Behaviour of solar cell in different shading condition and calculation of maximum power point at partial shading condition

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Abstract: ***Because of the presence of any obstacle some part of Solar Module (SM) may get shaded. This condition is called as partial shading condition (PSC). During PSC the output power from SM degrades severely. If the pattern of PSC is continuous for a longer period of time, hot-spot may generate because of which mechanical damage will occur in the module. So, it is utmost important to understand the behavior of SM in PSC and the root cause of the generation of the hot spot. So, in this paper, a detail description is given explaining the behavior of SM at different modes of lighting condition. Along with that, the characteristic behavior of SM is shown for different shading pattern and irradiance condition.***

Keywords: Solar Module, partial shading, maximum power point, solar array.

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I. INTRODUCTION

In the modern era of civilization, the energy demand is increasing exponentially across the globe. Since the energy production from fossil fuel is depleting day by day, so all the countries running after renewable energy with great emphasis. Again out of all the renewable energy solar energy has the highest potential in today's world energy market. As a result of that, a number of solar modules (SM) are designed by the researchers across the globe. Out of that, the most widely used solar cells are made up of silicon. Silicon solar cell module has the highest efficiency. But in PSC the efficiency degrades to a large extent. Because of the deposition of mud or any such obstacle, if the shading in that part is fixed for a longer period of time, the hot spot may generate in that portion. A number of researchers have given a number of methods to overcome from the creation of hotspot. Out of that, the most extensively used method is the use of the bypass diode. But if the bypass diode is used, the module cost increases significantly [1]. In line with this, to give a cost-efficient solution, it is very much necessary to understand the main cause of hot spot generation.

II. BEHAVIOUR OF THE SOLAR CELL AT DIFFERENT BIASED CONDITIONS

A solar cell is nothing but a PN junction. The exact interface layer is called as space charge region. Depending on different bias condition the width of the space charge region increases or decreases. In figure 1(a) we have a PN junction. The space charge region is shown in the middle of the PN junction. Space charge region is also called as the quasi-neutral region or depletion zone. The energy band diagram is shown in figure 1(d). The dashed line represents the chemical potential which is also called Fermi energy (FE) level throughout the entire device of the cross-section. So far we have described the solar cell as like coming in through the top. Now we have rotated the structure by 900 to represent the PN junction. Just to be totally clear, in a device like this, if it were subject to illumination we would have light coming in from the side (either from P side or from N side). So to transfer this into what we have seen so far with the solar cell devices facing up towards the sun, we would have to rotate this by 900.

To see the drift and diffusion current for electrons there is an abundance of electrons in the n-type side. So they want to diffuse over to the P-type. That is why the diffusion current is pointing left. Once they do to a certain degree they set up a field (the electrons and holes or the mobile charges set up a field) and that creates a drift current that counteracts the diffusion. Once these two are in equilibrium, there is no current flowing through the device. That is why current is equal to zero at point A in figure 1(g). Accordingly, there is no potential difference. Because the FE or the chemical potential is same on either side (P-side and N-side) of the device as shown in figure 1(d). So the voltage output of the solar cell would be zero.

During forward bias, it is forced to separate the chemical potential on either side of the device. If we connect the P-side and N-side to an external circuit the electrons will want to flow from N side to P side. But since we are forcing this condition here with a battery, we are reducing the barrier height as shown in figure 1(b). Electrons can now diffuse over from the N-side to the P-side and they do. Because of that the diffusion current increases. That is why now we have a positive value of current. We have defined the electrons traveling to the left as being a positive current.

When we reverse bias our device, we have to notice the separation of the quasi-Fermi energies as shown in figure 1(f). So our voltage sign flips from right to left (i.e from positive to negative values). Similarly, the drift current will outweigh the diffusion current in this particular case because the barrier for electrons to diffuse from the N side to the P side is very large. So they will have difficulty in going from N-side to P-side whereas the drift current is larger because of the large electric field. As a result, the drift current will dominate the diffusion current. That is why instead of electrons flowing from N-type to P-type it will flow from P-type to N-type which we defined as negative current. That is why the current has changed signs.

