Voltage Temperature Coefficient impact on four type silicon photovoltaic module technologies modeling under outdoor operating condition

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Abstract: In this paper, attention has been paid to the importance of knowing the exact values of the temperature coefficients used in modeling of four different types of photovoltaic modules these modules are; monocrystalline silicon m-Si, polycrystalline silicon p-Si, amorphous silicon a-Si, and micromorphous silicon thin film µm-Si installed in outdoor conditions in north-central Algeria. The value of the temperature coefficients provided by the module manufacturer in the datasheet is obtained under specific conditions called the standard test conditions STC, but in reality, these conditions vary significantly if the modules are operated in real climatic conditions, this will lead us to recalculate these coefficients again to improve our model using a database collected over a period of one year obtained by our characterization bench of PV modules using a two diodes model. A comparison was made between the simulation and the experimental data of the selected modules using the new values of the calculated temperature and those given at STC conditions, the obtained results show that the use of these new calculated temperature coefficients leads to a reduction of the the Mean Relative error MRE on the annual power from 2 to 7% depending on the PV module's technology which shows the importance of knowing the real value of the temperature coefficients that will be used in the PV module and system modeling.

Keywords: photovoltaic module, temperature coefficient, outdoor, solar irradiation

1. INTRODUCTION

In the field of modeling and sizing of photovoltaic systems, the influence of temperature on the electrical performance of photovoltaic modules is a very important, especially in regions with hot climates or which have four seasons where temperature and irradiation changes a lot as Algeria region. The manufacturers of photovoltaic modules provide the electrical characteristics under Standard Test Conditions (STC) i.e. irradiance of 1000 W/m², temperature at 25°C and solar spectrum of Air Mass 1.5, which makes it possible to compare the modules installed in different regions of the world. In order to have an accurate prediction model, the characteristics of the current-voltage (I-V) modules installed in outdoor must always be corrected using measurement data obtained from the experiment, not only for the irradiance but also for temperature. Those modules suffer degradation due to exposure to continuous changes in ambient temperature, humidity, and solar radiation, and the temperature coefficient may change due to aging [1].

The electrical efficiency of the photovoltaic module depends on temperature and it reduces when the temperature increases [2]. The use of the temperature coefficient values provided in STC is not sufficient to predict its performance [3]. Sandia laboratories has used module specific temperature coefficients to estimate the energy yield of photovoltaic modules [4-6]. The accuracy of the intended output is improved if the modulus is specific temperature coefficients are used compared to the technology average values [7]. Smith et al. evaluated the temperature coefficient for currents, voltage and power of 12 c-Si Modules on the NREL outdoor test bench using outdoor I-V data from these modules [8]. King and al have found that the influences can cause the temperature coefficient of the modules and arrays differ much from that of the constituent modules [9]. Many authors have investigated the temperature coefficients and its influence on photovoltaic modules [10-12].

In this study, an electrical model for PV module based on two-diode is used for prediction and validation the module's performance, this model was developed previously in our work using a new method

for adjusting the irradiation received by each type of module's technology [13]. The temperature coefficients of the open circuit voltage in outdoor condition were measured for four of different PV modules technologies using a database of one year of measurement of the electrical characteristics of PV modules, installed at UDES's site (Development Unit of Solar Equipment), in the north central of Algeria. The influence of irradiation on the calculated temperature coefficients was taken into account in order to improve our model and the reduce the gap between simulation and experimental data.

2. MODELING METHOD

A. Solar cell equivalent circuit:

The model used in this work is based on a two-diode equivalent circuit of a solar cell in this study, as shown in figure 2. The solar cell output current "I" is given by the following equation [14]:

$$I = I_{ph} - I_{rs1}\left[\exp\left(\frac{(V+IR_s)}{n_1 V_{t1}}\right) - 1\right] - I_{rs2}\left[\exp\left(\frac{(V+IR_s)}{n_2 V_{t2}}\right) - 1\right] - \frac{(V+IR_s)}{R_{sh}} \quad (1)$$

Where Iph is the photocurrent, Irs1 and Irs2 are the diode reverse saturation current of diode 1 and diode 2, respectively, where the Irs2 defines the recombination loss in the depletion region [14]. Vt1 and Vt2 present the thermal voltages of the two diodes. n1 and n2 are the diode ideality factors. The values of n1 and n2 are respectively 1 and 1.2 as recommended by [15]. Rs and Rsh are the series and the shunt resistance respectively.

