| ISSN: 2395-7852 | www.ijarasem.com | Bimonthly, Peer Reviewed & Referred Journal|

| Volume 8, Issue 6, November 2021 |

Performance Simulation of a PV Module with Shaded PV Cells

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ABSTRACT:PV modules are very sensitive to shading. It is a well-documented fact that partial shading of a photovoltaic array reduces output power capability. The conventional single diode model for solar cell with series and shunt resistance is used for illustration. The effect of change in environmental condition like irradiance and temperature on output of photovoltaic module isstudied. The effect of shading on solar Photovoltaic (PV) model is evaluated by using a simulation model for simulating both the I-V and P-V characteristics curves for PV panels. The results are simulated by using the Matlab software. The potential of the simulation analysis is highlighted as a flexible and powerful tool for the design of new and more competitive PV module configurations for the collectors in solar panels.

KEYWORDS: Photovoltaic, shading, avalanche breakdown.

I. INTRODUCTION

The photovoltaic (PV) industry is experiencing rapid growth due to improving technology, lower cost, government subsidies, standardized interconnection to the electric utility grid, and public enthusiasm for an environmentally benign energy source [1]-[2]. More precisely, PV usage worldwide has grown between 15% and 40% for each of the past 10 years, while the inflation adjusted cost of PV energy has declined roughly by a factor of 2 over the same time period [3].

The performance of a PV array can be affected by various factors, such as temperature, solar insolation, solar angle of incidence, shading, inclination, angle of panel and array configuration. The power output of a solar panel depends on the solar intensity and angle of a PV array. A PV array can get shaded or partially shaded by various factors such as trees, clouds, buildings etc [4]. Thus, monitoring of a PV array needs to be done for maximum output of a solar panel.

PV systems are sometimes subject to partial shading, which may produce a non-ideal characteristic curve, presenting global and local power maxima in the V -I curve [5].Measurements of every cell and of the whole module have been performed in direct and reverse bias, with the objective of documenting the scattering in cell parameters, working point of the cells and shading effects. Several shading profiles have been tested, and the influence of the reverse characteristic of the shaded cell in module output is stressed. Yet, this work has studied only the module-level and does not deal with the shading effects on a PV array.

The consequences, due to passing clouds, on the fluctuations of PV power generation, and performance of the electrical utility to which it is connected is studied [6-7]. Shading causes large performance drops and can even damage modules if not properly controlled [8]. MATLAB-based modeling and simulation scheme suitable for studying the characteristics of a series connected SPVA under partial shaded conditions is implemented [9]. The conventional model is modified to include the effect of shading in the SPV module parameters for simulation study. The simulation of MPPT algorithm to track the global maximum is also presented.

The change of I-V characteristics of a PV module with shaded PV cells was discussed by the shift of the avalanche breakdown voltage of shaded cells [10]. The conventional single diode model for solar cell with series and shunt resistance is used for illustration [11]. The effect of change in environmental condition like irradiance and temperature on output of photovoltaic module is shown. The effect of partial shading on photovoltaic module output is also considered. The photovoltaic module of 60 series connected cell is developed and the characteristic of proposed model is compared with the reference photovoltaic module.
It is a well-documented fact that partial shading of a photovoltaic array reduces output power capability. However, the relative amount of such degradation in energy production cannot be determined in a straight forward manner, as it is

often not proportional to the shaded area. This paper clarifies the mechanism of partial PV shading on a number of PV cells connected in series and/or parallel with and without bypass diodes [12].

II.MATHEMATICAL MODELING OF PV CELL

The modeling is based on mathematical expression which was found from equivalent circuit of solar cell. The effect of parameter variation on output of PV module is also considered [12][13-15].The developed model of PV module based on single diode model is shown in Fig.1. The available information from datasheet was used in simulation model. The specification of PV module considered for simulation is shown in Table 1. The modeling and simulation was performed using Matlab/ Simulink software.

