Australian Journal of Basic and Applied Sciences, 9(33) October 2015, Pages: 92-97

ISSN:1991-8178

Australian Journal of Basic and Applied Sciences

Journal home page: www.ajbasweb.com

A Virtual Study on the Effects of Partial Shading on the performance of Photovoltaic array

S. Malathy and R. Ramaprabha

Department of Electrical and Electronics Engineering, SSN College of Engineering, India

ARTICLE INFO

Article history:
Received 3 October 2015
Accepted 31 October 2015

Keywords:
Array configuration, bypass diodes, partial shading, PV.

ABSTRACT

Partial shading causes mismatch in the electrical characteristics of the constituent modules in a photovoltaic (PV) array and the mismatch degrades the performance of the system. The reduction in output is not proportional to the shaded area but depends on the number of bypass diodes included per panel, array configuration, location of shaded panels within the array, shade intensity and geometry. To enhance the performance of PV system under non-uniform irradiation conditions, it is necessary to analyze and understand the relationship between these factors and the output. This paper presents a comprehensive shading analysis at different levels and can be useful in understanding the negative effects of shading and identifying appropriate mitigation techniques to reduce the impact as, shading is inevitable in most of the urban building integrated PV systems.

To Cite This Article: S. Malathy and R. Ramaprabha., A Virtual Study on the Effects of Partial Shading on the performance of Photovoltaic array. ***Aust. J. Basic & Appl. Sci.,*** *9(33): 92-97, 2015*

INTRODUCTION

A typical PV system has PV generator, power conditioning units and other components. PV generator has PV modules connected in series and parallel and these modules are usually chosen to have similar electrical characteristics to avoid mismatch losses. However, the characteristics of PV modules depend on irradiation and temperature (Quaschning, V. and R. Hanitsch, 1996; Bishop, J.W., 1998). When a module is shaded, the photocurrent generated by the module decreases while the other shade free modules generate the rated current. When the shaded module is forced to carry more current, it gets reverse biased and may result in hotspot development. Bypass diodes are usually provided to prevent the modules from getting damaged as these diodes provide an alternative path for the current flow (Suryanto Hasyim, E., 1986-1978). However, the module may be bypassed totally even when few of its cells are shaded heavily. The shade tolerance of the PV module can be improved largely by integrating a bypass diode into the structure of each cell (Silvestre, S., 2009). As this integration increases complexity, one or more bypass diodes are connected externally at the junction box provided at the back of the PV panel. The PV panels with more bypass diodes offer more tolerance to shades. But, inclusion of bypass diodes introduces multiple peaks making maximum power point tracking difficult. Moreover, the output of the PV array also depends on the array configuration, shade intensity and pattern (Patel, H. and V. Agarwal, 2008; Woyte, A., 2013). This paper analyzes the influence of these factors on the characteristics and in turn on the output of the PV system to understand their inter dependencies in detail to gain better knowledge on the negative impacts of shading.

II. Analysis under partially shaded conditions:

2.1. Analysis at cell level:

The irradiation varies instantaneously making the practical analysis difficult. To carry out the analysis, MatLab based single diode model of PV module is developed utilizing the established equations (Villalva, M.G., 2009). The PV module considered in this work is a 40 Wp poly crystalline PV module with 36 cells. The open circuit voltage of the module is 21.24 V and the short circuit current is 2.55 A. The equivalent circuit representation of a PV cell is presented in Fig 1.

At standard temperature, T = Tn.

$$I_{ph} = S \times I_{pvn} \qquad (1)$$

where, Shading factor $S = G/G_n$

The photo current is proportional to the shading factor at standard temperature of 25^0C. The simulated electrical characteristics of the PV cell under various irradiation conditions at standard temperature are

Corresponding Author: S. Malathy, Department of Electrical and Electronics Engineering, SSN College of Engineering, India
Tel: 9144- 27456700; E-mail: malathys@ssn.edu.in

shown in Fig.1.b. Several PV cells are connected in series to form a PV module and commercial PV modules have 36, 60 or 72 cells. To understand the effect of shading in such series connections better, a string with two series connected PV cells serving a resistive load as shown in Fig.2.a is evaluated by shading one cell at different intensities.

