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Simulation Study of Partial Shading Effect on 150 W_p Photovoltaic Module

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ABSTRACT: The electrical performance of photovoltaic module is affected by several factors including temperature, solar irradiation, and shading. The occurrence of shading of panels is observed, and can be explained by the factors such as passing clouds, the presence of neighboring buildings, towers, trees, or the shadow of a solar array on another, etc. The performance characteristics of a single 150 Wp photovoltaic module are studied using MATLAB simulation. The results indicate a drastic decrease in output current following an increase in a shaded area but a marginal decrease in voltage, resulting in lower output power. The developed simulation model is then used to analyse the influence of shading direction and extent. Based on the influence of shading direction and extent, it is evident that increasing the shaded area by 11% (bottom to top and vice versa) and 25% (left to right and vice versa) had been noticed that % of power loss by 1-2% (bottom to top and vice versa) and 2-3% (left to right and vice versa). Partial shading is a crucial factor that reduces the overall power output of a photovoltaic module.

KEYWORDS: Partial shading, photovoltaic module, 150 Wp solar panel, power loss, mismatch losses, solar cell modeling, MATLAB simulation

I. INTRODUCTION

Photovoltaics has emerged as the most inexpensive means of electrical power in regions with high solar potential. One specific advantage of solar PV is that, once installed, its operation generates no pollution and greenhouse gas emissions. Several factors contribute to the efficient performance of photovoltaic panels. The photovoltaic system behaves extraordinarily due to its ability to react to light and, converting a part of it into electricity [1,2]. This conversion is considered novel and unique for several reasons. Firstly, it does not require any moving parts for the PV system, ensuring of no leakage of gas or fluid. Additionally, it operates without any fluid and produces no byproducts while generating electricity. When properly installed and maintained, it incurs minimal maintenance costs.

The scientists and researchers are involved in the evaluation of the functions and characteristics of photovoltaic cells in various aspects. Specifically, they focus on performance comparison, by comparing the current-voltage (I-V) and power-voltage (P-V) characteristics of the PV module.

The performance depends on various parameters, such as type of PV material used, intensity of solar radiation received, cell temperature, parasitic resistance, cloud and shading effects, fill factor, packing factor, dirt and dust, mismatch losses inverter efficiency, weather conditions, geographical location, and cable thickness.

An analysis of these factors in MATLAB were done. The simulated output revealed that all the factors have impact on electrical efficiency. The factors, namely, incident solar radiation and fill factor at constant temperature, were observed to have positive impact on the electrical efficiency. The remaining factors were observed to be inversely proportional to the electrical efficiency. Among all factors, partial shading and temperature play a major role.

In case of increase the temperature of the PV module, means entire panel gets raise temperature, corresponding declination of performance was observed, to eradicate different cooling methods are used in order to decrease that temperature of the panel. But, in partial shading on the PV module will not increase the whole panel temperature,

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instead it creates hot spots, leading to damage the module. Commonly, bypass diodes were used for the elimination of the hotspots in the PV module.

Shaded cells cannot produce a higher current compared to the unshaded cells when part of a PV module is shaded. The current flowing through every cell is the same as all solar cells in the photovoltaic module are connected in series. However, the unshaded solar cells cause the shaded cells to pass more current than their new short circuit current. This is the primary cause for net voltage loss in the system. This means that the shaded cells absorb power and start acting as a load. In other words, the shaded cells dissipate power as heat and create hot spots [3,4,5].

HOT SPOT PHENOMENON IN PV MODULE

The hot spot phenomenon occurs when one cell of the PV module is shaded while the others are fully illuminated. In this situation, the shaded cell does not have the ability to dissipate the power it generated. The shaded cell behaves like a reverse polarized diode and generates reverse power P_s. The remaining cells generate a current that flows through the shaded solar cell and the external load. Solar cells have critical power dissipation, P_c that should not be exceeded. This depends on their cooling and material structures, area, maximum operating temperature, and ambient temperature. A shaded cell may be destroyed when its reverse dissipation P_s exceeds P_c. This is the hot spot.

A circuit is required to bypass the partially shaded module in order to eliminate the hot spot phenomenon and maintain the other path for remaining modules. A bypass diode is used for this purpose, blocks when the solar cells are illuminated and conduct when cells are shadowed. Bypass diodes are placed on the rear side of the PV module and soldered within a junction box. The design of the solar system is shown in Figure 1.

