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Simulation and Analysis of the Effect of Change of Different Parameters on the Characteristics of PV Cell Using LTspiceIV

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Abstract: ***This paper presents the effect of change of temperature, solar irradiance, series resistance and shunt resistance on Photovoltaic (PV) cell. To observe these phenomena models of PV system are constructed using LTspice IV. The main aim of the work is to observe the output power for different environmental condition. The changes of these parameters have significant effect on the I-V and P-V characteristics curve of PV cell. Simulations are performed to exhibit these effects.***

Keywords: temperature, irradiance, series-resistance, shunt-resistance, PV cell.

1. Introduction

The renewable energy sources have become more desirable because of the critical situation of the conventional fuels. Over the past 20 years the demand of solar energy is increased by 20% to 25% [6]. PV cell involves the technology to convert the energy of the sun directly to electricity. But the electricity production has a great influence of the environment and the manufacturing of the solar cell. As the temperature is increased it is observed that the short circuit current is slightly increased and the open circuit voltage of PV cell is decreased rapidly [8]. With the reduction of solar irradiance the short circuit current is reduced. But the open circuit voltage is not changed significantly. After a certain point it is reduced drastically. Increase of series resistance of PV cell creates higher voltage drop between the junction and terminal and the current controlled portion of the I-V characteristics curve is moved towards the origin [10]. With the decrease of shunt resistance the current passing through the shunt resistance is improved and in the I-V characteristics curve the voltage controlled portion is moved towards the origin [10].

The change of different parameters has consequences on the characteristics curves of PV cell. This paper contains a brief description of the PV cell and provides the modelling in LTspice IV and simulations, which can be used as a reference.

LTspice IV is powerful, high-performance and fast enough software, it is easy to construct different circuit models and to simulate, also provides the accurate simulation result. The features of LTspice are that it can perform the simulations which are based on transient, AC, noise and DC analysis. Even the Fourier analysis is possible to implement [11]. To execute the simulations LTspice IV is used because of its benefits. This is a completely free simulation tool. It is available effortlessly from LTC website and is supported by many operating systems, such as Windows NT4.0, Me, XP, Vista, Windows 7, Windows 8, Windows 8.1. This software also runs on Linux.

2. PV Cell Modeling

A solar cell works as a current source. At the junction of n-type and p-type semiconductor material it behaves like a diode, which is considered to be parallel to the current source. The ideal equivalent circuit of a solar cell is shown in figure 1.

The diode current is given by the equation 1. Here, voltage across the diode is V_d, electron charge is q, T is the temperature at junction in Kelvin, K is the Boltzmann's constant and I_o is called the reverse saturation current.

$$I_d = I_o\,(e^{qVd/kT} - 1) \quad (1)$$

Equation of load current is,

$$I_L = I_{ph} - I_d$$
$$I_L = I_{ph} - I_o\,(e^{q\,Vd\,/kT} - 1) \quad (2)$$

When terminals are short circuited,

$$I_{sc} = I_{ph} - I_o\,(e^{q\,0/kT} - 1)$$
$$I_{sc} = I_{ph} \quad (3)$$

When terminals are open circuited,

$$V_d = V_L = V_{oc}$$
$$V_{oc} = (kT/q)\,ln\,(\,(I_{ph}/I_o) + 1\,) \quad (4)$$

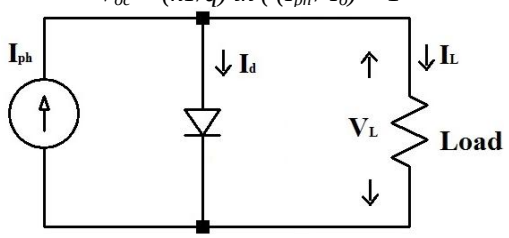


Figure 1: Ideal Equivalent Circuit of a Solar Cell

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A practical equivalent circuit of a solar cell (Fig. 2) contains a current source, a diode and a shunt resistance R_p parallel to it. A series resistance R_s connected in between the junction and the load [5].

