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Influence of Solar Insolation and Shading Coefficient on the Electrical Parameters of A Photovoltaic Module

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Abstract:-*The present work focuses on sunlight conditions and environmental influence on photovoltaic (PV) solar modules. These modules are often exposed to very severe operating conditions that induce defects in the cells that constitute the module. Defects on the solar modules are modelled as shading defects, dirt or dust deposits, and others. The study showed the dependence of the overall module temperature on the solar insolation level. The photovoltaic module comprises 72 cells divided into six (06) groups of twelve (12). The theoretical study was carried out in the case of shadowing defects on photovoltaic (PV) solar modules. This work also showed the negative influence of shading on the electrical parameters of a module.*

Keywords: Photovoltaic module, shading defects, solar insolation, temperature, electrical parameters

Introduction

Energy remains an essential factor for the socio-economic development of a society. It is becoming problematic with the rise in oil prices and the environmental consequences of using fossil resources. Today, different forms of renewable energy under different technologies (solar, wind, hydro, biomass, etc.) offer great flexibility and reliability to reduce the energy deficit due to increased demand. The solar photovoltaic energy sector is a relevant response to the World's energy problems [1], [2], [3]. Photovoltaic modules are often exposed to quite severe environmental conditions. The electrical performance parameters of a PV module are highly dependent on sunlight and environmental conditions such as ambient temperature, wind speed, shading, dust, etc. These severe operating conditions induce defects in the cells: cracking, delamination, discolouration, corrosion, hotspots PID (Potential Induced Degradation), and bubbles [4] - [9]. For this work, defects are modelled as shading defects, dust defects, and dirt deposits. A good evaluation of the electrical parameters of solar panels requires considering operating conditions [10], [11]. In this paper, we are interested in a study of solar insolation and shading effects on the electrical parameters of photovoltaic modules located at TEN MERINA in Thies climatic area.

I. Characteristics presentation of the considered photovoltaic module

The PV modules considered in this work are of type: JKM320PP-72. Each PV module is an assembly of six (06) groups of twelve (12) solar photovoltaic cells mounted in series mode [12]. The number of PV cells in series in Table 1 below gives the technical specifications of the module.

Table 1: Technical specification of the JKM320PP-72 module

Paramètres	**Valeurs**
Maximum Power (Pmax)	*320W*
Power Tolerance	*0 ~ + 3%*
Maximum Power Voltage (Vmp)	*37.4V*
Maximum Power Current (Imp)	*8.56A*
Open circuit voltage (Voc)	*46.4V*
Short circuit current (Isc)	*9.05A*
Nominal Operating Cell Temp (NOCT)	$45 \pm 2°C$
Maximun Système Voltage	*1000VDC*
Maximum Series Fuse Rating	*15A*
Operating Temperature	*-40°C ~ +85°C*
Application Class	*A*
Fire Class	*C*
Weight	*26,5 KG*
Dimension	*1956 x 992 x 40 (mm)*
STC	*1000 W/m2, AM1.5 25°C*

II. Theoretical study of photovoltaic modules with defects

In this work, we take into account shading defects. We use a module consisting of cells in the "standard" one-diode model established by "Shockley". This model represents the electrical behaviour of the P-N junction. Figure 1 below shows the equivalent diagram of the photovoltaic cell in a one-diode model [1], [2], [5].

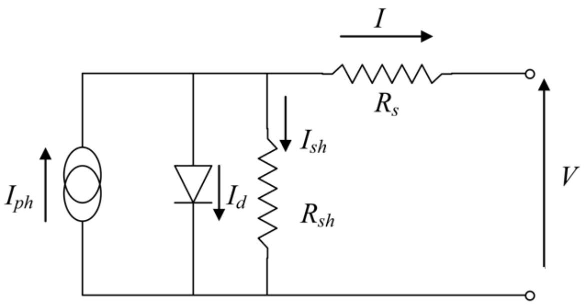

Figure 1: Equivalent diagram of a Photovoltaic cell in the one-diode model

II.1. Relationship between solar insolation and PV cell temperature

The module's temperature depends on the level of solar insolation, and its evolution is given by the following mathematical expression [1, 2].

$$T_C(G) = Ta + \frac{NOCT - T_{a,ref}}{800}.G \qquad \text{(II.1)}$$

With Ta: in [°C], $T_{a,réf}$: Ambient reference temperature (it is equal to 27°C)

II.2. Photocurrent

For a module, the photocurrent Iph is a function of temperature and solar insolation and the short-circuit temperature coefficient α_{sc} generally given by the manufacturer [1, 2]. The following relationship expresses the photocurrent.

$$I_{ph}(G,\alpha_{sh}) = \alpha_{sh}\left[I_{ph,STC} + \alpha_{sc}\left(Tc(G) - T_{C,STC}\right)\right]\frac{G}{G_{STC}} \qquad \text{(II.2)}$$

With

$$I_{ph,STC} = \frac{R_s + R_{Sh}}{R_{Sh}} \cdot I_{SC,STC} \qquad \text{(II.3)}$$

Where

$I_{ph,STC}$ is the module current under standard conditions in [A].