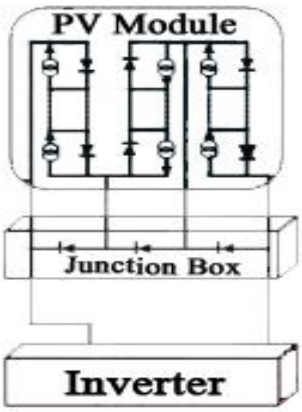

Figure 1 Solar system design

Theoretically, a bypass diode should have low forward voltage (V_F) and leakage current (I_R), and the maximum number of solar cells to bridge with bypass is decided by the breakdown voltage (V_c). The breakdown voltage (V_c) range for the poly-silicon cells is from 12 V to 20 V, and for mono-silicon cells, it extends up to 30 V. Efficient operation of the bypass diode requires the conduction of the bypass diode when one cell is shadowed and the shadowed cell voltage V_s should be less than its breakdown voltage (V_c). The maximum number of solar cells (n_{max}) to bridge is calculated using the Equation (1)

$$n_{max} < \frac{V_c - V_F}{0.5} + 1 \quad (1)$$

THERMAL RUNAWAY RISK

With sudden removal of the shading on PV modules, the bypass diodes can undergo thermal runaway due to the transition from forward bias state to reverse bias state. A difference of 20% between the light hitting the surfaces of different cells in a substring is enough to activate the bypass diode of a substring, which means that the PV cell becomes a power consumer instead of a power producer [6].

II. SIMULATION STUDY

Partial Shading of Single 150 W_p PV Module

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Simulation of the PV module was performed using a Matlab/Simulink environment. Figure 1 shows the physical model of the 150W$_p$ PV module for simulation and specifications of selected PV module are given in the Table 1. The subsystem has four connection ports, two for input (solar irradiation) and the other two output terminals (positive and negative). Two input ports are used to provide two different solar radiation values for the creating a partial shading conditions in the PV module. The blocks of the current sensor, voltage sensor, PS-Simulink converter, Simulink-PS converter are connected in between the output terminals. The scope block is used to obtain the output characteristics with respect to time. The XY graph block was used for getting the characteristics directly. The simulation data are stored in the workspace and imported to draw the output characteristics of the PV module.

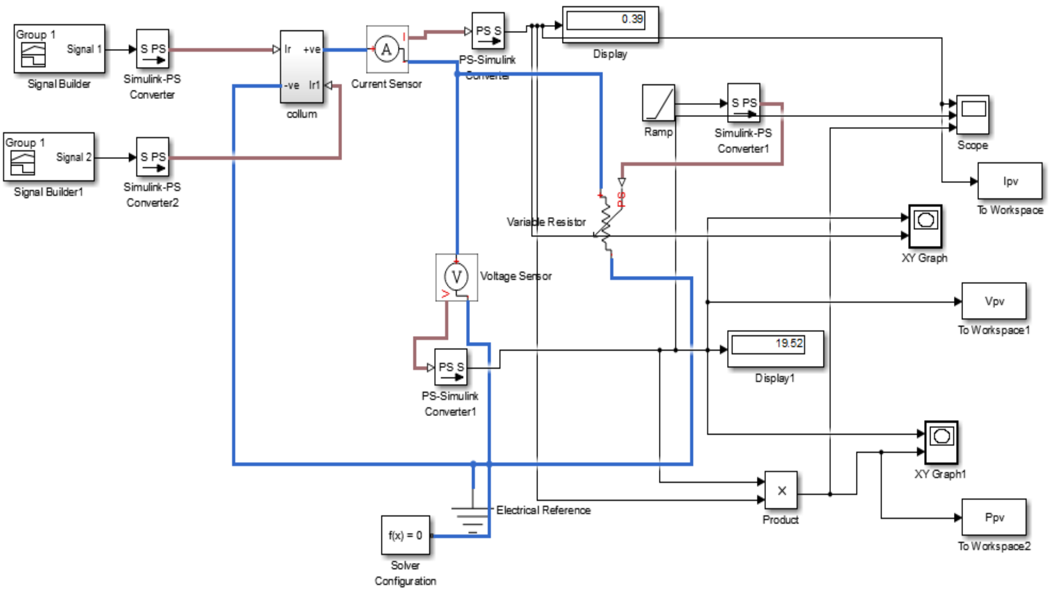
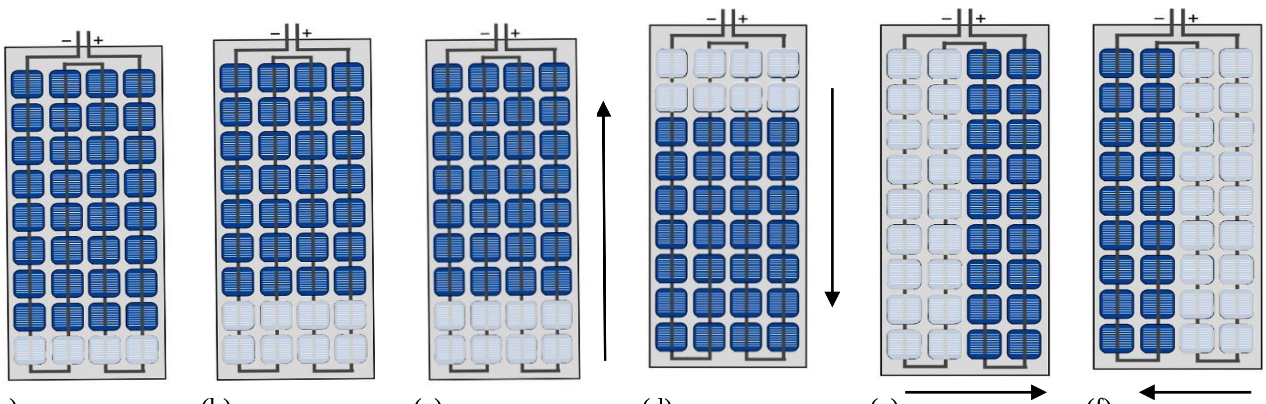


