



Shading Impact on Solar PV Module

Savita Kumari

Department: R&D Photovoltaic, Solar Energy Centre, Gwal Pahadi, Gurgaon, Haryana, INDIA

Maharshi Dayanand University, Rohtak

VPO- Birhi kalan, Th- Charkhi Dadri, Distt- Bhiwani (Haryana), INDIA

Abstract: In silicon solar cell the open circuit voltage of is around 0.6V. A solar module is constructed by connecting a number of cells in series to get a practically usable voltage. Partial shading of a Solar Photovoltaic Module (SPM) is one of the main causes of overheating of shaded cells and reduced energy yield of the module. The present work is a study of harmful effects of partial shading on the performance of a PV module. A PSPICE simulation model that represents 36 cells PV module under partial shaded conditions has been used to test several shading profiles and results are presented.

Index Terms: Partial Shading, Power loss, Heat dissipation.

I. Nomenclature

V and I - Module Voltage and Module current respectively

I_L - The current generation by absorption of photons at short circuit

R_{se} and R_{sh} - Series and Shunt resistances in the equivalent circuit of the module

I_0 - Diode reverse saturation current in the equivalent circuit of the module

F - Ratio of the photo absorption current generated by the shaded illuminated cells to that generated by the fully illuminated cells

V_s - Voltage across one of the shaded illuminated cells

V_i - Voltage across one of the fully illuminated cells

a - Number of cells under full illumination

b - Number of cells under shaded illumination

P_{DS} - Power dissipated by a cell under shaded illumination

$P_{\max(\text{module})}$ - Maximum power produced by the module

$P_{\max(\text{illuminated cells})}$ - Maximum power produced per cell by the fully illuminated cells

$P_{\max(\text{shaded cells})}$ - Maximum power produced per cell by the shaded illuminated cells

II. Introduction

In a series connected SPV module, if all its cells are not equally illuminated then its performance is adversely affected. All the cells in a series array are forced to carry the same current even though a few cells under shade produce less photon current. The shaded cells may get reverse biased, acting as loads, draining power from fully illuminated cells. If the system is not appropriately protected, hot-spot problem can arise and in several cases, the system can be damaged. In the new trend of integrated PV arrays, it is difficult to avoid partial shading of array due to neighbouring buildings throughout the day in all the seasons. This makes the study of partial shading of modules a key issue. With a physical Solar PV module it is difficult to study the effects of partial shading. A PSPICE model of a PV module consisting of 36 cells in series has been developed to carry out this study. The model is used to study the effect of shade on varying number of cells on the power output of the module.

III. PSPICE Equivalent Circuit for SPV Module

An equivalent circuit of a SPM is shown in Fig.1.

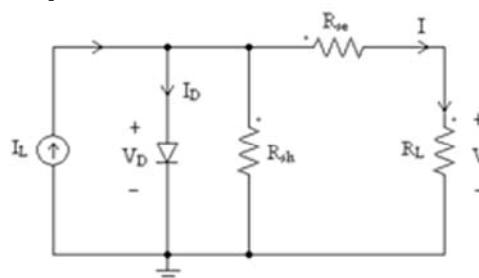


Figure 1. PSPICE equivalent circuit of SPV module consists of 36 cells in series with uniform illumination

The output current I through the load resistance is given by (1).

$$I = I_L - I_0 \{ \exp(V + IR_{se}/V_t) - 1 \} - (V + IR_{se})/R_{sh} \quad (1)$$

The circuit of Fig.1 is simulated using PSPICE software. The PSPICE model is validated against the practical characteristics obtained using Electronic load. Parameters like diode reverse saturation current I_0 , shunt and series resistances R_{sh} and R_{se} were tuned to match the characteristics of the PSPICE model with that obtained for realistic module and specifications supplied by the manufacturer. Specifications of the solar cell and module used in this simulation study are given in Table.1.

S. No.	Parameters	Single Cell	Module
1	Rated Power	1.03W	37.08W
2	Voltage at maximum Power (V_{mp})	0.46V	16.56V
3	Current at maximum power (I_{mp})	2.25A	2.25A
4	Open circuit voltage(V_{oc})	0.59V	21.24V
5	Short circuit current(I_{sc})	2.55A	2.55A

Table.1 Technical Specification of the solar cell and solar module used.

Values of R_{ses} and R_{shs} have been assumed to be constant for a particular value of F . These assumptions will not substantially affect the conclusions drawn.

