A review on Cooling Technologies Applied in Photovoltaic Systems

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Abstract
Cooling solar photovoltaic systems is a key aspect that needs to be addressed in the application of photovoltaic systems to achieve greater performance. Adequate amount of cooling will increase the life and efficiency of photovoltaic modules. For domestic and industrial use, the over-heat extracted via the cooling system can be used. This paper will discuss different cooling technologies that can be used to reduce the negative consequences of increased temperature and increase solar arrays performance when working outside normal temperature conditions. Various cooling techniques, including the forced water circulation photovoltaically cooled hybrid solar photovoltaic system; hybrid photovoltaic solar cooled with the spraying of water; increasing photovoltaic performance by using materials for phase exchange; photonic crystal cooling; hybrid solar photovoltaic thermal systems cooled with the use of forced air circulation;

1. Introduction: Photovoltaic systems are the most commonly used technologies for the generation of renewable energy that transform solar energy into usable electricity. Pollution is not caused by the electricity produced from solar cells and no fuel is needed as a consequence of which it is considered the favorable energy source[1]. Photovoltaic modules turn part of the solar radiation into electricity and heat and reflection waste the rest of the fuel. Conversion of solar energy to heat destroys solar cells, thus increasing electrical efficiency [2]. The absorption of heat by solar cells elevates solar cell temperatures and thus decreases the overall efficiency of the solar modules. The commercially employed electrical efficiency of the photovoltaic systems is 6-15% and this power output decreases by 0.2-0.5% per 1 K rise in the module's temperature [3]. Hence it becomes vital to remove the excess heat which is responsible for decreasing the efficiency of solar cells. To improve the efficiency of PV systems various cooling techniques are operated on solar modules. This review paper focuses on different cooling technologies which are applied in photovoltaic systems in order to negate the effects of increasing temperature. To achieve the objectives of the current review, a complete overview of different cooling technologies is obtained by carefully reviewing numerous research papers of different authors.

Various technologies that are explored and evaluated in the following work are: forced water circulation photovoltaically cooled hybrid solar photovoltaic system; hybrid photovoltaic solar cooled with the spraying of water; increasing photovoltaic performance by using materials for phase exchange; photonic crystal cooling; hybrid solar photovoltaic thermal systems cooled with the use of forced air circulation;

1.1 Solar photovoltaic system operation: As shown in Fig.1, The PV cell is composed of p-type and n-type semiconductors with sun-exposed p-n junction. The PV cell acts as a flat diode without solar irradiation, which provides the Shockley equation with the following I-V curve:

ID = IS [e (did/at) – 1]

Where ID and VD are diode current and voltage, IS reflects the diode saturation current, an ideal element, q is the electron's total electric charge value, T in Kelvin is temperature and K in Boltzman is constant [4]. The p-n interconnection absorbs the photon from incident light to create electron pits or conveyors in solar irradiation. This only functions in the absence of solar irradiation as a diode, as mentioned above. This creates a possible crossover gap and charging companies continue to move through the outside circuit. This photovoltaic effect is named and IPV shows the resulting Shockley's current implementation. IPV is a summary of the PV cell, which is parallel to a p-n junction diode and which contains the current source. The resultant circuit is known as ideal PV cell model and is depicted in the Fig .2.

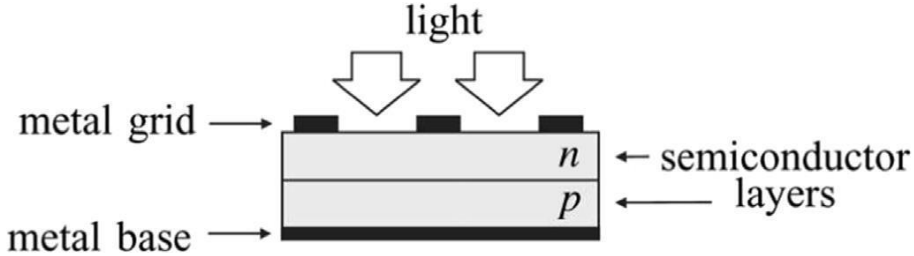

Fig 1: Physical Structure of a PV Cell [4]

