Performance Enhancement of Solar Photo Voltaic Array (SPVA) Through Partial Shading Effect

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Abstract

This paper focused on hot spot and module operating temperature variation due to partial shading effect in degrading the performance of practical PV module operation. It is shown that partial shading influences most of the perilous hot spot in PV module which is liable for total power dissipation. Here cracks have been discussed due to hot spot and other causes in detail. Cracks presenting in the solar module can degrade up to 10% of total power generation of a solar module. From analysis it is shown that solar modules containing hot spot are not homogeneous in elemental concentration. Reverse current due to partial shading can increase module temperature up to 130°C. The application of bypass diode model in PV device has been described to overcome the power degradation due to hot spot and temperature effect under partial shading condition.

Keywords: Solar cells, partial shading, renewable solar energy, P-V characteristics, bypass diode model, hot spot.

I. Introduction:

Solar energy is a vital and environment friendly energy. It is more flexible, cost effective and commercially widespread [1]. It can be considered to be limitless unlike the tapering conventional fossil fuel.

Solar cell is nothing but a pn junction diode made up generally by silicon based semiconductor materials. When visible solar radiation is incident on the solar cell then due to photoelectric effect pairs of electron & holes are generated. Hence, an electric field is developed with negative charge on sunlight facing side and positive charge on opposite side of the solar cell. If an electric circuit is formed by connecting the electrical contacts to positive and negative sides then a photocurrent flow [2]. Hence, conversion of solar energy into electrical energy by solar cells is achieved mainly by two steps: 1. Absorption of visible light subjected to the generation of electron-hole pairs., 2. Separation and accumulation of the generated electrons towards sun facing side ((i.e., negative terminal) and holes towards opposite side (i.e., positive terminal) thus causing flow of photo current if circuit is closed. Fig. 1 shows the structure of a crystalline solar cell with positive and negative terminals.

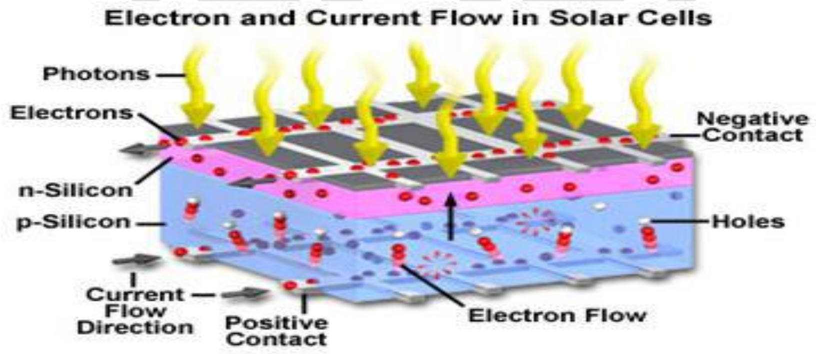


Fig. 1: the structure of crystalline silicon solar cell

As solar cells convert visible solar radiation into electrical energy and generate a photocurrent hence in the absence of light i.e., darkness, PV cells are inactive and do not convert visible solar radiation into electrical energy. Hence it becomes important to study the effect of shading on the performance of solar cell modules.

II. Solar Cell Model

The equivalent circuit of an ideal solar cell is exhibited by a corresponding single-diode model. In the single diode model, a source of current is connected in parallel with a rectifier diode. Fig.2 shows the equivalent circuit of an ideal solar cell. For the solar cell, the I-V properties are governed by the solar cell equation given by Schockley [1].

$$I = I_{PH} - I_O\left(A^{\frac{qV}{TK_B}} - 1\right) \qquad (1)$$

Where, K_B represent Boltzmann constant, T is Temperature (in K), q represent charge on electron, I_O is the saturation current and V is the voltage at the terminals of the cell. The photo generated current I_{PH} depends on photon flux which incident on solar cell and further its reliance on wavelength is represented with the help of quantum efficiency i.e., spectral response.

