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# A new algorithm described PV module's behavior under partial shading conditions

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**Abstract**

The shadowing of a single cell in string leads to reverse bias of the shadowed cell. The cell acts as a load instead of a generator in order to deal with this effect and the hotspots problems,  this paper focuses on the design of bypass diodes configuration and the behavior of a PV module (Suntech 85w) under partial shading divided from 36 cells into three parts of 12 cells and each part of these parts behaves like a single module,  The effect of shadow has been simulated on this module, based on the transmission of shadow for a single shaded cell, before increasing the number of shaded cells for the same shadow transmittance, and the effect of the shaded on the unshaded module and those in the presence and absence of bypass diodes. The simulation results show that the consequences of the shading phenomena can be limited by this configuration and thus increase the operating efficiency of photovoltaic (PV) systems.

**Keywords:** Photovoltaic module, shadow, by-pass diode, hotspot

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## 1. Introduction

Earth is the planet that provides us with the energy to live in. We have always used natural resources such as wood, carbon, petroleum, and gas but all of these resources are limited, and with a lot of exploitation we have affected our health and the environment. Right now, we have found several ways to get energy. We have found new sources that allow us to live and preserve the environment at the same time [1]. These sources are renewable energy sources such as Solar Energy. Photovoltaic technology is used to describe the hardware made of semiconductor materials, which converts sunlight into electrical power, however, their high dependence on weather conditions (temperature and irradiance) and relatively low conversion efficiency are their main drawbacks [2] [3]. Under such conditions, PV panels are exposed to partial shading due to clouds, buildings, and trees. Because this effect in turn reduces the PV panel output significantly. Furthermore, bypass diodes are mounted in PV modules to restrict the maximum reverse voltage produced through cells in the event of shading or malfunctioning of specific strings. Bypass diodes are an important part of PV modules and their failure can have a negative effect on the efficiency and durability of the modules. Due to shading and corresponding reliability problems including hotspots, the decrease in the output power of PV modules has been extensively studied [4]. Hot spots occur when a solar cell becomes reverse biased and dissipates energy in the form of heat, usually being part of a solar cell chain of serially attached solar cells. This appears as an influence on the PV module with a mismatch or in the presence of shadows. If the power dissipated in hot-spot conditions by the solar cell reaches the maximum power that the cell can absorb, this will be destroyed and an open circuit will emerge. The architecture of the PV array and the arrangement of the bypass diodes on the PV modules that form part of the array have a major impact on the likelihood of hot spot presence [5]. Various articles discuss the behavior of photovoltaic PV cells under partial shadowing, taking the diode into account. But there are only a few who take the significance of configuring the diodes into consideration [6]. A simulation approach to analyze various potential bypass diode configurations as part of the PV module is discussed in this article.

## 2. Shading description

Photovoltaic modules are very sensitive to shading. Photovoltaic modules cannot be obscured, mainly because of electrical connections (in series) between cells and between modules. There are two types of shading: total shading and partial shading. In this case of study, the focus is on the type of partial shading that will be simulated in the next part to see the behavior of the I-V and P-V curves of a PV module and the loss of photovoltaic production due to it [7].

### 2.1 Partial shading of the PV module

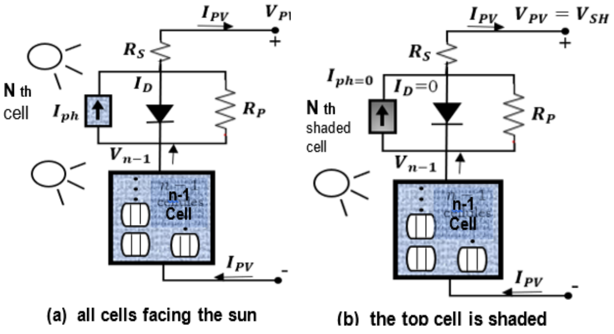
When PV cells are associated in series, the circulating current overall is limited by the current generated by the least efficient or less illuminated cell. Thus, a cell that would not receive the same amount of light as the rest of the set would produce a weaker current, this is called partial shading [8].

