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Effect of Ambient Conditions on Thermal Properties of Photovoltaic Cells: Crystalline and Amorphous Silicon

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ABSTRACT: The temperature of PV (Photovoltaic) modules is one of the most important factors because it affects both the efficiency of a Photovoltaic module and the energy load and it's also affected by several ambient conditions. Among these conditions, there is ambient temperature, direct irradiance and wind speed. There have been many studies that determine the effect of these parameters on the efficiency and performance of PV cells; but there is no particular study that has discussed the influence of these parameters on the thermal parameters of PV cells.
This paper evaluates the effects of ambient conditions on the Photovoltaic module's thermal characteristics of two photovoltaic modules: crystalline and amorphous silicon technologies. The results show that the ambient conditions affect the PV module temperature and also the thermal parameters.
The influence of these factors should be taken into account so as to have a deep insight in solar cell design.

KEYWORDS: Photovoltaic, PV efficiency, Module temperature, ambient temperature, direct irradiation, Wind speed.

I. INTRODUCTION

The world now knows a decline of fossil fuels for energy production. As a solution to this problem, there is an option of solar energy based on photovoltaic cells.

Certainly, the performance of these cells depends on ambient parameters including: ambient temperature, wind speed, direct radiation, etc. In this article, there will be a study of the impact of these parameters on the performance of photovoltaic cells.

II. MATERIALS AND METHODS

In this paper we study the influence of ambient conditions on thermal parameters of PV cells using crystalline and amorphous silicon.

Table: The thermal parameters of crystalline and amorphous silicon [10].

Parameter	Material	Value
Density ρ(g/cm3)	C-Si a-Si	2.329 2.2
Melt latent heat(J/g)	C-Si a-Si	1797 1317

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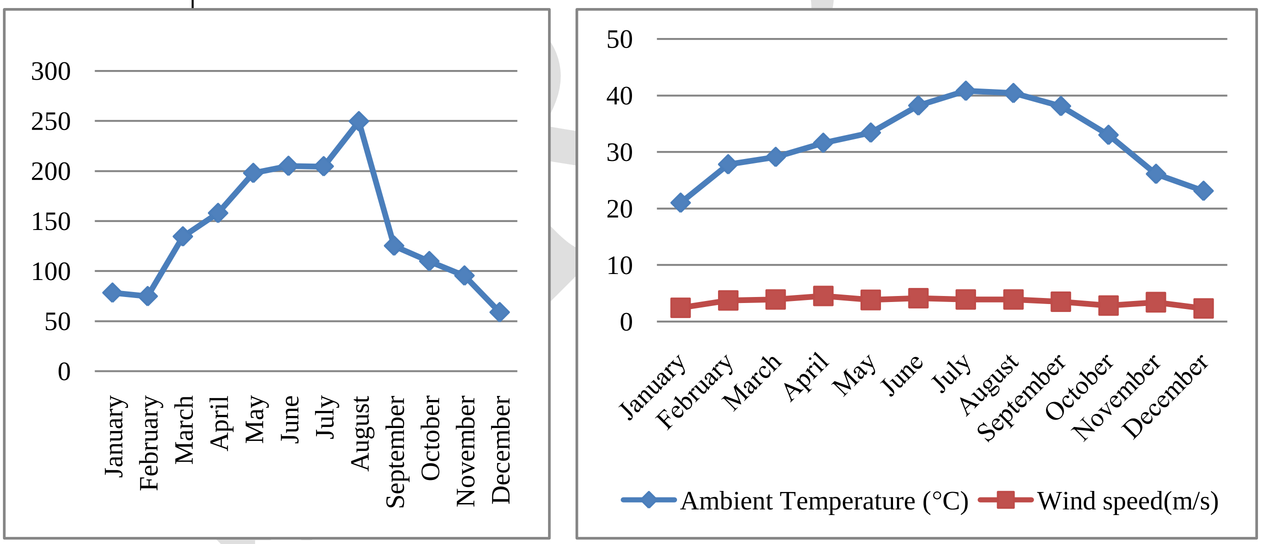
Melting temperature(K)	C-Si a-Si	1683 1420
Thermal conductivity((J/g.K)	C-Si a-Si	1521*Tc-1.226 (Tc<1200K) 8.99*Tc-0.502 (Tc≥1200K)
Specific heat Cs (J/g.K)	C-Si a-Si	0.184*exp(4.5*10-3*Tc) (Tc<300K) 0.1694*exp(2.375*10-4*Tc) (Tc≥300K) Cs(C-Si)-0.008+0.171*Tc/1685

This table lists the different thermodynamic parameters for these modules used in calculations.