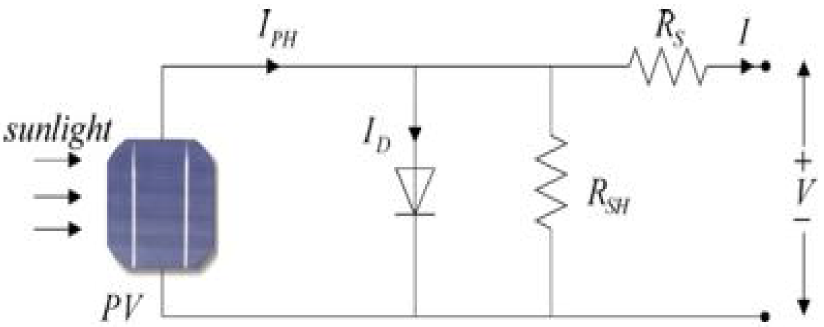
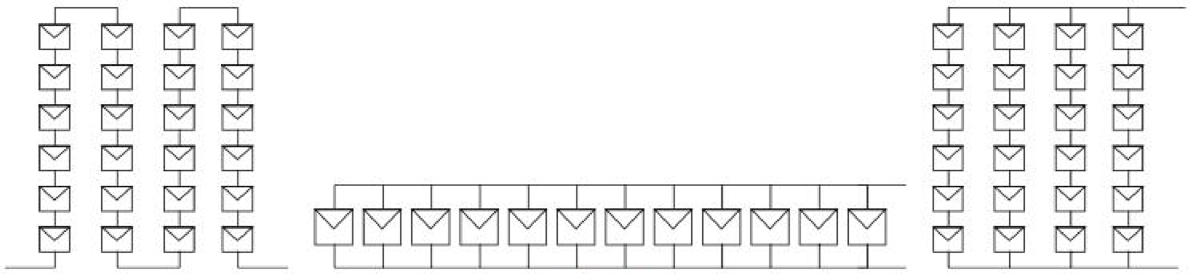


Fig. 2: Equivalent circuit of solar cell [8].

III. Configuration of PV array:

Simplest way of connecting the PV cell is the series connection, shown in Fig. 4(a). In this the currents will be matched and voltages will add up. In series combination of PV cells, voltages add. In series configuration of PV cells, the current should be same through all the cells but a mismatching in current will result in much bigger problem and hence for a given series configuration of PV solar cells, the net current for the entire chain of solar cells in series, is effected by the current of least working PV cell which further become worse it there is a condition of short circuit. Therefore, the main disadvantage of series connection is that there may be chances of minimal current flow due to mismatching in the whole circuit. On the other hand if we connect the PV cells in parallel circuit, shown in Fig. 3(b) then in this case, the total current is nothing but the sum of all the individual current generated by each PV cell but overall voltage remains the same. Hence to get the desired voltage at maximum output current, the solar cells are connected in combination of both series and parallel connections as shown in Fig. 3(c).



(a) Series array (b) Parallel array (c) SP array

Fig. 3: Schematic diagrams of SPVA configuration [11]

IV. Factors affecting the power generation of PV panels

In a PV array module, to get the desired voltage at maximum output current, the solar cells are connected in combination of both series and parallel connections. The electrical power output of the PV module is affected by a number of factors as listed below [12]:

i) Operating temperature

ii) Dirt and dust
iii) Solar intensity
iv) Sun angle
v) I-V operating point (load matching for maximum power)
vi) Partial and full shadow

V. Shading Effect

As the solar photovoltaic array module (i.e., SPVA) comprises series and parallel connections both, the main problem in SPVA is non-linear internal impedance which is associated with cells connected in series. Further the issue even get complex when SPVA are irradiated by non-uniform solar light i.e., shading effect.

