

Role of the wind speed in the evolution of the temperature of the PV module: Comparison of prediction models

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Abstract - *The prediction of the PV module temperature is necessary for the dimensioning of photovoltaic systems, particularly in desert areas where the very high temperature of the module can significantly affect the performance PV. Several mathematical models were developed to predict the temperature of the PV module. However, some models neglect the effect of wind speed (like NOCT). This factor, responsible of cooling PV module by convection, must be studied to predict better the evolution of the module temperature in any climate condition. For this, we followed the temperature of a monocrystalline silicon PV module. We then compare the evolution of the measured temperature with NOCT and SNL models according to the wind speed. The results show that even with the SNL model that takes into consideration wind speed, the predicted and measured temperature are similar only in high wind speed range.*

Résumé - *La prédiction de la température du module PV est nécessaire pour le bon dimensionnement des installations photovoltaïques, notamment dans les régions désertiques où la température très élevée du module peut affecter considérablement le rendement PV. Plusieurs modèles mathématiques sont développés pour prédire la température du module PV. Cependant, certains modèles négligent l'effet de la vitesse du vent (comme NOCT). Ce facteur étant responsable du refroidissement du module par convection doit être étudié pour mieux prédire l'évolution de la température du module dans toutes les conditions climatiques. Pour cela, nous avons suivi la température d'un module PV en silicium monocristallin. Nous avons, ensuite, comparé l'évolution de la température mesurée avec celle des modèles NOCT et SNL en fonction de la vitesse du vent. Les résultats obtenus montrent que même avec le modèle SNL qui prend en considération la vitesse du vent, la température prédite correspond à celle mesurée uniquement dans une gamme élevée de vitesse du vent.*

Keywords: Module PV - Temperature prediction – NOCT – SN.

1. INTRODUCTION

The electricity production from solar source depends mainly of the exploitation climate region. Indeed, photovoltaic production depends on the solar irradiation, but also of temperature of its cells [1-5]. However, the cell temperature depends on several meteorological factors (solar irradiation, ambient temperature and wind speed), encapsulation materials and the type of installation in the operating site.

These meteorological factors determine the module temperature, i.e irradiation such as a heat source (inflow) and the ambient temperature and wind speed as a means of heat dissipation (outflow).

In this regard, several research studies have brought on the measures of the junction temperature/module in different regions in the world, taking account of the parameters such as the type of the cell, the encapsulation materials and type of installation. Their results show that PV module temperature exceeds 65°C even though the ambient

temperature is lower than 40°C [6-10]. This temperature affects significantly the photovoltaic efficiency [11]. In Southern Algeria the summer ambient temperatures exceed 40°C; this makes the study of the effect and the evolution of the PV module temperature necessary before investing in solar energy.

1.1 Models of module temperature prediction

Several temperature prediction models were developed in the last years. Their main difference is in the consideration, or no, of some parameters such as wind speed (WS).

1.1.1 NOCT

The NOCT model is based on the nominal temperature of cell operation (NOCT). It takes account, more to this parameter, the ambient temperature and solar irradiation. Note that the NOCT is a value supplied by the manufacturer of the solar panel. It includes the type of the cell and the encapsulation materials. The module temperature in this model is given by [12]:

$$T_m = T_{amb} + \frac{(\text{NOCT} - 20) E}{800} \quad (1)$$

T_m , Module de temperature; T_{amb} , Ambient temperature; NOCT, Nominal temperature of the cell operation; E , Solar irradiation.

1.1.2 SNL

Sandia National Laboratories (USA) has developed another model (SNL) that integrates ambient temperature, solar irradiation and wind speed [13]. This model also takes account the nature of cell, encapsulation materials and type of installation. Module temperature is given by:

$$T_m = E \times e^{(a+b \times Ws)} + T_{amb} \quad (2)$$

T_m , Module de temperature; T_{amb} , Ambient temperature; E , Solar irradiation; Ws , Wind speed, a and b , Coefficients empirically determined.

a and b values are given in a **Table** based on the encapsulation material and the type of installation.

1.1.3 Heat balance of PV module (HB)

To better compare those model, we have developed a thermal balance of the PV module that we have established taking account the configuration of the PV module used in this work (encapsulation materials, thickness of the layers and installation type). We used a monocrystalline PV module, encapsulated between a glass plate and a layer of Tedlar®.

