40	0.848023	2. 99988	1.94276
50	0.837031	2. 99984	1.90362

The open circuit voltage decreases with increasing temperature, while short circuit current decreases only little, according to simulation results. At 0-degree output power is maximum. Power progressively decreases because with temperature changes, current voltage (I-V) characteristic of an illuminated photovoltaic cell changes. According to solid state theory, the impact may be explained. Higher temperature lowers open-circuit voltage and short-circuits current, and hence same is true for the P-V curve. As a result, changes in temperature have an impact on the cell's overall performance. The cell performs well at low temperatures, but as temperature rises, efficiency of the cell decreases.

Irradiance Effect

The value of I_{ph} changes when the value of solar irradiance changes. The current in a short circuit is proportional to sun irradiation, G. A solar cell is seen to act like a 3A current source when exposed to 1000 Wm^{-2} sun irradiation. If the obtained ratio is Kr = (3/1000), it is determined that the current sources for radiations of 1000 Wm^{-2}, 850 Wm^{-2}, 700 Wm^{-2}, 550 Wm^{-2}, 400 Wm^{-2}, and 250 Wm^{-2} are 3A, 2.55A, 2.1A, 1.65A, 1.2A, and 0.75A, respectively, using the equation;

$$I_{sc}= K_r*G \qquad (11)$$

The series and shunt resistances are 0.03 ohms and 500 ohms, respectively, in the model. Figures 8 and 9 show simulations of I-V as well as P-V characteristics curves for various solar irradiances.

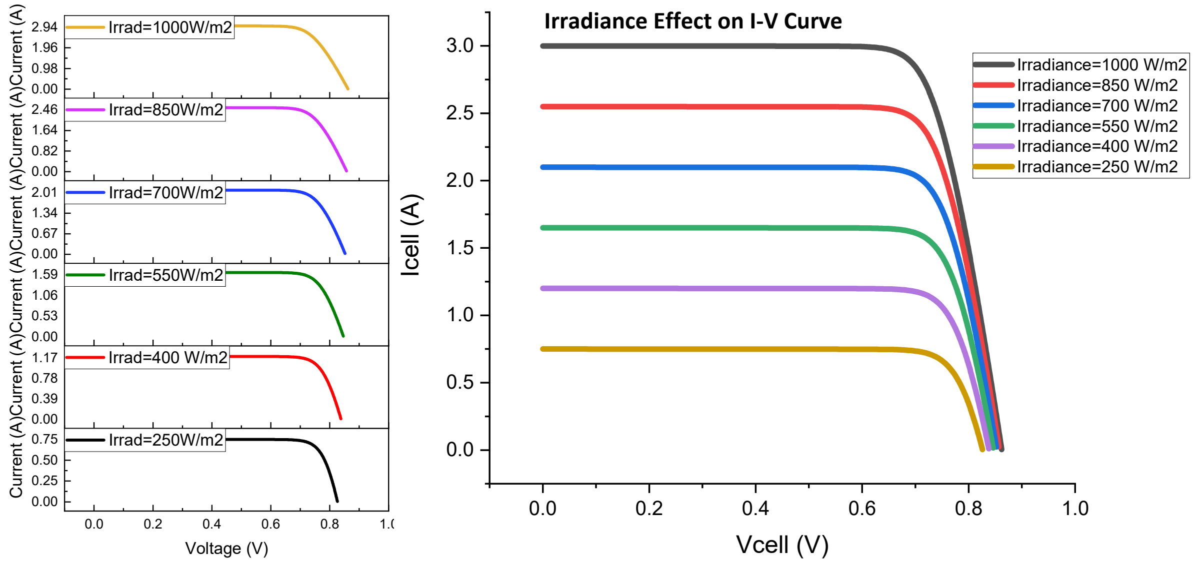
Table 3. Solar Cell Current (I_{sc}) effect by Irradiance (G)

I_{ph} (A)	$K_r = \frac{I_{sc}}{1000}$ (A)	$G\ (Wm^{-2})$	$I_{sc} = K_r x G\ (A)$
3	0.003	1000	3
3	0.003	850	2.55
3	0.003	700	2.1
3	0.003	550	1.65
3	0.003	400	1.2
3	0.003	250	0.75

I_{sc} is the current of the solar cell affected by the solar irradiance. These currents are being used to observe the affect of solar irradiance on I-V and P-V curve of the solar cell. The variation in the solar irradiance majorly affects the performance of the solar cell shown below in the graphs.