### 2.2. Partial shading of the PV module

Consider figure (1.(a)) representing a photovoltaic module with a cell that is separate from the others. All cells are exposed to the sun in this figure, and through each of them flows the same current. However, in figure (1.(b)), the cell at the top is affected by the shadow and its $I_{Ph}$ current is reduced to zero, meaning that the total current flowing through the module must pass through the two resistances $R_P$ et $R_S$of the shadow-affected cel. This causes the output voltage to drop ΔV [9]. which is given by the following relation:

$$\Delta V = \frac{V}{n} + R_P * I \qquad (1)$$

n: number of cells, I: total current in the module



(a) all cells facing the sun
(b) the top cell is shaded

Figure 1. Photovoltaic module with a cell touched by the shadow

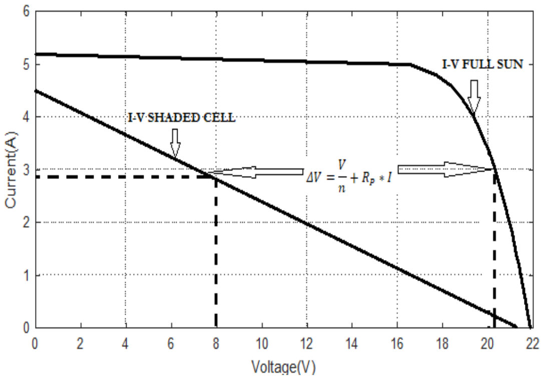


Figure 2. Effect of a single shaded cell on the module

The shadowing of a single cell in a string leads to a reverse bias of the shadowed cell when the photovoltaic cells or modules are connected in series. The cell acts as a load instead of a generator, causing the cell temperature to increase significantly if the temperature increases too high and if the system is not sufficiently protected, hot spot problems will occur and the cell or module can be irreversibly damaged in extreme cases and affect the entire PV module or PV array [10].

## 3. GPV classic protection

### 3.1. By-pass Diode

In order to avoid the "hot spot" phenomenon, by-pass diodes were connected to a solar cell in parallel, but with opposite polarity, as seen in figure (3), this technique effectively prevents shaded cells from hot spot damage and reduces power losses induced by partial shading.

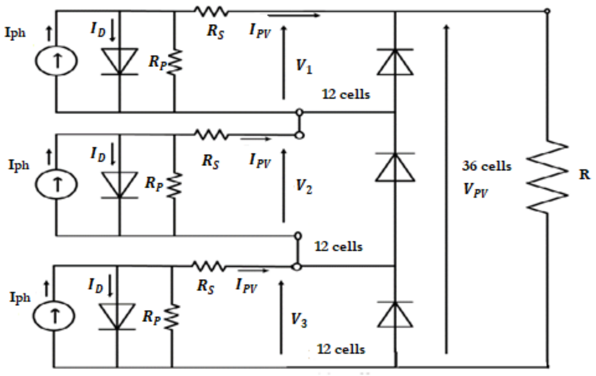


Figure 3. Equivalent schematic of the series connection of the PV cells with a bypass diode.

The PV cells will be forward-biased under uniform irradiance, so the by-pass diode will be reverse biased (open circuit). However, under non-uniform irradiance, by-pass diodes will be conduct and the current of non-shaded solar cells will pass through them (Figure 3).

In practice, one bypass diode per solar cell is normally too costly, usually, one bypass diode should be applied per 18 to 20 cells, it is often proposed that even a smaller number of cells per bypass diode might become necessary [10] [11].