Equations (3), (4) and (5) are obtained by the thermal balance of figure 1.

$$\varepsilon \sigma T_v^4 + \left(\frac{1}{R_{VE}} + \frac{1}{R_C} \right) T_v - \frac{1}{R_C} T_\infty - \varepsilon \sigma T_{sky}^4 - \frac{1}{R_{VE}} T_C = 0 \quad (3)$$

$$\varepsilon \sigma T_t^4 + \left(\frac{1}{R_{ET}} + \frac{1}{R_C} \right) T_t - \frac{1}{R_C} T_\infty - \varepsilon \sigma T_g^4 - \frac{1}{R_{ET}} T_C = 0 \quad (4)$$

$$T_C = \frac{R_{ET}}{R_{VE} + R_{ET}} T_v + \frac{R_{ET}}{R_{ET} + R_{ET}} T_t + \frac{R_{VE} \times R_{ET}}{R_{VE} + R_{ET}} \alpha \tau q \quad (5)$$

Resolution of these equations it's executed by numerical method, to obtain the temperature of the PV module.

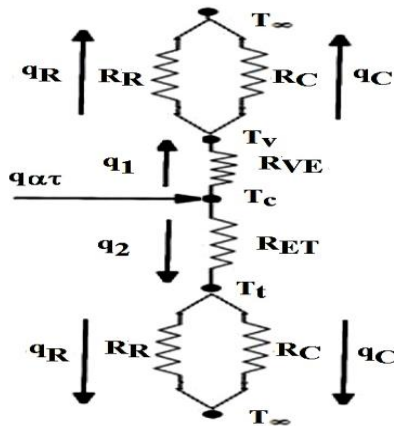


Fig. 1: Electrical analogy of the heat balance the PV module

2. EXPERIMENTAL MEASUREMENT

We used a monocrystalline silicon PV module with a power $P_{mpp} = 90.6 \text{ W}$, south oriented and tilted at 37° , the tilt of Algiers city. Temperature measurements were performed on three separate days, namely 10/01/13, 14/05/14 and 22/05/14. These days were chosen for their different wind speed values.

We used the J-type thermocouples temperature sensors. Three sensors were placed on the back of the module, thereby measuring the temperature of the backsheet of three different cells. We show in the graphs the average temperature of the three sensors.

Other meteorological parameters are taken from the measuring station CDER, on the same site (global irradiation, ambient temperature, wind speed). As shown in figure 2.



Fig. 2: -a- measurement of module PV temperature
 -b- metrological station of CDER

3. RESULTS AND DISCUSSION

Figures 3, 4 and 5 respectively show the evolution of the PV module temperature in the three days according to the three meteorological parameters, namely, ambient temperature, solar irradiation and wind speed.

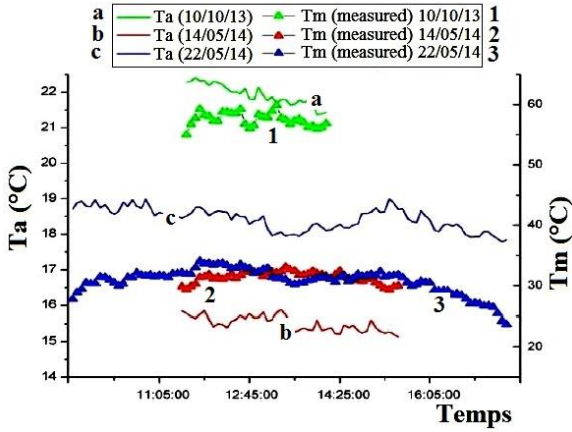


Fig. 3: Evolution of PV module temperature (T_m) and the ambient temperature (T_a) during the three measurements days

The PV module temperatures in the days of 14 and 22/05/14 are very similar (around 30°C). However, the ambient temperature of these two days recorded a difference of about 3°C . This shows that the room temperature is not the most influential parameter on the PV module temperature.

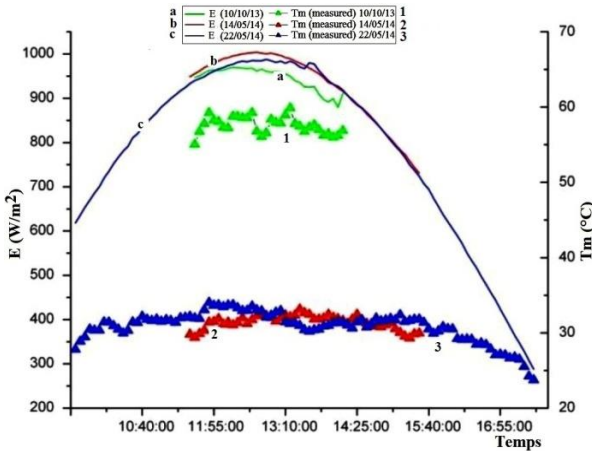


Fig. 4: Evolution of PV module temperature (T_m) and solar irradiation (E) during the three measurements days

In figure 4, the PV module temperature is significantly higher during the day of 10/10/13 despite lower solar irradiation. This shows that despite the higher heat flux in the other two days, probably higher heat dissipation has better cooled the PV module.