Here we can notice the width of the space charge region which changes as we forward and reverse bias our devices. As the barrier height decreases, we have a decrease in the built-in electric field as shown in figure 1(e). We have a decrease in the amount of charge on either side of the junction. That is why depletion width decreases. The opposite happens when it is under reverse bias.

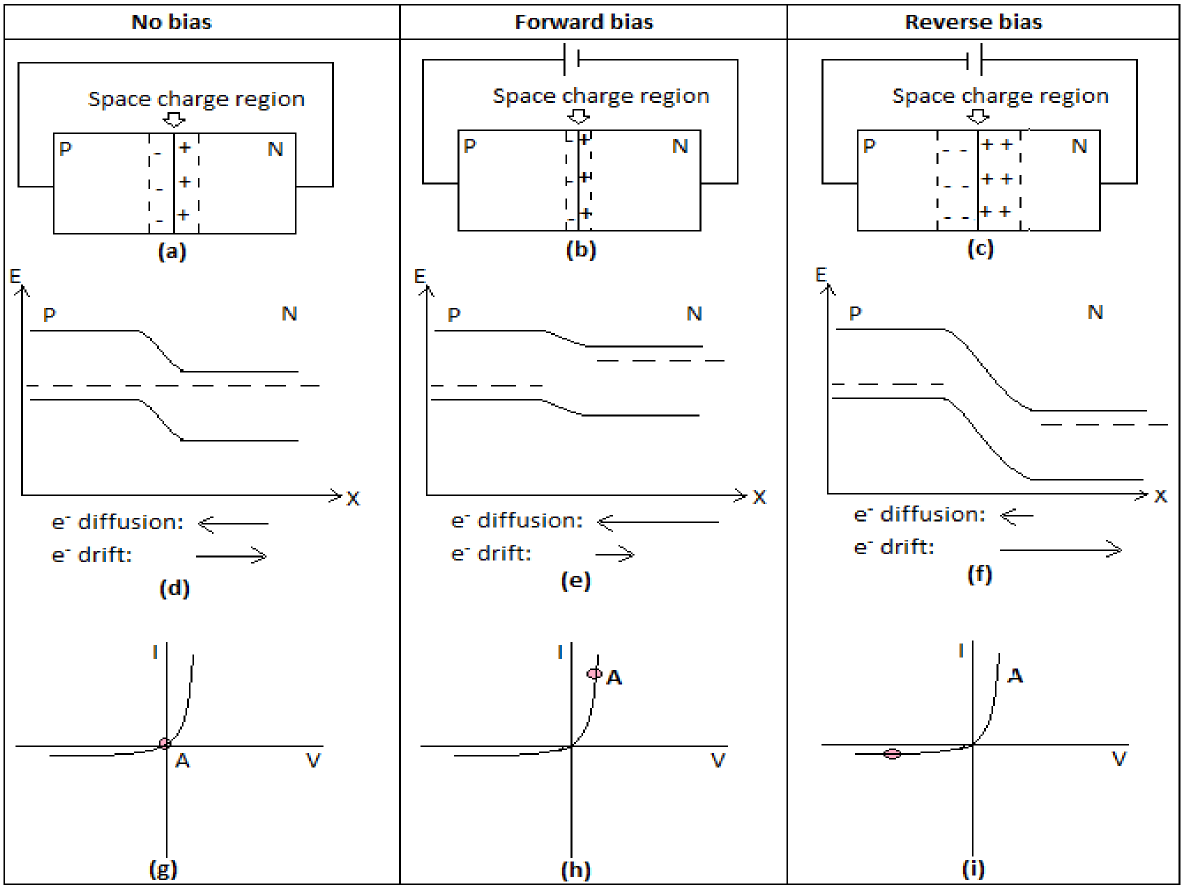

Figure 1: (a), (b), (c) - Model circuit. (d), (e), (f) - Band diagram. (g), (h), (i) – I-V curve

Till now we are not illuminating the solar cell. For the forward bias or reverse bias, we are taking the help of external battery. That is why we have current flowing from N-side to P-side. We are essentially forcing the electrons from the N-type to the P-type material.

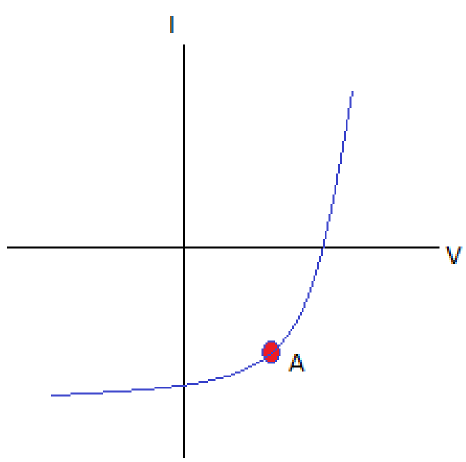

Figure 2: I-V characteristics of Solar cell in illumination

We are pushing the electrons up to the hill with a battery. That is why we have this diffusion current dominating in the dark.

When light will fall on the P-N junction the current-voltage (I-V) curve will shift down. If we shine the light on our system, we have electrons flowing from P side to N side. That will put us in the negative current territory. So, it shifts the entire I-V curve down. Now to represent illumination current we will add an arrow pointing to the right, which would mean that we would have current flowing through our device. But there still a difference in FE in the P-type and N-type, which means our voltage is equal to zero. It means that we are intersecting the Y-axis and our point A should be marked down as shown in figure1(i). Instead of a battery if we apply the bias voltage by giving illumination the V-I curve [2]-[4] will shift down to the fourth quadrant as shown in figure 2. This is how power is coming out of the solar cell device. Instead of having a battery if there is a resistor, the electrons will travel from the N-type material through the external load to the P-type material where the chemical potential is lower.

Because they will try to minimize the free energy. As a result, they will deposit that power across the resistance (i.e external load) in order to get back to the other side. That is the only path through which the electrons can travel easily. So the entire curve shifts down.

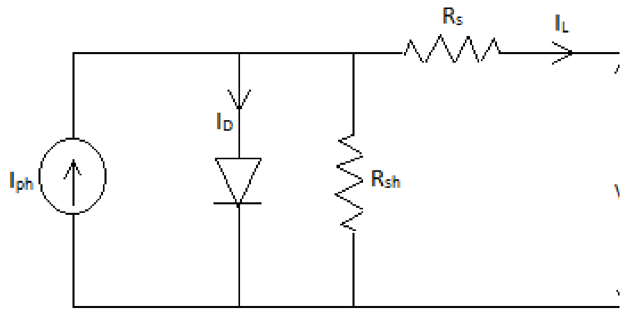

Figure 3: Equivalent diagram of solar PV cell

III. EFFECT OF PARTIAL SHADING IN AN SM

The equivalent diagram of a solar PV cell is shown in figure 3.
where, I_{ph}, I_D, R_{sh}, R_s, I_L, V_L are the photogenerated current, Diode current, Shunt resistance, Series Resistance, Load current and load voltage respectively. The expression of the load current in an SM is given in Equation (1).

$$I_L = I_{ph} - I_0\left\{e^{\frac{V_L+I_L.R_s}{N_s.V_t}} - 1\right\} - \frac{V_L+I_L.R_s}{R_{sh}} \quad (1)$$

Here N_s is the number of cells connected in series in the module and V_t is the thermal voltage which depends on the temperature. Normally in a module, all the cells are connected in series. By increasing the value of N_s the voltage level of the module can be also increased. But the total current will remain the same. To operate the current, the cells have to be connected in parallel. Now in a series connected module if at least one cell gets shaded the performance of the whole module degrades severely.

IV. SIMULATION SETUP

A total cross tied (TCT) connected 4x4 PV array is considered for simulation where each of the module is of 3Wp capacity. The generation of power from the array depends on the total number of connected SMs. If at least one SM gets shaded than also the efficiency of power generation degrades drastically. To study the power generation profile we have set up a simulation environment in MATLAB Simulink the block diagram of that setup is shown in figure 4.

