

Effect of Shading on the Performance of Solar PV Panel

Samah Bouanik¹, Toufik Sebbagh¹, Chahinaz Beldjatit¹ and Hocine Guentri²

¹ Department of Mechanical Engineering, Faculty of Sciences Engineering, 20 Aout 1955, Skikda University Skikda, Algeria

² Department of Mechanical Engineering, Faculty of Sciences Engineering, University Centre Abdelhafid Boussouf Mila, Algeria

*Corresponding author; Email: s.bouanik@univ-skikda.dz.

Article Info	ABSTRACT
Article history: Received , 17/01/2024 Revised , 05/05/2024 Accepted , 15/05/2024	Partially shaded solar modules are common in all types of photovoltaic (PV) systems. In many circumstances, passing clouds, surrounding buildings and towers, trees, or the shadow of one solar array on the other obscure the PV arrays completely or partially. The most important factor influencing the performance of a solar photovoltaic system is the solar radiation that contacts the panel surface. The primary cause of panel performance degradation is surface shading. Solar panels' lifetime and efficiency are reduced when they are partially shaded. This article includes a simulation-based assessment of a PV panel with and without a bypass diode under partial shadowing. Our research study examines the fluctuation in the features of a series-parallel solar array arrangement under partial shade conditions using MATLAB/Simulink-based simulation results.
Keywords: <i>Partial Shading</i> <i>Photovoltaic Module</i> <i>bypass diode</i> <i>PV cell</i>	

I. Introduction

Due to the current energy problem and the pollution caused by current energy sources (oil, gas, etc.), the world, including countries and governments, is being compelled to create and harness renewable energy sources (sun, wind, water,). In terms of diffusion and ease of use, the production of electrical energy using solar panels ranks first among these renewable energies. Photovoltaic (PV) systems convert the energy of the sun directly to electricity [1].

The series/parallel connection of numerous PV cells produces a photovoltaic generator with a non-linear current-voltage characteristic (I-V) and a maximum power point. The performance and deterioration of photovoltaic modules are affected by climatic variables such as irradiance and temperature, wind, and humidity [2]. PV arrays are made up of many cells that are linked together to produce the necessary voltage and current rating. At its maximum power point (MPP), the PV generator can give maximum power to the load. The location of this MPP fluctuates nonlinearly with irradiance and cell temperature [3].

Shading is a common phenomenon caused by passing clouds, shadows of trees, surrounding structures, dirt, debris, bird droppings, varying orientations and tilts, and so on, all of which face the PV array. Partial shade is an issue that interferes with the proper operation of the PV. The lighting is not spread evenly. Because of the emergence of several local maximum power points, this phenomenon makes extraction of the maximum power point problematic [4].

Shading a PV module not only cuts power, but it also causes hotspots and destroys the cells. To alleviate heat stress on shaded cells, a bypass diode is connected anti-parallel to a PV module. The impact of shadows varies depending on module type, bypass diode placement, string design, and severity. Shade and a current imbalance inside a PV system could cause power loss [5].

Shading is the complication. The current work investigates the influence of partial shade on the I-V and P-V characteristics of PV arrays, each of which consists of three modules: one with a bypass diode, one without, and one with both. The first section is an introduction, the second section is a brief discussion of PV systems, the third section discusses shading and bypass diode implementation, and the fourth section covers simulation details. Section five illustrates the results and debates. Finally, in section six the paper is concluded. common issue with the PV array [3].

II. Mathematical Model of Photovoltaic Module

In the literature, there are several electrical models to mathematically represent the photovoltaic cell. In this study, we are interested in the single diode model because of its simplicity to implement.

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II.1. Modeling of PV Cell

The PV cell's similar circuit is depicted in Figure 1. It consists of a current source I_{ph} , which shows the cell photo-current, a shunt, the cell's series resistances R_{sh} and R_s , and a diode. PV cells are typically joined into bigger components known as PV modules. PV arrays are created by connecting them in series or parallel to generate power in PV generation systems [3].