## 4. Method of simulating the behavior of a partially shaded PV module

Figure 3 shows the equivalent circuit of a shady-cell PV module. Non-shaded, so-called normal, and shady cells are linked together in series. $N_2$ less illuminated cells and $N_3$ shaded cells for a PV module with $N_1$ normally illuminated cells, as the cells are connected in series, it's given that:

$$V_{PV} = V_1 + V_2 + V_3 \qquad (2)$$

$$I_{PV} = I_1 = I_2 = I_3 \qquad (3)$$

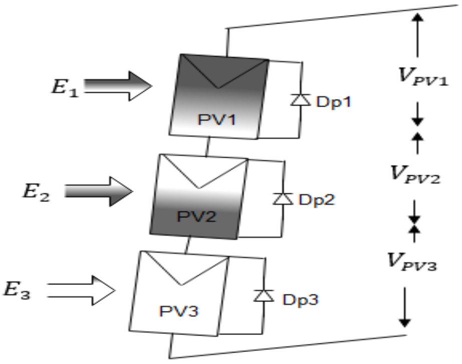


Figure 5. The equivalent circuit of a shady-cell PV module.

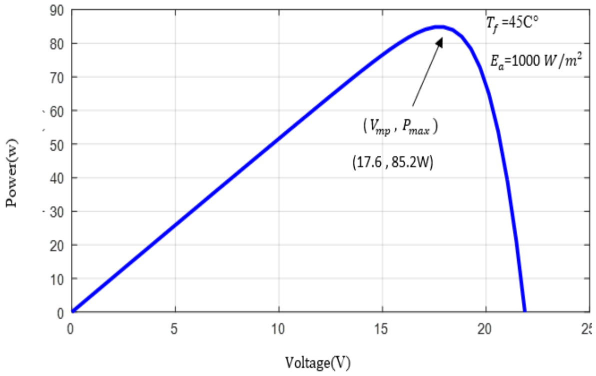


Figure 6. Characteristic power-voltage (P-V) of a photovoltaic module.

The PV module voltage is obtained as a function of the module current as presented in equation 4 [12]

$$V = V_T \times l_n\left(\frac{I_{Ph}+I_0-I\left(1+\frac{R_S}{R_P}\right)-\frac{V}{R_{sh}}}{I_0}\right) - I\,R_s \qquad (4)$$

This mathematical model describes the operation of the PV module to analyze the behavior of the I-V and P-V curves in the presence of partial shading problems. The use of the simulation program MATLAB/SIMULINK seems to be an effective approach for tracking the evolution of the various variables. Figure 6 shows the P(V) characteristics where the module is fully illuminated.

4.1. Simulation of the study case

To take into account the shading effect, the PV module (Suntech 85W) is divided from 36 cells into three parts of 12 cells and each of these parts behaves like a single module. The series and shunt resistances of each part are taken equal to 1/3 of the corresponding value for the complete module [13].

Table 1. Parameters of the photovoltaic panel

| Type | Suntech 85W |
|---|---|
| Number of cells in series | 36 |
| Maximum power (W) | 85.2 W |
| Maximum power voltage (V) | 17.60 V |
| Maximum power current (A) | 4.83 A |
| Open circuit voltage (V) | 21.9 V |
| Short circuit current (A) | 5.15 A |
| The series resistance of PV model (ohms) | 0.145Ω |

The effect of shadow will be simulated on this module, based on the transmission of shadow for a single shaded cell, before increasing the number of shaded cells for the same shadow transmittance, and the effect of the shaded module on the unshaded modules, those in the presence and absence of bypass diodes. The algorithm used to describe the behavior of the PV module under partial shading conditions is shown in Figure 7:

