Cooling Techniques Used for Photovoltaic Panels: A Review

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ABSTRACT
A brief review of various techniques used for cooling of solar Photovoltaic panels is presented. The operating temperature of PV module is an important parameter which influences the performance of PV panel. A small portion of solar energy is converted into electrical energy whereas major part of solar energy gets converted into heat which raises the temperature of panels and consequentially reduces efficiency. The reverse saturation current of a solar cell increases rapidly with temperature which decreases the cell voltage.

Key words: cooling techniques, photovoltaic, solar PV efficiency, renewable energy, solar cooling chimney.

I INTRODUCTION

In the last few decades, renewable energy sources are becoming more and more popular as they are pollution free, environment friendly and have become cost effective also. Solar energy is the most important source of energy. In a solar PV panel, in the process of converting solar light energy into the electrical energy, lot of heat is generated and raises the temperature of solar panel. The overall efficiency of solar PV cells generally ranges from 5% to 20%. The remaining solar energy which may be up to 87% gets converted into heat, resulting in rise in temperature of a PV cell. Thus, the cell works above the ambient temperature. Many researchers observed that overall efficiency of Photo Voltaic (PV) cells drop considerably with the rise in temperature. The rate of decrease in efficiency ranges from 0.25% to 0.5% per °C depending on the cell material [1-6]. The current-voltage (I-V) characteristic of a solar PV device depends on temperature variation under illumination. Open circuit voltage (V_{oc}) and the maximum generated power (P_{max}) reduce rapidly with the rise in temperature due to fast increase in reverse saturation current. If constant insolation level is maintained, the temperature rises and there is a marginal rise in the PV cell current but a remarkable fall in PV cell voltage. The power up to 5% can be conserved by cooling of panel [7]. Recent developments have also made use of the waste heat for applications. Normally, hybrid elements are called photovoltaic-thermal units (PV/T unit) which make use of both electrical and thermal solar energy. These units usually have a higher overall efficiency as compared to stand-alone photovoltaic and solar collectors [8,9]. They save considerably on cost and require less space for installation. The aim of this paper is to present an overview of various techniques used for cooling of solar PV panels.

II COOLING OF SOLAR PHOTOVOLTAIC PANELS

Cooling of photovoltaic cells improves the efficiency of solar panel and reduces cost of solar energy in following ways.

(a) Cooling of PV panels increase the efficiency.
(b) Cooling helps to limit the temperature of the PV cells from irreparable damage.
(c) Heat taken away from cooling PV system can be used for some applications.

III METHODS FOR COOLING OF PHOTOVOLTAIC CELLS

The photovoltaic cells can be cooled by passive system or active system. For heat removal, passive cooling uses natural convection/conduction whereas active cooling system consumes energy to operate cooling pump, fan, etc.

(a) Passive cooling methods: Air cooling, water cooling and conductive cooling are the three main types of passive cooling. Cuce et al. [10] worked on two PV cells, one with heat sink and other without heat sink. The aluminum fins with thermal grease duly applied act as heat sink. The illumination was varied from 200 to 800 W/m^2 in which increase in 9% efficiency was observed by passive cooling using a heat sink. Hernandez et al. [11] observed that the depth of flow channel below PV cells affect the passive cooling for larger PV surface (1.95 m^2). The authors noted that for a length-to-depth ratio of 0.085, the PV module temperature increased by 5-6° C.

(b) Active cooling methods: These methods are mainly based on air or water cooling. Fan/pump is needed for circulation of fluid (i.e. water, air etc.). Hence, it continuously consumes power for cooling the PV module. The active cooling methods are mainly used in large power plant and are more suitable for concentrated PV cells.

(c) Hybrid cooling systems: There are various combinations of passive and active systems as shown in Fig. 1. Proper combinations improve the results in terms of costs, output and energy etc.

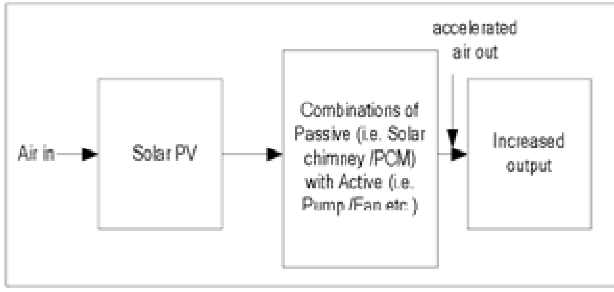

Fig No. 1 Hybrid solar PV systems

The combination of cooling systems in solar PV system increases air flow behind the panels improving the cooling of panels and in-turn the output. Some important technologies are discussed in this paper, namely phase change material (PCM), cooling in submerged water, hybrid PV/T system, micro-channel, thermo-electric cooling system, solar chimney cooling system.

IV PHASE CHANGE MATERIAL (PCM)

Phase change material (PCM) is excellent for special type of conductive cooling (shown as Fig. 2) [12]. Hassan [13] observed that decrease in temperature by 15° C relative to reference PV cell could be achieved in 5 hours by using right type PCM material, at an insolation of 1000 W/m^2. The author used 65 W solar PV panels with 50 mm thick PCM material on the back and vertical aluminum fins to improve conduction.