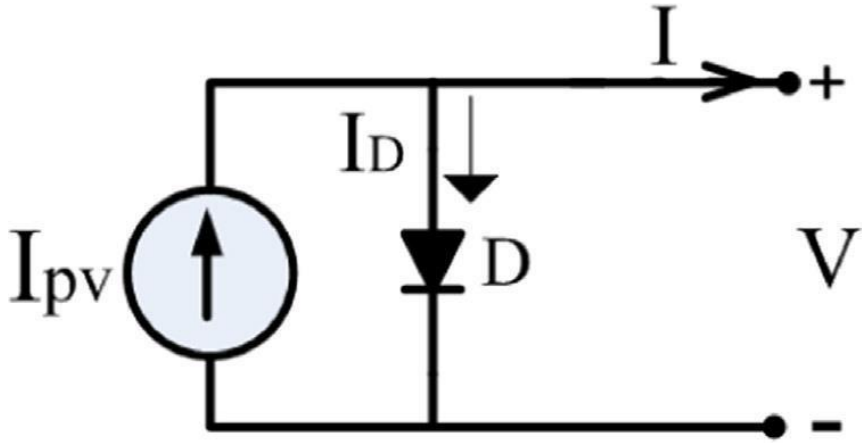

Fig 2: Ideal model of PV cell [4]

High ambient temperatures and high operating temperatures of PV panels cause the panel to overheat and thus drastically reduce the panel's performance. The efficiency of a photovoltaic cell is dependent on temperature and array irradiation and is defined by:

Ŋ= ηr [1-β (TC –TR) + γ □□□10 Iarray]

Where ηr is the efficiency of the array or the cell efficiency at the reference temperature β is a temperature coefficient for cell performance, TC is a cell temperature. μ is a coefficient of radiation intensity for cell output, and I array is an incident of radiation per unit area. [5].

2 Cooling technologies for rising PV system performance

2.1 Hybrid solar photovoltaic / thermal system cooled by water spreading: A positive displacement pump with a D.C engine is used in this process. Fig.3 shows the spraying process layout of the pumping system test stand. The power generated from the set is transferred to the pump's D.C motor. The pump is used to drain water out of the tank. With the help of spraying nozzles that are fixed on a tube, water is sprayed over the system. On top of the photovoltaic array, the tube is mounted. The cooling of the PV system is accomplished by increasing the array temperature as water is sprayed by the nozzles [6].

Fig.3: Pumping system test stand for spraying process

2.2 The use of photovoltaic and hybrid phase shift materials to boost efficiency of solar panels: Phase-changing materials are used to lower solar panel temperatures.. The latent heat storage material contained at the back of the PV panel as shown in the figures 4 is phase change materials (PCM), such as photonic tungsten crystals. As The Phase Changing Material absorbs latent heat as it melts from solid to liquid. As a consequence of heat processing, the temperature of the board is decreased by the change in process: PV Module and PCM Module [7].

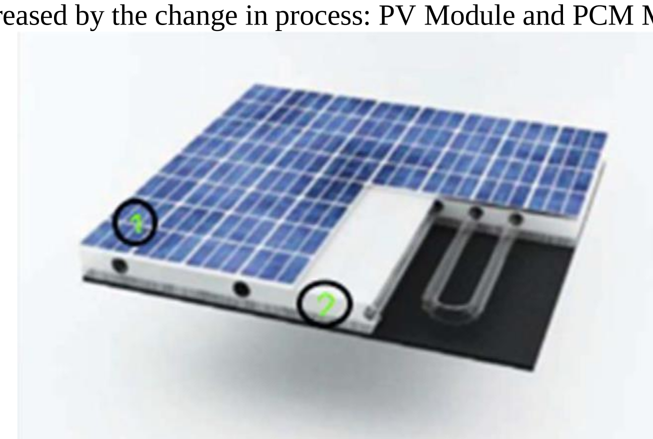

Fig 4: PV panel with phase changing materials

2.3 Water immersion cooling of solar panels: The power is equal to the normal photovoltaic range on the surface if a photovoltaic panel is submerged in a water body in a few centimeters. Nevertheless, when a panel is immersed in the water body, due to low temperatures, its performance is enhanced. The result can be seen in figure 5, where panels are shown at various depths in water in w.r.t panels (4 and 40 cm respectively) [8].

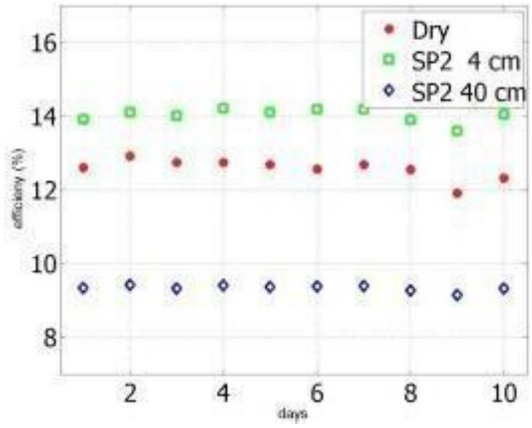

Fig.5: Calculated PV output in dry air comp with SP2 (submerged PV)

3.4 Photonic crystal cooling: A PV module is protected by a transparent layer consisting of photonic crystals for photonic crystal cooling or transparent photovoltaic device coating. Such crystals reflect the heat generated in the panels and thus help improve the efficiency of the photovoltaic system. A thermal black body made of silica crystal is this transparent cover and is located on the top of the panels. They also contribute to the absorption of the photons and thus help to absorb more light photons. [7].