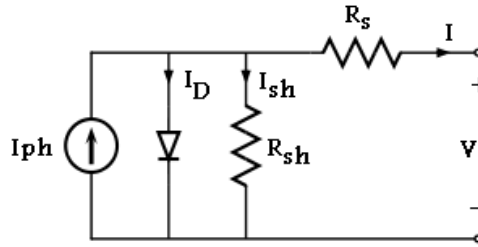


Figure 1. A PV cell's equivalent circuit [5].

The output current of a solar cell is then represented mathematically [6]:

$$I = I_{ph} - I_d - I_{sh} \quad (1)$$

With:

I : Photovoltaic current output.

I_{ph} : Photocurrent.

I_d : diode current.

I_{sh} : Parallel resistor current.

The current flowing through a parallel resistance is described by the equation below.:

$$I_{sh} = \frac{V + IR_s}{R_{sh}} \quad (2)$$

The junction current I_d is given by:

$$I_d = I_s \left[\exp \left(\frac{qV + IR_s}{N_s k A T_c} \right) - 1 \right] \quad (3)$$

With:

I_s : Reverse saturation current in amperes (A).

q : electronic load $q = (1.6 \times 10^{-19} \text{ C})$.

k : Boltzmann constant $K = (1.38 \times 10^{-23} \text{ J/K})$.

N_s : Number of solar cells connected in series.

T_c : Cell temperature in Kelvin (K).

A: Ideality factor of the diode which depends on the PV technology.

Reverse saturation current I_{rs} and Saturation current I_s are calculated by using Eqs. (4) and (5)

$$I_{rs} = I_{sc} / \left[\exp \left(\frac{qV_{oc}}{N_s k A T_c} \right) - 1 \right] \quad (4)$$

$$I_s = I_{rs} \left[\frac{T_c}{T_{ref}} \right]^3 \left[\exp \left(\frac{qE_g}{AK} \right) \left(\frac{1}{T_{ref}} - \frac{1}{T_c} \right) \right] \quad (5)$$

I_{rs} : Reverse saturation current of the cell at a reference temperature and solar radiation.

V_{oc} : Open circuit voltage.

E_g : Gap energy of the semiconductor used in the cell in electronvolt (eV).

Photocurrent is linearly dependent on solar radiation and is also affected by temperature, as seen in the following formula:

$$I_{ph} = I_{sc} + K_i \cdot (T_c - T_{ref}) \cdot \frac{G}{G_{ref}} \quad (6)$$

I_{sc} : Short-circuit current of the cell at 25°C and 1000W/m².

K_i : Temperature coefficient of cell short-circuit current.

T_{ref} : Reference temperature of the cell, in Kelvin (K)

G et G_{ref} : Irradiation and reference irradiation (G_{ref} = 1000W/m²).

II.2. Modeling of PV Module

The following equation describes the relationship between current and voltage in a PV module made up of many cells connected in series and parallel [7]:

$$I = N_p \cdot I_{ph} - N_p \cdot I_s \left[\exp \left(\frac{q \left(\frac{V_{oc}}{N_s} + \frac{I \cdot R_s}{N_p} \right)}{k \cdot T_c \cdot A} \right) - 1 \right] - \frac{\left(\frac{N_p \cdot V_{oc}}{N_s} + I R_s \right)}{R_{sh}} \quad (7)$$

$$\text{With: } I_{sh} = \frac{\left(\frac{N_p \cdot V_{oc}}{N_s} + I R_s \right)}{R_{sh}}$$

III. Partial Shading Effect on Solar Cells

The general problem with solar energy is partial shading of PV modules and non-uniform illumination. Non-uniform illumination can be caused by anything in nature, including clouds, leaves, electric poles, building shadows, guano, and so on. The amount of current passing through each cell must be the same. Shaded cells will be pushed to pass more current than the unshaded cells' new short circuit current. Shaded cells can only operate at currents greater than their short circuit current since they are in the negative voltage zone. As a result, the system loses net voltage. Shaded cells absorb electricity and start operating as a load. Shaded cells, in other words, generate hot spots by dissipating power as heat. As a result, the available current in a series string is limited by the current of the solar cell that receives the least amount of illumination [5].