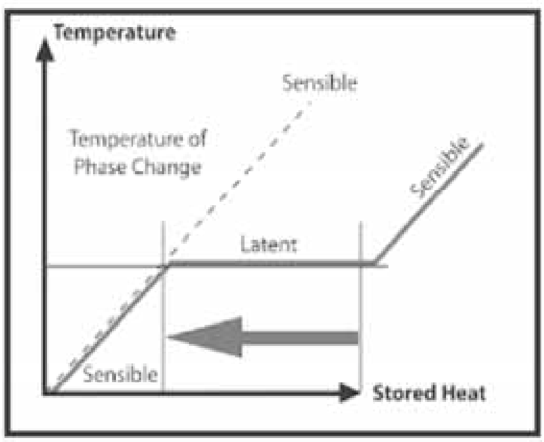

Fig No. 2 PCM cooling technology

Maiti et al. [14] used a V-through reflective panel. A PV panel of 0.133 m^2 surface areas was used by applying 5.5 kg of PCM material which resulted in decrease of the maximum temperature from 85° C to 65° C and increase in the efficiency by about 55% [15].

(a) **Cooling in water submerged panels-** Water cooling is efficient due to higher thermal capacity of water. A number of researchers worked with front and back cooling. Rosa-Clot et al. [16] experimented on submerged water technique to cool the mono-crystalline PV module. It was observed that when temperature was maintained at 30° C, an increase in efficiency in the range of 9 to 22% was noted. This wide variation in efficiency was due to the change in insolation intensity with the depth of water [16]. It was found that at a depth of 4 cm, efficiency increased by 11%.

(b) **Hybrid PV/Thermal (PV/T) system** - The solar heat energy is used for various purposes such as space heating, water preheating ventilation, food drying etc.[17]. Hybrid (PV/T) solar cooling improved the efficiency of solar PV panel by enhanced circulation of ambient air for heat removal as shown in Fig 3. By placing a solar thermal collector behind a solar photovoltaic (PV) array, the PV cell can be cooled. At the same time, the solar collector can gather most of the energy that passes through the array. PV/T systems are also categorized according to the process of heat removal.

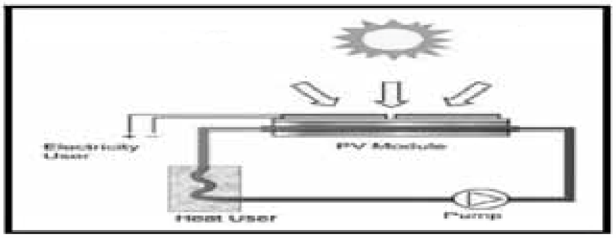

Fig No. 3 Hybrid PV/T solar cooling system

(c) **Micro channel cooling system -** The concept of micro channel/canal cooling was presented by Tuckerman and Pease in 1981[18]. Micro channel cooling system makes use of the concept of heat transfer in which fluid/liquid flows in cross confinement with typical dimensions below of silicon layer of panel, as shown in Fig. 4[19].

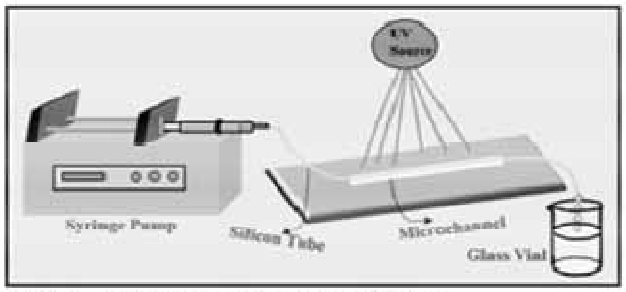

Fig No. 4 Micro channel cooling system

For cooling of electronic components in integrated circuits manifold micro channels/canals are fixed on the back. In electronic components, heat is dissipated by coolant through forced convection.

(d) **Thermoelectric cooling system-** The thermoelectric cooling system works on the principle of Peltier effect. In an electrical junction, one side is hotter than the other side and that is called Peltier effect. Thermoelectric device is made-up of two types of semiconductor materials viz. n-type and p-type. These two are connected electrically in series and thermally in parallel as shown in Fig. 5. In this cooling system, the majority carriers move in the direction from hot to the cold. Afterwards, an applied voltage forces a current through the materials causing an effective heat pump that cools one side and heats up the other. A heat sink must be connected to hot side to dissipate the heat [20].