In order to analyze the impact of the three ambient factors on thermodynamic parameters for crystalline and amorphous silicon, we used the monthly average variation of the ambient temperature, direct irradiation and wind speed of the site of Ouarzazate respectively for the year 2011 as shown in Figure 1.
From Figure 1 (b), it is seen that the ambient temperature varies with the different months of the year over the period of study. Two maximum values were observed: the first maximum value in the month of July and the second maximum value were obtained in the month of August.
In Figure 1 (a), the maximum is observed in the month of August.
The results were obtained using the following equations:

$$K(C-Si) = \begin{cases} 1521 * Tc - 1.226 & (Tc < 1200K) \quad (4) \end{cases}$$



(a) (b)

Fig. 4 Metrological data for the Year 2011 of Ouarzazate (a) The Monthly average variation of direct irradiation (b) The Monthly average variation of ambient temperature and wind speed.

$$8.99 * Tc - 0.502 \qquad (Tc \geq 1200K) \qquad (5)$$

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$$Cs(C - Si = \begin{cases} 0.184 * \exp(4.5 * 10 - 3 * Tc) & (Tc < 300K) \quad (6) \\ 0.1694 * \exp(2.375 * 10 - 4 * Tc) & (Tc \geq 300K) \quad (7) \end{cases}$$

$$Cs\ (a - Si) = Cs(C - Si) - 0.008 + 0.171 * Tc/1685 \quad (8)$$

But Equation (5) is not be used because the cell temperature of the cells does not reach this temperature.

III. SOLAR ENERGY

Other than causing a severe environmental degradation, the use of fossil fuels also causes serious environment problems especially the greenhouse. Nowadays, research efforts are taking place to develop alternative sources of energy, more efficient conversion technologies and environmentally sustainable applications. The use of solar energy technology is a viable solution to some of the environmental problems that were generated by the use of fossil fuels.

I. PHOTOVOLTAIC TECHNOLOGY AND THE PRINCIPLE OF PV CELL

One of the promising applications of solar energy technology is the use of photovoltaic systems to generate electric power without emitting pollutants. Solar energy may be used to produce electricity using photovoltaic solar cells and heat in photo collectors by a photo thermal conversion process which is called the photovoltaic effect.

Increasing efforts are directed towards reducing the installation costs and enhancing the performance of photovoltaic systems so that the system can be deployed on large scale.

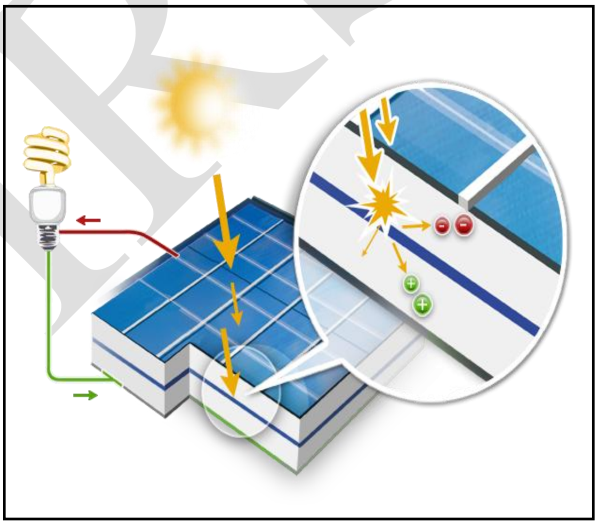

Fig. 2 The Photovoltaic effect.

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The Photovoltaic is a new and clean energy that uses semiconductor cells and converts the sunlight into direct current electricity energy by absorbing photons that hit the surface of PV material arranged in cells Figure 2. These transfer their energy to the electrons in the material and then start moving in a particular direction. The direct electric current is created and collected by very fine metal strings connected to each other and supplied to the next cell. The current is added through one cell to another to the limits of the connection of the panel, and it can then be added to other modules which are connected to the "fields". Several cells are assembled in a module to generate power.

Various studies have been conducted to give the influence of ambient conditions on the performance of photovoltaic cells as in the case of [1, 2, 3], which determines the impact of these ambient factors on operation and efficiency of photovoltaic cells. There are many technologies available to capture and use energy from the sun. Some use this energy in heating systems, some produce electricity and some can do both at the same time. Photovoltaic technology is used for domestic solar electric installations.

