Effects of climatic conditions on a polycrystalline photovoltaic module in Niger

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ABSTRACT. The main purpose of this paper is to evaluate the efficiency of a photovoltaic module operating in a sahelian country like Niger. A brief introduction to the behavior and the functioning of a photovoltaic module has been presented and the basic equations needed for a modeling based on ambient parameters have been also written. For the validation, characteristics of experimental purpose are presented with a satisfactory reliability degree. The effects of external parameters, mainly temperature, solar irradiance and wind speed have been considered on the output current characteristic and the output power characteristic. Due to their critical effects on the operation of the panel, effects of series resistances were also studied.

1. INTRODUCTION

Photovoltaic (PV) cells convert solar energy directly into electricity that can be used for many purposes. This technology is considered in many countries as an interesting alternative to fossil fuels. It can generate electricity with no CO₂ emissions and requires almost no maintenance. This sustainable source of energy has achieved tremendous growth in recent years and it is considered as the most promising renewable energy technology. However, the power delivered by a photovoltaic panel is highly dependent on climatic conditions: temperature, solar irradiation, wind speed, humidity, etc. [1-4].

Knowledge of the characteristic of a PV panel is a pre-requisite for modeling PV power supply. The power delivered by a PV module varies with the environment. The objective of this study is to estimate a simple model of current and power panel based on climatic parameters such as ambient temperature, solar irradiation and wind speed, and to analyze their effects on the efficiency of the module.

2. MATHEMATICAL MODEL OF A SOLAR CELL

The solar power is generated by direct conversion of the sunlight with a photovoltaic cell. Several cells are connected to each other in series and / or in parallel to form a solar panel [5, 6].

An association of identical number of cells (ns) in series increases the voltage of the panel and all cells are traversed by the same current.

Similarly, if the cells are associated in parallel, the current increases and the voltage at the terminals of each cell is the same.

The electrical characteristic of the current $I = f(V)$ of a photovoltaic cell can be schematically represented as shown in Fig. 1. [7-9]:

Fig. 1. Solar cell model

This circuit is composed of:

- A current source I_{PH} generated by light in the cell;
- A diode representing the PN junction in the cell and characterized by a current I_D ;
- A series resistor R_S which is the internal resistance of the cell, and which depends mainly on the semiconductor material used and the contact resistance of grids;
- A parallel resistor R_P due to the leakage current through the junction.

Applying Kirchhoff's law, the current delivered by the cell is equal to:

$$I = I_{PH} - I_D - \frac{(V + I * R_s)}{R_p} \quad (1)$$

$$I = I_{PH} - I_0 * e^{\left(\frac{V_D}{V_T} - 1\right)} - \frac{(V + I * R_s)}{R_p} \quad (2)$$

$$V_D = V + R_s * I \quad (3)$$

$$V_T = \frac{(n * k * T * N_s)}{q} \quad (4)$$

V_D : voltage of the diode,

I_0 : reverse saturation current of the diode,

V_T : the thermal voltage

n : the ideality factor,

k : Boltzmann's constant, q : electron charge,

T : temperature of the cell

N_s : number of associated cell in series.

The short-circuit current, representing the current for which the voltage across the cell is zero, can be obtained:

$$I_{CC} = I_{PH} - e^{\frac{(R_s * I_{CC})}{V_T}} - \frac{I_{CC} * R_s}{R_p}$$

$$I_{CC} \cong \frac{I_{PH}}{1 + \frac{R_s}{R_p}}$$

$$I_{PH} = [I_{CC0} + K_1(T - T_{ref})] \cdot \left(\frac{\Psi}{\Psi_{ref}} \right)$$

where I_{CC0} (A) is the short-circuit current for a standard solar irradiation Ψ_{ref} (W / m^2) and at the reference temperature T_{ref} , K_1 (% / °C) is the temperature coefficient of the cell and Ψ (W/m^2) the solar irradiation.

The saturation current of the diode depends strongly on the temperature and can be expressed as shown in Equation:

$$I_0 = I_{0n} \cdot \left(\frac{T}{T_{ref}} \right)^3 \cdot \exp \left[\frac{E_G \cdot q}{k} \cdot \left(\frac{1}{T_{ref}} - \frac{1}{T} \right) \right]$$

E_G is the band gap energy of the semiconductor and I_{0n} the saturation current defined as:

$$I_{0n} = \frac{I_{CC0}}{\exp \left(\frac{V_{CO0} + K_2 \cdot (T - T_{ref})}{V_T} \right) - 1}$$

K_2 (mV / °C) is the temperature coefficient of the open-circuit voltage nominal.