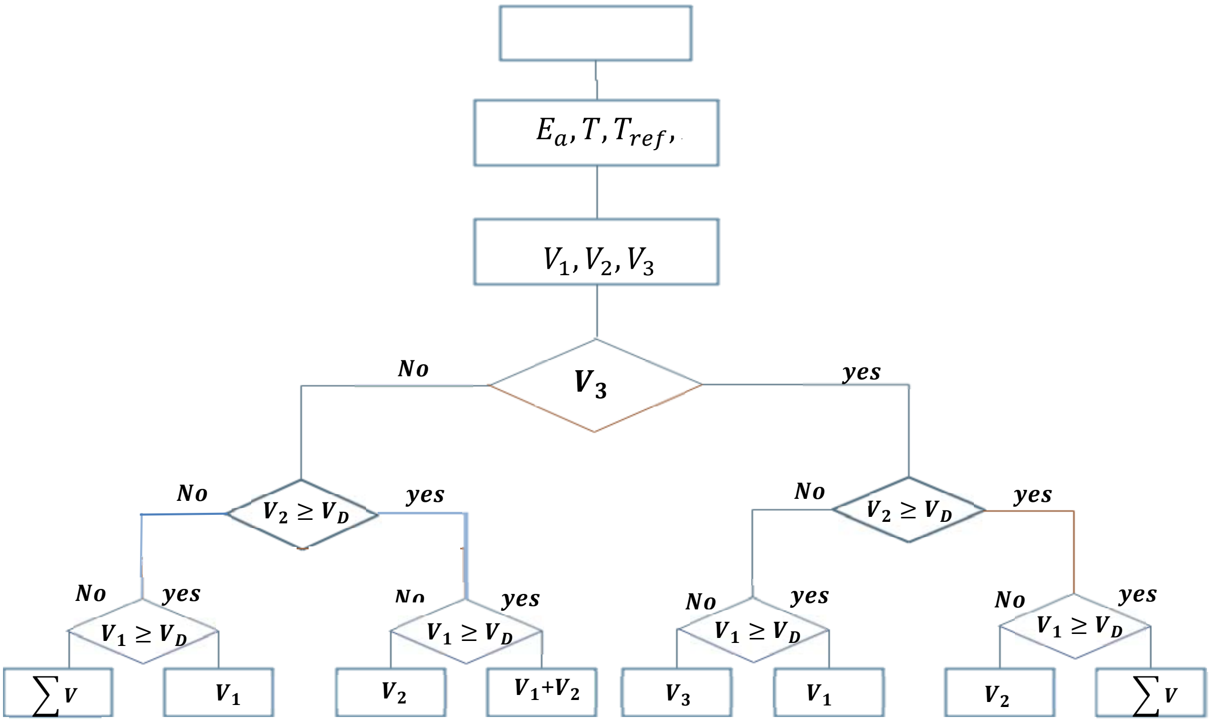


Figure 7. Algorithm described the behavior of the PV module under partial shading conditions

## 4.2. Simulation results

### 4.2.1. Without by-pass diodes

a) 04 shaded cells Case, with variable transmission

Figures 8 and 9 show simulation results of the I-V and P-V characteristics respectively when 04 cells are shaded with different values of shadow transmittance ($\boldsymbol{F_S}$=1, $\boldsymbol{F_S}$=0.75, $\boldsymbol{F_S}$=0.50, $\boldsymbol{F_S}$=0.35, $\boldsymbol{F_S}$=0.25)

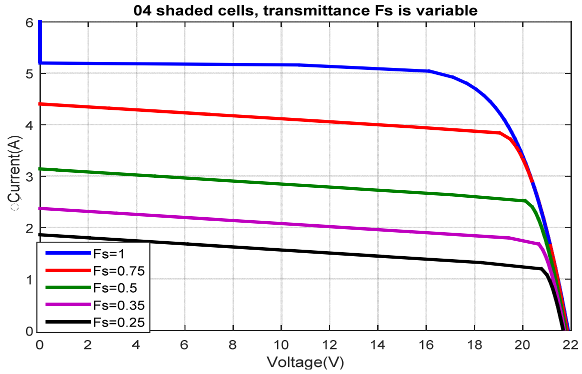


Figure 8. I-V curves of the PV module with 04 shaded cells for different values of shadow transmission.

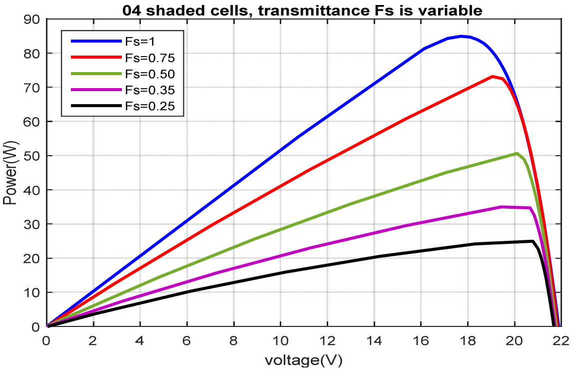


Figure 9. P-V curves of the PV module with 04 shaded cell for different values of shadow transmission

as shown in figure 8, it's clear that the partial shading of 04 cells of PV module causes the deformation of the shape of the I-V characteristic caused by the fact that the current decreases from the short-circuit point and more and more to around of the open circuit point. This decrease increases as shadow transmission decreases. Open circuit voltage is not affected but power decreases considerably when shadow transmission decreases as seen in Figures 9.