$I_{SC,STC}$ is the short-circuit current under STC

α_{sc} is the temperature coefficient for the current (A/°C).

G is the measured incident irradiance (W/m2)

$Tc(G)$ is the measured (or estimated) module temperature (°C)

$T_{C,STC}$ is the reference temperature of the module (25°C).

G_{STC} is the illuminance at STC,

α_{sh} is the shading coefficient

II.3. Photovoltage

The photovoltage characterises the potential barrier present at the transmitter-base junction. Its expression is obtained from Boltzmann's law. It is related to the short-circuit photocurrent by the following relation **[1, 2]**.

$$V_{ph}(G,Tc,\alpha_{Sh}) = \alpha_{Sh} \cdot n \cdot k \cdot \frac{T_c(G)}{q} \cdot \ln\left(\frac{\left[I_{ph,STC} + \alpha_{sc}\left(Tc(G) - T_{C,STC}\right)\right]\frac{G}{G_{STC}}}{I_0(Tc)} + 1\right) \qquad \text{(II.4)}$$

Where k is Boltzmann's constant
T is the ambient temperature (K)
q is the electron charge (C)
n is the ideal factor

II.4. Caractéristique I-V

The following mathematical expression gives the relationship to obtain the I-V characteristic profile of the photovoltaic (PV) solar module [1, 2, 10].

$$I(G,V,Tc,\alpha_{Sh}) = \alpha_{Sh} \cdot \left(\begin{array}{l} I_{ph}(G) - I_0(Tc) \cdot \left(\exp\left(\frac{V + Rs \cdot I(V)}{Vt}\right) - 1\right) \\ -\frac{V + Rs \cdot I(V)}{Rsh} \end{array}\right) \qquad \text{(iI.5)}$$

I.5. Power

The power is obtained by taking the product of voltage and current for a solar PV cell. The expression is given by:

$$P(G,V,Tc,\alpha_{Sh}) = I(G,V,Tc,\alpha_{Sh}) \cdot V(G,Tc,\alpha_{Sh}) \qquad \text{II.6}$$

II.6. Form Factor (FF)

The form factor (FF) of a PV cell indicates the effective surface area of the cell able to convert incident photons into electrons by the photoelectric effect. It's given by equation (II.7).

$$FF = \frac{V_m \cdot I_m}{V_{co}(G) \cdot I_{cc}(G)} \qquad \text{(II.7)}$$

II.7. Efficiency

The energy conversion efficiency is defined as the ratio of the maximum generated power (Pm) to the incident radiation power (Pinc) over the cell area [13, 14]. The following relationship, therefore, gives it:

$$\eta(G,Tc,\alpha_{Sh}) = \frac{P_m}{P_{inc}} = \frac{V_m \cdot I_m}{G \cdot S} = \frac{FF \cdot V_{OC}(G,Tc,\alpha_{Sh}) \cdot I_{CC}(G,Tc,\alpha_{Sh})}{G \cdot S} \qquad \text{(II.8)}$$

$$I_{CC}(G,Tc,\alpha_{Sh}) = \alpha_{Sh} \cdot \left[I_{ph.STC} + \alpha_{SC}\left(Tc - T_{C.STC}\right)\right] \cdot \frac{G}{G_{STC}} \qquad \text{(II.9)}$$

$$V_{OC}(G,Tc,\alpha_{Sh}) = \alpha_{Sh} \cdot n \cdot k \cdot \frac{T}{q} \ln\left(\frac{\left[I_{ph.STC} + \alpha_{SC}(Tc - T_{C.STC}) \right] \cdot \frac{G}{G_{STC}}}{I_0(Tc)} + 1 \right) \quad \text{II.10}$$

III. Study of the influence of solar insolation and defects on the electrical parameters of the photovoltaic cell

In this section, we will study the influence of solar insolation and the environment on the electrical parameters of a PV cell. The study will show the profile of a PV cell's electrical parameters (photocurrent, photovoltage, efficiency), considering the extrinsic defects according to the considered electrical model.