The effect of shading on SPVA of large size generally occurs due to: presence of clouds, shadows caused by nearby building/house construction, shadow by other SPVA module, due to tees etc. If any portion of SPVA is affected by the shading effect then in that portion, the solar cell produces significantly less photo-current and the result is the mismatching of current in series connection of solar cells in SPVA and this leads to the increase in non-linear impedance mismatching. Due to this the cells under the effect of shading and connect in series with fully sunlight irradiated cells are forced to carry same current (as that generated by full sun light irradiated cells). Hence, this may lead the shaded cells to be in reverse biasing and acting as an internal load for the whole SPVA which will cause a self power drain within the whole system itself and this may lead to a new phenomenon called as hot spot and can permanently damage the entire system.

In a larger SPVA, the occurrence of partial shading is common due to tree leaves falling over it, birds or bird litters on the array, shade of a neighboring construction, and so forth.

Hence the shading effect of SPVA is a major problem which causes performance's degradation summarized as given below:

i) In a SPVA module, solar cells under shading effect can become in reverse bias connection and due to this, rather generating electrical power, it start consuming electrical power from remaining solar cells connected in series with it and the result is a drastic decrease in the overall output.
ii) The drastic losses in electrical power of solar cells which are under shading effect would face a localized heating effect and due to this the temperature of this solar cell and other nearby solar cells will increase which will result in the form of a thermal stress on the whole SPVA module and hence possibly in a total shutdown of the whole module.
iii) If shading effect is huge then due to this the reverse- biased voltage may surpass the breakdown voltage of that solar cell and due to this solar cell will get damage and due to this no current will flow in the series connection and the overall circuit will be open circuit.

VI. Controlling Hot-spot effects in SPVA

As discussed above, the phenomenon of shading effect in SPVA would results in the generation of hot-spots in SPVA due to which, the overall output electrical power of the whole system is heavily compromised. Further as we know that every solar cell used in any SPVA has its rated critical power dissipation, P_c value given by any solar cell manufacturer under which a solar cell works well. Its value depends on the conditions of cooling so as to work below maximum operating temperature), structure of the materials used and its area. Thus if a SPVA is under the effect of shading then this may lead to the failure of the solar cell because due to this, the dissipative power may overpass the value of the P_c as shown in the Fig. 4 and this may lead to the failure of the solar cell. Hence controlling the effect of hot-spot is a prime factor of concern. Therefore, for controlling of the hot-spot, an extra but now highly desirable dedicated-circuit must be added so as to bypass the shaded solar cell/module but in the same, it must manage the working of the rest of the parts of SPVA module.

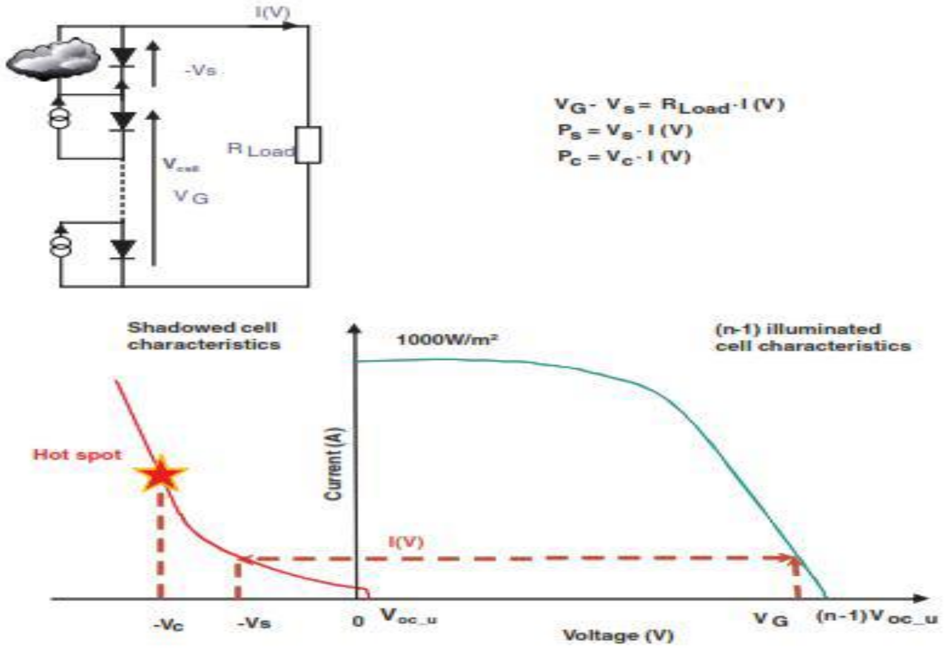


Fig. 4: Shows the hot-spot phenomenon [14]

VII. Bypass Diode

To avoid and remove the effect of hot-spot in SPVA, a bypass diode is used. For this purpose, a diode across solar cell with reverse terminals is connected which is shown in Fig. 5.

When SPVA works normally i.e., without any shading effect, then in this mode each PV cell is in forward biased condition while the bypass diode joined across it works as a open circuit (because it is in reverse biased condition). But on the other hand if any portion of the SPVA is under shading causes a flow of reverse current and this current make the conduction of the bypass diode and hence it will overpass this current to the external circuit. In this way, the solar cell will be protected and will not be having any possibility of damage caused due to the shading effect.

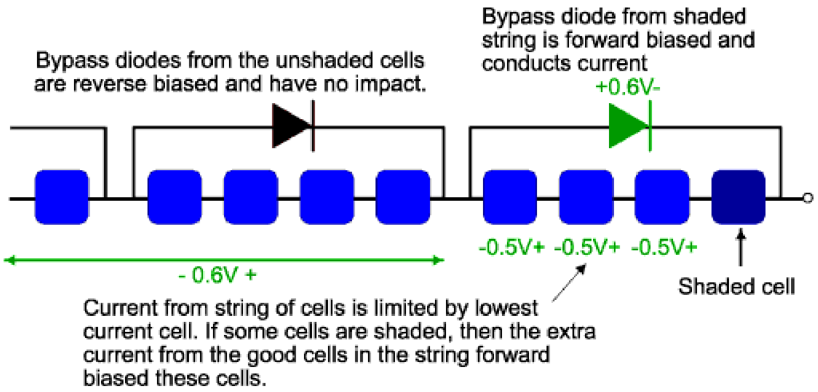


Fig. 5 Bypass diode working

Hence for removing the hot-spot, ideally, forward voltage and the leakage current must be small enough. But in actuality it may not be a feasible condition. Hence significant efforts are required to avoid any risk of occurrence of hot-spot formation in SPVA. Generally, Schottky diodes as a bypass diodes are installed externally in a separate box connected with the frame of SPVA.

VIII. Experimental Setup and Results

PV plant, photovoltaic system of five different technologies on both fixed and tracker mode of 5KWp has been installed. Technologies installed are Mono-crystalline, Multi-crystalline, Amorphous, Copper Indium Gallium Selenide (CIGS) each of 10KWp and High Concentration, high efficiency PV (HCPV) of 1.8 KWp. Each technology has been implemented in fixed angel mode and in 2D tracker mode at 5 KWp. All systems are equipped with voltage, current and temperature sensors for monitoring the system at array string level. For solar irradiance measurement, three pyranometers (Kipp & Zonen make) are used to get global solar irradiance in horizontal, in plane with fixed modules and on 2D tracker. Pyroheliometer (the Eppley Laboratory INC. make) to measure direct normal incidence of solar irradiance is mounted on

2D tracker. Anemometer and Hygrometer (R. M. Young make) with inbuilt temperature sensor are used to get the wind speed, direction, ambient temperature and humidity data.