b) Fixed transmittance, variable number of shaded cells

For a shadow transmission set at 50%, the number of shaded cells (from 0 to 3) is varied, and figures 10 and 11 represent the I-V and P-V characteristics.

For the same transmission, the increase in the number of shady cells makes the decrease in short-circuit current more important, but the shape of the I-V curve does not change and the power produced by the module decreases only slightly when the number of shady cells increases for the same transmission.

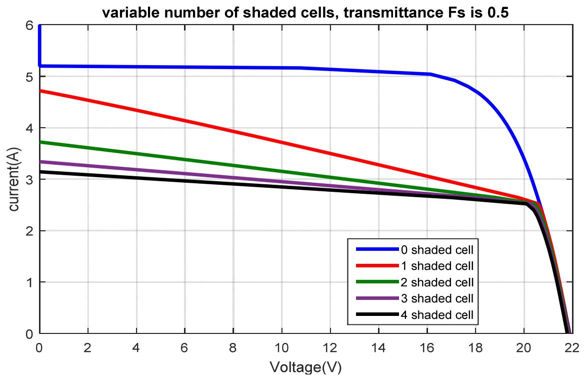


Figure 10. PV module I-V characteristics based on the number of shaded cells.

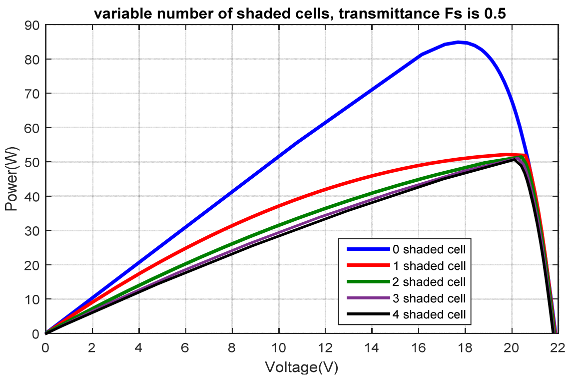


Figure 11. PV module P-V characteristics based on the number of shaded cells.

### c) The effect of the shaded module on the unshaded modules

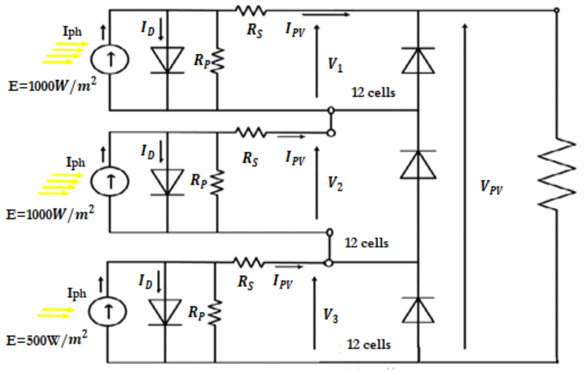


Figure 12. Equivalent circuit of three modules connected in series with bypass diodes.

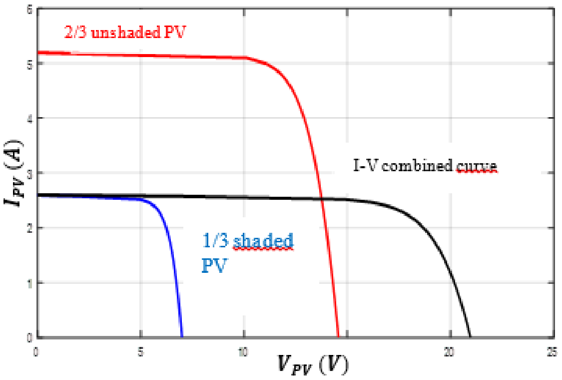


Figure 13. I-V Characteristic curve of four PV modules without bypass diode.