Figure 1 The final 150 Wp photovoltaic panel

Shading Pattern on a PV Module

The different shading patterns on a PV module shown in Figure 2



(a) (b) (c) (d) (e) (f)

Figure 2 Shading of Solar cells (a) 4 cells (b) 8 cells, Direction of shading in row wise (c) bottom to top (d) top to bottom, and shading in column wise (e) left to right (f) right to left

Table 1 Specification of 150 W$_p$ PV module

Description	Values
Maximum Rated Power, P_{max} (Watts)	150
Volatge at Maximum Power, V_{mp} (Volt)	17.5
Current at Maximum Power, I_{mp} (Amp)	8.57

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Open Circuit Voltage, V_{oc} (Volt)	21.5
Short Circuit Current, I_{sc} (Amp)	9.42
Tolerance	± 3%
Short Circuit Temperature Coefficient, ki (A/K)	0.0032
Number of series cells, N_s	36
Number of parallel cells, N_p	1
Diode Constant/Ideality Factor,A	1.3
Power measured at standard Test Conditions 1000 W/m^2, AM 1.5, 25° C	

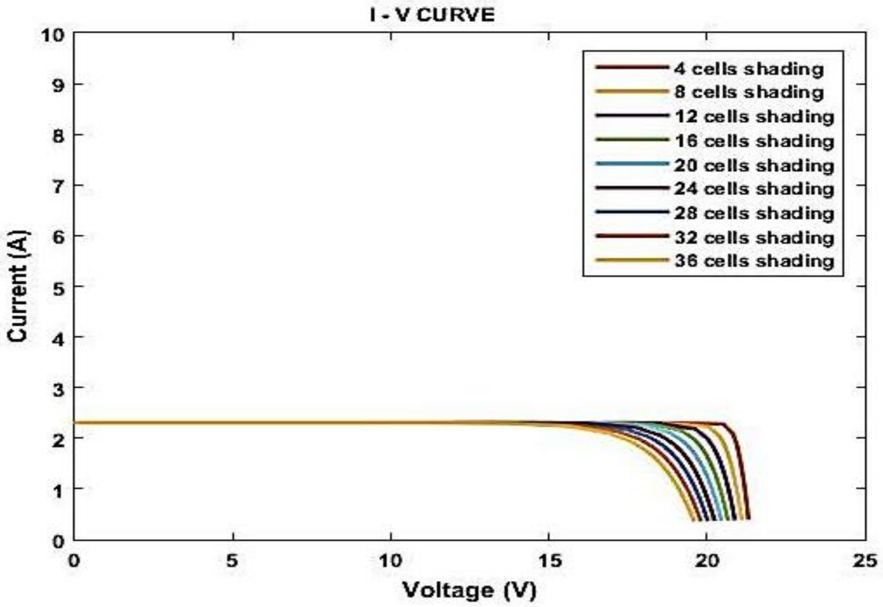
III. RESULTS AND DISCUSSION

Performance analysis of the PV module was simulated under various operating conditions and the results are discussed below.

3.1 Effect of Partial Shading on a 150W$_p$ PV Module

Simulation was carried out 4 cells shading and 8 cells shading as shown in Figure 2 (a) & (b). The study focused on partial shading on PV modules, taking into account the challenges associated with maintaining accurate solar radiation values. Analysis had been made based on influence of direction and extent of shading. For this study, the shading pattern of solar cells were shown in Figure 2 (c-f), with a left-to-right, right-to-left pattern, bottom to top and top to bottom of the solar cells. The solar radiation in the unshaded area was to be I_r = 1078 W/m^2, while in the shaded area, it was I_{r1} = 245 W/m^2. The performance characteristics of PV modules for top to bottom and bottom and top partial shading yielding the same output power were shown in Figure 3, and details of V_{mp}, I_{mp}, P_{mp} and % of power loss, for a different type of shading were provided in Table 2. The % power loss had been accounted as 60 to 80% and every increase in 11% shading resulted as 1 to 2% increase in power loss.

Similarly, simulation was done for left to right and right to left partial shading conditions, yielding the same output power as shown in Figure 4. V_{mp}, I_{mp}, P_{mp} and % of power loss for different types of shading, were summarised in Table 3. The results had been showed that decrease in output power with increase in the shading of the solar cells. The % power loss had been accounted as 70 to 80% and every increase in 25% shading resulted as 2 to 3% increase in power loss.



(a)

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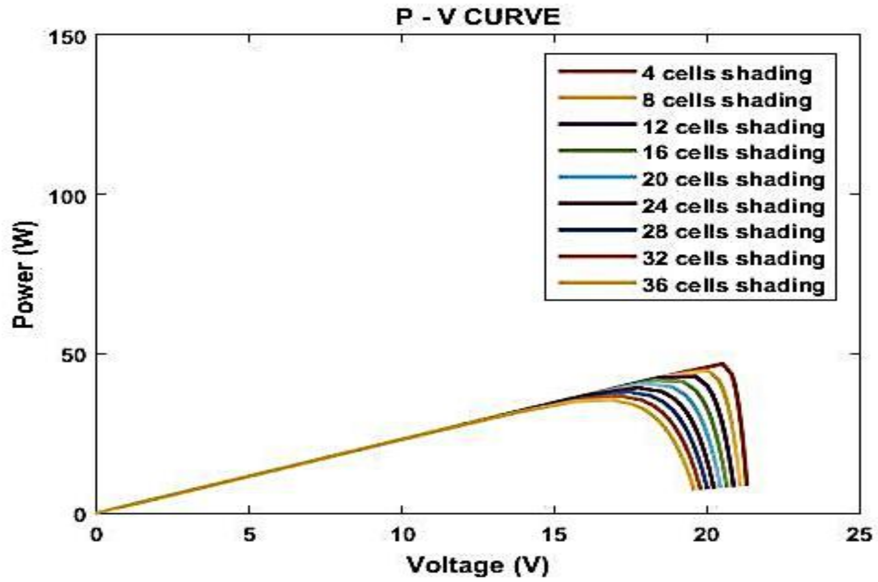
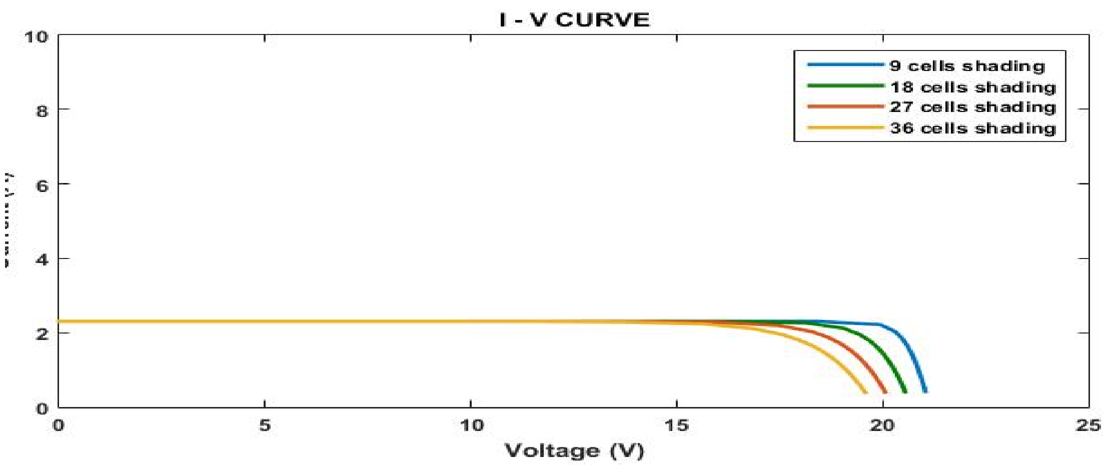


(b)

Figure 3 Performance Characteristics of PV module under top to bottom and bottom to top partial shading (a) I-V Characteristics (b) P-V Characteristics

