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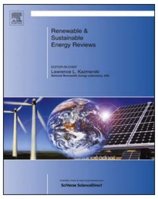

Performance enhancement of solar photovoltaic cells using effective cooling methods: A review

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ABSTRACT

The Photovoltaic (PV) cells are sensitive to temperature variations. When the ambient temperature and the intensity of solar irradiance falling on the PV cells increases, the operating temperature of the PV cells also increases linearly. This increase in operating temperature of the PV cells leads to reduction in open circuit voltage, fill factor and power output for mono and polycrystalline PV cells which are used in most of the power applications. The net results lead to the loss of conversion efficiency and irreversible damage to the PV cells materials. Therefore, to overcome these effects and to maintain the operating temperature of the PV cells within the manufacturer specified value, it is necessary to remove heat from the PV cells by proper cooling methods. This review presents an overview on passive cooling (heat pipe based and by fins), active cooling (by spraying water), liquid immersion cooling and cooling by employing phase change material (PCM) to enhance the performance of the commercially available PV and concentrated photovoltaic (CPV) cells.

Contents

1. Introduction

The standard of living of people in any country mainly depends on the industrial growth of that country, which in turn depends on the energy availability and energy consumption. There is a well-established relationship that countries having higher per capita annual energy consumption have higher literacy rates than the countries having lower per capita energy consumption. The energy demands in most of the countries are met out by fossil fuels such as coal, oil and gas but their availability is limited. Conversion of energy stored in the fossil fuels into useful form produces harmful pollutants and they leads to global warming, which is one of the major threats for the entire world.

One of the best alternative to the fossil fuels is the harnessing the solar energy into electrical energy. The power from the sun intercepted by the earth is about 1.8×10^{11} MW, which is many thousands times greater than the power consumption from all sources. Solar energy will not produce pollutants like fossil fuels during conversion into electricity and it is possible to protect the

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world from the global warming and also possible to preserve the fossil fuels for our future generation. The technology of converting solar energy into electrical energy was invented by Charles Feritts and is referred to as photovoltaic (PV) cell. When the solar irradiance is made to fall on the PV cells, the photons are absorbed by the PV cell materials and the photons having the energy above the band gap of PV cell materials will constitute the flow of electric current from the PV cell to external load. In general the wave length of solar irradiance from 400 nm to 1200 nm are strongly absorbed by the PV cells and converted into the electric power. The conversion efficiency of the commercially available module ranges from 12% to 18% and the laboratory cells have a record efficiency of 24.7%. The remaining solar irradiance falling on the PV cells are converted in to heat, which in turn increases the operating temperature of the solar modules. The increase in operating temperature of the PV cells results in decrease of open circuit voltage (V_{oc}), fill factor and power output of about 2–2.3 mV/°C, 0.1–0.2%/°C and 0.4–0.5%/°C respectively, with increase in short circuit current (I_{sc}) of 0.06–0.1%/°C for mono and polycrystalline PV cells, which results in the loss of conversion efficiency and irreversible damage to the PV cells materials [1]. Radziemska [2] investigated the influence of temperature and wavelength on electrical parameters of crystalline silicon solar cell module. The single crystalline solar cell is exposed to the halogen lamp irradiation of intensity 618–756 W/m^2. Figs. 1 and 2 showed that the maximum output voltage and power decreased with increase in operating temperature of the cell. The performance of the module was measured at module temperature of 25 °C and 60 °C. The results obtained indicated that the temperature co-efficient of the module was −0.66%/K. The fill factor and conversion efficiency was decreased by 0.2%/K and 0.08%/K respectively. Chander et al. [3] investigated the effect of cell temperature on the photovoltaic parameters of mono-crystalline silicon cell and reported that the open circuit voltage, maximum power, fill factor and efficiency were decreased with cell temperature. Zaoui et al. [4] studied experimentally and numerically, the effect of irradiance and temperature on the performance of PV modules and reported the similar results.

Therefore to overcome the effects of cell temperature and to maintain the operating temperature of the PV cells within the manufacturer specified value, it is necessary to remove heat from the PV cells by proper cooling methods. Passive cooling and active cooling techniques are used to remove heat in order to enhance the performance of PV cells.