Figure 2. PV Panel partially shaded.

IV. Implementation of a Bypass Diode

A bypass diode is used to reduce the effects of partial shading on P-V and I-V curves. It is connected in parallel with a series of cells. Figure 2 depicts four parallel-connected solar cells with a series-connected bypass diode in each. The energy generation in the other cells is drastically reduced when the shadow falls on the fourth cell and the diode is not employed; When a diode is utilized, however, the shadow's influence is limited to the shaded cell and the remaining cells are not affected by shading, lowering the loss in solar panel output. The shaded cell is generally bypassed because the diode is forced forward if the cell to which it is linked is shaded. [6].

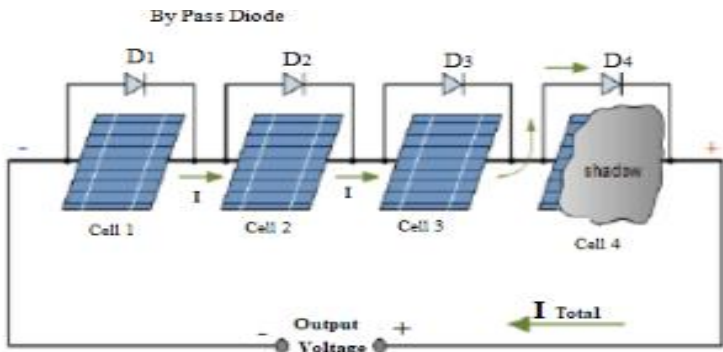


Figure 3. Connection of Bypass Diode across the module.

V. Simulations

In our simulation, we used three modules (1 Soltech 1STH-215-p) connected in series, with varying irradiation levels. We started our simulation without a bypass diode, then added one for each module (see Figure 4).

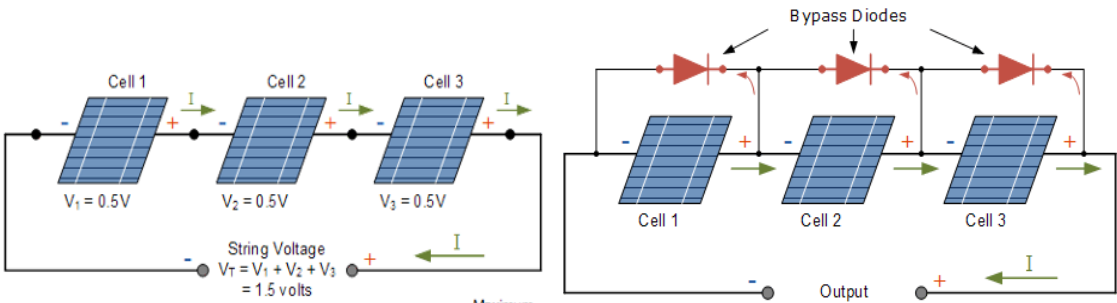


Figure 4. Three photovoltaic modules are connected in series without and with a bypass diode.

Table 1. Three photovoltaic modules are connected in series without and with a bypass diode.

Parameters	Symbol	Value
Maximum power	P_{max}	213.15
Voltage at Maximum Power	V_{mp}	29 V
Courant à Puissance maximale	I_{mp}	7.35 A
The Open circuit voltage	V_{oc}	36.3 V
short circuit current	I_{sc}	7.8 A

The numbered modules 1, 2, and 3 are lighted by a 1000 w / m² irradiation in both circumstances, i.e., without shadow, and then by the variant irradiancies (1000 w / m², 750 w / m², 500 w / m², and 100 w / m²) in both cases, see table 2.

Table 2. Various simulation situations with and without a bypass diode.

