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Effects of Bypass Diode Configurations on Solar Photovoltaic Modules Suffering from Shading Phenomenon

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***Abstract-* The temperature, radiation and other ambient environmental conditions are influencing the operation of solar cells. The shadowing phenomenon on solar cells causes the decrease of their output power. This paper analyses the effects of bypass diode configurations on photovoltaic systems operation under completely shadowed conditions. The authors analyze and propose several bypass diode configurations to limit the effects of this phenomenon and thus enhance the operational performance of photovoltaic (PV) systems. The case study deals with PSpice simulation of *I-V* and *P-V* characteristics of a real PV module type. The analysis of simulation results for *I-V* and *P-V* curves highlight the advantages and disadvantages of each type of bypass diode configuration, as well as its capability to be used in practice.**

***Keywords*: (no-) overlapped bypass diode, PV modules, PSpice, shadowed.**

I. INTRODUCTION

The advantage of solar photovoltaic systems to directly convert sunlight energy into electricity allowed them to be widely applied in residential and industrial production areas [1].

The maturity of these sources has enabled lower costs but also an enhanced performance. All these factors helped solar electric market to gradually expand, and it is forecasted that it will become the main source of renewable energy sources (RES) in the coming few years [2].

However, there are some issues in the operation of PV that reduce their operating efficiency and the output power. These well-known factors are: radiation, ambient temperature or humidity (environmental conditions), and among the unsupportive conditions, shadowing on PV module [2], [3].

Depending on their location and use, PV can be shadowed partly (with different levels) or entirely, by clouds covering the sun, shadow of trees or buildings.

For simulating photovoltaic system, different software packages can be used like Matlab [4], Simulink, PSCAD etc. These programming languages are very complex.

PSpice (Simulation Program with Integrated Circuit Power Emphasis) has the advantages of easy commands, clear and simple syntax for each type of equipment and the simulation results have high accuracy (as can be observed in Fig. 1). Also, allows an in-depth modeling of electronic devices and physical systems.

Besides, the software has built-in functions that determine the points of interest (maximum, minimum etc.), allowing the export of graphs fast and intuitive.

PSpice software is still quite new and it has not been applied in many modeling studies of renewable energy sources, such as the one the authors chose to study in this paper.

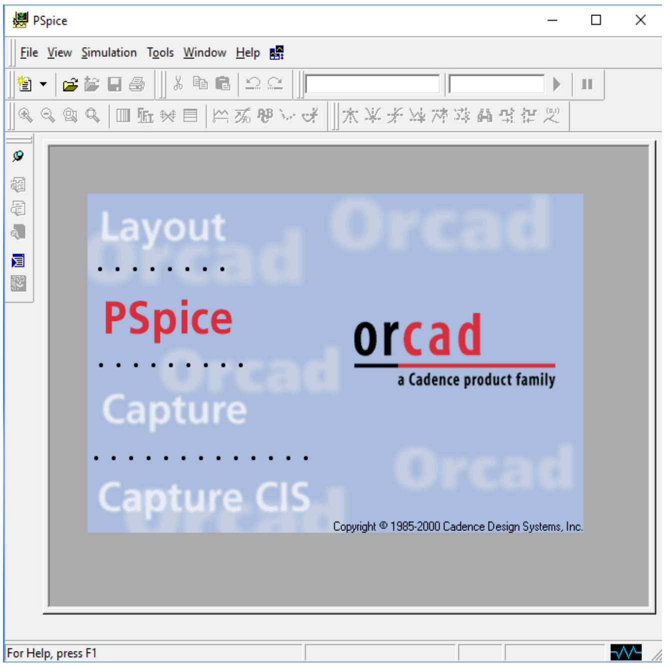

Fig. 1. PSpice software interface.

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In this study, CS6X-310P PV module type has been used to carry on simulations as it has good quality and many advantages like:

- long life span (guaranteed work well over 25 years) with high efficiency up to 16.68%;
- industry leading performance at low irradiation, + 96.5% module efficiency from an irradiance of 1000W/m^2 to 200 W/m^2 (AM 1.5, 25^{o}C);
- operating temperature ranges from -40^o C to +85^o C.

These features ensure their operation under different environmental conditions and it can withstand not only the weight of snow up to 5400 Pa, but also wind blows, or harsh climate conditions in the coastal areas, deserts, tropical etc. [5].