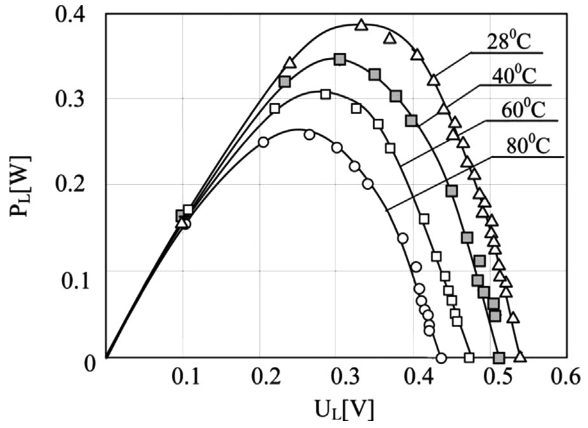

Fig. 1. Output power versus voltage of a single-crystalline silicon solar cell at various temperatures: 28 °C, 40 °C, 60 °C, 80 °C [2].

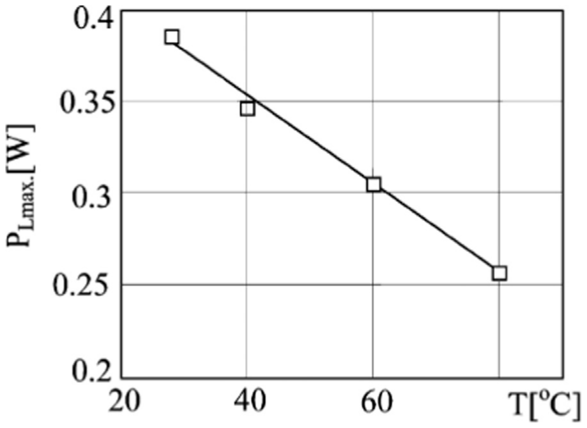

Fig. 2. Temperature dependence of the maximum output power $P_m(T)$ [2].

2. Experimental studies

2.1. Heat pipe passive cooling

Heat pipe is a device which is used to transport heat by two phase flow of working fluid from one place to other. The heat pipe consists of evaporator section, adiabatic section and condenser section. Heat absorption takes place in evaporator section; heat rejection at the condenser section and the adiabatic section is fully insulated. With vacuum pump the evacuation is made at the heat pipe to facilitate the filling of working fluid and the evaporator section of the heat pipe is attached to the back side of the PV cells to absorb the heat from them. Due to this, vaporization occurs so that the liquid inside the heat pipe vaporizes, hence the vapor carrying the latent heat of vaporization, flows towards the condenser section and gives up its latent heat to the surroundings by natural convection. Heat pipes are manufactured using envelop material, working fluid and wick material which must be compatible. For the temperature range of −20 °C to 100 °C, the two potential heat pipe wick and wall materials are copper and aluminum. The choice of working fluid for different heat pipe materials is given in Table 1.

Akbarzadeh and Wadowski [7] introduced a passive cooling method based on thermosyphon, which can effectively cool the solar cells under concentrated light. The proposed system for cooling of the solar cells contains two heat exchangers piped together, initially evacuated and filled with refrigerant R-11. As the convection heat transfer co-efficient is low, the external heat transfer area of the condenser is extended by fins. Polycrystalline solar cells having dimensions of 25 mm by 20 mm were installed on both sides of the evaporating surface of the cooling system. The test results showed that the maximum temperature of the cells without cooling was 84 °C and with cooling was 46 °C. The maximum power output was 10.6 W and 20.6 W without and with cooling respectively. Cheknane et al. [8] experimentally investigated the role of passive cooling on silicon based concentrator solar cell performance. They designed gravity dependent copper heat pipe using water or acetone as working fluid. They measured open circuit voltage (V_{oc}), short circuit current (I_{sc}), fill factor (FF) and series resistance. The results showed that the V_{oc} is smaller without concentration and increased more rapidly with intensity and its value is more for acetone than water. They also reported that the FF decreased with increasing intensity for both liquids and the efficiency increased with increase in intensity.

Anderson et al. [9] successfully demonstrated the feasibility of a heat pipe passive cooling solution to CPV cell. Copper/water heat pipe with aluminum fins can be used to remove the heat from the CPV cell passively by natural convection. Copper and aluminum heat pipe with various working fluids were examined and copper