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Performance of a silicon photovoltaic module under enhanced illumination and selective filtration of incoming radiation with simultaneous cooling

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Abstract

A promising option to reduce the cost of silicon photovoltaic systems is to concentrate the sunlight incident on the solar cells to increase the output power. However, this leads to higher module temperatures which affects performance adversely and may also cause long term damage. Proper cooling is therefore necessary to operate the system under concentrated radiation. The present work was undertaken to circumvent the problem in practical manner. A suitable liquid, connected to a heat exchanger, was placed in the housing of the photovoltaic module and unwanted wavelengths of solar radiation were filtered out to minimise overheating of the cells. The selection of the liquid was based on factors such as boiling point, transparency towards visible radiation, absorption of infrared and ultraviolet radiation, stability, flow characteristics, heat transfer properties, and electrical nonconductivity. Using a square parabolic type reflector, more than two fold increase in output power was realised on a clear sunny day employing a 0.13 m^2 silicon solar module. Without the cooling arrangement the panel temperature rose uncontrollably.

Keywords: Photovoltaics; Enhanced solar insolation; Liquid optical filter; Cooling; Power characteristics

1. Introduction

Silicon solar cells have limited use owing to their prohibitively high cost. Measures are required to reduce the photovoltaic (PV) power generation cost for widespread commercialization of the technology. Since power output is dependent both on panel area and light intensity, an attractive and promising option to a low cost silicon PV system is to concentrate the sunlight incident on the solar cells. This increases the power output per unit area of solar cell and the cell area can be reduced accordingly. There is thus significant potential for cost reduction since the concentrating devices are relatively inexpensive. Although the concept is simple, it is difficult to apply in practice, especially at high concentration ratios as the problem of overheating of the solar cells poses a challenge (Sangani and Solanki, 2007).

It is well known that only a small fraction of the solar spectrum is useful for generating power through conventional silicon solar cells. Consequently, the conversion efficiency tends to be low. An ideal mono-crystalline silicon cell can convert the 600–900 nm electromagnetic radiation into electricity with an efficiency of 55–60% whereas, with respect to the entire solar spectrum, the efficiency drops to between 5–15%, depending on the cell technology (Tonui and Tripanagnostopoulos, 2008). Worse still, the part of the spectrum that is outside the spectral response

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of the solar cell leads to unnecessary heating of the device. This problem would be further aggravated if concentrated solar radiation is employed. A better performance can be expected by preventing this unwanted radiation from reaching the cell as this would help lower the operating temperature of the cell. Indeed, it is desirable that for silicon solar modules the temperature be restricted to 50–60 °C. The heating up of the solar panel can be minimized using a liquid filter capable of absorbing unwanted radiation incident on the panel (Sabry et al., 2002). In this study, an attempt is made to devise a prototype for enhancing the output power from a commercially available silicon module. A manually tracked parabolic square concentrator is employed for this purpose. Over-heating of the module is prevented by circulating a liquid in front of the module, disposed in the path of the incident beam. This liquid filter absorbs the unwanted radiation and transmits only the useful part of the spectral band onto the module. A heat exchanger is employed to cool the warmed up liquid. This novel approach – which addresses the problem at source – may be a useful alternative to the various other approaches reported for cooling of photovoltaic panels (Kern and Russell, 1978; Raghuraman, 1981).

2. Experimental

2.1. Liquid selection

To design the system, the liquid flowing above the solar module had to be properly engineered. The characterisation of different types of inorganic and organic liquids was done based on density, specific heat, viscosity, refractive index and also using differential scanning calorimetry (DSC) (Mettler Toledo TGA/SDTA851, DSC822) and techniques like Fourier transform infrared red (FT-IR) (Perkin Elmer GX-2000) and ultraviolet–visible-near infrared (UV–VIS-NIR) (Shimadzu-3101PC, Varian) spectroscopy. The performance of each liquid was studied outdoors by measuring the solar radiation on a surface with and without the liquid. The total radiation was measured using a precision spectral pyranometer (Eppley model), the UV radiation by total UV radiometer (Eppley model), and the visible radiation by lux meter (Kusam-Meco; KM-Lux-99).

2.2. Prototype assembly

A solar panel (Central Electronics Limited, India; model PM621-127C78) of 0.13 m^2 area was used in the present study. The top glass cover of the module was removed. Baffles made out of float glass pieces (0.004 m thickness) were attached to a 0.008 m thick toughened ultra clear solar glass plate (0.28 m^2; 91% visible spectrum transmittivity) and the assembly mounted over the cells at a height of 0.02 m (based on optimisation of the liquid path length). The baffles prevented short-circuiting of liquid flow (Fig. 1). The heated liquid from the module was passed through a heat exchanger placed in an insulated cold water

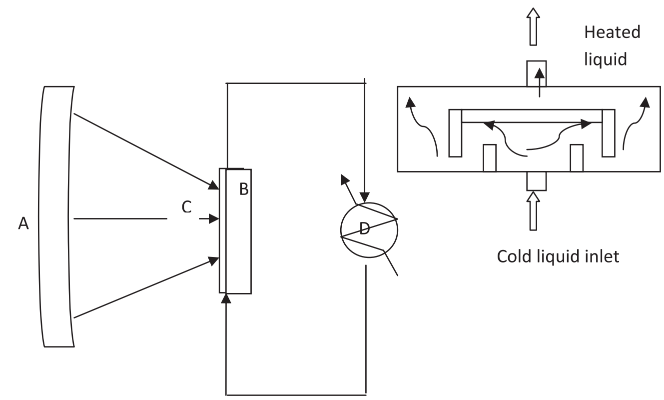

Fig. 1. Schematic diagram of the test set up for study of performance of PV module under enhanced insolation condition: A, parabolic square concentrator; B, solar module; C, liquid filter assembly; D, heat exchanger. The figure at top right shows the flow path through baffles in the liquid filter assembly.

tank. Insulation was provided on all the pipelines to minimise heat loss. The temperature of the water was controlled and maintained at $\leqslant$20 °C. To circulate the liquid, a 12 V DC pump powered by a PV module was used. Thermosyphonic flow mechanism was observed only at the peak period of the day. The flow was controlled using a one way valve at 5 L per minute. The entire assembly was positioned at the focal region of a 2 m^2 square parabolic trough reflector with manual tracking arrangement. The reflector material used for the study was anodized aluminium which could be coated with a UV protective coating. The assembly was so placed that a moderately uniform illumination was achieved on the module throughout the day.

2.3. Measurements

Current–voltage (I–V) data for the system were recorded with the help of multimeters and a rheostat. K-type thermocouples were used to measure the temperatures at the inlet (T_{in}) and outlet (T_{out}) points of the liquid filter and also at the backside of the module throughout the experiment. A pyranometer was used to measure the global insolation on a horizontal surface throughout the day. The measured temperatures were cross-checked using a non-contact IR thermometer. Throughout the experiment, wind speed, relative humidity and ambient temperature were monitored by a Technoline wireless weather station.

3. Results and discussion

3.1. Liquid selection

Cooling of photovoltaic cells is one of the main concerns when designing concentrating photovoltaic systems. In the present approach, this involved the development of a liquid filter which would transmit only the useful radiation onto the panel. The liquid filter was designed to have the following characteristics so as to enable it to be an effective medium for the intended purpose: