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The Effect of Temperature Variations on Solar Cell Efficiency

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Abstract: In this work, the influences of temperature variations on the different solar cell parameters are studied. It is useful to understand the effect of temperature on the solar cell and module performance, in order to estimate their performance under various conditions. The short circuit current I_{sc} increases so monotonous with temperature and then saturates to a maximum value before decreasing at high temperatures. The open circuit voltage V_{oc} increases linearly with temperature. The fill factor and efficiency, which are directly related with I_{sc} and V_{oc} follow the variations of the letters. The phenomenon is explained by the behaviour of the mobility which is a temperature activated process. The maximum efficiency of (27%) is obtained in which $I_{sc} = 92 \text{ mA}$ and $V_{oc} = 147 \text{ mV}$.

Keywords: solar cell; temperature; open circuit voltage; short circuit current; irradiance; efficiency.

I. Introduction

The most important parameters that describe the operating conditions of a solar cell are the total irradiance, the spectral distribution of the irradiance and the temperature. Usually the solar cell designer assesses their devices by evaluating the efficiency at standard reporting conditions (SRC: illumination $= 1000 \text{ W/m}^2$, temperature $= 25^\circ\text{C}$ and AM1.5 reference spectrum). However, these conditions practically never occur during normal outdoor operation as they do not take into consideration the actual geographical and meteorological conditions at the installation site ¹.

In this paper, we discussed the temperature variations effect on the parameters of the solar cells. This will be explained using crystalline silicon solar cells as an example, but the concept is also applicable to other types of solar cells.

II. Crystalline Silicon Solar Cells

Amongst the various existing photovoltaic (PV) technologies, crystalline silicon (c-Si) is the most developed and well understood due to mainly its used in the integrated circuit industry. In addition, silicon is at present the most abundant material found in the earth's crust and its physical properties are well defined and studied. Crystalline silicon (c-Si) dominates the PV technology market with a share of approximately 80% today. These technologies are the highly efficient but are at the same time the most expensive amongst the flat-plate existing PV technologies mainly because of their relatively costly manufacturing processes ^{2, 3}.

III. Experimental Work

This section describes the functioning of an idealized single-junction PV cell emphasizing its main parameters and the relation between these parameters and the temperature.

A. Open Circuit Voltage

The open circuit voltage (V_{oc}) corresponds to the voltage across the internal diode when the total generated photocurrent flows through this diode. The open circuit voltage is strongly dependent on temperature. This must be considered, as solar cells installed outdoors can reach temperature, depending on the installation (e.g., possibilities for ventilation), up to 40 K higher than the ambient temperature ⁴. For an ideal p-n junction, V_{oc} can be given as ^{5, 6}:

$$V_{oc} = \frac{KT}{q} \ln \left[\frac{I_{ph}}{I_s} \right] + 1 \quad [1]$$

Where, K, is Boltzmann constant, T, is the temperature, q is the electronic charge, I_{ph} , is the photocurrent, and I_s , is the diode saturation current.

B. Short Circuit Current

The short circuit current (I_{sc}) found to be dependent on the temperature. It is found that the short circuit current increases with temperature and tends to be saturated at a maximum value followed by a decrease at high temperatures⁷. For an ideal p-n junction, I_{sc} can be given as⁵:

$$I_{sc} = I_s \left[\exp \frac{q \cdot V_{oc}}{KT} - 1 \right] - I_{ph} \quad [2]$$

C. Fill Factor

The fill factor (FF) is the ratio of the peak power to the product of I_{sc} and V_{oc} . The fill factor determines the shape of the solar cell I-V characteristics. Its value is higher than 0.7 for good cells. The fill factor is useful parameters for quality control test⁶. The fill factor can be given as^{8,9}:

$$F.F = \frac{I_m \cdot V_m}{I_{sc} \cdot V_{oc}} \quad [3]$$

Where I_m is the maximum current and V_m is the maximum voltage.

D. Efficiency

Only part of the solar radiation incident on the solar cell is converted to electricity. The ratio of the output electrical energy to the input solar radiation is defined as the efficiency value. It depends on the type of cell. For the module efficiency value, the output power is divided by the total radiation incident on the module. Because the entire area of the module is not covered with solar cells, the module efficiency value is lower than the efficiency value of the single cell³. The efficiency (η) can be given as⁹:

$$\eta(\%) = \frac{V_{oc} \cdot I_{sc} \cdot FF}{P_{in}} \quad [4]$$

Where P_{in} is the power input.

IV. Result and discursions

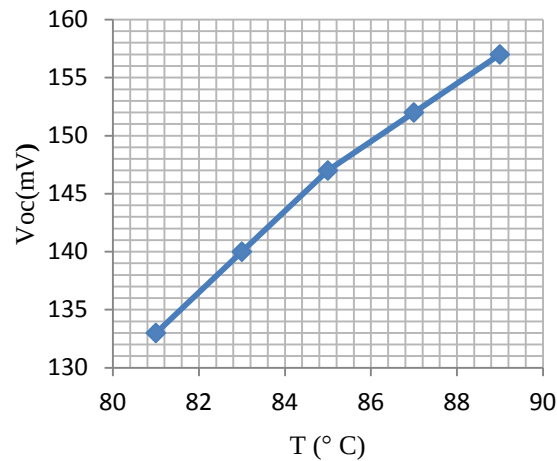
The open circuit voltage (V_{oc}) is one of the most important parameters for the solar cell efficiency. It is depended on temperature as shown in equation [1]. For $T = (81 \text{ to } 89)$ step 2, $I_{ph} = 50 \text{ mA}$, and $I_s = 1 \cdot 10^{-10} \text{ A}$. The V_{oc} increases as temperature increased as shown in table (1).