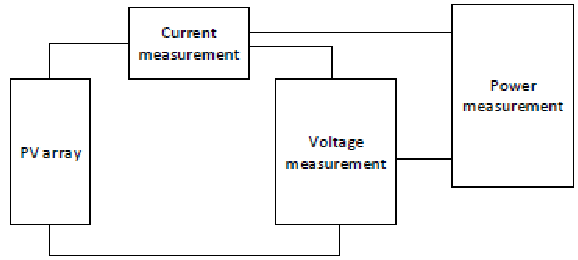

Figure 4: Block diagram of Simulation setup in MATLAB Simulink

In Fig-4, the PV array capacity is 48Wp at STC. To design the cells double diode model is considered. The different characteristic parameter of every cell of one module is as given in Table-1.

I. **TABLE 1:** CHARACTERISTICS OF ONE SOLAR CELL

Sl. No	***Parameter***	***Value***
1	Short Circuit current (I_{sc})	7.34 A
2	Open circuit Voltage (V_{oc})	0.6 V
3	Irradiance used for measurement, I_{r0}	1000 Watt/sq. meter
4	Quality factor, N	1.5
5	First order temperature co-efficient for I_{PH}, TIPH1	0 K^{-1}
6	Energy Gap, EG	1.11 eV
7	Temperature exponent for I_s, TXIS1	3
8	Temperature exponent for R_s, TRS1	0
9	Measurement Temperature	25 ^{0}C
10	Device simulation Temperature	25 ^{0}C

V. RESULTS AND DISCUSSION

To study the behavior of the module in different PSC a set of typical shading patterns are modeled. Four SMs are considered for shading out of total 16 SMs. During un-shaded condition, all the SMs experience 800 W/m^2 irradiation. During partial shading, a maximum of 4 SMs can get shaded with irradiance less than 800 W/m^2. To show the different irradiance condition in different SMs a set of typical combinations are shown in Table-2. Accordingly, the maximum power point (MPP) for that combination is also shown in Table-2.

II. TABLE 2 : GENERATION OF MPP IN DIFFERENT COMBINATIONS

Combination	***Irradiance in Watt/m²***				***MPP in Watt***
	Cell 1	***Cell 2***	***Cell 3***	***Cell 4***	
1	800	600	400	200	14.82
2	800	800	400	200	14.8 4
3	800	800	800	200	14.9012
4	200	200	200	200	13.9276
5	400	400	400	400	27.5488
6	600	600	600	600	40.0575

From Table-2 the below-mentioned remarks can be pointed out:

1. The MPP is directly proportional to the solar irradiance
2. The MPP is mainly governed by the SM where the solar irradiance is lowest.
3. The MPP does not change much if a number of SMs get shaded with the same irradiance.

MPP characteristic for different shading pattern is shown in figure 5.

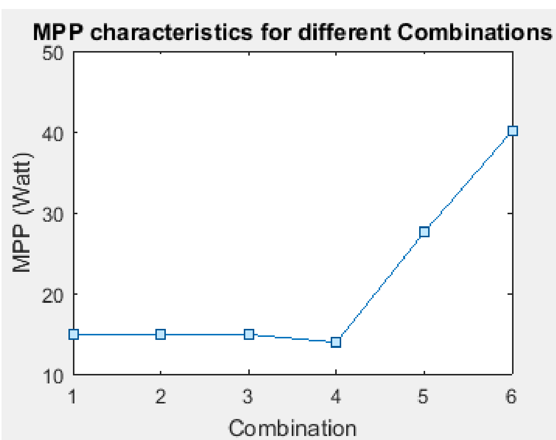

Figure 5: MPP characteristics for different combinations

VI. CONCLUSION

For the simulation purpose, the irradiance level in Guwahati City is considered i.e, 800 W/m^2 on 22nd February 2018. The irradiance level changes according to the climatic condition and seasonal changes. So the irradiance level may change according to the presence of cloud and atmospheric temperature. Due to that, the MPP may vary. Again if any researchers want to verify this simulation by practical experimentation, he/she must have to take care of the SM data sheet which is different for a different manufacturer. If we comply all these conditions, the remarks which are given for this PSC will be best suited everywhere.

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