Using characteristic data and operating principles of CS6X-310P, simulations of *I (V)* and *P (V)* characteristics of PV module were realized [6]. To implement the model in PSpice, a two-diode model of a PV cell was considered, a current source, a serial resistor and a parallel resistor (as shown in Fig. 2a). Based on the results of previous research [3], these cells can be connected together to form a module.

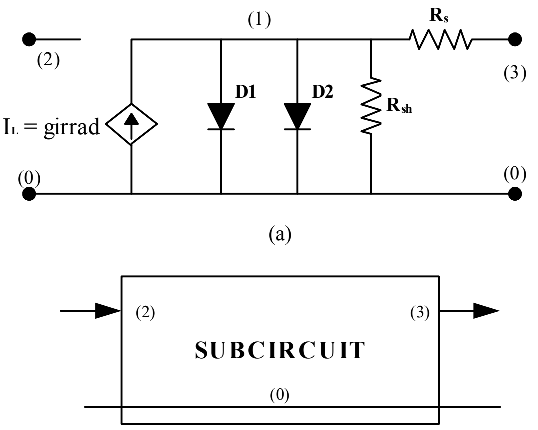
The parameters of PV module are reported in Table 1. The CS6X-310P module configuration of 72 photovoltaic cells connected in series with each other is illustrated in Fig. 3.

In Fig. 4a, b the I-V and P-V curves are shown. As it can be observed when one cell of the module analyzed is shadowed, the output power can be reduced by half (as shown in Fig. 4b).

As a result, not only that these shadowed cells are disabled, but also a large voltage drop on the cell occurs, which results a negative impact on the output voltage.

The power losses of these solar cells are dissipated as heat, and to reduce this phenomenon bypass diodes are connected on the parallel cells [7].

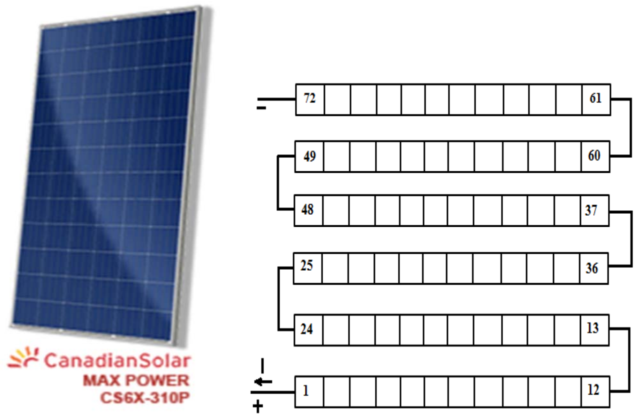
In this paper, the authors analyze various bypass diode configurations and their impact on PV characteristics through simulation carried on using PSpice software.



(a)

(b)

Fig. 2. (a) The equivalent circuits of double diode model (b) The sub-circuit model of (a) in PSpice

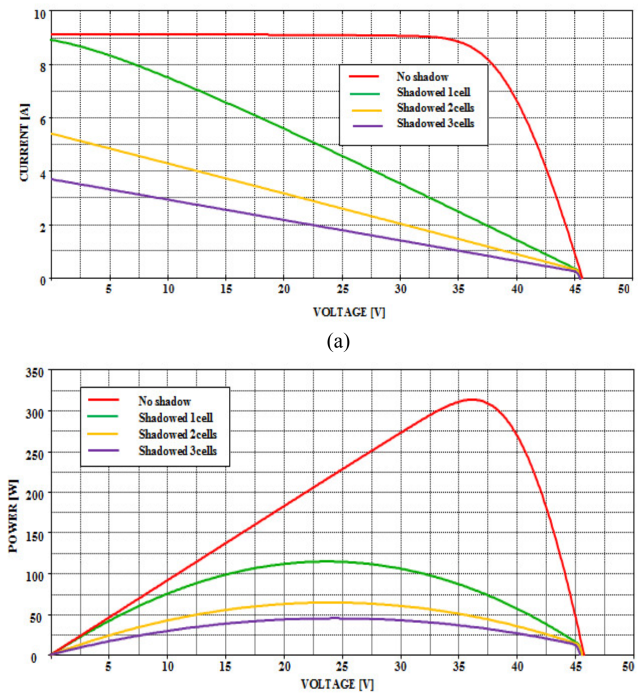


(a) (b)

Fig. 3. CS6X-310P (a) module and (b) model.