Cas	Module1 Irradiance(w/m ²)	Module2 Irradiance(w/m ²)	Module3 Irradiance(w/m ²)
I	1000	1000	1000
II	1000	1000	750
III	1000	500	500
IV	100	100	100

VI. Results and Discussions

We will explore the Effect of Shading on the Performance of Solar PV Panels using the block diagram standard using Matlab-Simulink software. Figures 5 and 7 illustrate our simulations for each module with and without a bypass diode. Figures 6 and 8 shows the I-V and P-V properties of three PV cells. With and without a bypass diode, at various irradiance levels :

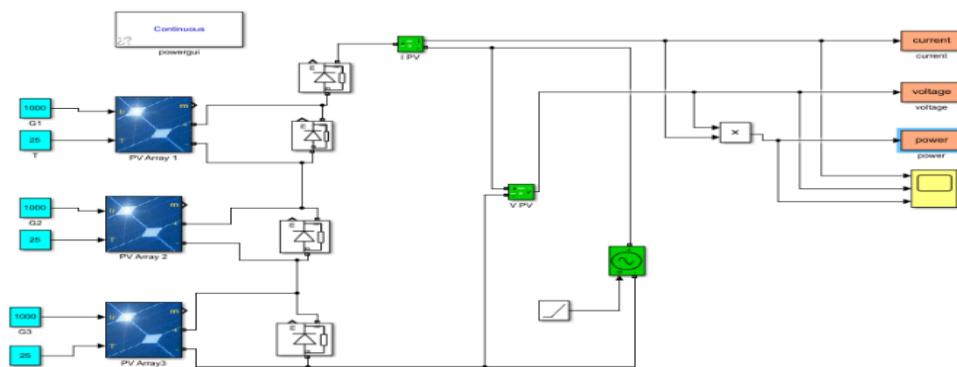


Figure. 5. Matlab/simulink model for scenario 4 with bypass diode

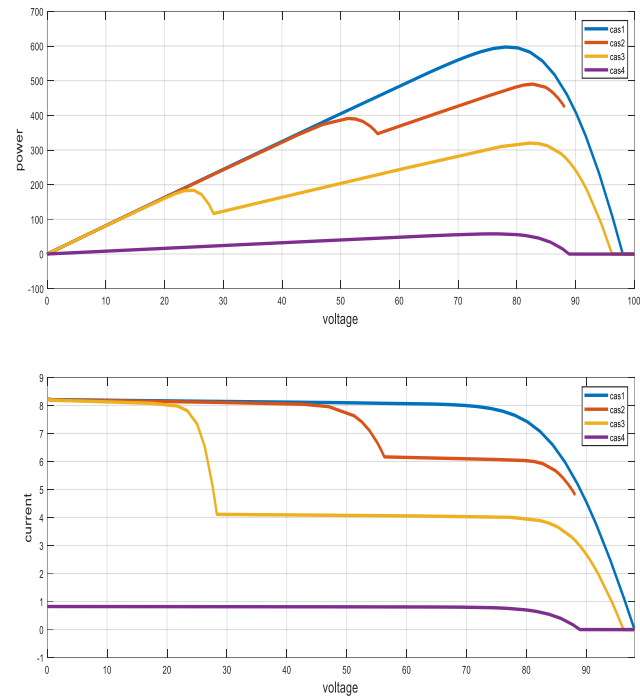


Figure 6. The resultant I-V and P-V Characteristics of three PV cells with different irradiances with bypass diode.