In figure 5, we see that wind speed is comparable during the days of 14 and 22/05/14. This is as true for the PV module temperature. For another day (10/10/13) wind speed is lower resulting an increase in PV module temperature.

The analysis of these three graphs shows that the wind speed is a critical factor in the prediction of PV module temperature. It controls the heat dissipation within the module.

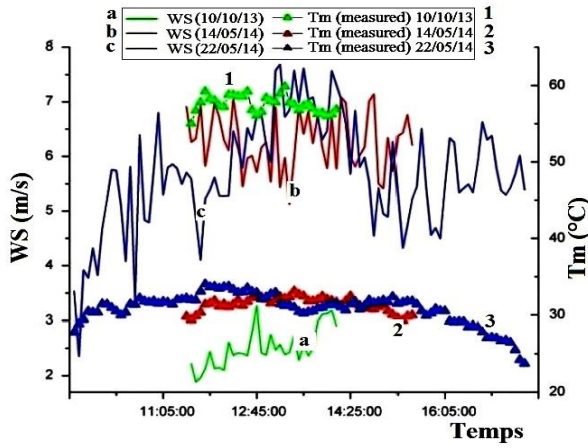


Fig. 5: Evolution of PV module temperature (T_m) and wind speed (WS) during the three measurements days

We will see the reliability of the temperature prediction models regarding the different wind speed ranges.

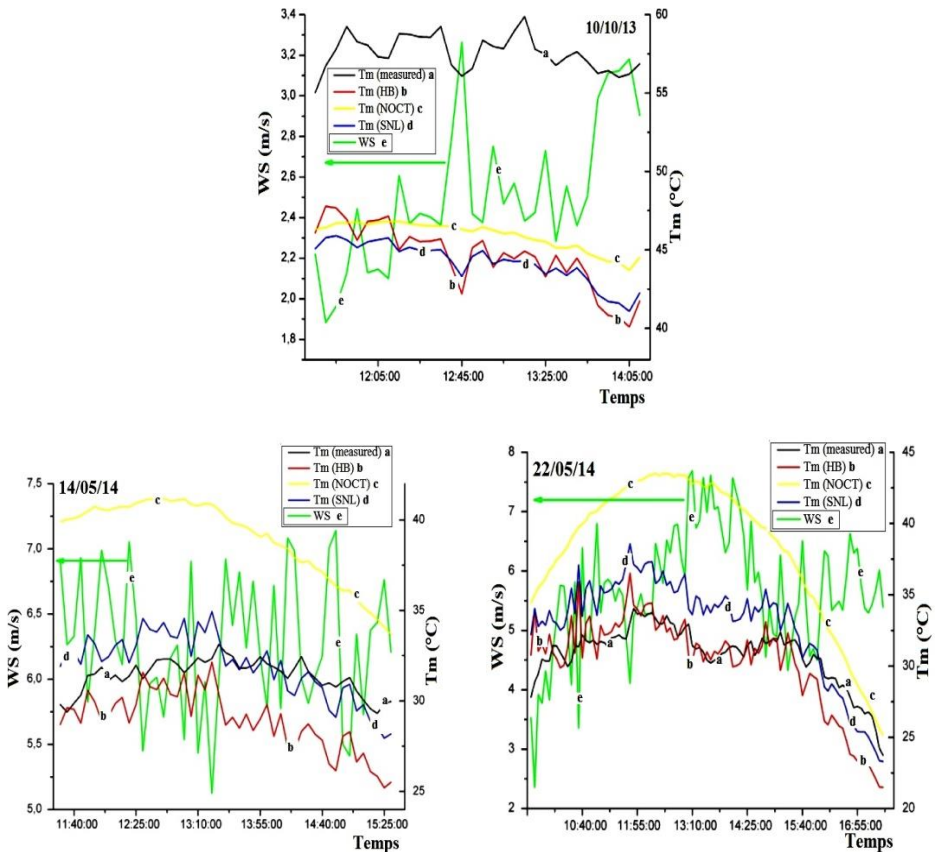


Fig. 6: PV module temperature (T_m) measured and calculated by the prediction models; NIGHT, SNL and heat balance (HB), and wind speed

For the first day, the measured temperature is much higher (more than 10 °C) compared to the temperatures calculated by different models. These fluctuations are inversely related to fluctuations in wind speed, which explains the peculiarity of the NOCT curve. The NOCT model takes a fixed value for wind speed ($WS = 1\text{ m/s}$).