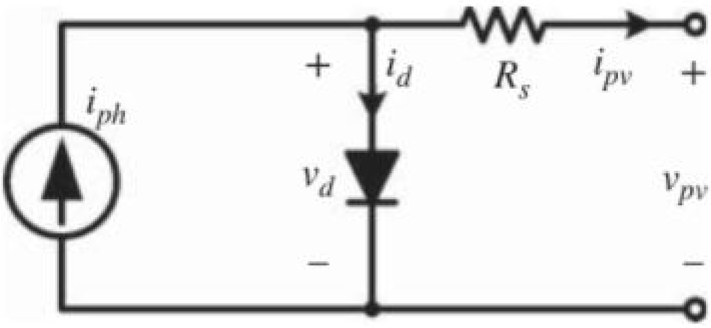

Fig. 1: Equivalent circuit of PV cell using single diode model.

Basic information			
Manufacturer	**Model**	**Cell material**	**Dimensions**
MOTECH	IM156B3-164	Multi-crystalline	156 × 156 ± 0.5 mm

Electrical performance at STC					
Efficiency	P_{MPP}	I_{MS}	V_{MS}	I_{SCS}	V_{OCS}
16.4 %	3.99 W	7.85 A	0.509 V	8.38 A	0.614 V

Table1: Specification of PV module at STC

The solar PV cell can be considered as current source. The output current (i) can be determined from Fig. 1. The output current is proportional to irradiance, temperature and resistances. The output current mainly depends on photocurrent (I_{ph}), Photocurrent increases with sun irradiance. The expression for output current (i) of solar cell from equivalent circuit in can be written as

$$i = I_{ph} - I_o\left(e^{\frac{v+iR_s}{n_s V_t}} - 1\right) - \frac{v + iR_s}{R_{sh}} \qquad (1)$$

where the junction thermal voltage V_t is defined by

$$V_t = \frac{AkT}{q} . \quad (2)$$

The circuit parameters defined in Equations (1) and (2) are defined as follows:

I_{ph} - photo-generated current,
I_0- dark saturation current,
R_s - panel series resistance,
R_{sh}- panel parallel (or shunt) resistance,
A - diode quality (or ideality) factor,
k - Boltzmann's constant,
q - electron charge,
$n_s$number of cells connected in series
T - cell temperature (in degree Kelvin).

I-V characteristics of a PV module with shaded PV cells are simulated in consideration of the avalanche breakdown voltage as shown in the following [16].

$$I = I_{ph} - I_0\left[\exp\left\{\frac{q(V/m + R_s I)}{nkT}\right\} - 1\right] - \frac{V/m + R_s I}{R_{sh}} - a\left(\frac{V}{m} + R_s I\right)\left(1 - \frac{V/m + R_s I}{V_{br}}\right)^{-nn}, \quad (3)$$

where m is the number of cells, k is the Boltzmann constant, q is the magnitude of theelectron charge, T is the absolute temperature, n is the diode factor, I_0 is the dark saturation current, I_{ph} is the photocurrent, R_s is the series resistance, R_{sh} is the shunt resistance, a and nn are the constant value, and V_{br} is the avalanche breakdown voltage.

III.RESULTS AND DISCUSSION

A Effect of Solar Irradiance Variation

The photocurrent varies with irradiance, the simulation was performed for different values of irradiance (1000, 900, 800, 700 W/m^2) at STC (Standard test condition). Fig. 2 and 3 shows I-V and P-V curve after simulation at different irradiance. The percentage change in short circuit current (I_{sc}) is much more than the percentage change in Open circuit voltage (V_{oc}).

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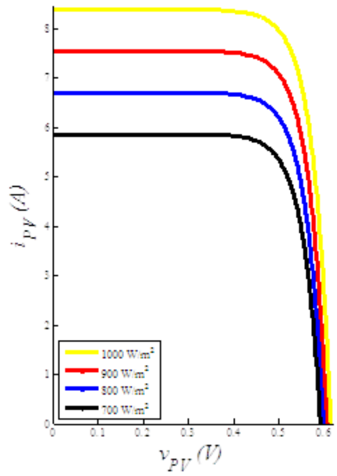

Fig2 Forward I-V characteristic of c-Si PV cell at different irradiance intensities.

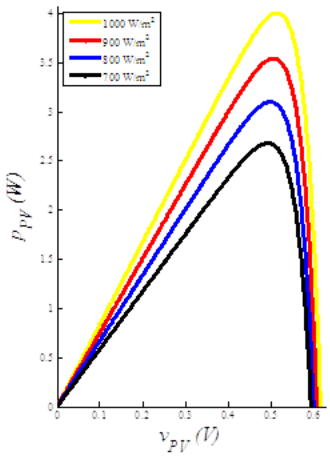

Fig3 P-V Characteristic of PV module at different irradiance intensities.