Also, the open circuit voltage which set the voltage at which the cell current is zero in the perfect case is slightly equal to [10-12]:

$$V_{CO} = V_T \cdot \ln \left(\frac{I_{PH}}{I_0} + 1 \right)$$

The cell temperature depends on the irradiance, the ambient temperature and the wind speed according to [15, 16]

$$T = a_0 + a_1 \cdot \Psi + a_2 \cdot T_a + a_3 \cdot W_S + T_{ref} + 273,15$$

where a_0 a_1 a_2 a_3 are constants equal to 3.12, 0.25, 0.899 and -1.3, respectively. In the equation, T is in °K, Ψ in W/m^2 , T_a in °C and W_S in m/s.

3. RESULTS AND DISCUSSION

The measures are achieved at Niamey (Abdou Moumouni University). Globally, experimental the task consisted of traducing the relationship between observed measures and issued model (e.g. Fig. 2.). It is composed of a photovoltaic module whose characteristics are detailed in the TABLE I and different sensors (anemometer, solar meter, thermometer, Hall Effect sensor, etc.) which are used to measure in real time the wind speed, the irradiance, the temperature and outputs of the PV module such as the voltage, the current (I) and the power (P).

Fig. 2. Experimental bench

Table 1. Electrical and geographical characteristics pv module

Maximun power (Pm)	70 W
Voltage at Pm (Vm)	15,5 V
Current at Pm (Im)	4,5 A
Open-circuit voltage (Voc)	21,8 V
Short-circuit current (Isc)	5,05 A
NOCT (Air 25°C; sun 1 kW/m ² ; wind 1 m/s)	47 ± 2°C
Temperature coefficient of Isc	(0,065±0,015)%/°C
Temperature coefficient of Voc	-(80±10) mV/°C
Temperature coefficient of power	-(0,5±0,05) %/°C
Tolerance	± 3
Solar Cell	72 cells
Connected cell number in series	36
Connected parallel strings	2
Latitude (Niamey/Niger)	13°31'01" North
Longitude (Niamey/Niger)	2°06'00" East
Slant of PV module	16 degrees South

For validation experiments we have considered a processing chain based on a single photovoltaic system with three following climatic parameters (irradiation, temperature and wind power).

It has been obtained considering interpolation technique applied on measured data points corresponding to the possible two operating voltage outputs such as the current and power keys. Note that the estimated mean squared error rate of the compared current is 0.0069539 for 300 W/m², 29 °C and 5 m/s. Moreover, this method gives correlation coefficients varying for the three mentioned climatic conditions between 97 and 99 % (e.g. Fig. 3.) [16]

Fig. 4. Electrical characteristics varying temperature -constant irradiance ($1000\text{W}/\text{m}^2$) and wind speed ($1\text{m}/\text{s}$)

The main parameters that affect the output current, power and voltage of the modeled panel have been considered. These are the solar irradiation, the wind speed and the temperature at the site. Note that if the temperature of the panel decreases, the output voltage increases for constant irradiation and wind speed. For instance (e.g. Fig. 4.), the photocurrent increases almost of $0.0005\text{ A} / ^\circ\text{C}$, leading to a reduction of the open circuit voltage of the order of $0.0685\text{ V} / ^\circ\text{C}$. This causes a reduction of the power of $0.3772\text{ W} / ^\circ\text{C}$ for a change of 0.56% . Figure 5 shows that the I-V and P-V output characteristics of a PV module depend on the irradiance fluctuation at constant temperature and wind speed. The PV output current and power vary with insulation conditions while the voltage output increases.

When the wind speed increases, the photocurrent decreases nearly of $6.10\text{-}4\text{A} / (\text{m} / \text{s})$ (e.g. Fig. 6). This causes an increase in the open circuit voltage. This growth is in the order of $99\text{ mV} / (\text{m} / \text{s})$ and results in a raise in the power of $0.5501\text{ W} / (\text{m} / \text{s})$, corresponding to a variation of 0.82% . This shows that the ventilation (natural or forced) of PV modules improves the productivity, because the performance is more important at lower operating temperatures. In fact, it plays the rule of regulator cooling cells.

The performance of a photovoltaic cell is even more degraded than R_s is large. Figure 7 shows the influence of the series resistance of the electrical characteristics. This is reflected by a falling in the slope of the I-V and P-V curves in the area where the panel will operate as a source of voltage.

Fig. 4. Electrical characteristics varying temperature -constant irradiance ($1000\text{W}/\text{m}^2$) and wind speed ($1\text{m}/\text{s}$)

Fig. 5. Electrical characteristics of PV module varying irradiance-constant temperature (25°C) and wind speed (1m/s).

Fig. 6. Electrical characteristics of PV module -varying wind speed-constant irradiance (1000W/m^2) and temperature (25°C)

Fig. 7. Electrical characteristics-varying Resistance series- NOCT (25°C , 1000W/m^2 , 1m/s)

4. CONCLUSION

The performances of a photovoltaic generator are strongly influenced by climatic conditions of the environment, especially solar radiation, temperature and wind speed. In this study, we used the empirical model with a diode to simulate the operation of the panel at different conditions and the model is validated with experimental data. The main interest was to show that taking into account the wind power parameter of the PV module is important so as to improve the electrical characteristics.

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