Table 2 V_{mp}, I_{mp} & P_{mp} for top to bottom and bottom to top shading

S.No	Shading Pattern	V_{mp}(V)	I_{mp}(A)	P_{mp}(W)	Power Loss %
1	4 cells Shading (11%)	20.52	2.28	46.79	68.8
2	8 cells Shading (22%)	20.05	2.228	44.69	70.2
3	12 cells Shading (33%)	19.63	2.181	42.82	71.5
4	16 cells Shading (44%)	18.25	2.281	41.62	72.3
5	20 cells Shading (55%)	18	2.25	40.49	73
6	24 cells Shading (66%)	17.72	2.215	39.25	73.8
7	28 cells Shading (77%)	17.43	2.179	37.99	74.7
8	32 cells Shading (88%)	17.15	2.143	36.75	75.5
9	36 cells Shading (100%)	16.86	2.108	35.54	76.3



(a)

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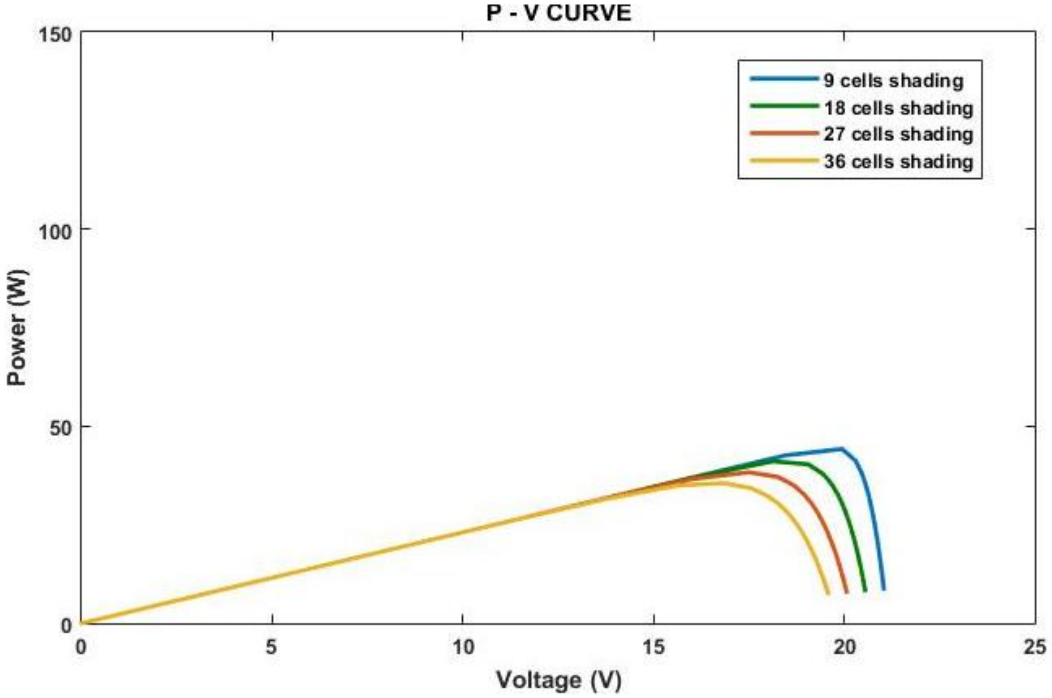

4(b)

Figure 4 Performance Characteristics of PV module under left to right and right to left partial shading (a) I-V Characteristics (b) P-V Characteristics

Table 3 V_{mp}, I_{mp} & P_{mp} for right to left and left to right shading

S.No	Shading Pattern	V_{mp}(V)	I_{mp}(A)	P_{mp}(W)	Power Loss %
1	9 cells Shading (25%)	19.95	2.216	44.2	70.5
2	18 cells Shading (50%)	18.13	2.266	41.08	72.6
3	27 cells Shading (75%)	17.51	2.188	38.3	74.5
4	36 cells Shading (100%)	16.86	2.108	35.54	76.3

IV. CONCLUSION

This simulation work presented a simulation analysis of the partial shading effect on a 150W_p photovoltaic module. The results indicate that panels generate the highest voltage, current, and power output when they are not in shaded state. However, shading reduces voltage, current, and power. The shading of the panel causes a change in the maximum power point. Based on the influence of shading direction and extent, it is evident that increasing the shaded area by 11% (bottom to top and vice versa) and 25% (left to right and vice versa) had been noticed that % of power loss by 1-2% (bottom to top and vice versa) and 2-3% (left to right and vice versa). Partial shading is a crucial factor that reduces the overall power output of a photovoltaic module.

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