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Steady State Thermal Analysis of Thermo Siphon Heat Pipe Photovoltaic Panel Cooling Mechanism

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ABSTRACT

Photovoltaic panels are designed to produce optimum power output only below a particular temperature which is called the nominal operating cell temperature. Higher operating temperatures of the photovoltaic panels have an adverse impact on the power output and efficiency. This is because of the predominant increase in the resistance to the current generated inside the photovoltaic cells which results in reduction of the power output. Temperature rise of photovoltaic panels due to high solar radiation intensity and ambient temperature is the problem discussed in this paper. Among various methods currently suggested and tested by researchers worldwide, thermo siphon heat pipe cooling mechanism is a feasible and low cost option. This method can be applied to both concentrating and non concentrating photovoltaic panels. The mechanism used for implementing this method of cooling is described. The effect of cooling on the panel temperature and the consequent rise in the power output and the efficiency of the photovoltaic panel is analyzed with the help of a simulation using ANSYS steady state thermal package. The results of using different phase change temperatures in the thermo siphon cooling mechanism are analyzed.

KEYWORDS: *Photovoltaic, Efficiency Enhancement, Thermo siphon, Panel cooling*

I. Introduction

Photovoltaic (PV) systems play a key role in substituting conventional energy sources by acting as a total or partial energy source as well as a decentralized energy source. Improvements in efficiency of these systems helps to enhance the power output and helps to replace more and more conventional energy sources with renewable solar energy. Photovoltaic cells convert only a small fraction (less than 20 %) of the solar radiation energy into electrical energy [1]. The balance is converted into heat within the cell. This makes cell operating temperature to reach much above the ambient temperature. Operating temperature plays a crucial role in the efficiency of photovoltaic conversion process. Electrical efficiency and power output of a PV module decreases linearly with increase in the operating temperature [2]. Cooling options for photovoltaic panels therefore contribute to improvement in its efficiency. This can be achieved by both passive and active methods. While passive methods involve extra manufacturing cost, they do not have additional power requirements as in the case of active mechanisms.

Passive mechanisms using sheet fins at bottom of panel with air flow by buoyant effects was reported to produce marginal efficiency enhancement [3]. Phase change material used to absorb a part of the heat produced by the panel produced positive results [4]. The above methods gave higher power output from the panel.

Heat pipes are devices used to transport heat from a high temperature area to a low temperature area by continuous evaporation and condensation of a working fluid. Heat is absorbed in the evaporation region which is usually a conduit below the solar photovoltaic panel and rejected to the surroundings in the condensation region which is the upper portion of the pipe extending above the panel. The condensed fluid heat is then returned back to the evaporator region. Usually a wick in used to transport liquid from the condenser region to the evaporator region. Heat pipes were used for cooling concentrating photovoltaic panels resulting in panel operating temperatures as low as 40^{0}C at an ambient temperature of 34^{0}C [5]. Thermo siphon heat pipes (THP) are heat pipes which work by fluid flow due to gravity effects in contrast to normal heat pipes which use a wick structure to transport the fluid by capillary effect. This method was tested and significant improvement in performance was reported [6]. However, ineffective thermal contact between the heat pipe surface and the back of the solar panel resulted in poor heat transfer performance. Experiments on an array of micro heat pipes with air cooling and water cooling on the condenser side were also reported [7].

Since the fluid is pressurized inside the thermo siphon during evaporation within the restricted volume, elevation of the boiling point occurs. Hence both the nature of the fluid and its operating pressure determine its operating temperature. Selection of the proper thermo siphon fluid and operating pressure determines the thermo siphon temperature and consequently the panel temperature. Cooling temperature requirement depends on the local solar radiation levels, ambient temperature and wind speed. In order to study the effect of the thermo siphon fluid phase change temperature, a steady state model was analyzed using the ANSYS steady state thermal workbench. Temperature variation in the panel was simulated by using two different phase change temperatures in the thermo siphon. Results show significant variation in the operating temperature of the panels.

II. THEORETICAL BACKGROUND

A. Structure of solar panels

Commercial photovoltaic panels are mostly polycrystalline silicon wafers which are encapsulated in a layer of ethylene vinyl acetate (EVA) in order to give rigidity to the wafers [8]. This encapsulation is further supported at the bottom by a substrate layer made of tedlar (0.0001m thick) which is a commercial polyvinyl fluoride film. The top of the wafer encapsulation is covered by a glass sheet (0.032m thick). The bottom of the glass sheet which is in contact with the wafer is provided with a layer of anti reflective coating (ARC) which enables more solar radiation to fall on the cells. Fig. 1 gives the general arrangement of a panel.