Fig. 6: Multi-Crystalline PV system (tracker)

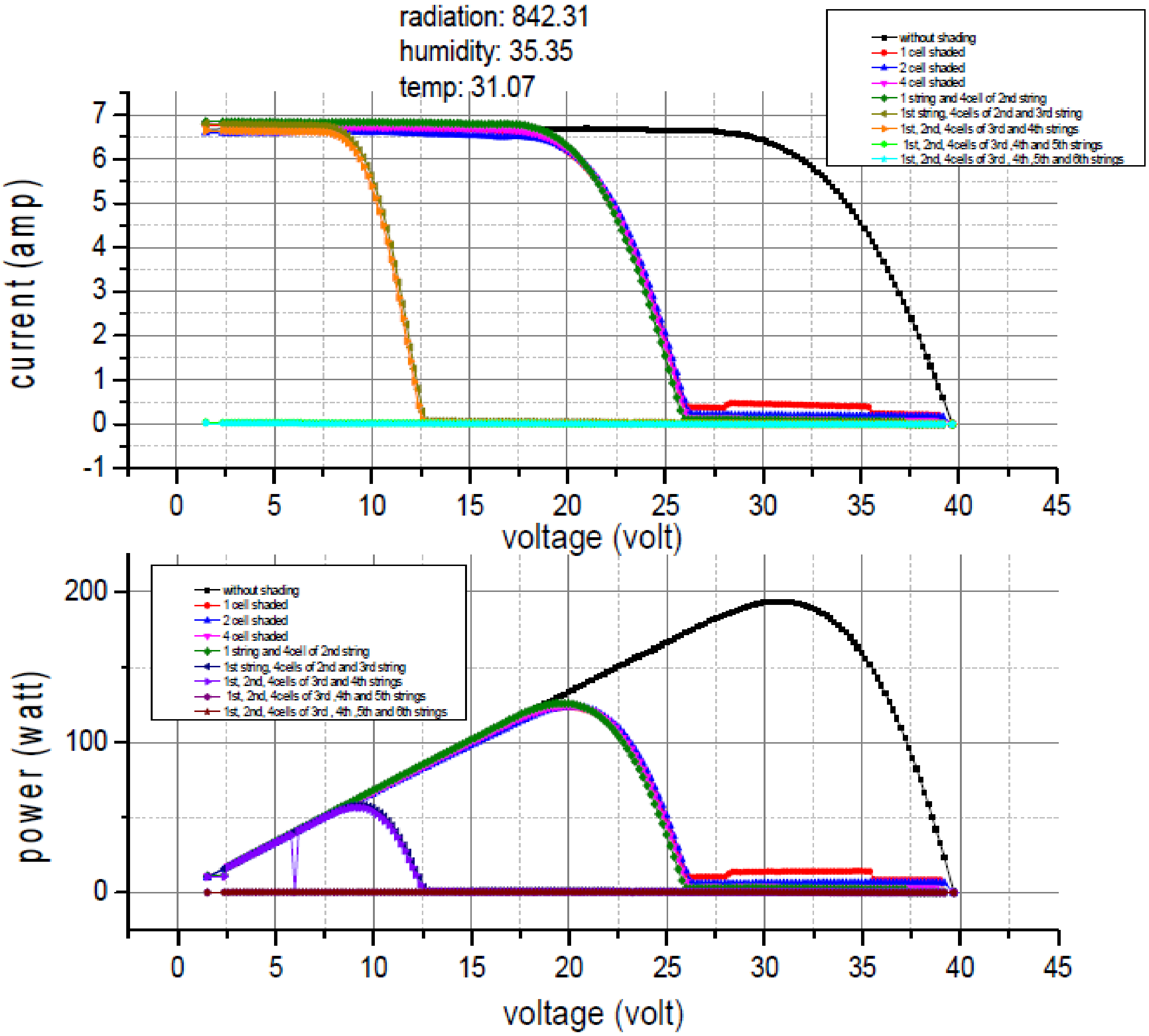


Fig. 7: I-V and P-V characteristics of multi-crystalline module under different shading Profile

In multi-crystalline panel there are 72 cells connected in series with 6 bypass diodes in each panel. Bypass diodes are connected in reverse biased configuration across 24 cells in parallel with it. As the current limit of these bypass diode is 6 Ampere, 2 bypass diode connected in parallel with these 24 cells because short circuit current of panel is more than 6 Ampere. The bypass diode divides the module in three equal subsections.