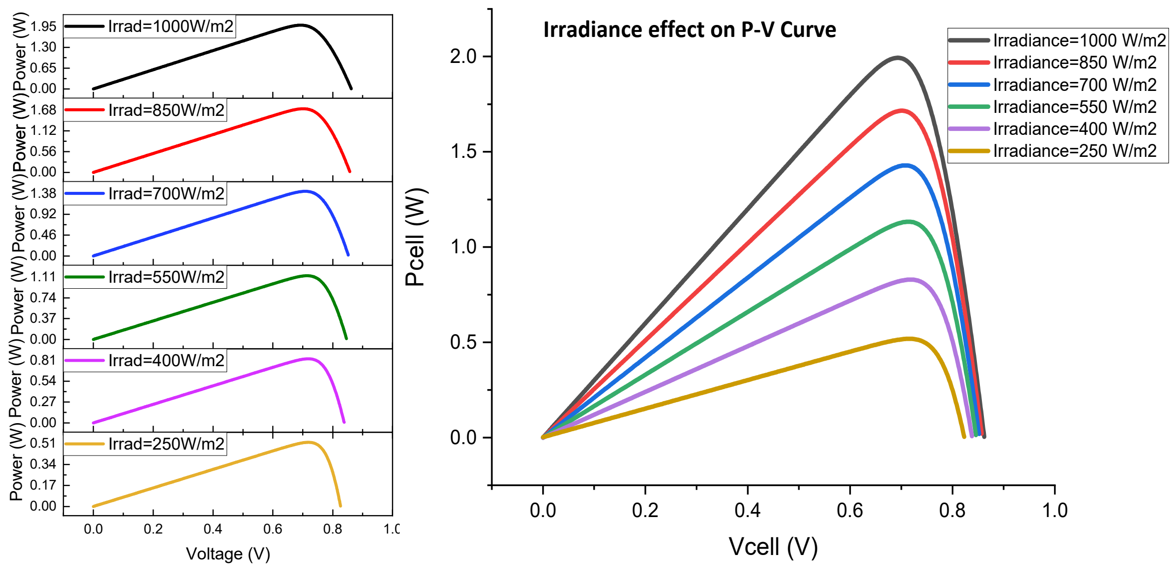
As the solar insolation changes during the day, the I-V and P-V properties change as well. With rise in solar irradiance, open circuit voltage and short circuit current rises as well, causing maximum power point to shift downward. Solar cell performance is affected by irradiance, with a drop in sunshine resulting in a fall in current and, as a result, a loss in power production. The observed changes in parameters are presented in Table 4 resulting in a decrease in solar irradiation.

Open circuit voltage and short circuit current are lowered as sun irradiation reduced, according to the simulation results. The output power is highest when the irradiance is at its highest, then progressively decreases when the irradiance is reduced.