B. Conversion efficiency

Conversion efficiency depends on different factors including the nature of the photovoltaic cell material and its temperature. Study of performance

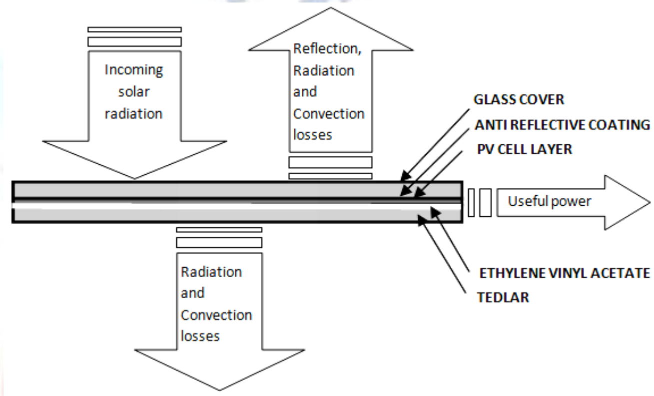

Fig.1 Arrangement of photovoltaic panels

of photovoltaic cells was conducted and its efficiency is given by the following equation [9].

$$\eta = \eta_r \left[1 - \beta \times (T_C - T_r) + \lambda \times \log(\phi)\right] \qquad (1)$$

In the above equation η_R is the reference module efficiency at reference cell temperature T_r equal to 25 °C for a reference solar radiation, I_{ref} of 1000 W/m²K. β is the temperature coefficient equal to 0.0045 K^{-1} and λ is the solar irradiation coefficient equal to 0.12, respectively. T_C represents the cell temperature and Φ represents the actual intensity of solar radiation.

C. Thermo siphon cooling mechanism

Four rectangular tubes are attached to the bottom of the panel under perfect thermal contact. The tubes contain the phase change liquid that evaporates when the panel temperature rises above its boiling temperature. The vapor condenses when it contacts the cooler side which is exposed to the ambient. It then trickles down and evaporates again when it contacts the hotter surface of the panel. This evaporation and condensation cycle continues as long as the panel temperature is above the phase change temperature. Fig. 2 shows the arrangement of the thermo siphon tubes in the panels. Four tubes of rectangular cross section are used as thermo siphons at the bottom of the panel.

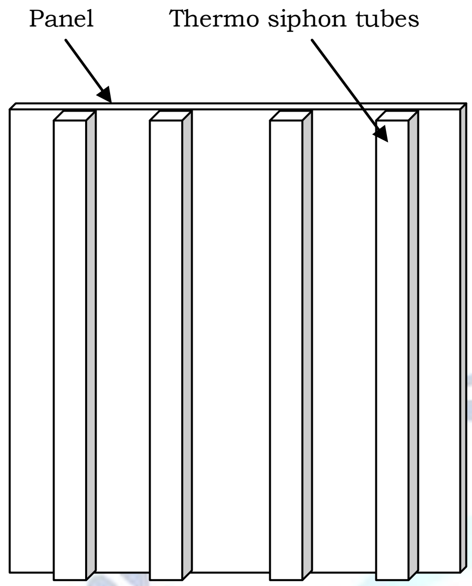

Fig.2 Thermo siphon tubes attached behind panel

III. THE MODEL

The steady state model is made based on the following assumptions:

- Perfect thermal contact between the panel and the thermo siphon tubes
- The phase change liquid operates at a constant boiling temperature
- The vapor cools uniformly at the side exposed to atmosphere
- The temperature of the tube is uniform throughout its length
- Steady state conditions are assumed
- Heat produced in the cell layer is conducted across the glass layer on the top and the tedlar layer at the bottom of the cell layer.

Solar radiation falls on the panel which is partially converted to electrical power and the remaining is lost to the ambient by convection and radiation. Under steady state condition, the heat generated (q) by the cell layer of particular volume (V) for a particular value of radiation depends on the efficiency (η) of the panel.

$$\frac{q}{V} = (1-\eta)A\Phi \qquad (2)$$

'A' represents the sun exposed surface area of the panel and 'Φ' indicates the intensity of solar radiation.

The one dimensional model is governed by the equations for conduction and convection. Heat flux produced by the cell layer ($\dot{q}$) is equal to the heat conducted on the top and bottom of the cell layer in one dimension.

$$\dot{q} = K_g\left(\frac{dT}{dx}\right)_g + K_t\left(\frac{dT}{dx}\right)_t \qquad (3)$$

Kg and Kt represent the thermal conductivity of glass and tedlar layers. The heat is further lost by convection and radiation from the top surface and bottom surface of the panel.

$$\dot{q} = h_T(T - T_\infty) + h_B(T - T_G) + \sigma(T^4 - T_{sky}^4) + \sigma(T^4 - T_G^4) \qquad (4)$$

h_T represents the heat transfer coefficient from panel top and h_B represents the heat transfer coefficient form the bottom of the panel. $T_\propto$ T_a represents the free stream ambient temperature and T_G represents the ground temperature. σ represents the Stefan Boltzmann constant.

IV. SIMULATION

The model is meshed with 30238 nodes and 4740 elements. Relevance center is set to fine mesh and smoothing was set to medium. Fig. 3 shows the mesh used.