Table 1
THE ACTUAL PARAMETERS OF CS6X-310P MODULE AT STC (G = 1000W/m^2, AM 1.5 AND T = 25^{o}C)

Data of CS6X-310P module	
Nominal Max. Power (Pmax)	310Wp
Opt. Operating Voltage (Vmp)	36.4V
Opt. Operating Current (Imp)	8.52 A
Open Circuit Voltage (Voc)	44.9 A
Short Circuit Current (Isc)	9.08 A
Temperature Coefficient (Isc), KI	0.053%/^{o}C
Temperature Coefficient (Voc), KV	-0.31%/ ^{o}C
Power Tolerance	0 ~ +5 W



(a)

(b)

Fig. 4. (a) I-V and (b) P-V curve of PV module when cells shadowed.

II. Analysis of Bypass Diode Configurations

The output power of PV modules depends on the degree of shadowing, the number of cell covered with bypass diode and the voltage value decreases when the cell is shadowed.

This paper focuses on the case in which the shadowing has the maximum degree and is continuous (100%).

The voltage drop and power loss in full shadowed cell could be improved by bypass diode across cells. The various bypass diode configurations have different impact on the operational performance of PV [7]-[9].

For the simulation, the shadowed area of the continuous cells was considered according to the size of: 1 cell (1.39%), 6 cells (8.33%), 12 cells (16.67%), and 36 cells (50 %).

A. Adding overlapped bypass diodes

The modeled and simulated PV modules consist of 12 bypass diodes, each diode in parallel with 7 cells.

When several solar cells are shadowed and at the same time have more than one bypass diode, then these cells are named overlapped solar cells.

As can be observed in Fig. 5, adding the bypass diode limits the shadowing phenomenon. However, if too many solar cells (50%) are shadowed, the number of forward-biased bypass diodes is large, and causes a large voltage drop and the power output is significantly reduced [10], [11].

The main disadvantage of the model is the fact that if one cell is covered, the other cells in the group will not work. Thus, the performance of this PV module depends on the number of cells that are "infected" by 1 bypass diode.

B. Adding no-overlapped bypass diodes

In this case, there are 6 bypass diodes, each one in parallel with 12 cells, as illustrated in Fig.6a.

It can be seen that this is an improved model when the cells are shadowed in a row.

This model reduces the effects of voltage drop (as shown in Fig. 6 a, b), as the number of bypass diodes connected in parallel with each cell group is lower.

The number of cells that are arranged in parallel with a bypass diode has to be investigated in order to achieve the optimal performance in each environment [12]-[15].

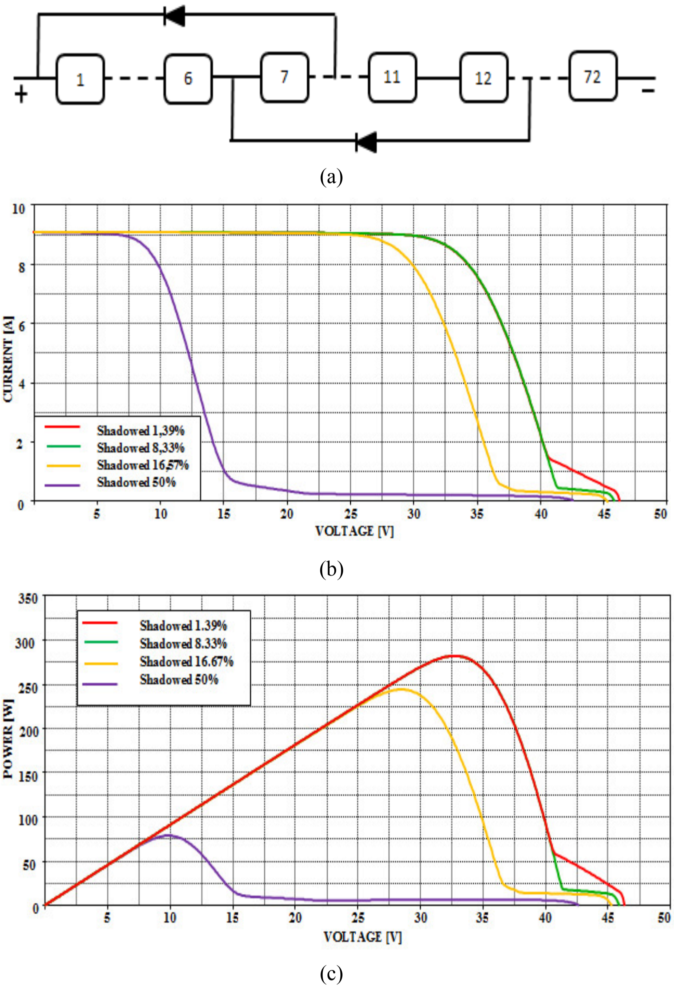


Fig. 5. (a) Overlapped bypass diode configuration and effects of shading to them with (b) I-V and (c) P-V characteristics.

