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Effect of Spectral Irradiance Distribution on the Performance of Solar Cells

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In this paper, the global and diffuse solar radiation incident on solar cells is simulated using a spectral model SMARTS2, for varying atmospheric conditions on the site of Setif. The effect of changes in total intensity and spectral distribution on the short circuit current and efficiency of different kinds of thin film solar cells (CdTe, nc-Si:H and copper indium gallium selenide, CIGS) is examined. The results show a reduction in the short circuit current due to increasing turbidity. It is 18.82%, 27.06% and 26.80% under global radiation and for CdTe, nanocrystalline silicon (nc-Si:H), and CIGS solar cells, respectively. However it increases under diffuse radiation. Increasing water vapor in the atmosphere leads to a reduction in the short circuit current of 3.15%, 2.38%, and 2.45%, respectively, for CdTe, nc-Si:H, and CIGS cells under global radiation and it is not influenced under diffuse radiation. The performance of the solar cells is notably reduced, both in terms of efficiency and open circuit voltage, with increasing air mass.

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1. Introduction

When elaborating the photovoltaic cells, they are tested under standard reporting conditions (SRC)of illumination and temperature (illumination = 1000 W/m^2, temperature = 25 °C and air mass (AM) 1.5 reference spectrum). However, these conditions practically never occur during normal outdoor operation [1] as they do not take into consideration the actual geographical and meteorological conditions at the installation site. The solar irradiance at ground level varies in intensity and spectrum due to varying atmospheric parameters such as albedo, atmospheric turbidity, the water vapor content and the zenith angle [2–5]. Before striking the solar cell, the solar rays are submitted to different transformations through the atmosphere. It acts as a continuously variable filter affecting the solar radiation propagating to the ground. Atmospheric gases, aerosols and particles, water vapor and droplets and various pollutants modify the distribution of solar energy with respect to wavelength. The result is a wide range of variation in the spectral distribution of natural sunlight. There are wide variety of spectral distributions functions. The combination of the variability in natural spectral distributions and spectral response functions make designing, evaluating and predicting the performance of photovoltaics (pv) devices in the real world challenging [6, 7]. The effect of the variations of the solar spectrum on the performance of the different photovoltaic devices is not yet quantified on a large scale because of the difficulty to obtain spectral solar radiation measurements. Therefore, it is rather important to elaborate methods to estimate the influence of the varying atmospheric conditions on the solar cells performance.

The aim of this study is to evaluate the effect of changes in spectral distribution of global and diffuse irradiation due to the variation of environmental parameters such as air mass, turbidity, and water vapor content on the performance of three kinds of solar cells, (CdTe, (*nc*-Si:H) and CIGS). The solar irradiance striking solar cells is estimated using the spectral irradiance model for clear skies SMARTS2 [8–12].

The short circuit density J_{sc} of device, which is the value of the photocurrent density [10] is directly linked to the spectral irradiance $E(\lambda)$ and can be calculated as

$$J_{\mathrm{sc}} = \int E(\lambda) SR(\lambda)\,\mathrm{d}\lambda\,, \tag{1}$$

where $E(\lambda)$ is the energy of the incident light and SR(λ) is the spectral response at the given wavelength. This implies a linear relationship with irradiation.

The fill factor (FF) is determined as [13]:

$$\mathrm{FF} = \frac{v_{\mathrm{co}} - \ln(v_{\mathrm{co}} + 0.72)}{v_{\mathrm{co}} + 1}\,, \tag{2}$$

where

$$v_{\mathrm{co}} = \frac{V_{\mathrm{co}}}{n\left(\frac{kT}{q}\right)}\,. \tag{3}$$

The open circuit voltage is calculated using

$$V_{\mathrm{oc}} = n\frac{kT}{q}\ln\left(\frac{I_{\mathrm{sc}}}{I_{\mathrm{s}}} + 1\right). \tag{4}$$

The ideality factor n, and the saturation current, I_{s}, are computed from the I–V characteristics using an approach that involves the use of an auxiliary function [14].

The fill factor and the conversion efficiency of the solar

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cell are linked through

$$\eta = \mathrm{FF}\frac{V_{co}I_{sc}}{P_i S}\,, \tag{5}$$

where I_{sc} is the short circuit current, S is the solar cell area, and P_i is the total irradiance in $\mathrm{W/m^2}$ and is given by

$$P_i = \int_0^\infty E(\lambda)\,d\lambda\,, \tag{6}$$

where $E(\lambda)$ is the spectral irradiance.

The I_{sc}, V_{oc} and FF all depend on the irradiance, incident spectrum,and temperature. Figure 1 shows the measured spectral response of the different thin film solar cells [15–16] considered in this study. It is clear that each technology has a specific spectral response and associated with this, an effective spectral range.

