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The temperature functional dependence of VOC for a solar cell in relation to its efficiency new approach

M.K. El-Adawi*,**, I.A. Al-Nuaim

Physics Department, Faculty of Science for Girls,
P.O. Box 838, Dammam 3113, Saudi Arabia

Abstract

The temperature functional dependence of the solar cell efficiency is studied without neglecting (dI_{sc}/dT). The temperature dependent parameters that determine the value of the short circuit current I_{sc} are considered I_{sc} is also given as a function of the incident solar irradiance. The variation of the efficiency with temperature along the local day time is also evaluated. The conditions governing the sign of (dV_{oc}/dT) are indicated an illustrative example for a silicon cell is given.

Keywords: Temperature functional dependence; Solar cell efficiency

1. Introduction

The efficiency of the solar cell and the methods to increase it, have aroused the interest of many investigators [1–16]. The efficiency is a measure of the cell performance. The operating cell temperature affects its efficiency through the functional dependence of the different psychical quantities limiting its value.

Three main parameters are usually used to characterize the solar cell outputs [17], these are

– I_{sc}, the short-circuit current. Ideally, this is equal to the light-generated current.
– The open-circuit voltage V_{oc} which in principal depends on I_o, the diode saturation current.
– The fill factor FF, which in turn is a function of V_{oc}.

The above mentioned parameters dependent on the cell temperature, nevertheless, different authors assume in evaluating the efficiency and its rate of variation, that the increase of I_{sc} with temperature is negligible and accept its temperature rate of variation to be zero [17].

The aim of the present work is to clarify to what extent this assumption is valid, and to

*Corresponding author.
**On leave: Ain Shams University, Faculty of Education, Vice Dean Physics, Department Helliopolis, Cairo, Egypt.

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study the efficiency behavior with temperature not neglecting the dependence of I_{sc} on the cell temperature.

2. Derivation of the basic equations

Let us define the efficiency η as [17]

$$\eta = \frac{V_{oc}\, I_{sc}\, FF}{P_{in}} \tag{1}$$

where, P_{in} is the total power is the light received by the cell.

For an ideal p–n junction cell, where [17]

$$V_{oc} = \frac{kT}{q} \ln\left(\frac{I_{sc}}{I_0} + 1\right) \tag{2}$$

where, q is the charge of the electron = 1.6×10^{-19}. The saturation current density as a function of the band gab and temperature can be written in the form:

$$I_0 = AT^{\gamma} e^{-\frac{E_{g0}}{kT}} \tag{3}$$

The value of $\gamma = 3$ is accepted in the present work, also the value of the non-ideality factor A is taken as unity. The relation between short-circuit current and open-circuit voltage is:

$$I_{sc} = I_0 \left(e^{qV_{oc}/kT} - 1\right) \tag{4}$$

$$I_{sc} \approx I_0 e^{qV_{oc}/kT} \tag{5}$$

In Eq. (3), the factor A is independent of temperature, and γ includes the temperature dependencies of the remaining parameters determining I_0, its value generally lies in the range 1–4.

E_{go} is the linearly extrapolated zero temperature band gap of the semiconductor making up the cell.

Let us find from Eq. (2) the rate of temperature variation of V_{oc}, this is obtained in the form:

$$\frac{dV_{oc}}{dT} = \frac{V_{oc}}{T} + \frac{AkT}{q} \frac{1}{\left(I_{sc} + I_o\right)} \left[\frac{dI_{sc}}{dT} - \frac{I_{sc}}{I_o}\left(\frac{dI_o}{dT}\right)\right] \tag{6}$$

Experimentally, it is shown, that V_{oc} decreases with temperature the condition for that is given from eq. (6) as

$$\frac{AkT}{q} \frac{I_{sc}}{I_o} \frac{1}{\left(I_{sc} + I_o\right)} \frac{dI_o}{dT} > \frac{V_{oc}}{T} + \frac{AkT}{q} \frac{1}{\left(I_{sc} + I_o\right)} \frac{dI_{sc}}{dT} \tag{7}$$

If both sides of Eq. (7) are equal, then V_{oc} will be no longer dependent on the temperature T.

If the R.H.S of Eq. (7) is greater than its L.H.S, then the behaviour of V_{oc} with temperature will be reversed, and the rate (dV_{oc}/dT) will be positive.

From Eq. (3) it can be proved that:

$$\frac{1}{I_o} \frac{dI_o}{dT} = \left\{\frac{\gamma}{T} + \frac{E_{go}}{kT^2}\right\} \tag{8}$$

Substituting Eq. (8) into Eq. (6) one gets

$$\frac{dV_{oc}}{dT} = \frac{V_{oc}}{T} + \frac{AkT}{q} \frac{1}{\left(I_{sc} + I_o\right)} \left[\frac{dI_{sc}}{dT} - I_{sc}\left\{\frac{\gamma}{T} + \frac{E_{go}}{kT^2}\right\}\right] \tag{9}$$

Neglecting I_o with respect to I_{sc}, and neglecting (dI_{sc}/dT) in comparison with more significant terms in Eq. (9), results in the expression:

$$\frac{dV_{oc}}{dT} = \frac{V_{oc}}{T} - \frac{AkT}{q} \left\{\frac{\gamma}{T} + \frac{E_{go}}{kT^2}\right\} \tag{10}$$

Since $E_{go} = V_{go}\, q$, Eq. (10) for $A = 1$, gives

$$\frac{dV_{oc}}{dT} = -\frac{\left(V_{go} - V_{oc} + \gamma\left(kT/q\right)\right)}{T} \tag{11}$$