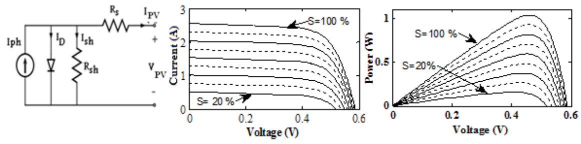

Fig. 1: Equivalent circuit and Characteristics of PV cell.

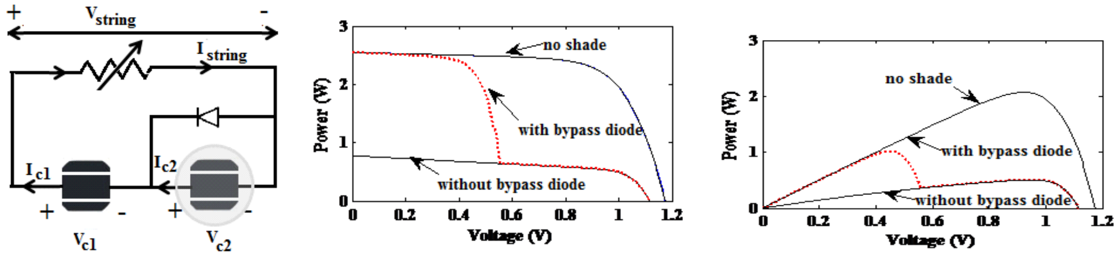

Fig. 2: Series connection of PV cells and its Characteristics.

The string current and voltage are given by

$$I_s = I_{c1} = I_{c2} \quad (2)$$

$$V_s = V_{c1} + V_{c2} \quad (3)$$

When cell 2 is shaded, the cell's current drops and I_{c2} is now lesser than I_{c1}. The shaded cell thus limits the current of the string. When the load current is lesser than I_{c2}, both the cells deliver power to the load. However, when the load current is greater than the shaded cell's current I_{c2}, cell C2 is forced to carry load current and operates in reverse bias mode to accommodate this current and starts consuming power instead of delivering. This may lead to hotspot development if the current is locally shunted and eventually damage the cell. Thus, in a module with 36 cells, one or two shaded cells can bring down the output of the entire module. Bypass diodes are usually introduced to protect the cells from these destructive effects as they provide an alternate path for the current flow. For example, let the shadow transmittance of cell 2 be 25% (G = 250 W/m^2). When the load current is lesser than I_{C2}, bypass diode is inactive and if cell 2 is operating at its MPP, cell 1 will be operating at point which is very far from its MPP. This mismatch pulls the output power down. For higher load currents, cell 2 is bypassed and the MPP shifts to the lower voltage region. As the shaded cell is bypassed it does not contribute any power while the un shaded cell still contributes. The change in electrical characteristics when a cell is shaded and the improvement brought in by the inclusion of bypass diode are presented in the Fig.2.

The analysis is done with ideal bypass diode and the improvement in the performance for various depths of shading is presented in the Table 1. The introduction of bypass diode has improved the output under heavily shaded conditions (for example from 26% to 49% for 25% shade transmittance), introduced multiple peaks and shifted V_{max} to lower voltage region (at lower G) as shaded cell is bypassed.

Table 1: Performance of series and parallel connected cells at different grades of shading.