IV. Shadow effect on Module

A shadow falling on a group of cells will reduce the total output by two mechanisms: 1) by reducing the energy input to the cell 2) by increasing energy losses in the shaded cells. Problems become more serious when shaded cells get reverse biased. In Fig.2, a group of cells under full illumination is connected in series with another group of cells under shaded illumination. The photon current of fully illuminated cells I_{Li} is high compared with that of the shaded illuminated cells I_{Ls} . If the module current $I < I_{Ls}$, diode D_s is forward biased and there is no risk for the shaded cells. But if $I > I_{Ls}$, then the diode current I_{Ds} flow through the diode in the reverse direction, which offers high resistance will consume power and will significantly reduce the load current I itself. The point B will assume negative potential. If the difference in illumination levels is high, D_s may get damaged due to overheating.

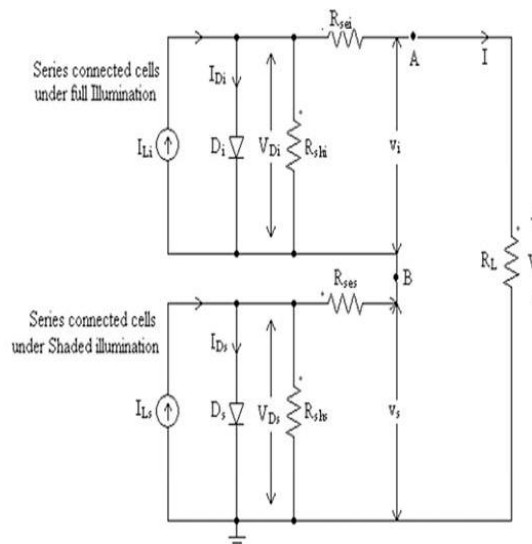


Figure 2. PSPICE equivalent circuit of SPV module consists of 36 cells in series with non uniform illumination
The photo current generated by the shaded illuminated cell is FI_L , where F is the ratio of photo current generated by the shaded cell to that of the fully illuminated cell. $F=0$ means, fully shaded and $F=1$ means fully illuminated. When a solar cell in a series array is under shadow, its current output is given by

$$I_s = FI_L - I_0 \{ \exp(V_{Ds}/V_t) - 1 \} - V_{Ds}/R_{shs} \quad (2)$$

$$\text{Where, } V_{Ds} = V_s + I_s R_{ses} \quad (2^*)$$

Similarly the current through the illuminated cells is given by equation,

$$I_i = I_L - I_0 \{ \exp(V_{Di}/V_t) - 1 \} - V_{Di}/R_{shi} \quad (3)$$

$$\text{Where, } V_{Di} = V_i + I_i R_{sei} \quad (3^*)$$

As the shaded and illuminated cells are connected in series, the same current is forced to flow through both. So in the equations (2), (2*), (3) and (3*), I_i and I_s replaced by the same current I . Therefore,

$$I = F I_L - I_0 \{ \exp(V_{Ds}/V_i) - 1 \} - V_{Ds}/R_{shs} \quad (4)$$

$$I = I_L - I_0 \{ \exp(V_{Di}/V_i) - 1 \} - V_{Di}/R_{shi} \quad (5)$$

As the value of F decreases from 1 to 0, $\exp(V_{Ds}/V_i)$ tends to zero. Therefore (4) can be simplified as,

$$I = F I_L + I_0 - (V_s + I R_{ses})/R_{shs} \quad (6)$$

Rearranging (6), the expression for the voltage across the shaded cell V_s can be obtained as,

$$V_s = (F I_L - I) R_{shs} - I R_{ses} \quad (7)$$

In the above equation $I_0 R_{sh}$ is neglected in comparison with larger terms. The total module output voltage is the sum of voltages across each cell operating at the same current I . So the module consists of 36 identical series connected cells, the output voltage can be expressed as,

