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Analysis of Multi-junction PV cells

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***Abstract*—As the demand of the renewable energy sources is increasing tremendously due to the lack of fuel reserves. So we are trying to move towards the renewable sources and among all the renewable sources, solar energy is the most important and has large potential with environment friendly. This paper presents the idea of Multi-junction solar cell and their simulation on MATLAB. A comparison is made between conventional single-junction and multi-junction PV cell by comparing its maximum power point and open circuit voltage. In this paper, triple junction PV cell has taken which includes InGaP, InGaAs, Ge subcells. The various criterion used for selecting the material for making the multi-junction PV cell is also listed by the author.**

Index Terms—PV cells, multi-junction,

1. INTRODUCTION

As we all know that the conventional sources of energy such as coal, petroleum, etc are going to be replenished very soon in coming future. Also these sources of energy are degrading our environment by causing various kinds of pollutions. So our focus is to utilize more and more renewable sources of energy such as wind, solar, tidal, geothermal, hydro, etc. Due to latest advancements in semiconductor technology and magnetic material such as high frequency switches, inductor cores, etc has made us to think more about extracting solar energy. Solar energy is a clean and green energy, which can be directly converted into electrical energy with the help of PV cells/ solar cells. It do not involve any rotating part, so its efficiency can be high ideally. But practically, the efficiency of solar cell is quite low, which is about 25% for single-junction solar cell. Because its efficiency depends upon:

- Temperature and solar radiations, which is natural and can't be controlled manually.
- Absorbed portion of the solar spectrum.

So various researches are going on to improve the efficiency of the PV cell . which led to the development of multi-junction solar cell .As , the photons fallen on the solar cell can only be absorbed if the energy of the falling wavelength(photon) is approximately equals to the energy band gap(E_g) of the junction. So in single junction, to full fill this energy criteria, most of the falling solar energy is reflected back and some is dissipated as heat in the cell. Only some of the portion of the solar spectrum is absorbed by solar cell. This lowers the efficiency of the single-junction solar cell. But this factor can be improved by using the multi-junction solar cell, which is made of number of junctions instead of only one junction as in single-junction solar cell. In multi-junction solar cell we fabricate different materials on a single chip at a nano level during manufacturing of the cell. It looks like a single cell but it has made from three different materials to develop various junctions , so named as multi-junction solar cell.

Actually, here each junction has its own tendency to absorb the solar radiation of particular wavelength depending upon the energy band gap(E_g) of each cell. In this way we can absorb more portion of the solar spectrum and hence efficiency can be

Improved. Figure below showing the basic constructional difference between multi-junction and single-junction solar cell.

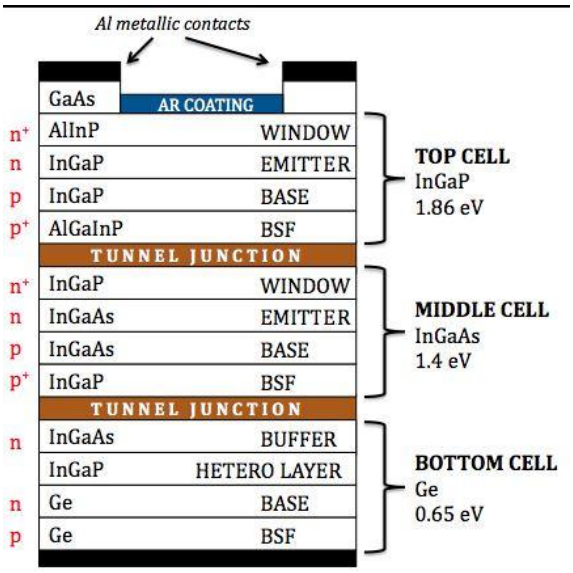

Fig1(cross sectional view of multi-junction solar cell)

Ideally, in triple junction we have achieved the efficiency of 43%. But is not so that we can obtain the efficiency of 100% by using infinite number of junctions. We can only achieve the efficiency of 83% by using the infinite number of junctions, which is the limit of the multi-junction solar cells. But as we know even the increase of 5% in efficiency plays a vital role and very much considerable in PV system. Hence the multi-junction solar cells are one of the important constituent of solar system. Although it is not very much popular till now due to its high cost. But it is going to replace the conventional single junction solar cell in few coming years, as the advancement and researches are going on this topic.