Equation of load current is,

$$I_L = I_{ph} - I_d - I_p$$

$$I_L = I_{ph} - I_o\,(e^{\,q(VL\,+\,IL\,Rs)\,/kT} - 1) - (\,(V_L + I_L R_s)\,/\,R_P\,) \quad (5)$$

When terminals are short circuited,

$$I_{sc} = I_{ph} - I_o\,(e^{\,q\,Iph\,Rs\,/\,kT} - 1) - (\,I_{ph} R_s / R_P\,) \quad (6)$$

When terminals are open circuited, the obtained V_{oc} is same as ideal case.

$$V_{oc} = (kT/q)\,ln\,((I_{ph}/I_o) + 1\,)\,(7)$$

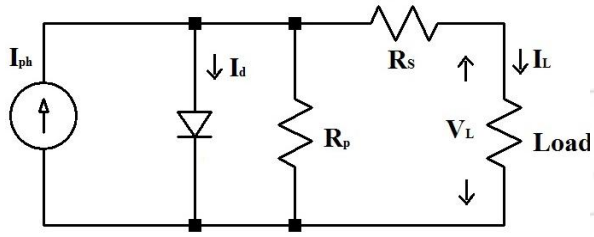


Figure 2: Practical Equivalent Circuit of a Solar Cell

3. Background of Research

Figure 3 shows the I-V and P-V characteristics curve of the solar cell.

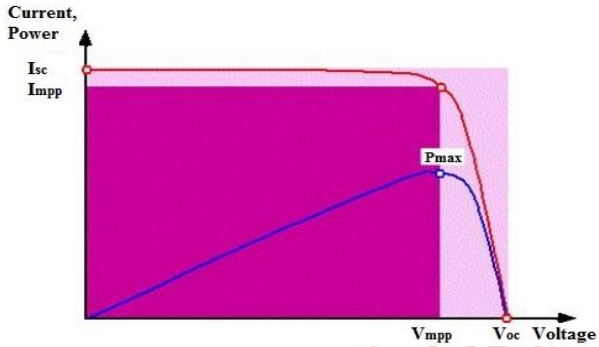


Figure 3: I-V and P-V Characteristics Curve of Solar Cell

Maximum power is obtained at the output of a solar cell for a single operating point. If a certain amount of load is connected, for the load current I_L and load voltage V_L the obtained power at load is P_L. But for a specific value of load connected the load current ($I_L = I_{mpp}$) and load voltage ($V_L = V_{mpp}$) and the power acquired is maximum, P_{max}. Fill factor which indicates the quality of a solar cell, is defined as the ratio of maximum power and the product of V_{oc} and I_{sc}. Change in parameters effect the I-V characteristics curve as well as the value of maximum power. So, it is important to realize the influence of the change of these parameters.

4. Development of Equivalent Cell

When single cells are connected in series, the voltage at the output is increased. This is because the cell voltage of every cell will be added (Figure 4).

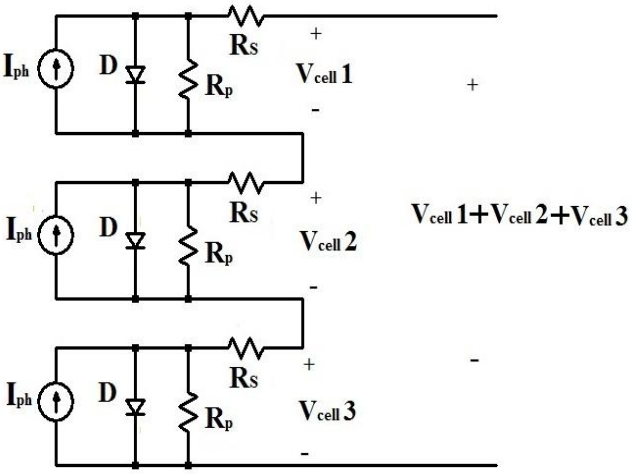


Figure 4: Cascading single Cells in series

Instead of the construction above the cascaded cell can be represented as figure 5.

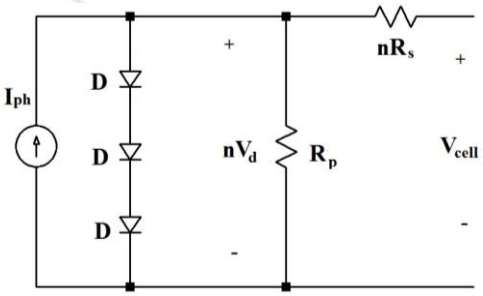


Figure 5: Reconstruction of three single cells in series.

Equation for load voltage for n numbers of cells connected in series,

$$V_L = nV_d - nR_S I_L$$

$$V_L = n\,(\,V_d - R_S I_L\,) \quad (8)$$

If the single cells are connected in parallel the cell current is increased, as because the current of each cell is being added (figure 6).