Three PV modules in series with a resistor as load (without bypass diode) are connected in this test, the irradiance of the first two PV modules is 1000 W/m2 (unshaded modules), and the irradiance of the third is 500 W/m2 Compared to the unshaded PV module, the generating current of a shaded PV module decreases significantly in Figure 13. Moreover, even if only a very small part of the PV module is shaded, the generation current is reduced to a much larger degree than we would expect.

As a result, the combined output power of the non-shaded and shaded PV modules connected in series decreases significantly, it is also clear that the short circuit current of the three PV modules falls to the short circuit current of the shaded PV module without bypass diode since the current of the shaded PV module is lower than the optimum current of the other non-shaded PV modules.

### 4.2.2. With by-pass diodes

### a) 04 shaded cells Case, with variable transmission

Figures 14 and 15 represent the results of the simulation of I-V and P-V characteristics in the case that these by-pass diodes are connected by varying the transmission of the shadow for a single shady cell.

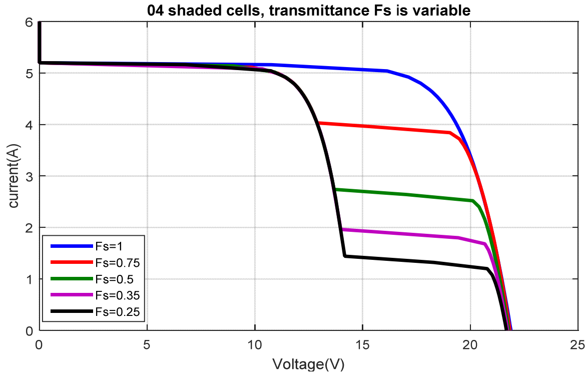


Figure 14. I-V curves of the PV module with 04 shaded cell for different values of shadow transmission.

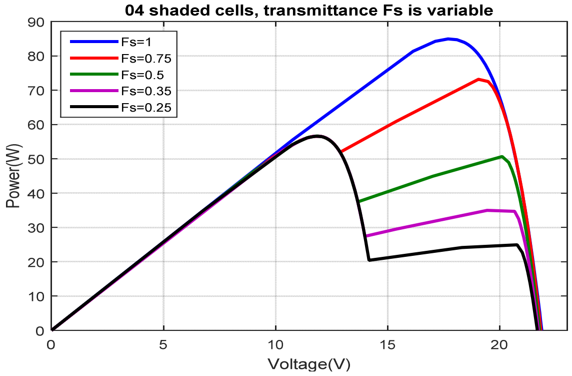


Figure 15. P-V curves of the PV module with 04 shaded cell for different values of shadow transmission

The effect of by-pass diodes results in the disconnection of the entire part that contains the 4 shaded cells as long as it is polarized in reverse. The current from which the shady part reconnects to the other part of the module decreases with the decrease in shadow transmission. The action of the by-pass diode makes two points of maximum power appear on the P-V curve.

### b) Fixed transmittance, variable number of shaded cells

Figures 16 and 17 represent the simulation results of the I-V and P-V characteristics for this module with by-pass diodes by varying the number of shaded cells (from 0 to 3) for a shadow transmission set at 50%. As the number of shaded cells increases, the current from which the shaded part connects decreases. But, from a number of shady cells (3 cells for our case) this part remains disconnected regardless of the load.

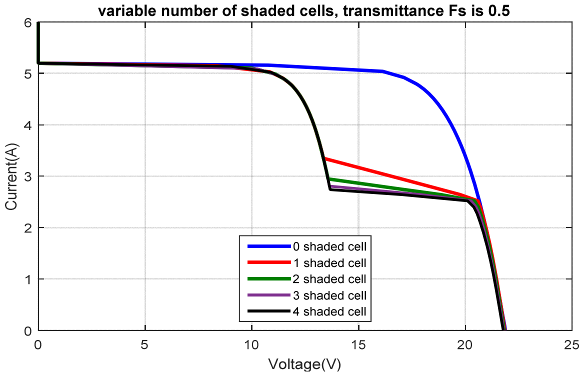


Figure 16. PV module I-V characteristics based on the number of shaded cells.