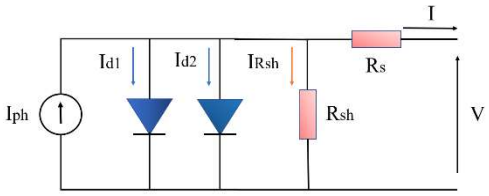


Fig. 1 Two-diode model cell equivalent circuit.

The values of the photo generated current, the diode reverses saturation currents, the series and shunt resistances are calculated at the similar method described in our previous work [13].

B. Adjusting the model

In this work, we used a model already improved in our previous work, this model is based on an algorithm for calculating the real irradiation absorbed by each type of PV module, This is based on the fact that there is no has only one value of G which guarantees that Isc,m = Isc,e where Isc,m and Isc,e are respectively the adjusted and experimental short-circuit current. Figure 2 illustrates the explanation of this iterative process of the algorithm used. The goal is to know the value of G which causes the calculated short-circuit current Isc,m to coincide with the experimental short-circuit current Isc,e. This requires many iterations until Isc,m = Isc,e, where G must be incremented slowly from G = 1 [13].

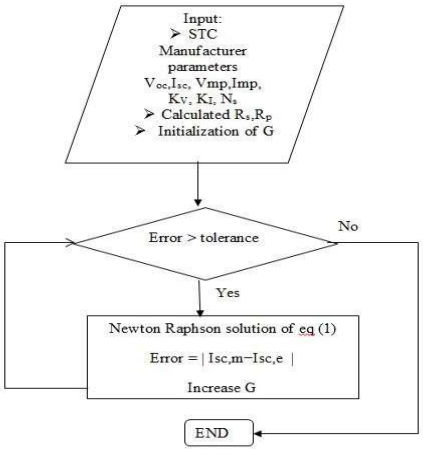
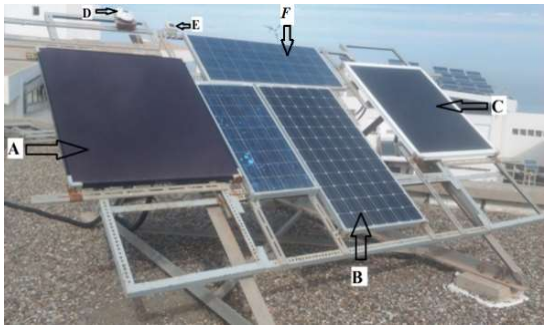


Fig. 2Algorithm for calculating the adjusted irradiation value used in the two-diode model [13].

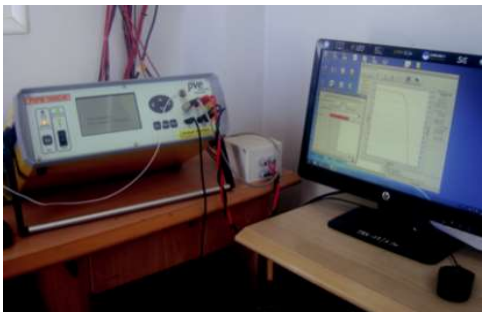
3. EXPERIMENTAL

The PV characterization outdoor test bench is set up at UDES's site, as shown in figure 3. It is composed of a test platform on which are mounted the PV modules, including a standard pyrometer of "kipp & zonen", the reference solar cell and the temperature sensors, an electronic load and a computer for the data acquisition. In this work the PV modules investigated, are based on four varied silicon material technologies which are: monocrystalline, polycrystalline, amorphous and micromorphous (amorphous and micro-crystalline multi-junction thin film). All module's specifications under STC conditions are given in table I. A comparison between the experimental temperature of the four PV modules studied in this work is

presented in Figure 4, for a period of one year.



(a)

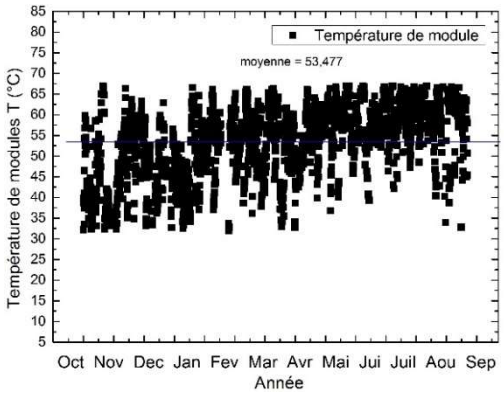


(b)