There are three main types of PV modules:

- Monocrystalline: the cells in a monocrystalline module are made from a single silicon crystal.
- Polycrystalline: the modules are made from cells including lots of small silicon crystals, which makes them cheaper to produce but they are less efficient than
- monocrystalline modules. It is also known as multicrystalline.
- Thin-films: which use less material and they are cheaper than crystalline modules. But the efficiency of thin-film panels is only about 10%.

Generally, monocrystalline modules are the most expensive but most efficient. Thin film is the cheapest but least efficient and polycrystalline is in between these two types. The efficiency of these three types of photovoltaic modules is mentioned in [4].

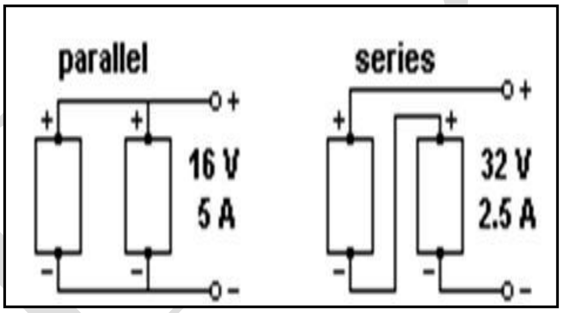

Fig. 3 Combinations of PV cells.

PV modules can be connected in series or parallel in order to increase the current and voltage. In the case of series connected cells, the combined output current is the same for all the cells. The combined power is the sum of the individual cells power .But for the parallel connected cells, the combined output voltage is the same for all the cells. Then, the parallel connected photovoltaic solar cells can be used to increase the current output. The combined power is the sum of the individual cells power. A solar panel is a group of several modules connected in series–parallel combination. Series and parallel connection of modules in a panel is shown in Figure 3.

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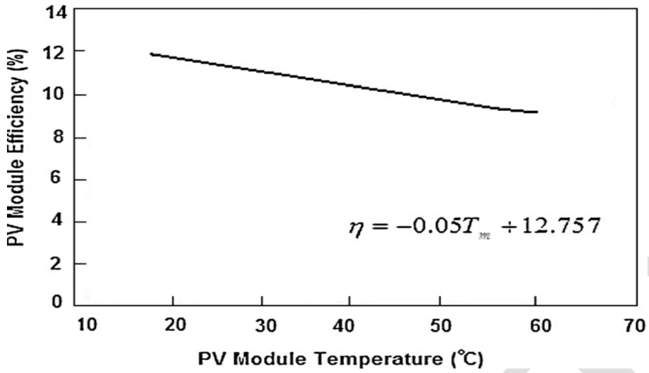

Fig. 4 Relationship of the PV module efficiency Ƞ and PV module temperature Tm [5].

Module temperature is a parameter that has great influence on the function of a PV system, as it modifies system efficiency and output energy as shown in the Figure 4 [5].

The operating temperature has an important impact on the photovoltaic conversion process [6, 7]. In addition to this, the atmospheric parameters such as irradiance level, ambient temperature, and wind speed have influence on the photovoltaic conversion process.

Both the electrical efficiency and the power output of a PV module depend linearly on the operating temperature. The various correlations proposed in the literature represent simplified working equations which can be applied on PV modules.

One of the correlations used for the calculation of cell temperature from ambient temperature, available solar irradiance and NOCT following the known [8]:

$$Tc = Tamb + (NOCT - 20)\frac{G}{800} \qquad (1)$$

In which Tc is the cell temperature (°C), Tamb is the ambient temperature (°C), NOCT is the Nominal Operating Cell Temperature (°C) and G is irradiance level (W/m2).

Another model of calculating the cell temperature that is used by Kurtz et al. [10] is:

$$Tc = Tamb + G \times \exp[-3.473 - 0.0594 \times V] \qquad (2)$$

In which V is the wind speed (m/s).

The PV module efficiency can be formulated [9:

$$\eta = \eta_{T_{ref}}\left[1 - \beta_{T_{ref}}(Tc - T_{ref})\right] \qquad (3)$$

In which $\eta_{T_{ref}}$ is the module's electrical efficiency at the reference temperature, $\beta_{T_{ref}}$ is the temperature coefficient (%/°C) and T_{ref} is the reference temperature (°C).