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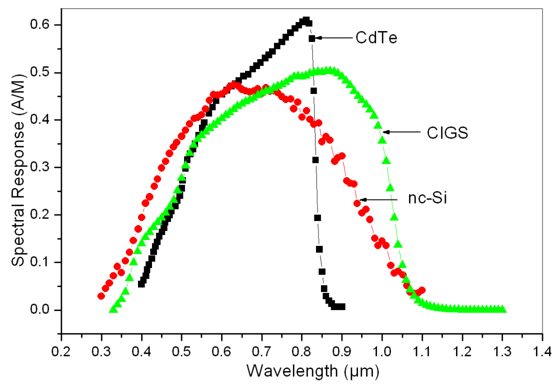

Fig. 1. Spectral response of three types of solar cells.

2. Results and discussion

The global and diffuse solar irradiance are calculated at Setif (Algeria) (36.11°N, 5.41°E and 1081 m) on a horizontal surface by varying one environmental parameter and maintaining the other fixed, using SMARTS2. Then for each value of the environmental parameter in the study, we calculated the short circuit current, the open circuit voltage, the fill factor and the conversion efficiency of three kinds of solar cells.

2.1. Air mass effect

Figure 2 shows the influence of air mass on the different considered solar cells. The output current is reduced but in different proportion for each type of cell according to the situation and shape of the spectral response. The short circuit current decreases with increasing air mass for the different types of solar cells. On the other hand, the efficiency decreases with increasing air mass for CdTe, nc-Si:H and CIGS cells. The reduction in the short circuit current due to increasing air mass is 88.37%, 81.86%, and 81.56%, respectively, for CdTe, nc-Si:H, and CIGS solar cells under global solar irradiance. The current of the CIGS cell is subjected to a larger reduction than that of nc-Si:H because the spectral response of CIGS covers a larger area than does nc-Si:H. However, the spectral response of the CdTe cell is narrower than both of CIGS and the nc-Si:H. For diffuse solar irradiance this reduction is 56.09%, 37.47%, and 41.97%, respectively, for CdTe, nc-Si:H, and CIGS solar cells. The variations of the short circuit current as a function of the air mass are illustrated in Table I.

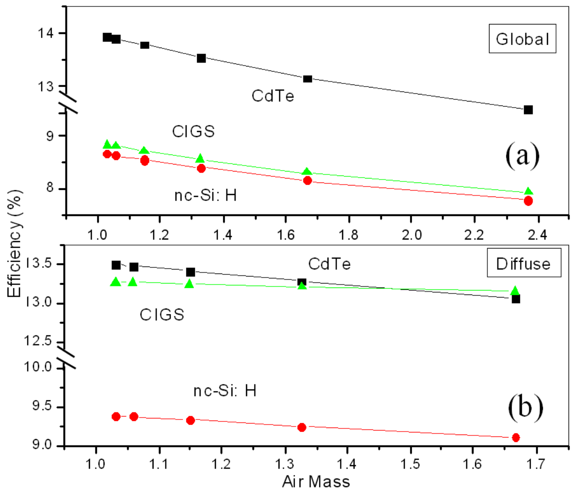

Fig. 2. Efficiency as function of air mass under global (a) and diffuse (b) irradiance for CdTe, nc-Si:H, and CIGS solar cells.

2.2. Turbidity effect

The variations of the short circuit current as a function of the turbidity are illustrated in Table II. The short circuit current decreases with increasing turbidity for the different types of solar cells. However, the efficiency decreases with increasing turbidity for CdTe, nc-Si:H, and CIGS solar cells. The reduction in the short circuit current due to increasing turbidity is 18.82%, 27.06%, and 26.80%, respectively, for CdTe, nc-Si:H, and CIGS solar cells, respectively, under global solar irradiance. On the other hand, the efficiency increases with increasing turbidity for CdTe, nc-Si:H and CIGS solar cells under diffuse solar radiation. This is illustrated in Fig. 3.

2.3. Water vapor effect

The solar spectral irradiance is reduced by increasing water vapor in the atmosphere at larger wavelengths to which only CIGS and nc-Si:H cell is sensitive. Figure 4 shows the efficiency as function of water vapor on a horizontal surface for the different cells. The reduction is less than in the case of turbidity because water vapor affects only narrow spectral intervals and the spectral responses at those wavelengths are weaker than the ones affected by the turbidity.

TABLE I

Influence of air mass on J_{sc} on a horizontal surface under global and diffuse irradiance.

Air mass	J_{sc} [mA/cm^2]					
	CdTe		nc-Si		CIGS	
	glob.	diff.	glob.	diff.	glob.	diff.
1.031	25.1041	4.2549	27.7147	5.2090	52.3827	10.0508
1.058	24.4021	4.2105	26.9327	5.1557	50.9080	9.9500
1.148	22.2987	4.0724	24.6159	4.9884	46.5402	9.6332
1.327	18.9507	3.8234	20.9146	4.6866	39.5643	9.0619
1.666	14.5625	3.4279	16.0650	4.2067	30.4177	8.1504
2.370	9.4679	2.8219	10.4304	3.4597	20.0600	9.3557

TABLE II

Influence of turbidity on J_{sc} under global and diffuse irradiance.