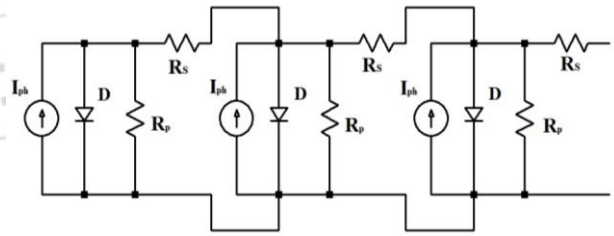


Figure 6: Cascading single cells in parallel.

Instead of the construction above the cascaded cell can be represented as figure 7.

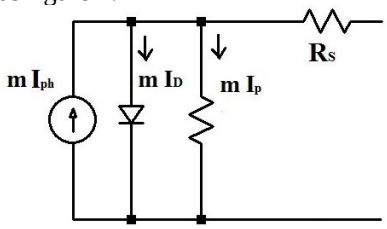


Figure 7: Reconstruction of three single cells in parallel.

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Equation for load current for m numbers of cells connected in parallel,

$$I_L = mI_{ph} - mI_D - mI_p$$
$$I_L = m\,(I_{ph} - I_D - I_p) \quad (9)$$

Figure 8 shows the diagram where n numbers of cells connected in series and m number of cell connected in parallel.

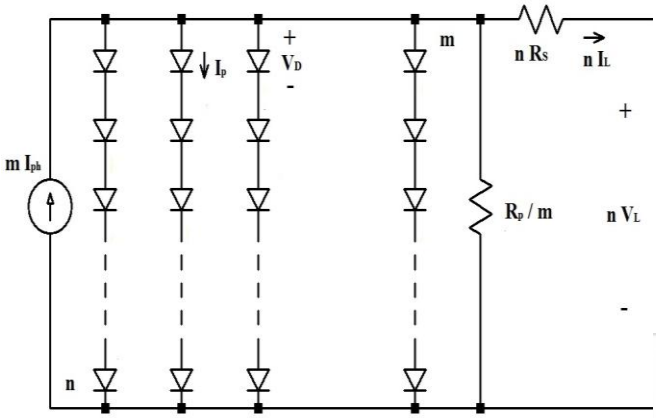


Figure 8: Cascading single cells series and parallel.

Instead of the construction above the cascaded cell can be represented as figure 9.

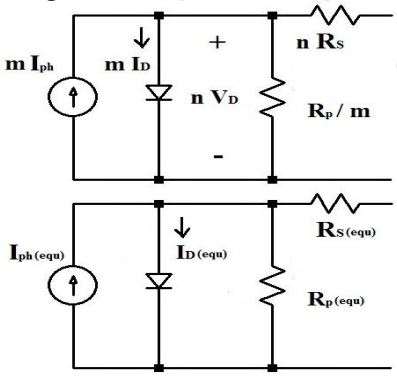


Figure 9: Final equivalent circuit of the cascaded circuit.

5. Development of PV Cell Modeling using LTspiceIV

Figure 10 shows the schematic diagram of the model where five individual PV cells are used. This PV system-1 is used for simulating the effects of change of solar irradiance, series resistance and shunt resistance.

To show the effect of change of temperature another model is used, PV system-2 is shown by figure 11.