Irradiation in W/m^2		Series connection						Parallel connection		
		Without bypass diode			With bypass diode					
Cell 1 G_1	Cell 2 G_2	V_{max} (V)	P_{max} (W)	Peaks	V_{max} (V)	P_{max} (W)	Peaks	V_{max}	P_{max}	Peaks
1000	1000	0.92	2.07	1	0.92	2.07	1	0.458	2.07	1
1000	750	0.96	1.64	1	0.96	1.64	2	0.458	1.79	1
1000	500	0.96	1.09	1	0.96	1.09	2	0.455	1.51	1
1000	250	0.95	0.50	1	0.45	1.01	2	0.450	1.23	1
1000	100	0.81	0.16	1	0.45	1.01	2	0.442	1.07	1

When PV cells are connected in parallel, the load current is sum of the cell currents and both the cells share the same voltage. The shaded panel also contributes its share of power however low. Hence, parallel configuration is robust under shaded conditions and inclusion of bypass diodes does not alter the characteristics. The analysis is repeated for parallel connection and the results are tabulated in table 1. It is worth noting that for different grades of shading, there is very negligible change in the V_{max}. This implies that when one cell is operating at its MPP, the other cell connected parallel (and hence share the same voltage) will also operate in a region that is very close to its MPP and this ensures maximum output under all irradiation conditions.

2.2. Analysis at module level:

Commercial PV modules have 36, 60 or 72 cells connected in series. As provision of bypass diode to each cell is not feasible, cells are grouped in to sub modules and each sub module is provided with a diode. Each sub module may have 18, 20 or 36 series connected cells. The sub modules are then connected in series to form a module. Provision of additional bypass diodes per module significantly improves performance in such cases. This analysis is of particular interest as in most of the cases only part of a PV module (few cells) is shaded.

A module with 36 cells series connected cells is considered in this work. The impact of shading is analyzed by three tests as depicted in Fig.3. In the first test, single cell is shaded at different depths. In the second test, two cells that belong to the same sub module is shaded and compared with the case when one cell from each sub module is shaded. The third test evaluates the change in output with moving shades.

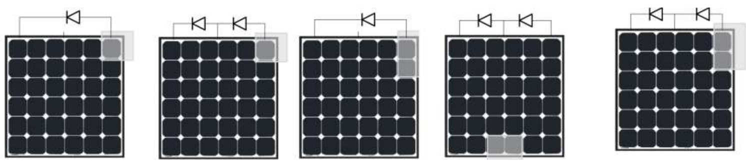

Fig. 3: Shading conditions with one and two bypass diodes per module.

2.2.1 Case A: Analysis with single shaded cell:

In the first case, one cell is shaded at different grades (25%, 50%, 75 % and 90 %). The short circuit current of the shaded cell reduces and limits the current of the sub module and in turn reduces the power output. The module current depends only on the shade intensity and not on the number of cells shaded in a sub module. Inclusion of one bypass diode per module (36 cells) does not have any impact on the output of the module. However, they protect the module from hot spots when they are part of a larger array. Provision of additional bypass diode improves the output significantly, as the number of cells bypassed is less. The VP characteristics with one and two bypass diodes per module are presented in Fig. 4. The maximum power point has shifted to the lower voltage region when the shaded heavily.

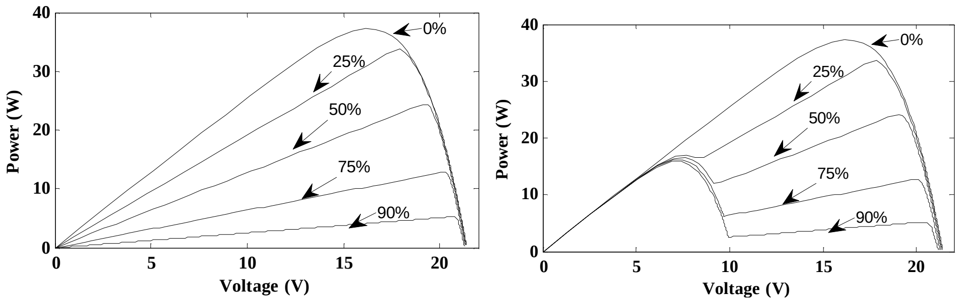

Fig. 4: Characteristics with one and two bypass diodes at various grades of shading.