Specification of multi-crystalline panel is given as, Voc = 45.1 V, Isc = 8.07 Ampere, P_{max} = 272.9 watt, V_{mp} = 35.7 V, I_{mp} = 7.65 Ampere

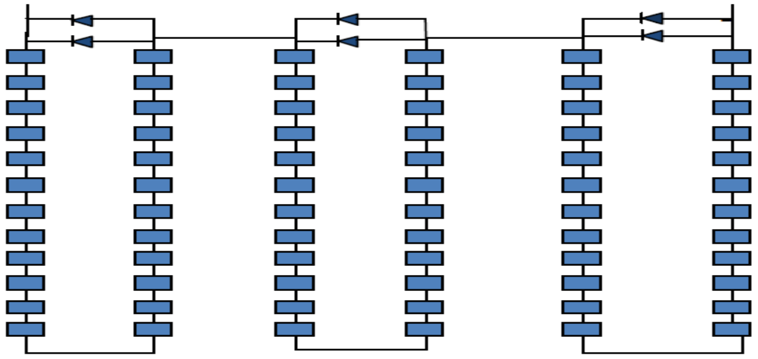


Fig. 8: Bypass diode connection in multi-crystalline solar panel

TABLE 1: Variation of power with shading (cells are partially and perpendicularly shaded)

Shading Profile	P_{max} (Watt)	V_{mp} (Volt)	I_{mp} (Amp)	Power at 200V (Watt)
Without shadow	132.015	195	0.677	129.82
With 25% of 160 cells are shaded	105.684	194.99	0.542	105.684
With 50% of 160 cells are shaded	65.566	197.49	0.332	65.566
With 75% of 160 cells are shaded	62.497	97.5	0.641	37.048