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The next thing is choosing particular materials for making multi-junction cells. We can not take any material randomly to form sub cells . the choice depends upon the various factors such as:

- Lattice constants(a).
- Energy gap

Also the photocurrent generated by each cell needs to be matched by each other otherwise the electrons will remain absorbed in the layers itself. So a proper matching is required between materials of subcells which is met by III-V elements. Conventionally we used to use silicon or germanium. But for triple-junction we generally use InGaP, InGaAs on the germanium wafer.

II. ANALYSIS OF MULTI-JUNCTION SOLAR CELL.

A PV cell at no load condition act as a voltage source and at full load condition it act as current source.

In multi-junction PV cells the voltage of each sub cell gets added up to the overall output voltage but the current remains the same throughout. Hence for sake of convenience we can consider the multi-junction cells as the group of series connected subcell/ junction. Each material has different values of parameters like short circuit current (I_{sc}), ideality factor(n), resistance(r),etc.

Table 1 Parameters for triple-junction InGaP/InGaAs/Ge solar cell.

	Top sub-cell InGaP	Medium sub-cell InGaAs	Bottom sub-cell Ge
E_g (eV) at 298 K	$E_{g1} = 1.976$	$E_{g2} = 1.519$	$E_{g3} = 0.744$
I_{sc} (mA)	$I_{sc1} = 6.7522$	$I_{sc2} = 7.7126$	$I_{sc3} = 10.094$
K (A/cm^2 K^4)	$K_1 = 1.86\times10^{-9}$	$K_2 = 1.288\times10^{-8}$	$K_3 = 10.5\times10^{-6}$
n	$n_1 = 1.97$	$n_2 = 1.75$	$n_3 = 1.96$
γ	2	2	2
α	7.5×10^{-4}	5.405×10^{-4}	4.774×10^{-4}
β	500	204	235

MODELLING OF TRIPLE-JUNCTION PV CELL.

The sub cells are arranged with decreasing energy gap from top to bottom. i.e. InGaP has higher energy gap then InGaAs and Ge. Due to this arrangement the losses can be minimized which could be due to thermalization of hot carriers. This structure also increases the transmission of low energy photon which results in efficiently converting the solar energy to electrical energy than single-junction solar cell. Multi-junction solar cells have now been used for space crafts due to their ultra high efficiency. Fig 2 represents the series connected sub cells used in forming the triple-junction. Each cell is arranged according to the energy gap of materials used.

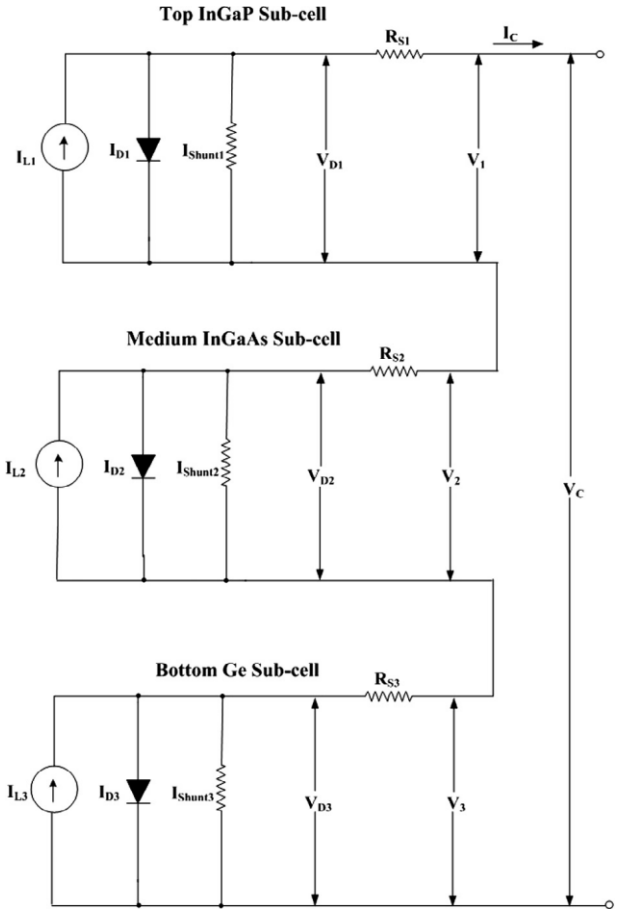

Fig 2

From the fig (2), the solar output current can be expressed as:

$I_C = I_{Li} - I_{Di} - I_{shunt\ i}$ (1)

Where i=1 for top cell
2 for medium cell
3 for bottom cell.

