NRIAG Journal of Astronomy and Geophysics (2016) 5, 23–29

National Research Institute of Astronomy and Geophysics

NRIAG Journal of Astronomy and Geophysics

www.elsevier.com/locate/nrjag

Temperature optimization of high concentrated active cooled solar cells

M. Sabry

National Research Institute of Astronomy and Geophysics, Solar Research Department, Cairo, Egypt

Received 8 January 2016; revised 27 February 2016; accepted 14 March 2016
Available online 31 March 2016

KEYWORDS

Concentrated PV;
Water cooled;
Active cooling;
CFD

Abstract Active cooling is essential for solar cells operating under high optical concentration ratios. A system comprises four solar cells that are in thermal contact on top of a copper tube is proposed. Water is flowing inside the tube in order to reduce solar cells temperature for increasing their performance. Computational Fluid Dynamics (CFD) simulation of such system has been performed in order to investigate the effect of water flow rate, tube internal diameter, and convective heat transfer coefficient on the temperature of the solar cells. It is found that increasing convective heat transfer coefficient has a significant effect on reducing solar cells temperatures operating at low flow rates and high optical concentration ratios. Also, a further increase of water flow rate has no effect on reducing cells temperatures.

1. Introduction

Solar energy is going to be a main substitute for fossil fuels in the coming years for its clean and renewable nature. As the country population progresses, the energy consumption increases (Royne et al., 2005). Incident solar radiation elevates the temperature of PV cells, resulting in a drop of their electrical efficiency (Tripanagnostopoulos, 2007). The integration of photovoltaic and solar thermal technology increases the energy output per unit collector area (Omer, 2008; Royne et al., 2005).

E-mail address: mohamed.ma.sabry@gmail.com
Peer review under responsibility of National Research Institute of Astronomy and Geophysics.

ELSEVIER Production and hosting by Elsevier

Concentration of sunlight onto photovoltaic cells, and the consequent replacement of expensive photovoltaic area with less expensive concentrating device, is seen as one method to lower the cost of solar electricity. Because of the reduction in solar absorber area, more costly, but higher efficiency PV cells may be used. However, only a fraction of the incoming sunlight striking the cell is converted into electrical energy. The remainder of the absorbed energy will be converted into thermal energy in the cell and may cause the junction temperature to rise unless the heat is efficiently dissipated to the environment (Min et al., 2009; Mosalam Shaltout et al., 2000, 1994; Sabry et al., 2004).

The solar cell output is strongly related to its temperature as shown clearly in Eq. (1), which gives the *I-V* characteristics of the solar cell especially at $T > 300$ K according to the well-known one-diode model:

http://dx.doi.org/10.1016/j.nrjag.2016.03.002
2090-9977

Nomenclature

E_g	band gap voltage	R_t	tube reflectivity
FR	flow rate	R_{sc}	solar cell reflectivity
h_{ct}	heat transfer coefficient	T_t	tube transmissivity
I_{ph}	photo-generated current	T	cell temperature
I_0	dark current	V_{oc}	open circuit voltage
k	Boltzmann's constant	η	electrical efficiency
n	ideality factor	ϕ	the rotation rate tensor
q	electron charge	$\boldsymbol{\kappa}$	turbulent kinetic energy
R_s	series resistance	$\boldsymbol{\varepsilon}$	dissipation rate
R_{sh}	shunt resistance	ρ	density

$$I = I_{ph} - I_o\left[\exp\left(\frac{q(V+R_sI)}{nkT}\right) - 1\right] - \frac{V+R_sI}{R_{sh}} \quad (1)$$

V_{oc} is related inversely to the cell temperature according to the differential Eq. (2) (Yoon and Garboushian, 1994):

$$\frac{dV_{oc}}{dT} = -\left[\left(\frac{E_g}{q} - V_{oc}\right) + \frac{3kT}{q}\right]\cdot\frac{1}{T} \quad (2)$$

The important part of Eq. (2) is $(E_g/q - V_{oc})$. For high voltages, those are reached at high concentration levels, E_g stays nearly constant and V_{oc} increases. Thus, the temperature coefficient of V_{oc} decreases with increasing concentration. At one sun the temperature coefficient is around 1.7 mV/°C for highly efficient solar cells, at 200 sun the coefficient decreases to around 1.4 mV/°C (Yoon and Garboushian, 1994).