$$V = \sum_{j=0}^a V_{ij} + \sum_{k=0}^b V_{sk} \quad (8)$$

where, $a+b=36$

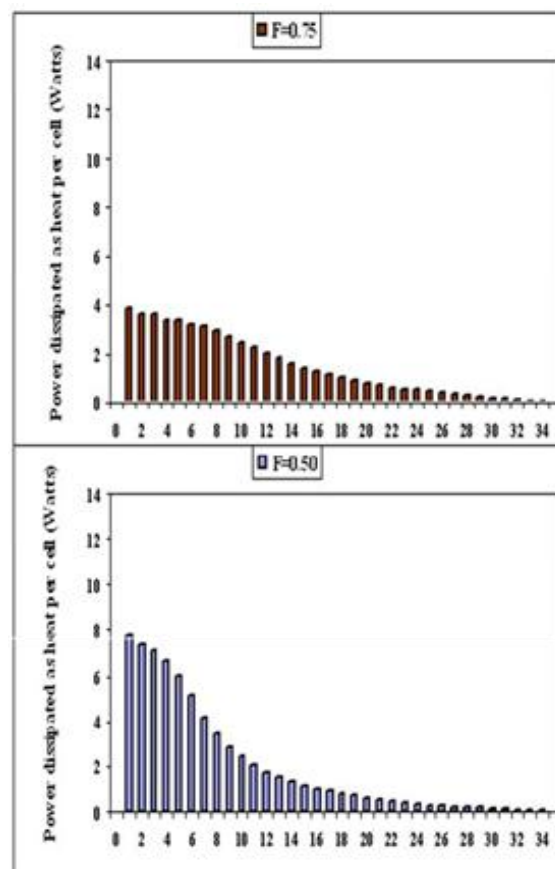
The power dissipated by the shaded cell is obtained by using (7) as

$$P_{Ds} = I * V_s = I \{ (F I_L - I) R_{shs} - I R_{ses} \} \quad (9)$$

Power dissipation in the shaded cell may be substantial leading to increase in its temperature. Due to increased temperature, the cell current gets concentrated in an increasingly small region of the cell, producing the hot spot. This can damage the cell encapsulation and eventually produce module failure. series connected cells with non uniform illumination.

To vary the number of cells under full illumination and shaded conditions the corresponding group diode reverse saturation current, R_{se} and R_{sh} has been varied i.e. the I_0 values of D_i and D_s , R_{sei} , R_{shi} , R_{ses} and R_{shs} . For full illumination I_{L_i} is fixed to 2.55A and for partial shading I_{L_s} is varied by the factor F (say $F=0.25$, $F=0.5$ and $F=0.75$). Power dissipated by the shaded cells is calculated by observing the maximum negative voltage appearing across the shaded cells multiplied by the module current. Fig.3 shows the plot between number of cells under shadow and the power dissipated by the shaded cells.

From Fig.3 it can be inferred that as the proportion of shading increases, power dissipated by the shaded cells also increased. Heat dissipation in all the cases will be high when the number of cells under shaded illumination is less than that under full illumination.



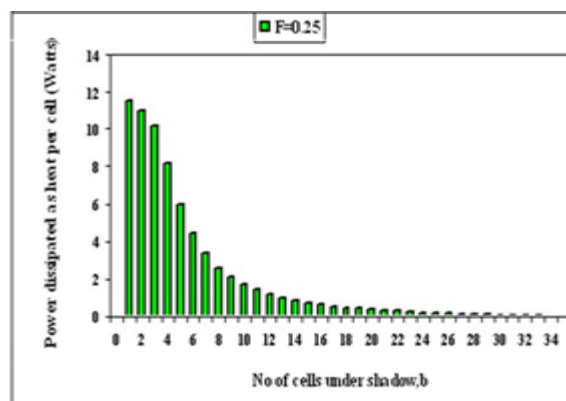


Figure 3 . Relation between power dissipation P_{DS} due to shaded cells 'b' as a function of F
Mismatch power loss is the loss of available power due to series connection. It can be defined as,

$$P_{\max(\text{mismatch losses})} = (\sum P_{\max(\text{illuminated cells})} - \sum P_{\max(\text{shaded cells})}) - P_{\max(\text{module})} \quad (10)$$

V. Conclusion

A solar module consists of series connection of solar cells to get practically utilisable voltage. From the results and inferences from this paper, it is concluded that there is a substantial power loss due to non uniform illumination of a series string. The power generated by highly illuminated cells is wasted as a heat in the poorly illuminated cells. So care should be taken to see that all the cells connected in series receive the same illumination under different patterns of shading. Such a care will give a better protection to the array and at the same time the total energy output will also be higher.

VI. Acknowledgement

The author is thankful to the Faculty of R&D Photovoltaic of Solar Energy Centre (MNRE) for providing all the experimental and computational facilities to carry out this work.

VII. References

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