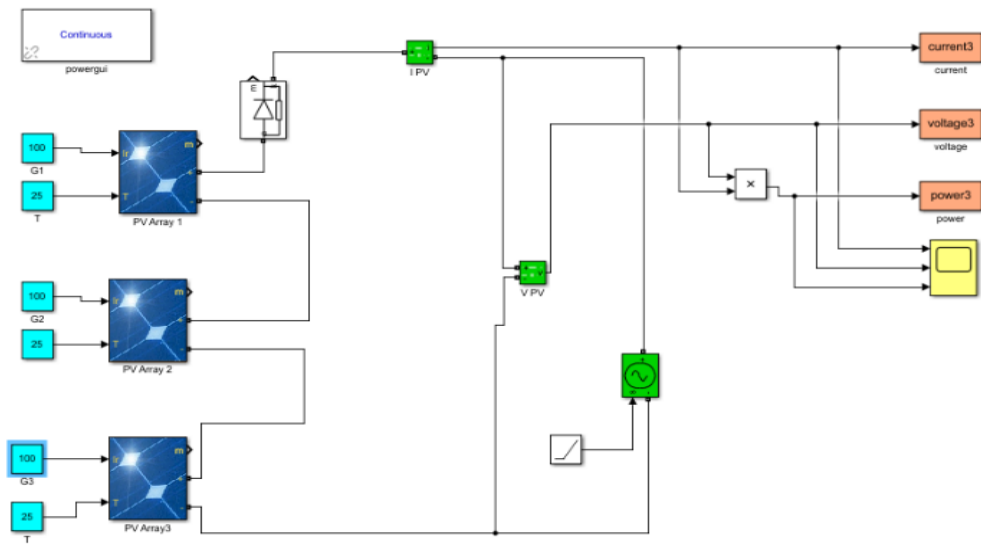


Figure.7. Model in Matlab/Simulink for Scenario 4 without a bypass diode.

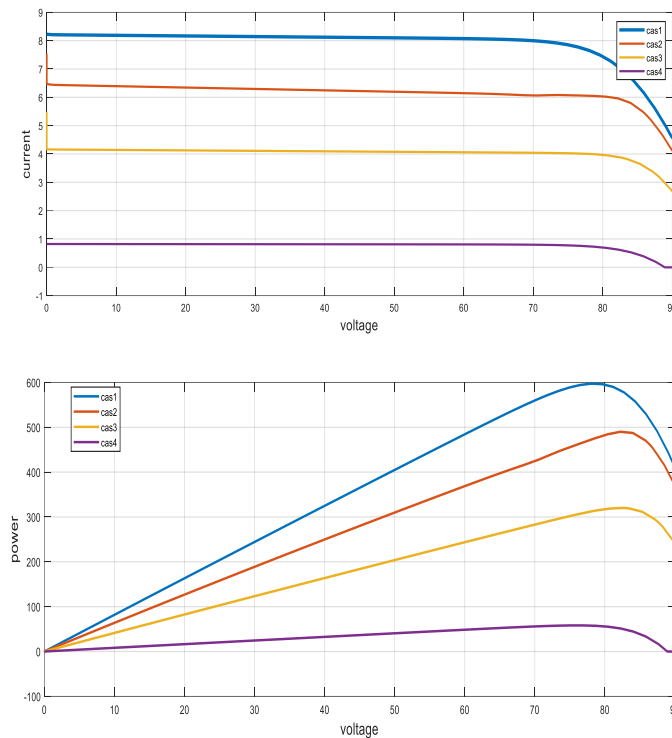


Figure 8 shows the I-V and P-V characteristics of three PV cells with various irradiances that do not have a bypass diode.

Figures 6 and 8 demonstrate the (P-V) and (I-V) properties of PV modules with changing illumination that are the same for all modules at constant temperature in the presence and absence of the bypass diode.

The following are the simulation results findings:

- Because of partial shading, the ISC lowers as the percentage of shading increases, and a linear relationship was observed between them. when a result, when the amount of shade increased, so did the power output.
- Many peaks in the output P-V curve can be attributed to shaded modules. When multiple threads are connected in parallel using bypass diodes. As the number of shaded modules grows, so does the frequency of these peaks.
- A solar PV system that includes bypass diodes generates more electricity than a system that does not. According to this claim, bypass diodes improve the performance of series modules in solar PV systems.
- No power is created when a module is completely shaded; The bypass diode linked across the module bypasses the power output of unshaded modules. As a result, while preserving the rated Isc, the array operates at a lower voltage.

VII. Conclusion

In this research, a simulation-based study of partial shadowing situations on PV panels is conducted. All PV cell and panel simulation models are created using Simscape in a Matlab/Simulink environment. After modeling the aforesaid models and comparing them, it is discovered that under partial shading, not only is the voltage and power output lowered, but numerous peaks of maximum power are obtained instead of a single peak. The inclusion of a bypass diode also influences the properties of a PV array. The simulation findings validate the system performance with and without a bypass diode under partial shading conditions.

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