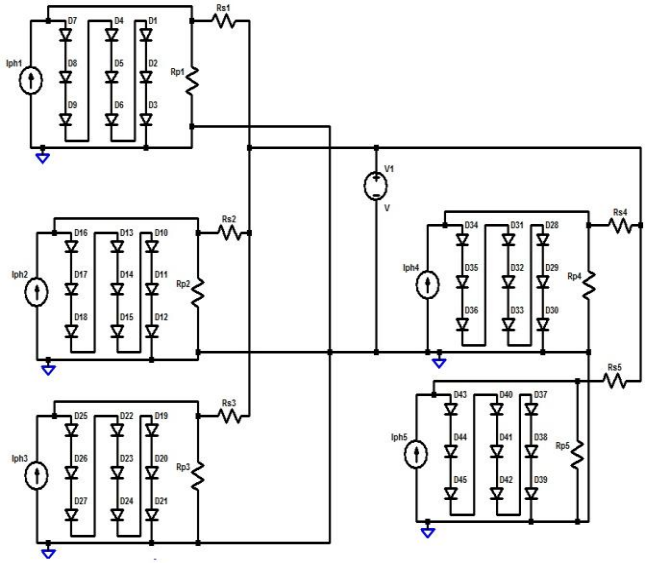


Figure 10: Schemetic diagram of the PV system-1 in LTspiceIV

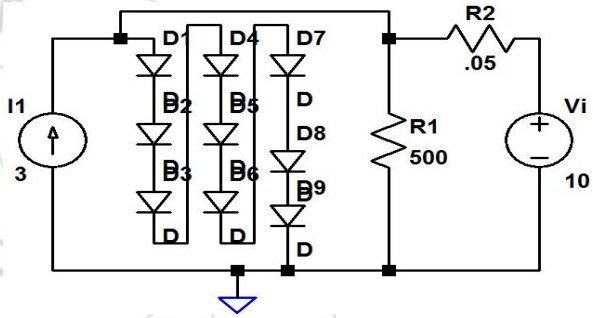
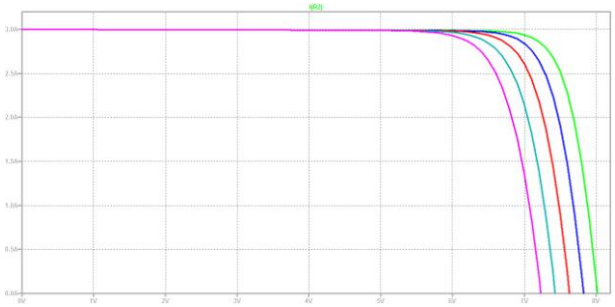


Figure 11: Schemetic diagram of the PV system-2 in LTspiceIV

6. Effect of Change of Different Parameters

6.1 Temperature Effect

To show the effect of change of temperature PV system-2 is used. To execute the simulation the command used in LTspice IV is (.step temp 0 80 20). The starting temperature is considered to be 0 degree, the step size is 20 degrees and the final temperature is 80 degrees. In the model the series and shunt resistances are considered as 0.05 Ohm and 500 Ohms respectively. The irradiance is considered to be 1000 Wm^{-2}, so the current source is taken as 3A. In figure 16 the simulation for temperature effect is shown. The curve at the right is for 0 degree and then the curves toward left are for 20, 40, 60 and 80 degree Celsius.



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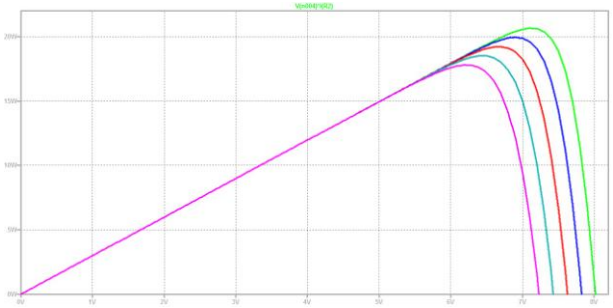


Figure 12: Temperature effect on I-V and P-V curves

6.2 Irradiance Effect

The value I_{ph} is varied due to the change in value of solar irradiance. At short circuit condition the current is proportional to solar irradiance, G. It is observed that, for 1000 Wm^{-2} solar irradiance a solar cell behaves like a 3A current source. If the obtained ratio is, $K_r = (3 / 1000)$, with the help of the equation, $I_{sc} = K_r * G$, it is calculated that for radiations of 800 Wm^{-2}, 600 Wm^{-2}, 400 Wm^{-2} and 200 Wm^{-2} the value of the current sources are 2.4A, 1.8A, 1.2A and 0.6A. In the model the series and the shunt resistances are considered as 0.05 Ohm and 500 Ohms respectively. The simulations of I-V and P-V characteristics curves for different solar irradiance are demonstrated in figure 13.