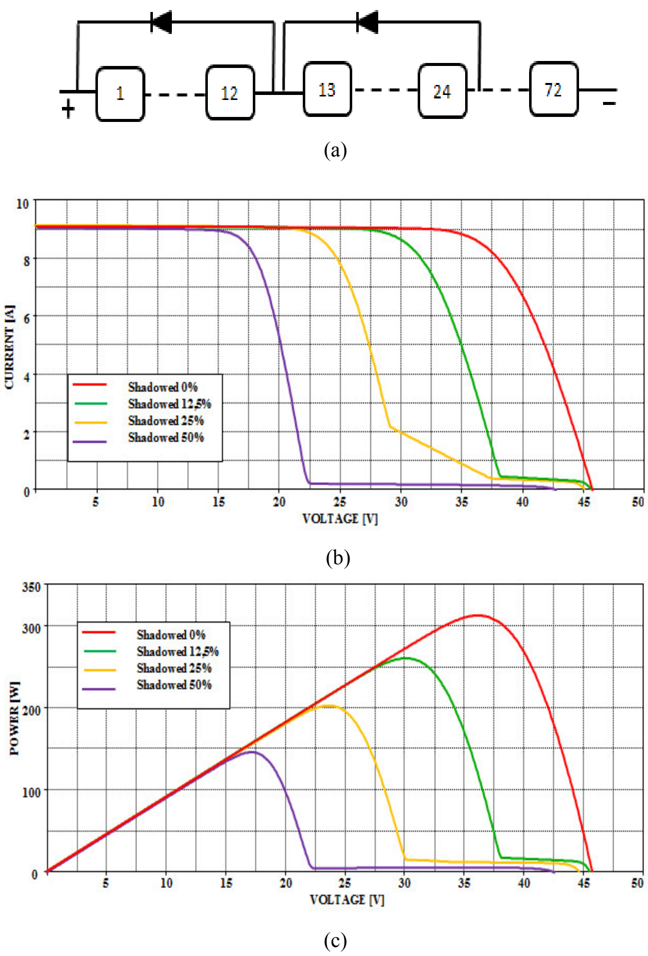


Fig. 6. (a) No-overlapped bypass diode configuration and effects of shading to them with (b) I-V and (c) P-V characteristics.

III. COMPARING THE CHARACTERISTICS OF THE BYPASS DIODE CONFIGURATIONS

This section compares the results of simulation characteristics of PV between two diode bypass configurations for the following cases: shadowed in a row and shadowed randomly.

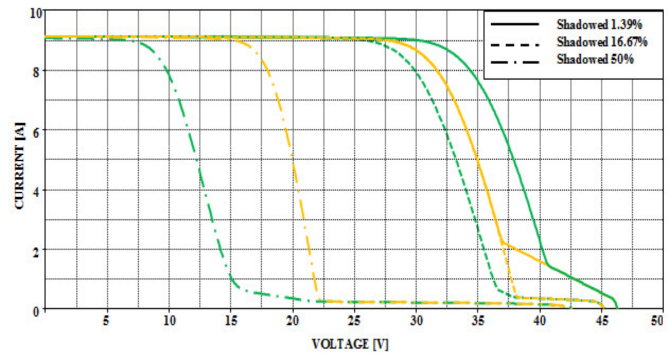
A. Shadowed cells in a row

The green lines illustrated in Figure 7 represent the *I-V* and *P-V* curves of PV module with overlapping bypass diode. The yellow lines represent the *I-V* and *P-V* curves with no-overlapping bypass diode. The solid lines represent the number of shadowed cells accounted for 1.3% of PV module (1 cell). The dash lines represents the number of shadowed cells accounted for 16.67% of PV module (12 cell), and the long dash-dot lines represents the number of shadowed cells accounted for 50% of PV module (36 cells).