III.1. Influence of sunlight on electrical parameters

Figure 2 shows the temperature variation profile as a function of solar insolation.

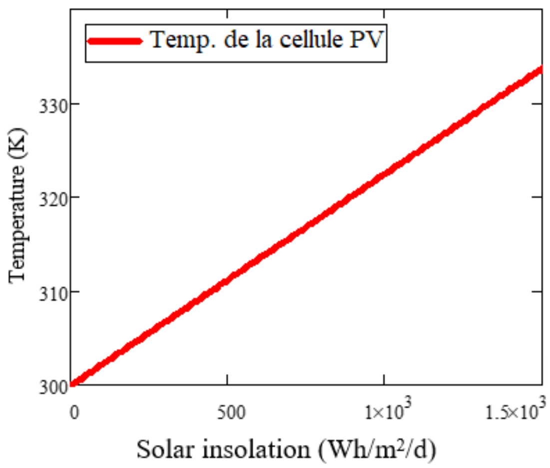

Figure 2: solar cell temperature variation profile as a function of solar insolation

Figure 2 shows a linear variation of the temperature as a function of the sunlight. Indeed, the electrons acquire additional positive energy, leading to thermal agitation by breaking some covalent bonds are explains the temperature increase.

III.2 Influence des défauts d'ombrage sur un module PV

The solar cell model considered for this work is the single-diode model connected in the shunt. This type of diode limits the current flow through the shaded cells. I(V) and P(V) characteristics of the PV module are shown for different shading level values [4].

III.2.1 Photocurrent

Figure 3 shows the profile of photocurrent variation as a function of sunlight level.

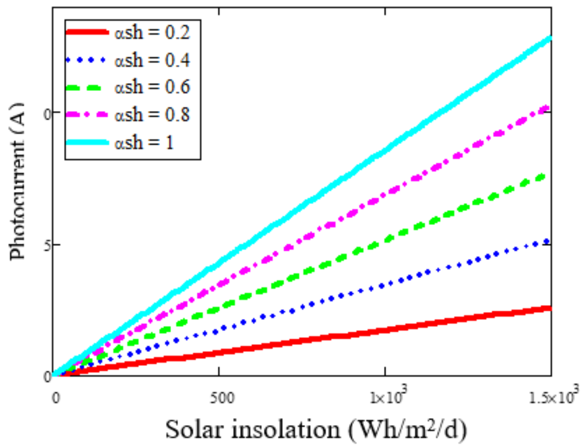

Figure 3: Photocurrent variation profile as a function of solar insolation for different shading coefficient values αsh

Figure 3 shows the photocurrent density modulus as a solar insolation function. The coefficient αsh, which takes values between zero (0) and one (1), models the shading level of PV modules or deposition of dirt or dust. The maximum photocurrent density profile is obtained for αsh=1 corresponding to a clear sky, without dirt or dust deposits on the PV panels. An increase in the shading rate decreases the rate of photogenerated carriers, which will no longer have enough energy to reach the ZCE junction. For αsh=0, corresponding to total shading, the current produced by the PV module is low. The cell dissipates its power in the form of heat that can reach quite high temperatures of around 100°C, which can burn out the module, the so-called "hot spot" phenomenon [16]-[18].

III.2.2 Photovoltage

It represents the voltage across the cell under illumination. Figure 4 below shows the variation profile of the photovoltage as a function of sunlight.

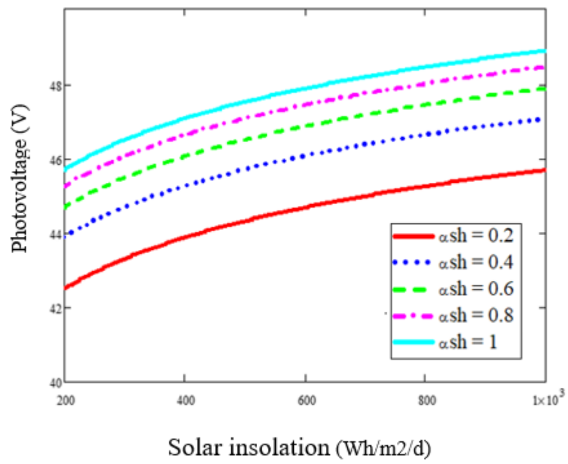

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Figure 4: Photovoltage variation profile as a function of solar insolation for different values of the shading coefficient

When photons of energy hν >Eg illuminate a cell, minority carriers pass through the junction: holes accumulate in the p region and electrons in the n region. This excess of negative charges on the n side and positive charges on the p side biases the junction forward, resulting in a photovoltage. Figure 4 shows an increase in photovoltage as a function of solar insolation. As the shading coefficient increases, there is a decrease in the number of photogenerated carriers on both sides of the junction, resulting in a decrease in photovoltage. The shaded cells behave as receptors and do not participate in the photovoltage.