Turbidity	J_{sc} [mA/cm^2]					
	CdTe		nc-Si		CIGS	
	glob.	diff.	glob.	diff.	glob.	diff.
0.1	25.1041	4.2549	27.7147	5.2590	52.3823	10.0508
0.2	23.9859	7.0708	26.2317	8.4077	49.4822	16.1223
0.3	22.4794	8.7233	24.0865	9.9104	45.2331	18.8121
0.4	18. 3785	9.1687	21.0123	9.6913	38.9185	18.8902

TABLE III

Influence of water vapor on J_{sc} under global and diffuse irradiance.

Water vapor	J_{sc} [mA/cm^2]					
	CdTe		nc-Si		CIGS	
	glob.	diff.	glob.	diff.	glob.	diff.
0.1	25.1041	4.2549	27.7147	5.2590	52.3823	10.0508
0.2	23.9859	7.0708	26.2317	8.4077	49.4822	16.1223
0.3	22.4794	8.7233	24.0865	9.9104	45.2331	18.8121
0.4	18. 3785	9.1687	21.0123	9.6913	38.9185	18.8902
0.1	25.1041	4.2549	27.7147	5.2590	52.3823	10.0508

The reduction in the current (Table III) is 3.15%, 2.38%, and 0.12%, respectively, for CdTe and microcrystalline silicon (μc-Si) cells. But it does not influence the cells parameters under diffuse irradiance.

3. Conclusion

The global and diffuse solar irradiance incident on different types of solar cells are simulated using the spectral irradiance model SMARTS2 (simple model of the atmospheric radiative transfer of sunshine) for varying atmospheric conditions on the site of Setif (Algeria). The analysis shows that the efficiency increases with increasing turbidity for CdTe, nanocrystalline silicon (nc-Si:H) and CIGS solar cells under diffuse solar irradiance but it is the opposite for global irradiance. The efficiency decreases with increasing air mass under both global and diffuse solar irradiance. The efficiency increases with increasing water vapor for the different kinds of solar cells under global irradiance but it does not influence the cells parameters under diffuse irradiance. From this analysis, we conclude that the air mass, water vapor amount, and the turbidity have a significant influence on the overall performance of the examined solar cells.

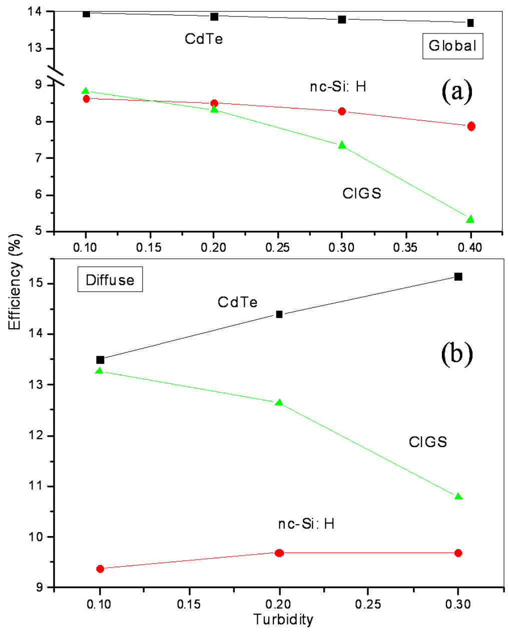

Fig. 3. Efficiency as function of turbidity under global (a) and diffuse (b) irradiance for CdTe, nc-Si:H, and CIGS solar cells.

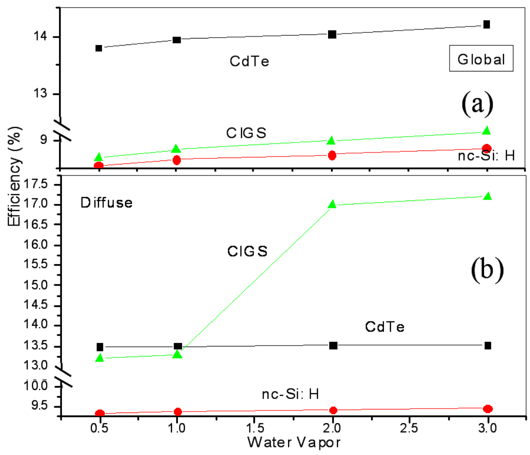

Fig. 4. Efficiency as function of water vapor under global (a) and diffuse (b) irradiance for CdTe, nc-Si:H, and CIGS solar cells.

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