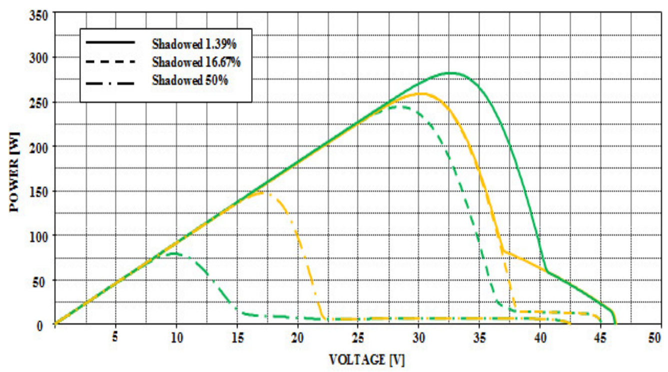
Comparing the *I-V* and *P-V* curves for the different analyzed cases, it results that when are added different bypass diode configurations in terms of consecutive shadowed cells, if a large quantity of cells are shadowed, no-overlapped bypass diode configuration is optimal.

B. Random shadowed cells

Taking into account the effectiveness of these two models, the case in which the cells are shadowed randomly in any position of the PV module is considered, and the number of shadowed cells is 6 cells (8.33%), 12 cells (16.67%) and, respectively 36 cells (50%).



(a)



(b)

Fig. 7. Effects of shading to I-V (a), P-V (b) curves when shaded 1.39% , shaded 16.67%, and shaded 50%.

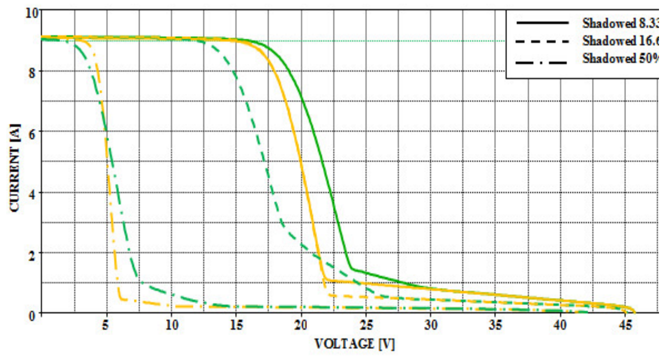
As it can be observed in Fig. 8, the operating performance of PV modules when the cells are shadowed randomly is significantly reduced compared to the case when the cell is shadowed in a row. Therefore, it is necessary to propose a diode configuration that can effectively limit the influence of this phenomenon.

From the analysis of each type of various bypass diode configuration and comparative case studies presented, it can be concluded that:

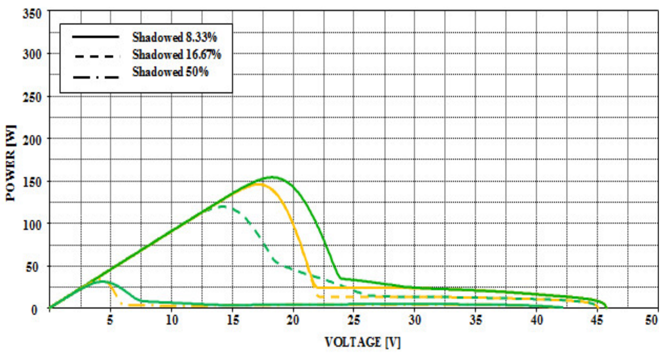
1) The model configuration and shading location affects significantly the operational performance of PV modules.
2) Bypass diode overlapped or no-overlapped presented advantages when the cell is shadowed more, consecutively. So, it is necessary to consider the environmental factors in the place where PV modules are installed.
3) For a tropical climate, the no-overlapped bypass diode configuration is optimal and is used commonly.

IV. CONCLUSIONS

The study presented different bypass diode configuration models considering the purpose of use, environmental factors and installation condition to analyze the configuration and the number of diode bypass to be used to achieve the best performance of PV modules.



(a)



(b)

Fig. 8. Effects of shading to I-V(a), P-V (b) curves when shaded 8.33% Shaded 16.67% and shaded 50%.

The simulation results showed that these models are able to decrease the loss of power output when the module is obstructed.

In the developed case study, the advantages and disadvantages of each model were presented, and recommendations on the optimal solution were formulated.

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