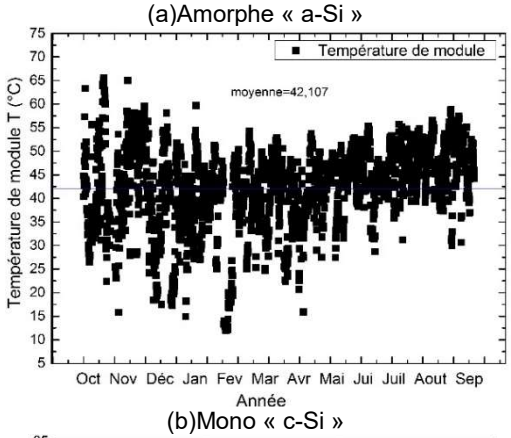
Fig. 3Characterization (a) Outdoor characterization bench of PV modules characterization; A: Amorphous, B: Monocrystalline, C: Thin film, F: Polycristalline, D: Pyranometer and E: Reference solar cell.(b)Data acquisition: Computer and PVPM 100C40 electronic load.

Table 1Specifications of the PV modules in Manufacturer's datasheets at STC conditions

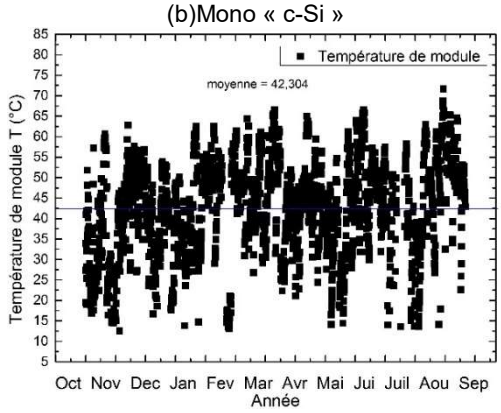
	Values of modules parameters at STC			
Specifications	m-Si [16]	p-Si [17]	a-Si [18]	µm-Si [19]
Maximum power (P_{max})	185W	135W	100W	110W
Open-Circuit Voltage (V_{oc})	43,2 V	22,3V	40,9V	87V
Short-Circuit Current (I_{sc})	5,76 A	8,2A	3,85A	1,98A
Maximum power current (V_{mpp})	36 V	17,5V	30,7V	64V
Maximum power voltage (I_{mpp})	5,14 A	7,71A	3,25A	1,76A



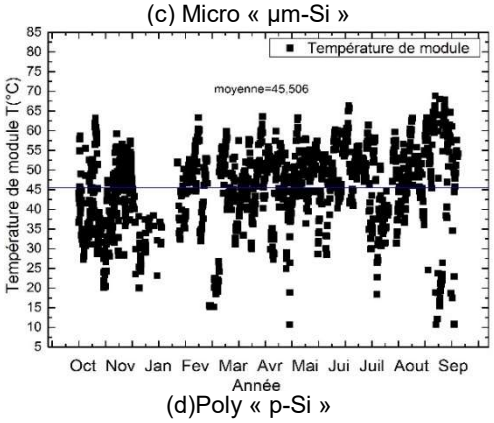
(a)Amorphe « a-Si »



(b)Mono « c-Si »



(c) Micro « µm-Si »

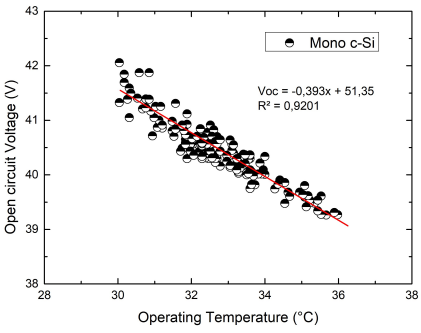


(d)Poly « p-Si »

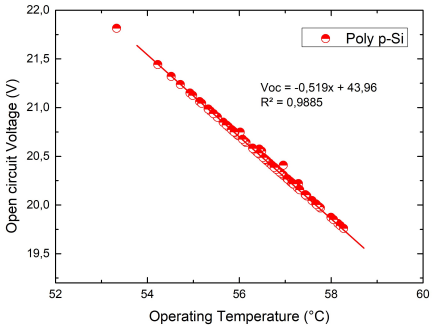
Fig. 4Annuel Temperature Comparaison of all PV modules (from October 2019 to September 2020).