III.2.3 I-V Characteristics

Figure 5 below shows the profile of the I-V characteristic of the module for different values of the shading coefficient.

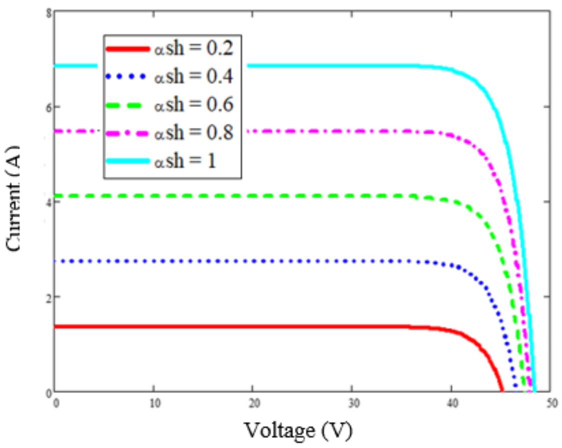

Figure 5: I-V characteristics of a PV module for different values of the shading coefficient αsh

Figure 5 shows that for αsh = 0, the current is maximum in a short circuit situation, and the same is noted for the voltage in the open circuit. The increase in the shading coefficient decreases carriers' generation and the carriers' accumulation on both sides, which explains a decrease in the current and voltage values noted on the I-V characteristic. Thus, the maximum power point shifts to lower values.

III.2.4 Power

Figure 6 below shows the Power profile as a function of voltage for different values of the shading coefficient.

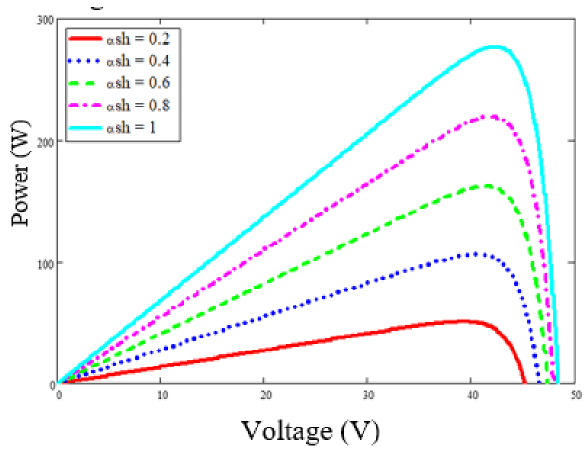

Figure 6. Power versus voltage profile for different values of the shading coefficient αsh

Figure 6 shows the power curve of the PV module. It shows a decrease in the maximum power as the shading coefficient increases due to a decrease in photocurrent and photovoltage. It confirms the observed situation at the I-V characteristic.

III.2.5 Efficiency

Figure 7 below shows the evolution of the module efficiency as a function of solar insolation for different values of the shading coefficient.

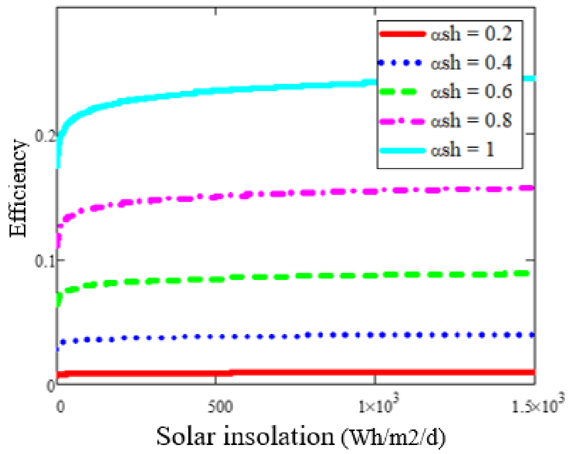

Figure 7. Effect of shading on PV module efficiency

Figure 7 shows that the conversion efficiency decreases considerably with the shading phenomenon due to a decreased current and voltage at the module, as observed earlier.

Conclusion

In this paper, we are mainly interested in the effect of solar insolation and the environment on PV systems. This effect manifests in the form of defects that affect PV modules' good functioning through electrical parameters' degradation. The study showed that solar insolation increases cell temperature. The study also showed the negative impact of the shading phenomenon, which significantly reduces the module's current, voltage, power output, and efficiency.

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