2.2.3 Case B- Analysis with two shaded cells:

To analyze the improvement brought in by increasing the number of bypass diodes, two cells are shaded in a module. The output now depends not only on the shade intensity but also on the location of the shaded cells. When the two shaded cells are in the same sub module, the output of the sub module falls as low as if the entire sub module is shaded and the bypass diode connected to that sub module is activated while the other sub module delivers the rated power. On the other hand, when one cell is shaded in each sub module, the shaded cell limits the current through the sub modules by the same amount and the output falls as low as if the entire module is shaded. Inclusion of additional bypass diodes has no impact in this case and the output is low as the case with single diode or no diode. The VP characteristics of the module with one and two bypass diodes at 75% shading is shown in Fig.5. The maximum power of both the cases at various shade intensities are presented in table 2.

It is inferred from the table that, when one or two cells are shaded, inclusion of single bypass diode per module does not have any impact on the module output. The output is dependent only on the shade intensity and not on the number of cells shaded or the location. The output improves significantly when the number of cells bridged by the diode reduces. However, the output in this case is dependent not only on the shade intensity but also on the location.

For example, for when a single cell is shaded by 75% (G=250 W/m^2) the output power has reduced to 35% in the absence of diode. Inclusion of single bypass diode to the module does not have any impact on the output. On the other hand, when two diodes are provided, there is 8% increase in the output. Moreover, as the shade intensity crosses 68%, the V_{mp} shifts to the lower voltage side. The output is independent of the number of shaded cells if the shaded cells are located in the same sub module. Else, bypass diodes has no effect and power is limited only by the shade intensity.

Table 2: Comparison of maximum power.

G W/m^2	P_{max} when One cell is shaded: No diode	1 Diode	2 Diodes	P_{max} when 2 cells are shaded: No diode	1 Diode	2 Diodes (same sub module)	2 Diodes (different sub module)
1000	37.23	37.23	37.23	37.23	37.23	37.23	37.23
750	33.93	33.93	33.93	33.55	33.55	33.55	33.55
500	24.38	24.38	24.38	24.18	24.18	24.18	24.18
250	12.87	12.87	16.11	12.67	12.67	16.11	12.67
100	5.27	5.27	15.83	5.16	5.16	15.83	5.16

2.2.3. Case C Analysis under moving shades:

The third factor that affect the output under shaded condition is the direction of movement of shade as it is explained previously that the location of shaded cells too affects the output. The behavior of the PV module under moving shades with different bypass diode configuration is evaluated in this test. Two common directions such as horizontal and vertical as shown in Fig.6 are considered. The test mimics the real world case where shade is caused by moving clouds or fixed structures (chimney, over head tanks, parapet wall, nearby buildings etc.) that changes with position of the Sun.

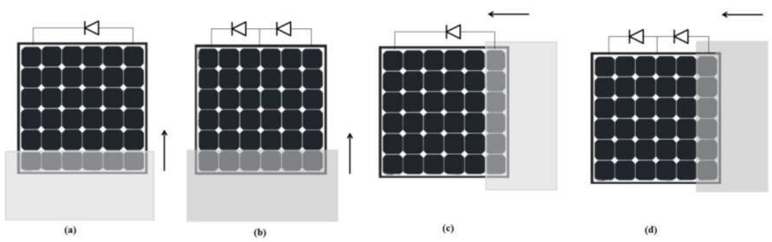

Fig. 6: Horizontal and vertical movement of shade.

When the shade moves over the panel horizontally, the rows are shaded. The shaded row limits the current of the entire module and the bypass diode configuration too does not play any role as cells in both the sub modules are shaded. Fig. 7 shows that the output of the module depends only on the shade intensity and not much on the number of rows shaded.

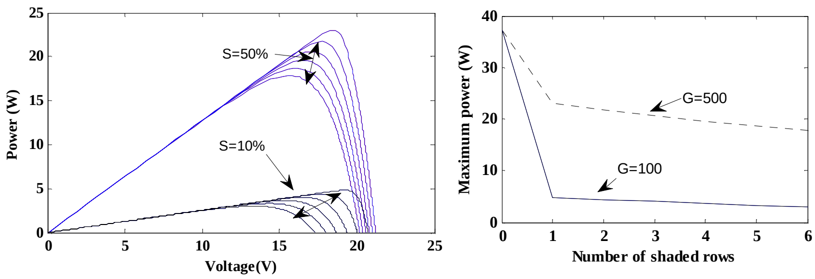

Fig. 7: Results of horizontal shade movement.