The concept of photovoltaic/thermal (PV/T) solar collector was first put forward by Kern and Russell (1978). The outcome brought a great lift to the overall efficiency of solar energy conversion (Ghitas, 2000; Ji et al., 2008; Sabry et al., 2004). This could be well established by the use of Fresnel lenses coupled to high efficiency solar cells. Thermal energy could be extracted from the back of the solar cell by means of active cooling subsystems in order to maintain its performance and use such thermal energy as well (Mosalam Shaltout and Ghitas, 1993). The cell efficiency varies with both temperature and concentration. There are various models for temperature and concentration dependency found in the literature (Edenburn, 1980; Florschuetz, 1975; Luque, 1989; Mbewe et al., 1985; O'Leary and Clements, 1980).

As shown in Fig. 1 (Royne et al., 2005), for monocrystalline Si solar cells, most of the models predict quite similar dependencies in the lower temperature range; most models assume straight lines. The different values predicted arise from the fact that monocrystalline Si solar cells have different peak efficiencies. Generally, the relation between cell efficiency with cell temperature is inversely proportional, especially at $T > 300$ K.

As the solar cell performance is very sensitive to its operating temperature, active cooling, preferably by flowing water has to be applied especially at high concentration ratios in order to reduce the solar cell's temperature. On the other hand, thermal energy absorbed by water could be domestically used, adding to the total system efficiency.

In the past, few papers discussed economic evaluation of active cooled concentrator-photovoltaic systems e.g. (Kern and Russell, 1978; Sharan et al., 1985) considering a unique value of water flow rate without optimizing the cooling rate according to the incident illumination intensity and other system parameters.

In this study, a system consists of water passing through a copper tube. We propose a tube of length 1 m and four solar cells connected on top of the tube. Those cells are high-efficiency squared solar cells (~32%) with side length of 5 mm, in thermal contact with the tube's top centre, and exposed to concentrated solar radiation collected by Fresnel lenses, which is proposed. Flowing water aims at sufficiently cooling the four solar cells with a minimum water flow rate. The first solar cell will be highly cooled as it is in contact with flowing water near the inlet, while the 4th solar cell will be hot because water will be hot itself. System parameters such as concentration ratio and water flow rate are to be optimized in order to increase the solar cell electrical output, maximizing thermal gain, and in the same time, minimizing the energy consumed in the process of water pumping and circulation.

Fig. 2 shows schematic of a segment of a copper tube with solar cells thermally attached and exposed to concentrated solar radiation collected by Fresnel lenses. The whole system is proposed to be attached to a solar tracking subsystem to follow the sun during the operating hours.

2. System design and simulation technique

Detailed analysis of conductive and convective heat transfer processes occurring within the system containing the tube,

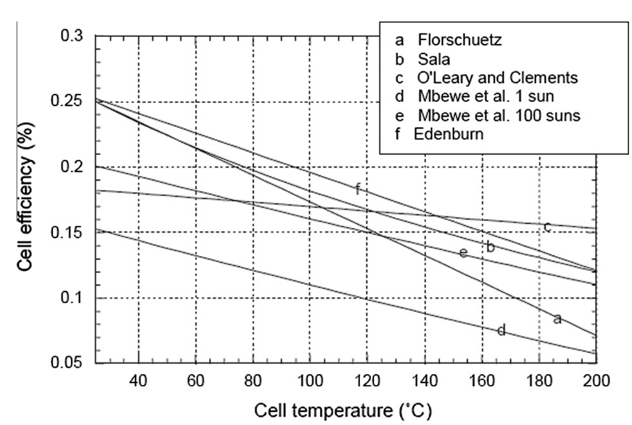

Figure 1 Dependence of cell efficiency on cell temperature and illumination intensity (Royne et al., 2005).