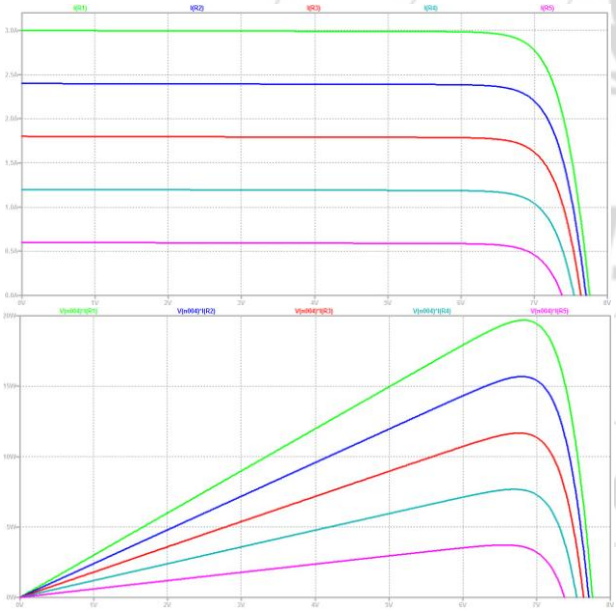


Figure 13: Irradiance effect on I-V and P-V curves

6.3 Effect of change in series resistance

Figure 14 demonstrates the simulation for different values of series resistance. The solar irradiance is kept fixed at 1000Wm^{-2}, the temperature is 25 degree Celsius, and the shunt resistance is 500 Ohms. The values of series resistance used are 0.05 Ohm, 0.5 Ohm, 1 Ohm, 5 Ohms and 10 Ohms.

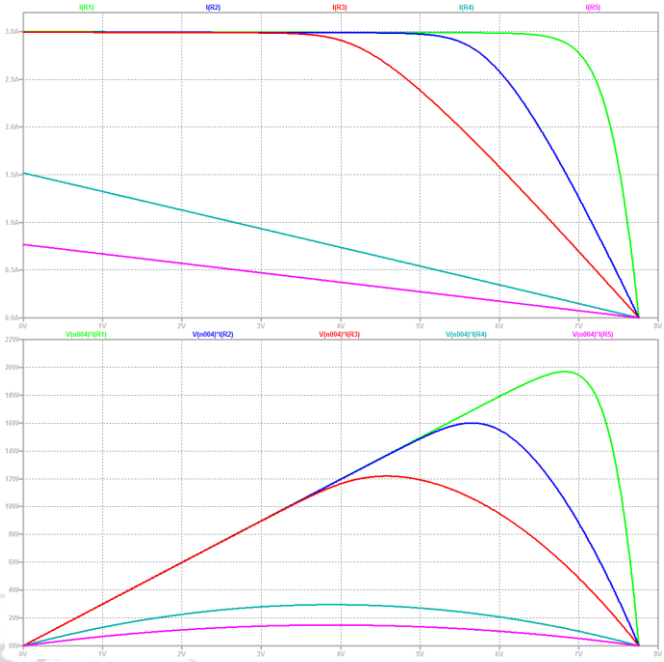


Figure 14: Effect of change of series resistance

6.4 Effect of change in shunt resistance

Figure 15 shows the simulation for different values of shunt resistance. The solar irradiance is 1000Wm^{-2}, temperature is 25 degree Celsius, and series resistance is 0.05 Ohm. Values of shunt resistance are 500 Ohms, 50 Ohms, 10 Ohms, 3 Ohms, and 1 Ohm.

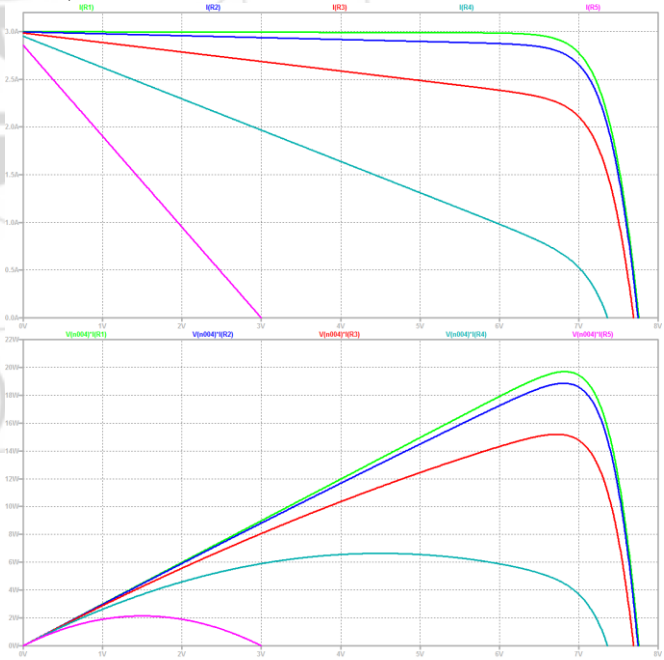


Figure 15: Effect of change of shunt resistance

7. Simulation Results

From the simulations implemented for temperature effect (Figure 12), the observed differences in parameters due to the increase in temperature are summarised in table 1.