The $\beta_{T_{ref}}$ and T_{ref} depends on PV material and are usually specified by the cell manufacturer [10].

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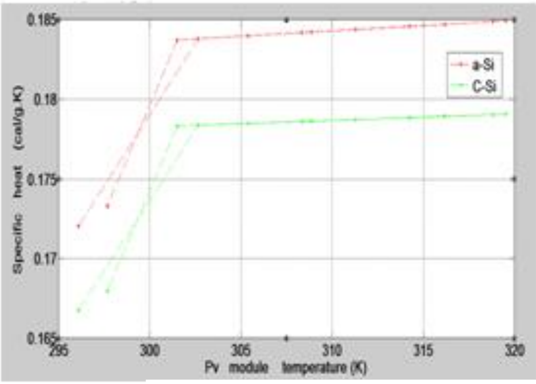
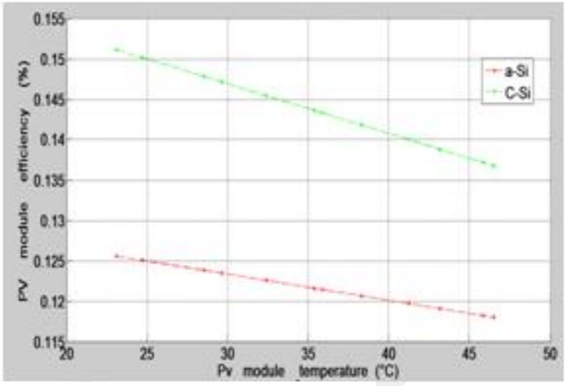
II. RESULTS AND DISCUSSION

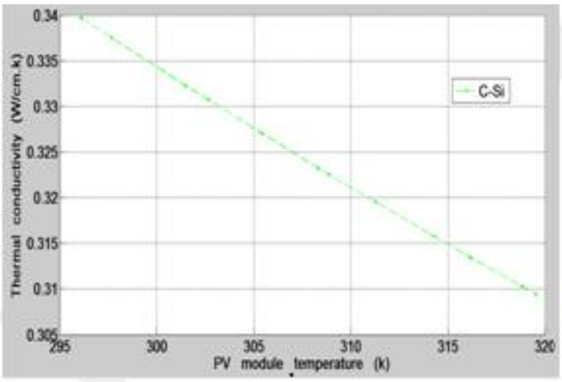
There are various ambient conditions that affect the output of a PV power system and then the efficiency of the PV system. These factors should be taken into consideration and any PV module must include adjustment for the temperature effect.



(a)



(b)



(d)

Fig.5 The results (a) Specific heat of PV module with module temperature (b) Efficiency of PV module with module temperature (d) Thermal conductivity C-Si PV module with module temperature.

The influence of cell temperature on the thermal characteristics such as the specific heat and thermal conductivity of the cells are shown in Figure 5 (a) and (d). These results shown in these Figures are similar to those founded in [11].

As seen from these two figures, Figure 5 (a) show us the specific heat increases exponentially by increasing the cell temperature, whereas Figure 5 (d) indicates the thermal conductivity decreases linearly for both crystalline and amorphous silicon.

The main effect of the increase in cell temperature is on open circuit voltage that decreases linearly with the cell temperature; thus the cell efficiency drops as seen in Figure 5 (b).
As the air velocity increases, the cell temperature will drop and so the PV cell efficiency will be better. By increased wind velocity more heat can be removed from the PV cell surface. In the same vein, higher air velocity lowers the

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relative humidity of the atmospheric air in the surroundings which leads to better efficiency. On the contrary, wind lifts dust and scatters it in the environment resulting in shading and poor performance of PV cells.

III. CONCLUSION

Among the most popular applications of renewable energy technology is the installation of PV systems using sunlight to produce electricity. This paper has presented a detail overview of the ambient factors that affect the thermal parameters of C-Si and amorphous-Si and also the efficiency of PV of these two types. The important theme of these factors is ambient temperature, direct irradiance and wind speed.

However, the main effect of the increase in cell temperature is on open circuit voltage, which decreases with the cell temperature. The short circuit current increases slightly with the increase of the cell temperature, thus the cell efficiency drops. An effective way of improving efficiency of a PV module is to reduce the cell temperature. This can be achieved by cooling the module and reducing the heat stored inside the PV cells during operation.

In conclusion, ambient temperature, direct irradiance and air velocity can drop the efficiency of PV cells so they should be studied in evaluating the cell efficiency.

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