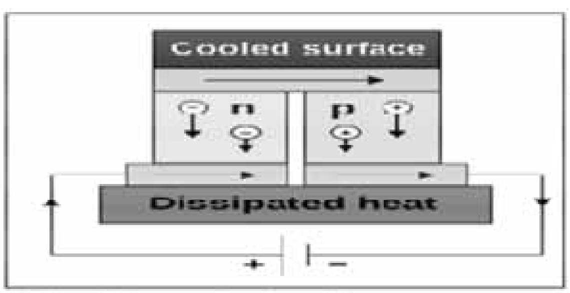

Fig No. 5 Thermoelectric cooling systems

V SOLAR COOLING CHIMNEY (SCC)

A solar chimney is a device that uses solar radiation to move air upwards to create air circulation. At constant pressure, air density decreases with increase in temperature. Air above ambient temperature is driven upwards by the buoyancy force. This physical phenomena is used in solar chimney.

A solar chimney contains a solar absorber, which allows solar heat to be transferred to air. Solar chimneys utilize the 'greenhouse' effect by providing a transparent material (glass) on one side and a solar absorber on the other side while maintaining a gap for air in between the two. Tall chimney provides a pressure difference between the bottom and the top due to which air is drawn from the bottom tap [21, 22].

Tonai [23] suggested a design which consists of an absorber section such that it helps to increase the natural draft of air to improve cooling of PV panels. The velocity of air rising up in the chimney is directly proportional to the energy absorbed by air.

Solar Cooling Chimney (SCC) has two main parts: top part, and the middle part as shown in Fig. 6.

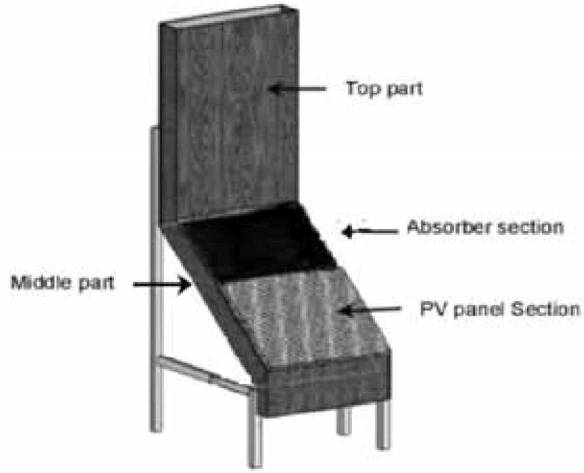

Fig No. 6 Solar chimney cooling system

Top part of the SCC acts as chimney whereas vertical extension to the middle part enhances the natural draft created by rising of the warm air.

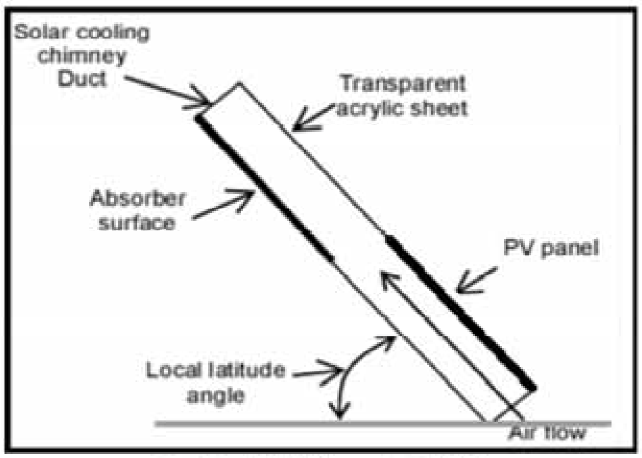

Fig No. 7 Middle part of SCC

The middle part of SCC can be divided in two sections, viz., PV panel section and absorber section and planned such that its length is twice that of PV panel. As shown in Fig. 7, PV panel is placed on the lower half and transparent acrylic sheet is placed on the top half of the SCC duct. To receive maximum solar radiation throughout the year, middle part of solar cooling chimney is installed inclined at an angle equal to local latitude. Black paint is applied on absorber surface to maximize the energy absorption. Most of the incident solar radiations pass through the transparent acrylic sheet and fall on absorbing surface. Thus, the temperature of absorbing surface will rise. High temperature surface transfers the heat to the air entering from the PV panel.

Warm air from absorbing surface has lower density which rises upwards to the top section. If height of chimney is increased, the air velocity increases. From the bottom of SCC, ambient cool air flows through the heated PV panel surface and decrease its temperature.

VI CONCLUSION

It is noted that cooling of solar PV panels increases overall efficiency by 3 to 5% whereas other factors i.e. size of the panels, topographical position, and season of the year also make influence, Passive cooling systems also result in significant improvement in efficiency. The solution lies in solar chimney based air cooling system which provides passive cooling. The combination of both the systems i.e. taller chimney (passive) with fan (active) increases the velocity of air which further reduces the working temperature of PV panel and makes it more efficient. The height of solar chimney needs to be optimized for the cost and effect of shading.

It is found that active cooling techniques yield higher efficiency than passive ones. Active water cooling gives excellent performance by increasing the efficiency. It requires space for water storage and provision for pumping.

Hybrid (PV/T) solar cooling improves the efficiency of solar PV module by enhanced circulation of ambient air for heat removal; the hybrid cooling system can replace active cooling keeping in view the efficiency, cost, system requirements, etc.

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