When the shade moves over the panel vertically, the columns are shaded. The output in this case depends on all the three factors, the intensity, the number of columns shaded and the bypass diode configuration. The output is similar to that of horizontal movement when single bypass diode is employed. On the other hand when two bypass diodes are used, the output depends on the shade intensity and the number of columns shaded (number of active bypass diodes). When a column is shaded, the bypass diode connected to that sub module is active and all the cells in the other sub module contribute the output. When the shade extends to the fourth column, the output is similar to the case of single bypass diode. The maximum power point shifts to the lower voltage region when the shading intensity is more as shown in the Fig. 8. In general, the output of PV module improves significantly when multiple bypass diodes are used.

2.3. Analysis at array level:

At array level, besides the shade geometry and the location of shaded modules in the array, the interconnections between the modules also play a significant role in determining the output (Malathy S. and Dr. R. Ramaprabha, 2015). The basic interconnections schemes are series (S), parallel (P) and series parallel (SP). In series connection, single shade module can bring down the output of the entire array. Parallel connections on the other hand are resilient as all the modules operate at closer vicinity of the respective MPPs. It is hence recommended to go for short parallel strings when shading or partial shading conditions are anticipated. However, this configuration results in high current and relatively low voltage. Few other configurations are derived from these basic configurations and the derived configurations are bridge link (BL), honey comb (HC) and total cross tied (TCT) configuration. Their performance is analysed by subjecting them to to a randomly generated shading pattern where the intensity of shading is in the rage of 0% to 90%. An array with 36 PV modules can be arranged in different ways like 2×18, 3×12, 4×9, 6×6, 9×4, 12×3 and 18×2. The test is simulated on all array sizes and the results are shown for array with short, medium and long series strings (2×18, 6×6 and 18×2) for the derived configurations in Table 3.

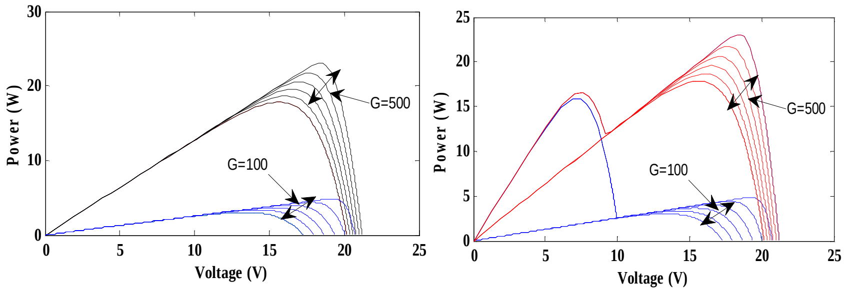

Fig. 8: Results of vertical shade movement.

Table 3: Results of random shading test.

Array Size	Type	V_{mp} (V)	P_{mp} (W)	V_{mp}(V)	P_{mp} (W)
		without diode		with bypass diode	
2×18	SP	33.13	444.5	33.09	498.3
	BL	33.13	530.8	33.03	531.8
	TCT	33.13	621.7	33.03	622
6×6	SP	83.69	244.3	68.22	427.7
	BL	101.1	388.7	80.39	485.3
	HC	100.7	416.3	86.22	474.8
	TCT	102.4	424.5	84.4	499
18×2	SP	229.4	239	205.3	406.4
	BL	260	279.8	183.9	434.5
	HC	260.4	378.4	290.3	451.3
	TCT	274.4	410.4	286.8	453.1

It can be inferred from the table that the array with short series strings yields better under shaded condition and inclusion of bypass diodes brings in little enhancement in the output. Further, TCT configuration gives better output due to the presence of crossties. For arrays with medium or long series strings, the bypass diodes enhance the output largely and TCT configuration is the better option as it yields better output. In general, TCT is a better option for shaded conditions.