4. RESULTS AND DISCUSSIONS

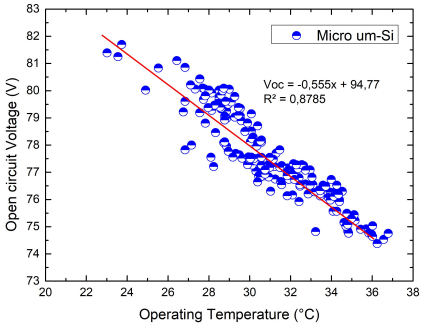
The plot of open circuit voltage versus module temperature, for all PV modules, measured in outdoor condition (October 2019-September 2020), shows linearly decreasing trend (Figure 5). The temperature coefficients for voltage (Kvstcm) are calculated from the slope of this plot using narrow band of measurements taken between 910 and 1010 W/m2 of irradiance. The ±10 W/m2 range around the standard test conditions (STC) irradiance was selected, as it gives a reasonable compromise as suggested by [20]. Their values lie within the range of the technology-specific limits reported in the literature and the behavior of the temperature coefficient as function of the irradiance are presented in table II. Figure 6, shows the plot of measured open-circuit voltage coefficient as function of irradiance level, where the amorphous has the low linearly relation plot, then come the mircromorphous, monocrystalline and the polycrystalline which has the higher dependence values of the voltage temperature coefficient for all irradiance selected levels.



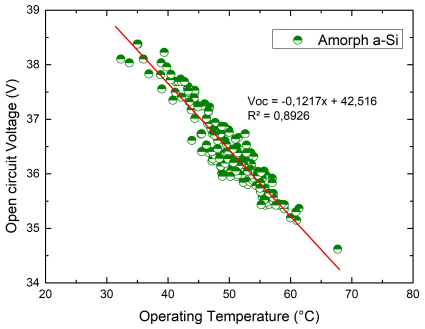
(a)



(b)



(c)



(d)

Fig. 5Open-circuit voltage versus temperature for all PV modules at around 1000W/m² (from October 2019 to September 2020). (a): Monocrystalline, (b): Polycristalline, (c) Micromorphous (d):Amorphous.

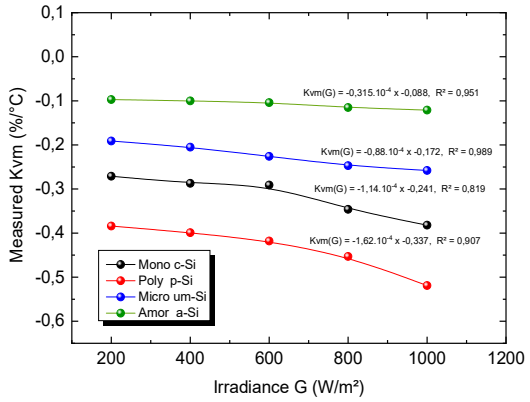


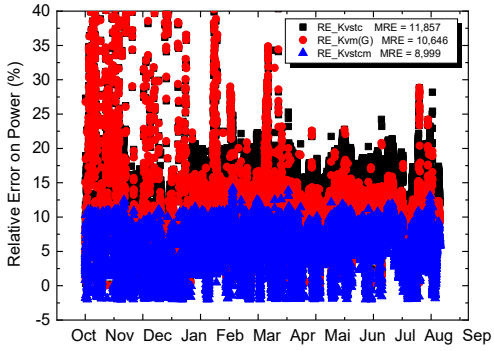
Fig. 6Measured Open-circuit voltage coefficient 'Kvm' versus irradiance level.

Table 2Temperature coefficient of the open circuit voltage (%/°C).

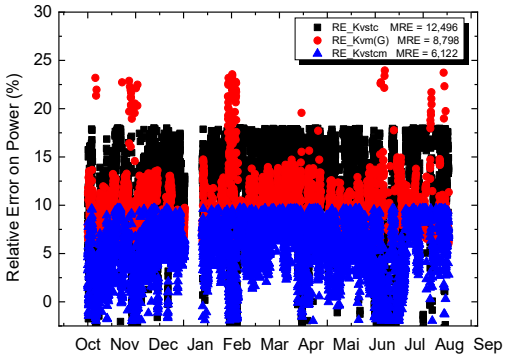
PV Module Technology	Irradiance levels (Kvm(G))					Manufacturer's datasheets (Kvstc)	Reported in Literature [20,21]
	200 W/m²	400 W/m²	600 W/m²	800 W/m²	1000 W/m² (Kvstcm)		
Mono c-Si	-0,271	-0,287	-0,291	-0,346	-0,385	-0,34	-0.22 to -0.58
Poly p-Si	-0,384	-0,399	-0,418	-0,453	-0,519	-0,55	-0.18 to -0.55
Micro µm-Si	-0,191	-0,205	-0,226	-0,247	-0,254	-0,33	-0,24 to -0,39
Amor a-Si	-0,097	-0,1	-0,104	-0,115	-0,121	-0,37	-0,11 to -0,37