(a) **(b)**

Figure 8. Irradiance effect on I-V curves (a) Stack (b) Batch



(a) **(b)**

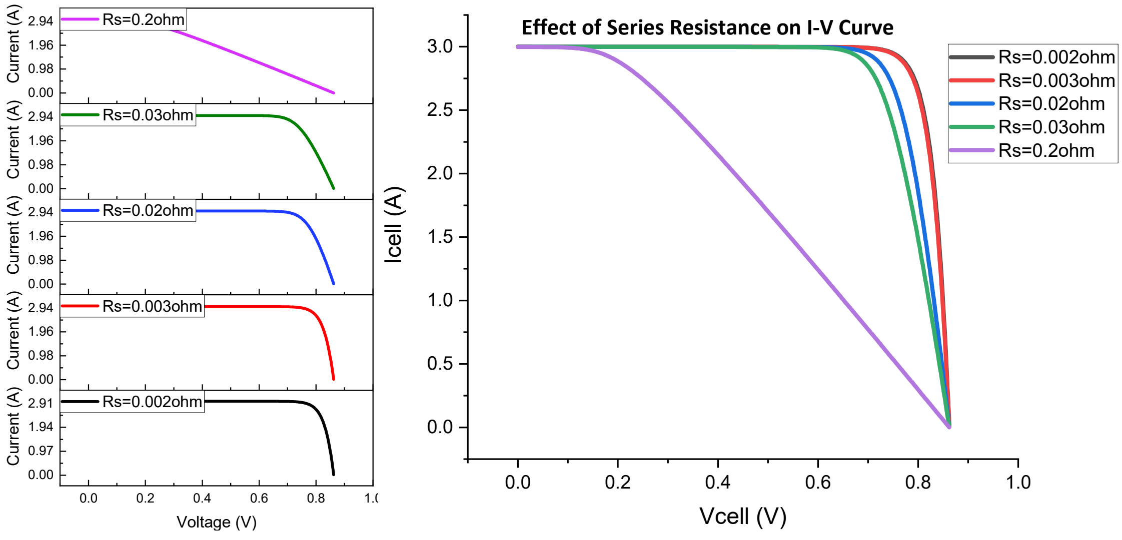
Figure 9. Irradiance effect on P-V curves (a) Stack (b) Batch

Table 4. Effect of Irradiance

Irradiance, G (Wm^{-2})	**Open circuit voltage, V_{oc} (V)**	**Short circuit current, I_{sc} (A)**	**Maximum Power, P_{max} (W)**
250	0.826288	0.749955	0.518568
400	0.838466	1.19993	0.829345
550	0.846713	1.6499	1.13318
700	0.852957	2.09987	1.42888
850	0.857982	2.54985	1.71582
1000	0.862188	2.99982	1.99361