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Table 1: Effect of temperature

Temperature (degree)	Open circuit voltage, V_{oc} (V)	Short circuit current, I_{sc} (A)	Maximum Power, P_{max} (W)
0	8.02	3	20.66
20	7.83	3	19.96
40	7.63	3	19.22
60	7.43	3	18.51
80	7.23	3	17.81

From the simulation data it is obtained that the open circuit voltage is decreased with increase in temperature, but the short circuit current is reduced negligibly. At 0 degree the output power is maximum. Then it is reducing gradually.

Due to the decrease of solar irradiance the observed differences in parameters are summarised in the Table 2.

Table 2: Effect of Irradiance

Irradiance, G (Wm^{-2})	Open circuit voltage, V_{oc} (V)	Short circuit current, I_{sc} (A)	Maximum Power, P_{max} (W)
1000	7.76	3	19.70
800	7.71	2.4	15.68
600	7.64	1.8	11.67
400	7.54	1.2	7.69
200	7.38	0.6	3.71

From the simulation data it is observed that the open circuit voltage and short circuit current is reduced with the reduction of solar irradiance. The output power is maximum at height irradiance and then it is gradually decreased with the irradiance reduction.

Observed differences due to the change in series resistance is summarised in the Table 3.

Table 3: Effect of change of series resistance

Series resistance, R_S (Ohm)	Open circuit voltage, V_{oc} (V)	Short circuit current, I_{sc} (A)	Maximum Power, P_{max} (W)
.05	7.76	3	19.74
.5	7.76	3	15.99
1	7.76	2.99	12.24
5	7.76	1.52	2.97
10	7.76	0.77	1.48

With the increased series resistance short circuit current is reduced insignificantly, but for much high value of series resistance the short circuit current is decreased appreciably. But the open circuit voltage remains the same and the value of maximum output power is also reduced.

Observed differences due to the change in series resistance is summarised in the Table 4.

Table 4: Effect of change of shunt resistance

Shunt resistance R_P (Ohm)	Open circuit voltage, V_{oc} (V)	Short circuit current, I_{sc} (A)	Maximum Power, P_{max} (W)
500	7.76	3	19.70
50	7.75	3	18.85
10	7.69	2.99	15.17
3	7.36	2.95	6.68
1	2.99	2.86	2.15

With the decreased of shunt resistance the open circuit voltage is slightly reduced, but for a very low value of shunt resistance it is decreased significantly. The short circuit current is affected very less. The output power is reduced and for a very small shunt resistance the power is very low.

8. Conclusion

As the temperature is increased in a semiconductor, the energy band is reduced. Due to this the solar cell absorbs more photon of incident radiation. The photo current I_{ph} is slightly increased. But the reverse saturation current increases appreciably with the increase of temperature. Due to this the open circuit voltage is reduced [9].

The short circuit current is proportional to solar irradiance G. In case of open circuit voltage V_{oc}, it is proportional to ln(G). With the decrement of irradiance there is no significant change in V_{oc}. Later from a certain value of radiation V_{oc} is reduced radically.

If the series resistance of PV cell is increased, that will cause higher voltage drop between the junction and the load terminal for equal of initial current. Due to this, in the I-V characteristics curve the current controlled portion is moved down towards the origin. The short circuit current decreases slightly with the increase of series resistance. If a large value of series resistance is used then short circuit current will decrease significantly [10]. But the open circuit voltage is not influenced much because of series resistance value [1].

When the shunt resistance is decreased, the portion of the total current passing through the shunt resistance is increased. As a result of this, in the I-V characteristics curve the voltage controlled portion is moved down towards the origin. The open circuit voltage decreases slightly with the reduction of shunt resistance. If a very small value of shunt resistance is used then open circuit voltage will decrease significantly [10]. The short circuit current is less affected.

It is essential to know the impact of change of different parameters on the I-V and P-V characteristics curve of solar cell. They vary the open circuit voltage, short circuit current as well as the maximum power. In case of tracking the maximum power point of solar cell using different algorithms, the effect of these parameters can be very useful.

9. Future Scope

In this research PV system-2 is designed by using a code in LTspice IV to study the temperature effect. In future new models should be designed using codes to observe the effect of the other three parameters. To design a circuit which is smaller than PV system-1 using codes in LTspice IV will save time and reduce complexity. With the knowledge of these impacts on the output it is possible to improve the efficiency of the solar cell.

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