III. Conclusion:

The impact of partial shading has been analyzed thoroughly in this work with MatLab based simulations. In general, shading reduces photo current, causes mismatch and degrades performance. The performance under shaded conditions can be enhanced by providing additional bypass diodes per module as the number of cells bypassed by the active bypass diode is less. Among the interconnection schemes, yield is better for derived configurations due to the presence of cross ties than the series configuration. The output of the PV array is almost independent of the interconnection scheme when the deviation in the shade intensity is narrow. TCT configuration is found to be a better option. Generally, providing additional bypass diodes per module and employing TCT configuration will result in better energy yield under shaded conditions. The output can further be improved by changing the location of the shaded modules by employing static or dynamic reconfiguration techniques which is however not the focus of the paper. The work presented in this paper may be useful in understanding the impacts of shading on the output and the relationship between the influencing factors and the output power.

ACKNOWLEDGMENT

The authors wish to thank the management of SSN College of Engineering, Chennai for providing all the computational and experiment facilities to carry out this work.

REFERENCES

Quaschning, V. and R. Hanitsch, 1996." Numerical simulation of current–voltage characteristics of photovoltaic systems with shaded solar cells." Solar Energy, 56.6: 513–520.

Alonso-Garc´ıa, M.C., J.M. Ruiz and W. Herrmann, 2006. "Computer simulation of shading effects in hotovoltaic arrays." Renewable Energy, 31.12: 1986–1993.

Bishop, J.W., 1998. "Computer simulation of the effects of electrical mismatches in photovoltaic cell interconnection circuits." Solar Cells, 25.1: 73–89.

Suryanto Hasyim, E., S.R. Wenham and M.A. Green, 1986-1987. "Shadow tolerance of modules incorporating integral bypass diode solar cells" Solar cells, 19: 109-122.

Silvestre, S., A. Boronat and A. Chouder, 2009."Study of bypass diodes configuration on PV panels." Applied Energy, 86.9: 1632–1640.

Villalva, M.G., J.R. Gazoli and E.R. Filho, 2009."Comprehensive approach to modeling and simulation of photovoltaic arrays." IEEE Transactions on Power Electronics, 24.5: 1198–1208.

Patel, H. and V. Agarwal, 2008."MATLAB-Based Modeling To Study The Effects of Partial Shading on PV Array Characteristics" IEEE transactions on energy conversion, 23.1: 302-310.

Ramaprabha R. and B.L. Mathur, 2009. "Impact of Partial Shading on Solar PV Module containing Series Connected Cells." International Journal of Recent Trends in Engineering, 2.7: 56-60.

Lijun Gao, Roger A. Dougal, Shengyi Liu and Albena P. Iotova, 2009. "Parallel-Connected Solar PV System to Address Partial and Rapidly Fluctuating Shadow Conditions." IEEE Transactions on Industrial Electronics, 56.5: 1548-1556.

Bidram, A., A. Davoudi, R.S. Balog, 2012. "Control and circuit techniques to mitigate partial shading effects in photovoltaic arrays—an overview." IEEE J. Photovoltaics, 2.4: 532-546.

Shams El-Dein, M.Z., M. Kazerani and M.M.A. Salama, 2013. "An Optimal Total Cross Tied Interconnection for Reducing Mismatch Losses in Photovoltaic Arrays." IEEE Transactions on Sustainable Energy, 4.1: 99-107.

Woyte, A., 1. Nijs, R. Belmans, 203. "Partial shadowing of photovoltaic arrays with different system configurations: literature review and field test results." Solar Energy, 74: 217-233.

International Conference on Renewable Energy Sources, 2008. On the impact of partial shading on PV output power;[proceedings of International Conference on Renewable Energy Sources (RES"08) Corfu, Greece] Dezso Sera and Yahia Baghzouz.

Malathy S. and Dr. R. Ramaprabha, 2015. "Comprehensive analysis on the role of array size and configuration on energy yield of photovoltaic systems under shaded conditions." Renewable and Sustainable Energy Reviews, 49: 672-679.