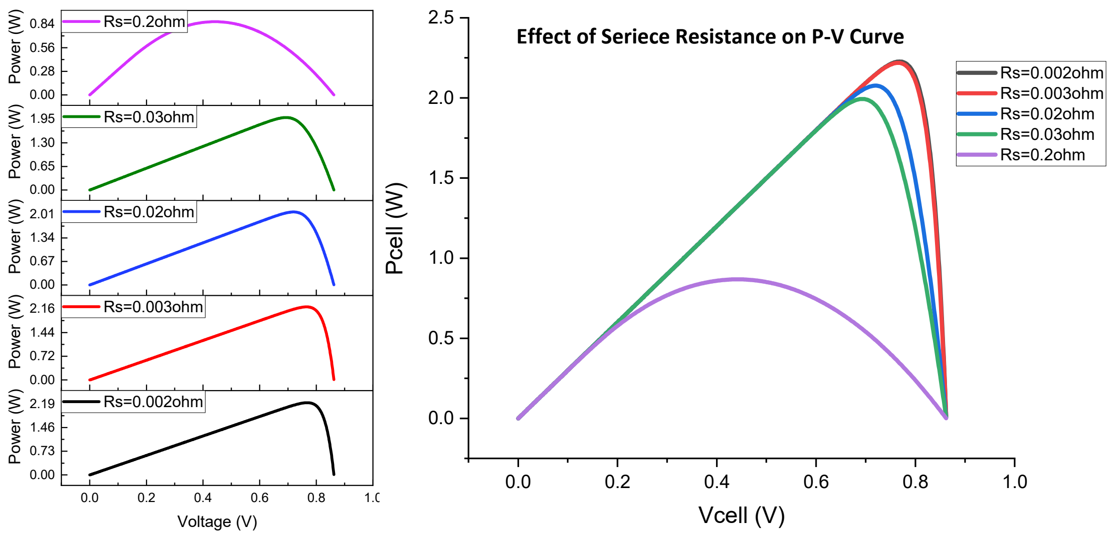
Effect of Change in Series Resistance

Figures 10 and 11 show the simulation results for various series resistance levels. The solar irradiation is set to $1000Wm^{-2}$, temperature is set to 20°C, and shunt resistance is set to 500 ohms. 0.03 ohm, 0.3 ohm, 3 ohm, 4 ohms, and 5 ohms are the series resistance values utilized.



(a) **(b)**

Figure 10. Effect of change of series resistance on I-V curve (a) Stack (b) Batch



(a) **(b)**

Figure. 11. Effect of change of series resistance on P-V curve (a) Stack (b) Batch

At open-circuit voltage, series resistance has no effect on the solar cell since entire current flow through solar cell, and therefore via series resistance, is zero. Series resistance, on the other hand, has a significant impact on I-V curve at open-circuit voltage. Table 5 summarizes the observed variations owing to changes in series resistance.

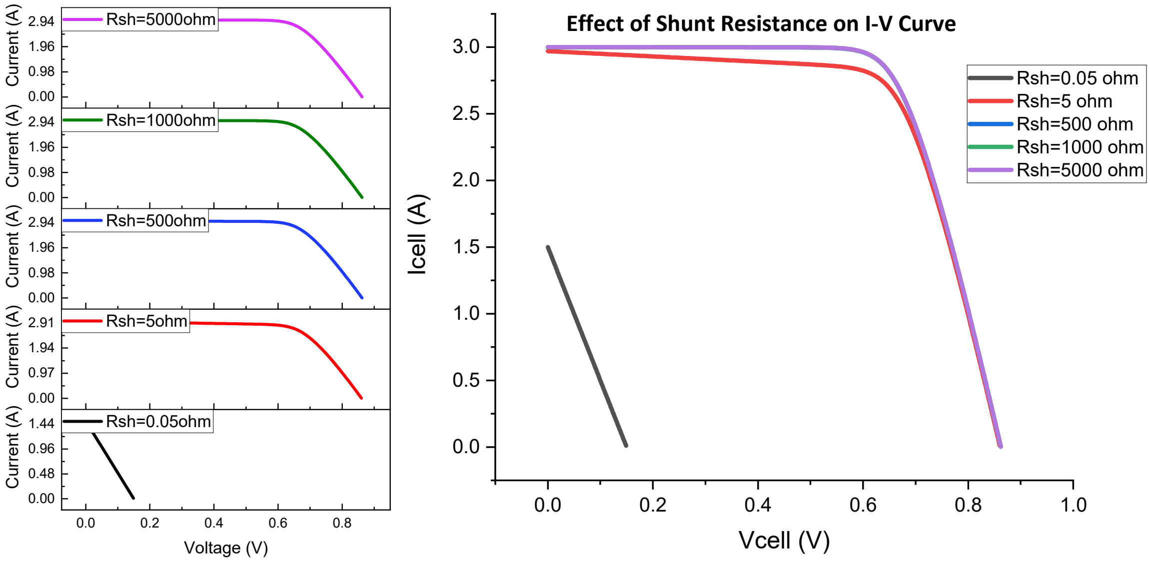
Table 5. Effect of change of series resistance

Series resistance, Rs (Ohm)	Open circuit voltage, V_{oc} (V)	Short circuit current, I_{sc} (A)	Maximum Power, P_{max} (W)
0.002	0.862186	2.99999	2.22728
0.003	0.862187	2.99998	2.21887
0.02	0.862188	2.99988	2.0766
0.03	0.862188	2.99982	1.99361
0.2	0.862188	2.99868	0.867814