For the second day of measurement, SNL and HB models provide two temperature curves very similar to that measured in inverse proportion to the fluctuations of wind speed curve. These fluctuations are slightly offset to the measured temperature. This is due to permanent regime assumed in both models unlike the reality in which the regime is transient which creates a time lag. The temperature obtained by NOCT is significantly higher than the measured temperature, because the wind speed in this day is much higher than 1 m/s (5 to 7 m/s).

The day 22/05/14 is similar to 14/05/14, we have a strong wind speeds and the temperatures obtained by SNL and HB are close to the measured temperature. The temperature obtained by NOCT is completely different from the measured, in term of value and fluctuations. It should be noted that the NOCT curve is dominated mainly by the curve of solar irradiation. In late day the solar irradiation decrease (less than 600 W/m^2) and the four curves converge because PV module temperature decline with the decreasing of solar radiation; heat source. In this irradiation range of temperature measured curve converge to NOCT curve despite a higher wind speed of 5 m/s.

To compare the impact of wind speed on the prediction of temperature we took the values of the three days when the radiation is greater than 950 W/m^2 . We also normalized these values relative to an ambient temperature of 20°C. Figure 7 shows a comparison of the evolution of measured temperature and the temperature calculated by different models depending on the wind speed under the conditions mentioned above.

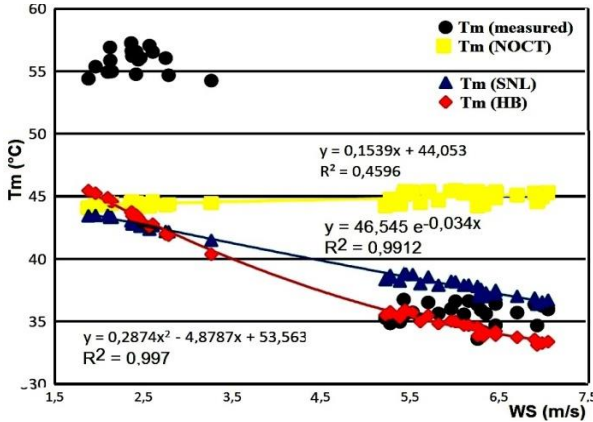


Fig. 7: Evolution of measured and calculated temperatures according to the wind speed

The evolution of the temperature according wind speed obtained by the models is coherent with their mathematical equations. Indeed, the temperature in the NOCT model is almost constant (a slight variation mainly due to radiation varied between 950 and 1000 W/m^2). This model takes constant wind speed of 1 m/s. The temperature of the SNL model varied exponentially with wind speed as shown in equation (2) of SNL model. The HB temperature varies according polynomial function as indicated by equations (3), (4) and (5).

However, the evolution of the measured temperature is not related to any of these three models. It shows an evolution in two different intervals of wind speed. A first on

low wind speeds between 1.5 and 3.5 m/s and a second between 5 and 7.5 m/s. This difference may be explained by the existence of two convection regimes for heat dissipation, which intervene depending on wind speed.

In our heat balance, the average convection coefficient between the glass, the Tedlar® and ambient air, h_c , was calculated using the empirical correlation [14]:

$$\bar{h} = 2.8 + 3V_\infty \tag{6}$$

Figure 7 shows that this estimate corresponds better to higher wind speeds of 5 m/s and does not correspond to those between 1.5 and 3.5 m/s.

4. CONCLUSION

We have shown in this study the importance of wind speed in the prediction module temperature. The temperature measurements of the PV module made during three different days show that reliability prediction models depends, among others, on the wind speed. SNL and HB models give good estimates of the temperature when the wind is strong (greater than 5 m/s). This estimate is less accurate for low wind speeds (between 1.5 and 3.5 m/s). The NOCT is less accurate because it fixes the wind speed at 1 m/s that don't reflect the real conditions. The origin of these differences between the models and the measurement is explained by different convection regimes that can be set up according to wind speed. It is therefore more judicious to integrate this parameter in the temperature prediction models.

NOMENCLATURE

q , Solar irradiation	q_R , Heat dissipation by radiation
q_1 , Heat dissipation by conduction glass face	q_2 , Heat dissipation by conduction on back sheet
q_C , Heat dissipation by convection	
R_{VE} , Thermal resistance of glass and EVA	R_{ET} , Thermal resistance of tedlar and EVA
R_R , Thermal resistance by radiation	R_C , Thermal resistance by convection
T_C , Cell temperature	T_T , Tedlar temperature (module)
T_V , Glass temperature	T_∞ , Ambient temperature
α , Absorptivity	τ , Transmission coefficient of glass

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