B Effect of Temperature Variation

The simulation was performed for different values of temperature (0^0,25^0,50^0,75^0) at STC. Fig. 4 and Fig 5 shows I-V and P-V graph of simulation result for different cell temperature. The current I_{sc} increases in very small amount but decrement in open circuit voltage V_{OC} is considerable with increase in temperature.

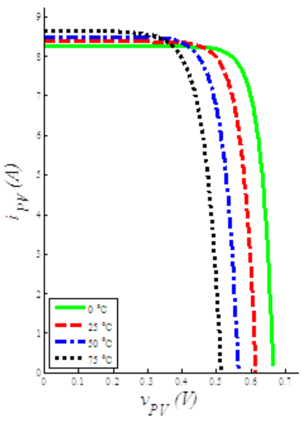

Fig4 P-V Characteristic of PV module at different temperature

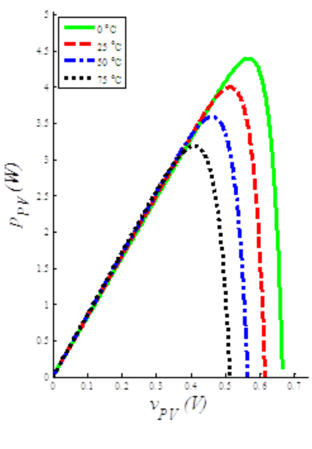

Fig5 I-V Characteristic of PV module at different temperature

C Effect of Partial Shading

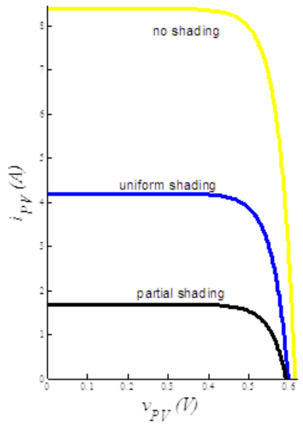

Fig 6 I-Vplot for shading and partial shading

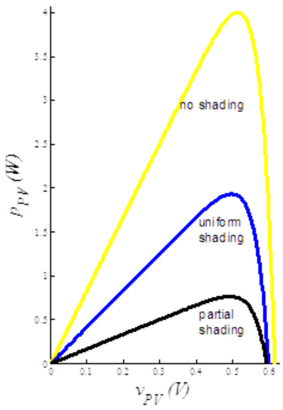

Fig 7 P-V plot for shading and partial shading

The PV cells are generally connected in series to form a PV module and in case of partial shading of PV module, the current is limited due to shaded cells and all cells connected in series are forced to carry minimum current even though only few cells or even one cell is shaded. The shaded cells get reverse biased and act as a load which may cause hot spots to arise and PV cell might get damaged permanently. It can be seen that the current lowering nearby short-circuit current as shown in Fig. **6** is the influence of avalanche breakdown voltage of the shaded PV cell.

The effect of shading is shown by simulation. The simulation is performed under the following three conditions: no shading, uniform shading and partial shading. I-V and P-V graph of simulation result is shown in Fig.6 & Fig.7 for the above-mentioned condition. In no shading condition all 36 cells receive irradiance of 1000 W/m^2 and shown by yellow line in curve. In uniform shading, irradiance received by all cell is 500 W/m^2 and it is shown by blue colour line. In case of partial shading only five cells are shaded and receives irradiance of 200 W/m^2 and other cells are at irradiance of 900 W/m^2, it is indicated by black line. It can be clearly seen that from simulation results, in partial shading condition, current is limited at minimum current produced by shaded cell. Bypass diodes are used to overcome the problem of hot spot that arises due to partial shading. Bypass diode provide path for current flow for shaded cells.

IV. CONCLUSION

In this paper, we have investigated the relation between the output lowering due to a shaded PV module and the change of I-V characteristics, utilizing the computer simulation. The change of I-V characteristics of a PV module with shaded PV cells was discussed by the shift of the avalanche breakdown voltage of shaded cells. The simulation results show that current is reduced in very large amount due to partial shading.

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