Short circuit current is lowered insignificantly when series resistance is raised, while short circuit current is reduced significantly for very high series resistance values. However, open circuit voltage stays same, whereas maximum output power is decreased. The flow of current between emitter and base of solar cell, contact resistance between metal contact and the absorber layer, and resistance of top and rear metal contacts are the three reasons of series resistance in a solar cell. Although extremely high values may also lower short-circuit current, the major effect of series resistance is to diminish the fill factor. At open-circuit voltage, series resistance has no effect on solar cell since entire current flow through solar cell, and therefore via series resistance, is zero. Series resistance, on the other hand, has a significant impact on I-V curve at open-circuit voltage. Finding slope of I-V curve at open-circuit voltage point is a simple way to estimate series resistance of a solar cell.

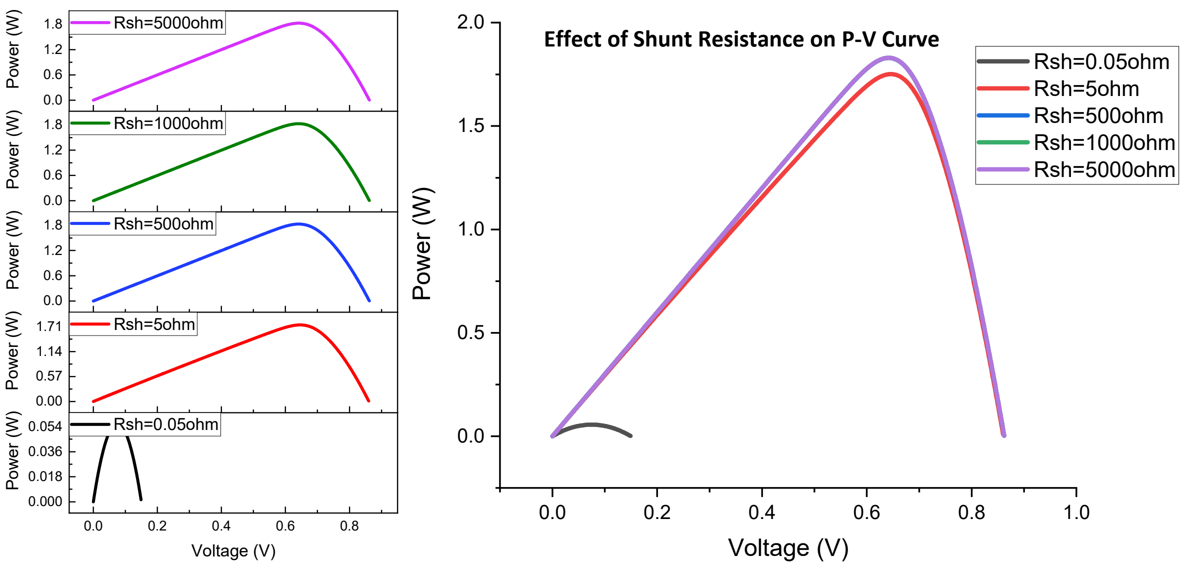
Effect of Change in Shunt Resistance

Figures 12 and 13 illustrate the simulation for various shunt resistance levels. The irradiation of the sun is 1000Wm^{-2}, the temperature is 20°C, and the series resistance is 0.03 Ohm. 5000 Ohms, 1000 Ohms, 500 Ohms, 5 Ohms, and 0.05 Ohms are the shunt resistance values.



(a) **(b)**

Figure 12. Effect of change of shunt resistance on I-V curve (a) Stack (b) Batch



(a) **(b)**

Figure 13. Effect of change of shunt resistance on P-V curve (a) Stack (b) Batch

By offering an additional current channel for light-generated current, low shunt resistance becomes the reason of power losses in solar cells. An amount of current passing through solar cell junction is reduced, and voltage from solar cell is reduced as a result of this diversion. Because there is less light-generated current at low light levels, effect of a shunt resistance is more severe. As a result, loss of this current due to shunt resistance has a greater impact on solar cell performance. Furthermore, at lower voltages, when solar cell's effective resistance is considerable, influence of a parallel resistance is significant. Table 4 summarizes the observed variations owing to changes in series resistance.