In order to show the influence of the measured temperature coefficients of the open circuit voltage, the validation of the model is investigated by calculating the Relative Errors between the simulated "estimated" and the measured power for one year (Oct 2019-Sep 2020), as shown in Figure 7, where RE_Kvstc, RE_Kvm(G), RE_Kvstcm are: the relative error on the temperature coefficient provided by the manufacture's datasheet at STC, measured as function of irradiation (G) and measured at STC (irradiation around 1000 W/m²). It can be seen from this figure, that for all PV modules using the temperature coefficient given by the manufacture the RE error is high, which leads us to recalculate this coefficient in order to reduce the error.

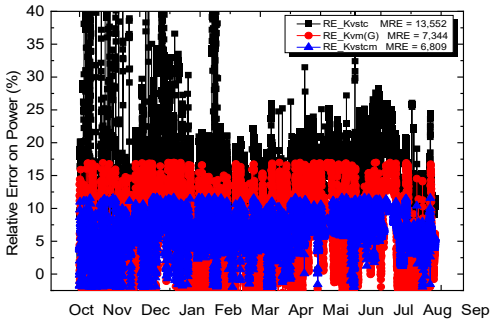
The mean Relative Errors (MRE) on the power are listed in table III, where it was found a reduce of the MRE of (1% - 6%) compared to the manufacturer's value using the measured temperature coefficient as function of irradiation, and of (2%-7,3%) if we use the temperature coefficient measured at 1000W/m².



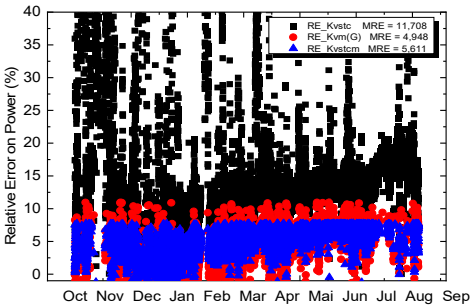
(a)



(b)



(c)



(d)

Fig. 7Relative Errors on the Power; RE_Kvstc vs RE_Kvm(G) vs RE_Kvstcm. For a period of one year (Oct 2019-Sep 2020).
(a): Monocrystalline c-Si, (b): Micromorphous µm-Si, (c): Poly-crystalline p-Si, (d): Amorphous a-Si.

Table 3Mean Relative Error MRE on power of the four photovoltaic modules.

	Mean Relative Error MRE on the power(%)				
	RE_Kvstc	**RE_Kvm(G)**	**RE_Kvstcm**	**RE_Kvstc −RE_Kvm(G)**	**RE_Kvstc −RE_Kvstcm**
Mono c-Si	11,857	10,646	8,999	1,211	2,858
Poly p-Si	12,496	8,796	6,122	3,7	6,374
Micro µm-Si	13,552	7,344	6,809	6,208	7,344
Amor a-Si	11,708	4,948	5,611	6,76	4,948

5. CONCLUSION

In the modeling's field, researchers always try to reduce the gap between the results of the simulation and the experimental in order to have a more accurate model. The value of the temperature coefficients at STC vary when the modules are outdoor installed under real climatic conditions, for this aim the present paper was carried out by studying the impact of calculation of the open circuit voltage temperature coefficients at a fixed irradiation (1000W/m²) and for the other values (200, 400, 600 and 800 W/m²), using a one-year experimental database of four different types of modules; monocrystalline silicon c-Si, polycrystalline silicon p-Si, amorphous silicon a-Si, and micromorphous silicon thin film µm-Si installed in outdoor conditions. We have found different values of temperature coefficient values not too far from those given by the manufacturer, but which led to a reduction in the Mean Relative error MRE on the annual power between 2% and 7% depending on the PV module's technology. This study will help to improve the prediction models of the electrical characteristics of PV modules and the system's sizing.

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