I_{Li} is the light generated current and is given by-

$I_{Li} = RKc[Isci + \propto (Tc - Tcref)]$ (2)

Here, Tcref - reference temperature in $°C$
$\propto$ - temperature coefficient (A/$°C$)
Kc- concentration ratio.
R - solar radiation (kw/m^2)

I_{Di} is the diode current and is given by-

$I_{Di} = Ioi[e^{\left(\frac{Vdi}{niVT}\right)} - 1]$ (3)

Where n_i- ideality factor of diode.
V_T =volt equivalent of temperature=q/K_BT.
K_B = Boltzmann's constant.
q = electron charge.
T = absolute temperature.

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$V_{Di}=V_i + I_c * R_{si}$

Where R_s – series resistance of the cell.

I_c - o/p current of cell(which remains constant through each subcell)

$$I_{oi} = Ki*T^{(3+\gamma i/2)}[\, e^{-\left(\frac{Egi}{niKBT}\right)}] \qquad (5)$$

Where Egi – energy band gap of each sub cell

Ki and γi – constants.

The variations of energy band gap with temperature is given by the formula –

$$Eg(T)=Eg(0)+\alpha T^2/(T+\beta) \qquad (6)$$

The total output voltage of multi-junction cell is given by-

$$Vc=V_1+V_2+V_3 \qquad (7)$$

Where V_1, V_2, V_3 are the output voltage of individual cell.

If R_{shunt} is very very large, then I_{shunt} can be ignored.

Therefore $Ic=I_{L1}-I_{D1} = I_{L2}-I_{D3} = I_{l3}- I_{D3}$ (8)

Or $I_{D1} = I_{L1} - I_c$ (9)

$$V_1=n_1/V_T \ln[\frac{ID1}{I01} + 1] - Ic*Rs1 \qquad (10)$$

$$V_2=n_2/V_T \ln[\frac{ID2}{I02} + 1] - Ic*Rs2 \qquad (11)$$

$$V_3=n_3/V_T \ln[\frac{ID3}{I03} + 1] - Ic*Rs3 \qquad (12)$$

Hence,

$$Vc = n_1/V_T \ln[\frac{ID1}{I01} + 1] + n_2/V_T \ln[\frac{ID2}{I02} + 1] + n_3/V_T \ln[\frac{ID3}{I03} + 1] - Ic*Rs \qquad (13)$$

Where Rs = Rs1+Rs2+Rs3

By using these basics equations of solar cell we model our triple-junction PV cell in MATLAB. The simulink model of triple-junction solar cell is shown in fig(3) and the results are shown in the next section.

As shown in the diagram, there are three subsystem blocks connected in series to each other. The first subsystem block is representing the top cell which is made up of InGaP material. Similarly the second and third subsystem represents the block of InGaAs and Ge material. Each block is similar in modeling. The only difference is the parameters values, which varies from material to material. Fig (4) represents the innerportion of first subsystem. And rest are similar to first one.