Table 6. Effect of change of shunt resistance

Shunt resistance, R_{sh} (Ohm)	**Open circuit voltage, V_{oc} (V)**	**Short circuit current, I_{sc} (A)**	**Maximum Power, P_{max} (W)**
0.05	0.150000	1.87500	0.0703125
5	0.860675	2.98211	1.89965
500	0.862188	2.99982	1.99361
1000	0.862196	2.99991	1.99408
5000	0.862201	2.99998	1.99446

The open circuit voltage decreases little as shunt resistance decreases, but it decreases considerably for very low shunt resistance values. The short circuit current is little impacted. The output power is decreased, and the power is very low for a very tiny shunt resistance.

Optimized Results

From the above results and discussion, we concluded that at 0^0C temperature, 1000w/m^2 irradiance, 0.002 ohm series resistance and 5000 ohm shunt resistance give the fruitful results. The optimized values were simulated on 1D5P model solar cell as shown in the following circuit diagram.

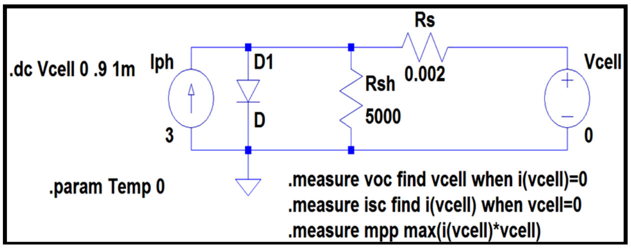
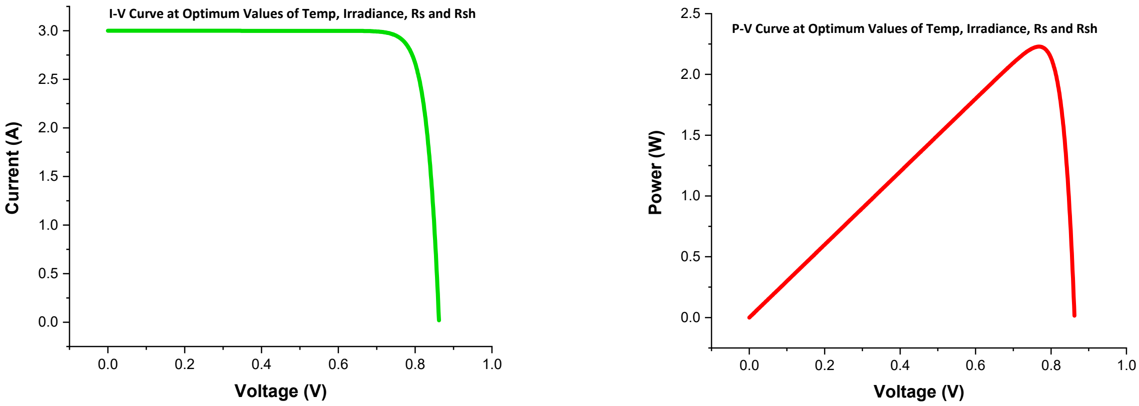


Figure 14. Real Valued Circuited simulated on optimum values

The effect of these optimum values is clearly shown in the following graphs.



(a) (b)

Figure 15. (a) I-V curve at optimum values (b) P-V curve at optimum values

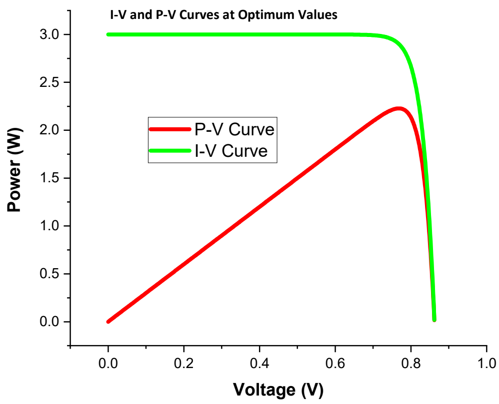


Figure 16. Improved I-V and P-V curves

From the above graphs it is clear that at the optimum values, the curves have become straighter showing the improvement in the performance of 1D5P model solar cell.