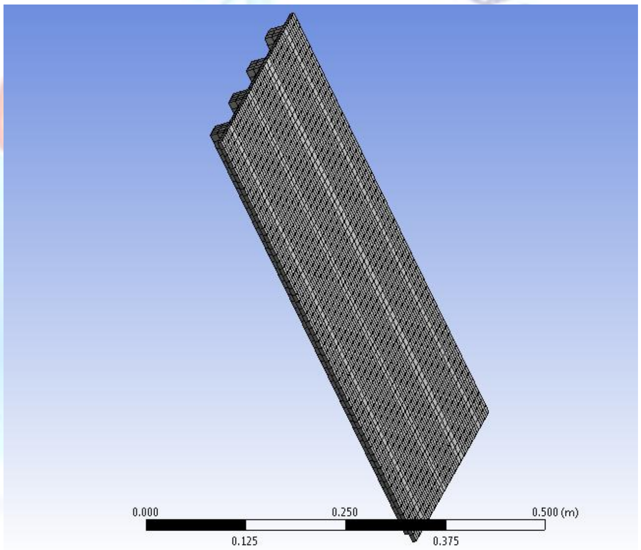

Fig.3 Model with fine meshing

The phase change temperature of the thermo siphon fluid is maintained at 40^{0}C and 50^{0}C. Heat transfer coefficient is calculated using the following relation for a normal wind speed (V) of 5 m/s [10].

$$h_T = 2.8 + 3.8V \qquad (5)$$

The value of heat transfer coefficient used was 21.8 W/m^{2}K. Solar radiation intensity of 800 W/m^2 on the tilted plane was used for a panel surface area of 0.32 m^2 area. Thermo siphon tube size was 0.05 m square.

V. RESULTS AND DISCUSSION

Results of temperature contours obtained after simulation showed direct relation between the temperature maintained in the thermo siphon and the average panel temperature.

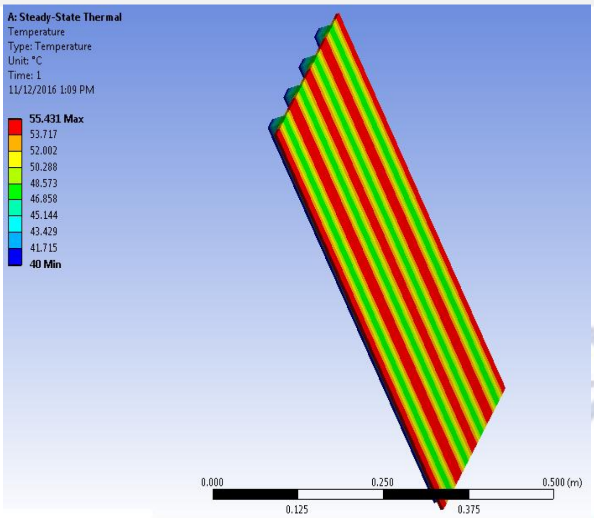

Fig. 4 Results of phase change temperature of 40^{0}C.

In the case of phase change temperature of 40^{0}C, panel temperature reached a maximum value of 55.43^{0}C and minimum temperature of 48.57^{0}C (Fig. 5). In the case of phase change temperature of 50^{0}C, panel temperature reached a maximum value of 64.33^{0}C and minimum temperature of 57.96^{0}C (Fig. 6). A closer examination of the result indicates that a 20% reduction in the phase change temperature produces a 13.8% reduction in the maximum panel temperature. However, the variation of panel temperature between maximum value and minimum value is about 7^{0}C in both the cases. This variation is attributed to the poor thermal conductivity of glass which forms the main constituent of the panel, other components being of negligible thickness. Increasing the size of the thermo siphon tubes or the number of tubes can help to reduce the panel temperature at high solar radiation intensities or ambient temperature conditions. But this will prove to be counterproductive at low solar radiation and ambient temperature conditions when the solar panel temperature is below the phase change temperature.

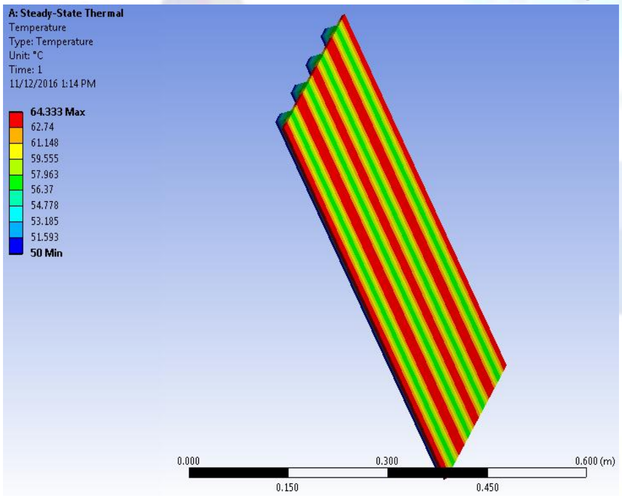

Fig. 5 Results of phase change temperature of 50^{0}C.

VI. Conclusion

A solar photovoltaic panel with thermo siphon cooling mechanism was modeled and simulated for two different phase change temperatures. Results show considerable increase in the cooling effect when phase change temperature was reduced. However, poor thermal conductivity of glass produced large variation in the minimum and maximum temperature in the panel temperature. Optimization of the arrangement has to be done which depends on the actual site conditions.

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