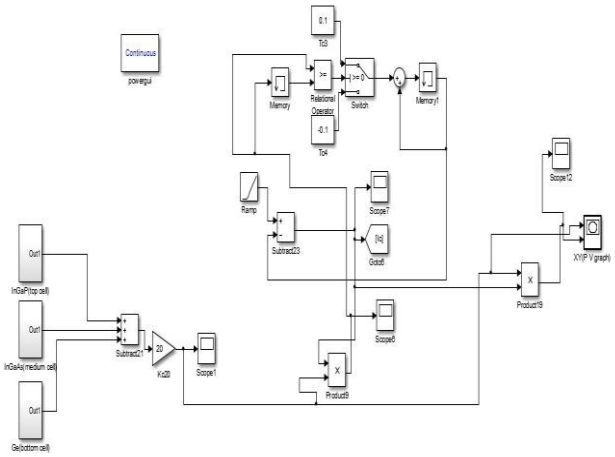

Fig (3) Simulink model of triple-junction solar cell

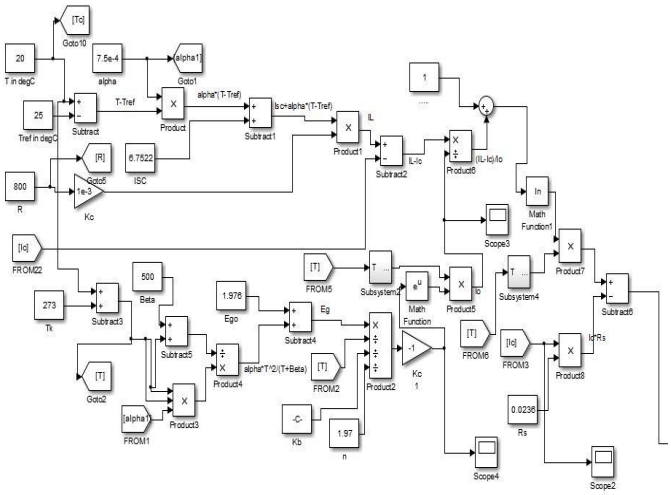

Fig (4) Modeled block of InGaP (subsystem 1)

In this modeling, we are using P&O algorithm for obtaining the maximum power point at all the conditions of environment.

And here the current is being used as ramp signal as reference signal. Because the ramp signal can go its maximum value at very fast rate as compare to any other type of signal. And at the various values of currents, the power and voltages are obtained. The perturbation and observation flow chart is as shown below, which fully describes the operation of the simulink model which the author has made.

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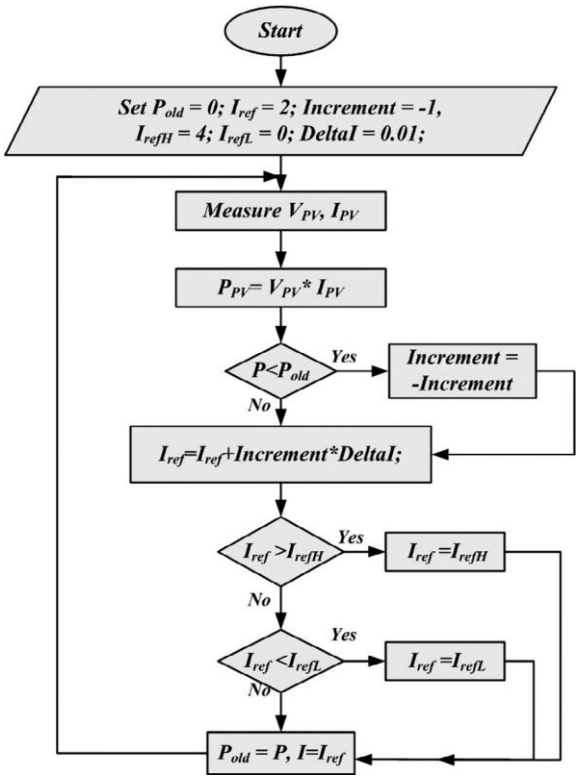


Fig (5) Flow chart of P&O MPPT algorithm

III RESULTS AND DISCUSSIONS.

On simulation of triple-junction solar cell, various waveform we got are shown below:

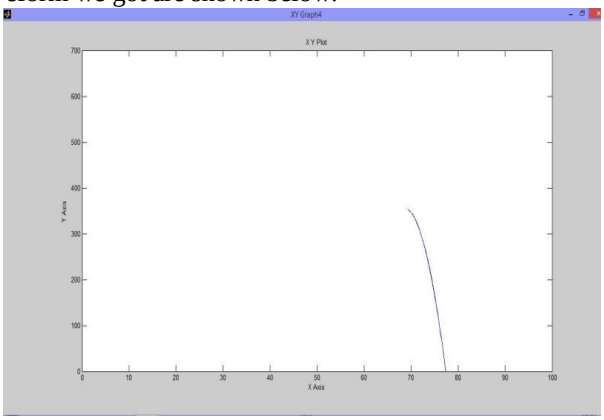
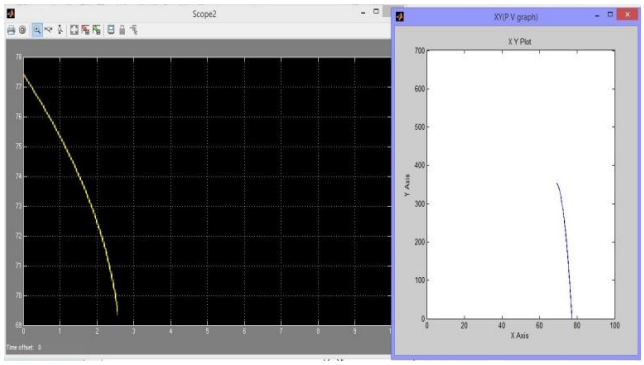