CONCLUSION

The numerical simulation was done with LTSpice. The short-circuit current and electrical characteristics of certain cell components such as the diode, shunt resistance, and series resistances are illustrated and analyzed using numerical data. These impacts are demonstrated using simulations. The major goal of the project is to measure output power under various environmental conditions such as temperature, solar irradiance. Changes in these parameters have a major impact on the PV cell's I-V and P-V characteristics curves. Temperature was varied from 0^0C to 50^0C. With increase in temperature the I-V and P-V curves were affected. Hence the case with solar irradiance varied from 250 to 1000 Wm^{-2} was observed. The shunt and series resistances of the solar cell play an important role in the performance of the solar cell. Optimum values of the temperature, solar irradiance, shunt and series resistance values have be calculated for one diode five parameters (1D5P) solar cell.

FUTURE WORK

The presented work gave the effect of different parameters variations on I-V and P-V curves of 1D5P model solar pv cell. If a DC-DC converter is applied at the output of this model, the voltages and currents, and hence the power of the cell can be enhanced as well as the smooth curves can be obtained.

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ВПЛИВ ПАРАЗИТНИХ ПАРАМЕТРІВ ТА УМОВ СЕРЕДОВИЩА НА I-V ТА P-V ХАРАКТЕРИСТИКИ МОДЕЛІ 1D5P СОНЯЧНОГО ЕЛЕМЕНТА З ВИКОРИСТАННЯМ LTSPICE-IV

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У цій дослідницькій роботі виконано електричне моделювання сонячної батареї моделі 1D5P за допомогою програмного забезпечення моделювання LTSpice-IV. У цій роботі здійснювався вплив умов навколишнього середовища, тобто температури, сонячного опромінення, а також паразитних параметрів, послідовних шунтів. Було виявлено, що в міру підвищення температури продуктивність сонячних батарей знижується, оскільки температура призводить до посилення явища рекомбінації і, отже, до зниження продуктивності. Однак, коли температура підвищується від 0^0С до 50^0С, криві I-V і P-V переміщаються до початку координат, показуючи негативний вплив підвищення температури на сонячний елемент. Сонячне опромінення відіграє важливу роль у продуктивності сонячних елементів. Зі збільшенням сонячного опромінення з 250 Вт·м$^{-2}$ до 1000 Вт·м$^{-2}$ продуктивність сонячного елемента відповідно збільшується, і крива I-V, а також P-V віддаляється від початку координат. Зроблено висновок, що для різних послідовних опорів I V разом із P-V характеристикою сонячного елемента моделі 1D5P змінюється, оскільки при послідовному опорі 0,02 Ом отримується максимальний струм короткого замикання та максимальна потужність. Але коли послідовний опір збільшився лише на 2 Ом, криві I-V і P-V різко рухаються до початку координат. Опір шунта – це шлях до зміни струму елементу. Зі збільшенням опору шунта шлях зворотного струму зменшується, отже, весь струм йде на навантаження, отже, досягається максимальна потужність. Аналогічно, коли значення опору шунта зменшується, керована напругою ділянка кривої вольт-амперних характеристик переміщується ближче до початку координат, що знижує продуктивність сонячних елементів. Важливо зрозуміти, як різні фактори впливають на криві I-V і P-V характеристик сонячних елементів. Напруга холостого ходу, струм короткого замикання та максимальна потужність змінюються. Вплив цих факторів може бути надзвичайно корисним при відстеженні найвищої точки потужності сонячної батареї різними методами.
Ключові слова: сонячна батарея, 1D5P, моделювання, температура, освітленість, LTSpice