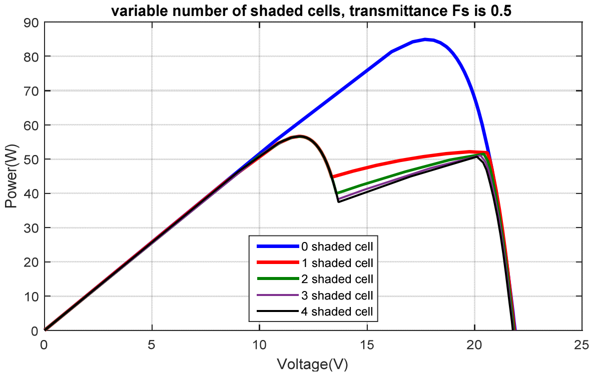


Figure 17. PV module P-V characteristics based on the number of shaded cells.

c) The effect of the shaded module on the unshaded modules

In this test, the same conditions as test 1 are used, except that the bypass diode is connected with each PV module in parallel.

The bypass diode does not function at region 1 in Figure 18, the current of the two unshaded PV modules falls to the current of the shaded PV module, leading to a significant decrease in output power, whereas the shaded PV module produces maximum power at point A. (the unshaded modules generate power but does not generate maximum power).

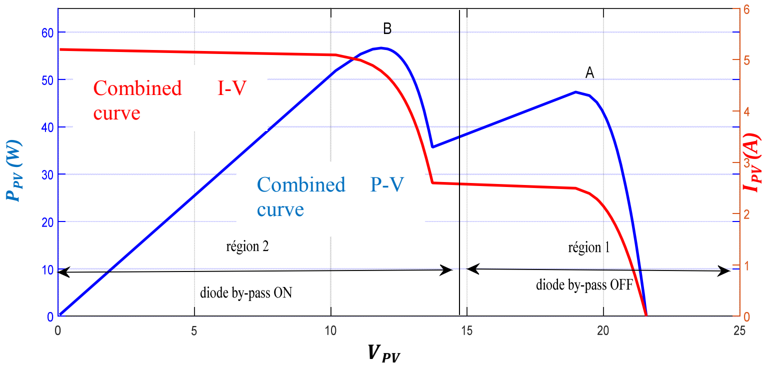


Figure 18. Effect of bypass diodes on I-V & P-V Characteristics

## 5. Results and discussion

A reverse voltage may be too high or too much current may be crossed by the occulted cell, which may result from irreversible damage that may lead to the collapse of an entire station. Occultation is a random phenomenon, so the dissipated power is the main drawback.

In practice, penetration in this area is all the more detrimental to the life of the module as it is deep and prolonged.

The importance of the Fs shadow factor is observed during the simulation by acting directly on the direct and inverse characteristics of PV. It is necessary to keep it above 0.5 and it is more than desirable to have it close to the unit.

The By-Pass diode is required for any PV installation and even becomes mandatory to ensure circuit protection and at the same time recover dissipated power.

When installing, it is always necessary to minimize the probability of having a large number of cells obscured because this is a definite danger to the equipment

## 6. Conclusion

In this paper, a method has been implemented to simulate the electrical behavior of a partially shaded PV module. With this configuration, it turns out that it's possible to study the effect of the shading rate as well as the influence of the number of shaded cells and modules on the I-V characteristic for both cases: without the bypass diodes and with the bypass diodes. This method applies to any PV module for which the parameters are known. It is particularly important for PV systems integrated into buildings where the risk of shading is greater. This digital simulation is used to understand the operational behavior of these components and the interactions between them. From the simulation of the performance of a system, one can trace all the stages of energy conversion and identify in detail the losses through the system.

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