Fig (6) P-V curve of triple-junction solar cell.

The curve in fig (6) represents the maximum power point of triple-junction solar cell and the voltage at which it is attained (Vm).



Fig(7) maximum power point and voltage point

In fig(7) both the maximum power and maximum voltage point are relatively shown in one diagram. the power is getting fixed at maximum point only. It don't trace the whole path from zero voltage to zero current.

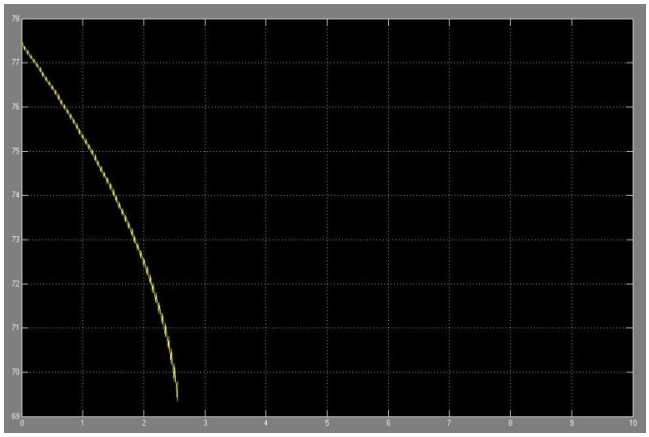


Fig (8) output voltage with gain 20

Here in this figure, the output voltage is shown which is summed of all the three cells of triple-junction solar cell. The output voltage is further multiplied with gain of 20 which is representing the number of cells connected in series and parallel combination.

Characteristics	specifications
Maximum power	350.2 VA
Open circuit voltage	77.7 V
Voltage at MPP	69.8

IV. COMPARISON OF SINGLE-JUNCTION AND MULTI-JUNCTION PV CELLS.

Here the simulink block of single-junction solar cell is shown and the result of single-junction are being compared with the previous multi-junction solar cell in the form of P-V curves.

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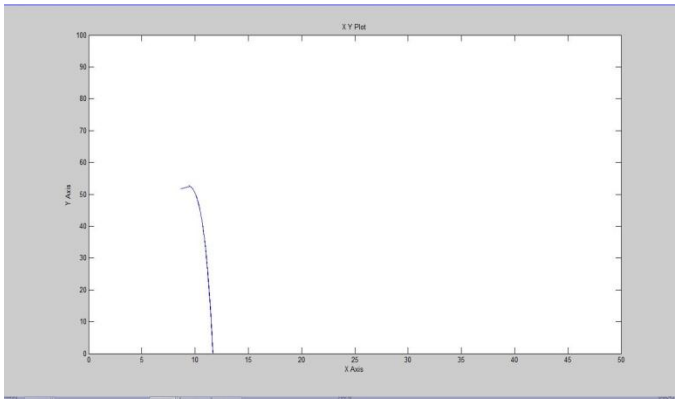

Fig (9) p-v curve of single junction solar cell.

The fig (9) represents the curve of a single –junction silicon solar cell. When these solar cells are connected in series to get the summed output voltage as of multi-junction, the efficiency will not be high and output power and voltage will also be very low as compare to multi-junction solar cell.

V CONCLUSIONS

An analysis of triple-junction is done on the basis of their equations. And MATLAB is chosen as the platform for this analysis .As we have seen that the output power of triple-junction solar cell is more as compare to single-junction solar cell. Also the voltage at which the maximum power is obtained is also shifted toward right by using multi- junctions in the solar cells. Hence the efficiency is increased. So if a system is using multi-junction solar cell in place of single-junction solar cell, the efficiency of overall system can be increased .

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