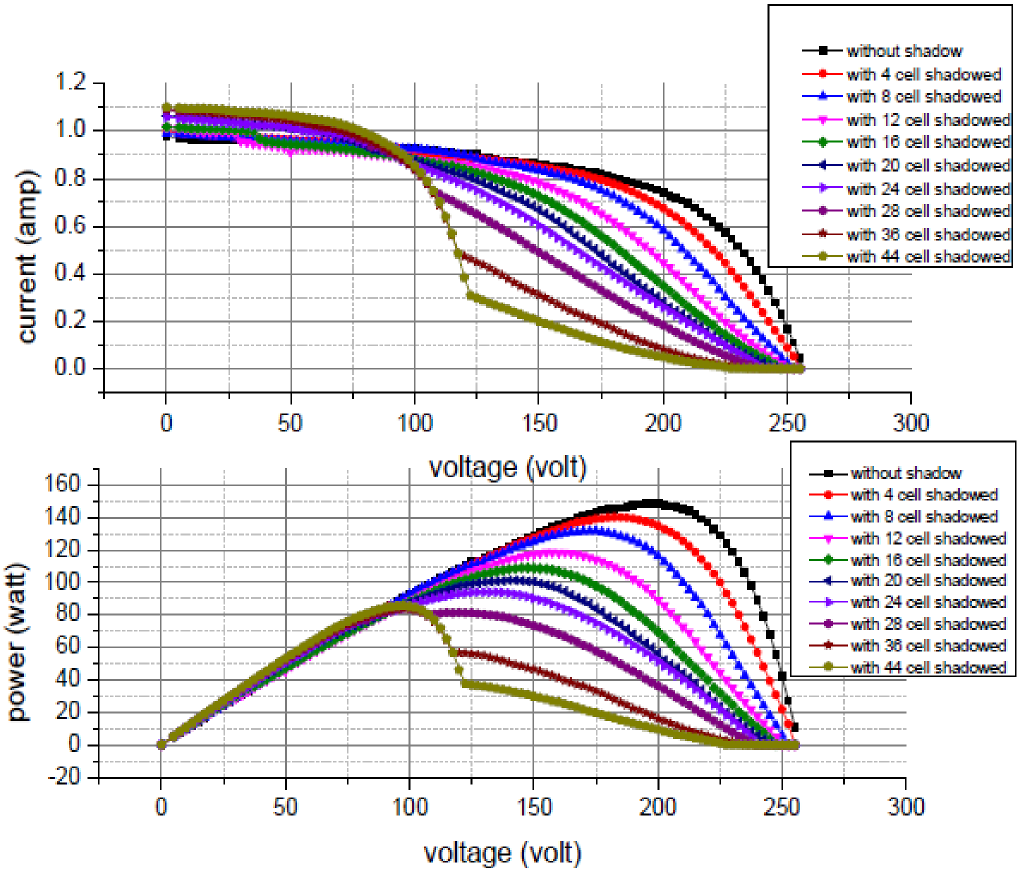


Fig. 9: I-V and P-V Characteristics of two amorphous modules connected in series under different shading profile (cells are completely and parallel shaded).

In fig. 9, the effect of shading a complete cell on power generation is illustrated. The maximum power decreases and series resistance increases as the number of shaded cell increase. In the case of no shadow the series resistance is 50ohms and it increases to 271ohms when 44 cells are shaded. The maximum power point is shifting towards the origin due to the increase in series resistance. At the point when 44 cells are shaded, series resistance becomes very high (271ohm) , due to which these shaded cells does not allow the flow of current generated by un shaded cells through it and it makes the bypass diode active. The variation in power and series resistance is summarized in table 3 and table 4 respectively. It is observed that, in the case of amorphous modules, with 4 cells and 8 cells shaded, the power is reduced 5.6% and 11.3% respectively. In the case of multi-crystalline modules, the reduction in power is 35.88% even with single cell fully shaded. With 2 – 24 cells in a substring, the power loss is same. The bypass diode becomes active at the moment a single cell is fully shaded.

Table 2: Variation in Power with shading (Cells are completely and parallel shaded)

Shading Profile	Pmax (Watt)	Vmp (Volt)	Imp (Amp)	Power at 200V (Watt)
Without shadow	148.41	195.02	0.761	147.781
4 cells are shaded	140.052	185.01	0.757	134.69
8 cells are shaded	131.609	172.49	0.763	116.63
12 cells are shaded	118.44	157.5	0.752	89.84
16 cells are shaded	109.009	147.51	0.739	69.91
20 cells are shaded	101.317	142.5	0.711	56.83
24 cells are shaded	99.08	132.51	0.71	51.84
28 cells are shaded	84.24	97.5	0.864	36.27
36 cells are shaded	83.752	97.5	0.859	16.33
44 cells are shaded	85.8	97.5	0.88	9.901

Table 3: Variation in series resistance with shading

Shading Profile	Series Resistance (ohm)	% increase in series resistance
Without shadow	50.18	---
4 cells are shaded	52.15	5.6
8 cells are shaded	89.15	11.3
12 cells are shaded	107.297	20.19
16 cells are shaded	120.476	26.54
20 cells are shaded	124.483	31.73
24 cells are shaded	148	33.23
28 cells are shaded	202.26	43.23
36 cells are shaded	180.227	43.56
44 cells are shaded	271.66	85.8

IX. Conclusion

In this chapter we explained about the effect of the different shading-profile with variations from 0% to 100% on both the amorphous and the poly-crystalline modules. In poly-crystalline module, cells are completely shaded and shading profile is varied from 1 cell to 72 cells. In amorphous module, (i) cells are shaded completely and parallel to the cell; (ii) cells are shaded partially and perpendicular to the cell.

Different system topologies are utilized in PV generation plants to improve the overall system efficiency. Series-Parallel configurations are the most widely used PV array topologies in order to reduce the negative effects of partial shadings mostly caused by passing clouds. A Matlab/SIMULINK based simulation model of a solar module has been utilized to analyze and compare the performances of each configuration type PV array. Different shading scenarios are defined to present a cloud passage and also the use of bypass diodes is considered and the results are analyzed with and without the mentioned bypass diodes.

The results provide useful and reliable information on the performance of array topologies under changing shading conditions and can be utilized during system design to improve the overall efficiency of the PV system.

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