Table I Open circuit voltage versus temperature

T (° C)	V _{oc} (mV)
81	133
83	140
85	147
87	152
89	157

Figure (1) shows the effect of temperature variation on the V_{oc} . At 81°C the V_{oc} has it lower value of 133 mV and increased with temperature to reach its maximum value of 157mV at 89°C.

Figure1 The relation between open circuit voltage and temperature



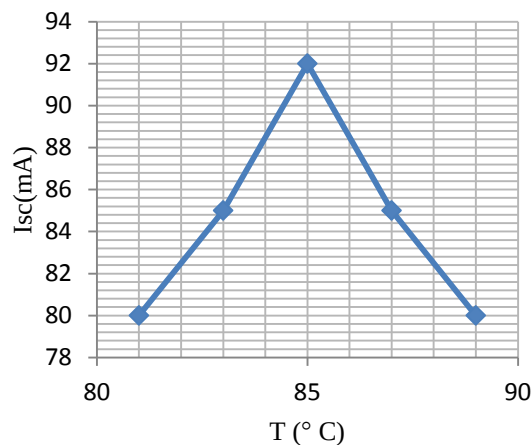
The short circuit current I_{sc} of the solar cell depending on the V_{oc} and temperature as shown in equation [2]. The short circuit current, I_{sc} , versus temperature is shown in table below:

Table II Short circuit current versus temperature

T (° C)	I_{sc} (mA)
81	80
83	85
85	92
87	85
89	80

Figure (2) shows the effect of temperature variation on the I_{sc} . The short circuit current I_{sc} increases with temperature and tends to reach its maximum value of (92 mA) at temperature of (85°C). After (85° C), the I_{sc} start to decrease with temperature increase and return to 80 mA at T=89°C.

Figure2 The relation between short circuit current and temperature

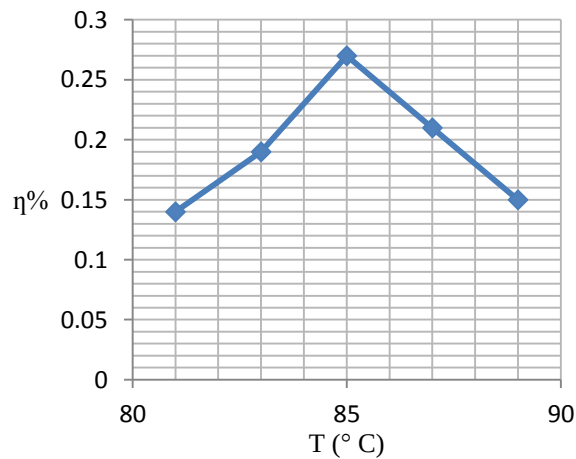


Solar cell efficiency considered the most important indicator shows how the solar cell works according to different parameters conditions. Solar cells efficiency can be obtained as shown in equation [4]. Where FF and the P_{in} are kept constant, which are equal to 0.85 and 1000 W/m² respectively. The efficiency at different temperatures is shown in table below:

Table III The efficiency solar cell versus temperature

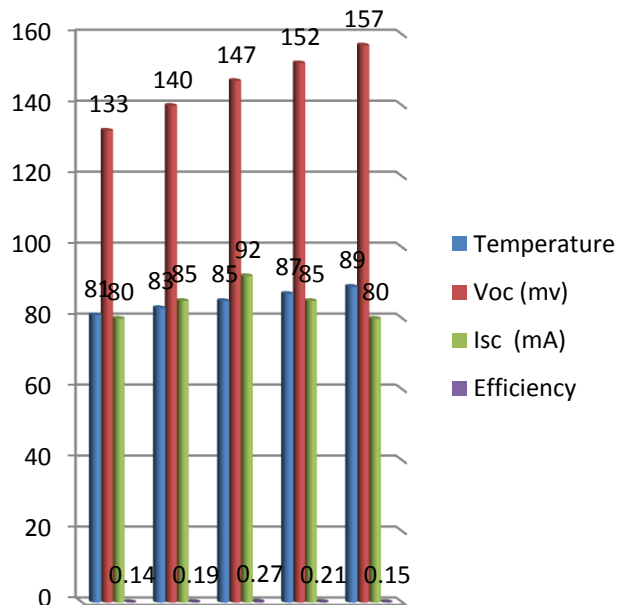
T (° C)	I _{sc} (mA)	V _{oc} (mV)	η%
81	80	137	14%
83	85	140	19%
85	92	147	27%
87	85	152	21%
89	80	157	15%

Figure (3) shows that at T=81°C, the efficiency of 14% is obtained and as the temperature increased the efficiency increased to reach its maximum value of 27% at T=85°C, after that the temperature still increased and the efficiency start to decreased after 85°C. The efficiency of 15% is obtained at higher temperature of (89°C).

Figure3 the relation between the efficiency and temperature

V. Conclusion

The efficiency of a crystalline silicon solar cells photo module depends on the sun insulation reaching its surface, and in this paper we have studied the influence of temperature variations on the solar cell parameters. The open circuit voltage (V_{oc}) increases linearly with temperature and a maximum value of 157 mV at 89°C is obtained. The short circuit current (I_{sc}) increase with temperature increases until reaching a maximum value of 92 mA at 85°C and then decreases for highest temperatures. The efficiency follows the changes of open circuit voltage and short circuit current. The maximum efficiency obtained is 27%. Figure (4) show the changes of V_{oc}, I_{sc} and η in each case.

Figure4 Solar cell characteristics at different cases of parameter variation

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