3.5 Photovoltaic / Hybrid thermal solar system cooled in forced circulation: Air circulation is pumped in forced through the PV / T system, preventing it from reducing electrical output. In terms of cost and construction, the air-cooled PV / T system is considered to be the best. With the aid of fans, air is passed under the panel in this process. The easiest model is that it is made up of an air duct PV board. Other designs include a single pass or a double pass.

3.6 Thermoelectric cooled solar panel: To through the panel temperatures, the thermoelectric module is attached to the back of PV panels for cooling purposes. The thermoelectric module is generated by a series and parallel thermally connected thermoelectric module. When voltage is applied at the junction of a thermoelectric cooling effect known as the Pettier-Seeback effect, it is also produced [9].

3.7 Improving photovoltaic efficiency by multi-concept cooling technique: Multi-concept cooling is a mix of passive cooling technologies such as leading, air cooling and passive water cooling. During peak sunlight hours the performance and power production of the PV-module decreases due to heat loss. This challenge can be overcome by multi-concept cooling. The module has ample space to cool the air naturally. The surface of the module is cooled with water. The heat piping is accomplished via a heat sink in aluminium on the rear of the board. The heat sink in aluminum consists of a frame with fins fixed to help the module cool [1].

4 Latest state of art

Nizemetic et.al used water spraying technique to cool the photovoltaic device. To investigate water spraying technique cooling effect on the performance of PV panel during peak hours of sunlight, both sides of panel were sprayed simultaneously. The experiment showed a total increase in photovoltaic panel electrical efficiency by 14.1 percent and an increase in electrical power output by 16.3 percent. The panel temperature was also reduced from 54 ° C (uncooled panel) to 24 ° C if the front and back side of the panel were cooled simultaneously[10].

The phase changes in materials (PCM) used by Pascal Henry Biwole et.al to maintain a panel temperature near the atmosphere. The simulation of the Impure PCM was conducted for computational fluid dynamics as regards heat and mass transfer. Variation of enthalpy method has been simulated for the thermo-physical change of PCM material.

Navier stokes the equation of momentum conserving and is considered zero when the PCM is solid in the region of equation velocity. Simulations measure isotherms and velocity fields and equate them with experimental tests. The results showed that the panel managed to operate at less than 40 ° C for 80 minutes, with the addition of PCM on the back, continuous solar radiation of 1000W / m^2. [11].

An experimental investigation on the use was carried out by Mousavi Baygi, S.M. Sadrameli. To maintain solar cell temperature close to optimal operating temperature of phase-changing material in the solar cell. The goal was to control solar photovoltaic cells thermally using polyethylene glycol 1000 PEG (1000) as a product that switches phase. The panel's inclination was held at zero and 15 degrees below 800W / m2 solar irradiation. In solar-electric efficiency, increase of 8 percent efficiency was observed while using polyethylene glycol as a PCM. In the solar panel, a 15 ° C decrement was observed in contrast to the panel without the use of PCM.

PCM as coolant for photovoltaic applications used by Müslüm Arıcı et.al. The improvement of efficiency with the PCM as coolant and reduction of the operating temperature of the panel have been studied using a numeric model. The numerical model was matched with the experimental results of the existing literature and a maximal deviation of 1-3.1% was observed. The PCM's having different melting points and latent heat of fusion were studied and that PCM was selected which was suitable for the photovoltaic panel according to the given climatic conditions. The application of PCM reduced temperature of the PV panel up to 10.26°C and increased the efficiency upto 3.73% [12].

The new CPV device with deionized water for immersion cooling was examined by Li Zhu et.al. The PV method calculates time dependent temperature distributions and I-V curves. It was analyzed that the cooling capacities of this technology are favorable. The temperature of the module was cooled to 45°C under a constant normal irradiance of 940W/m2 with ambient temperature being 17°C and temperature of water as 30°C at the inletThe temperature distribution of the module was tested to be consistent but due to long immersion of the panel into the de-ionized water the electrical effectiveness was lower. [13].

Bin Zhao et.al used comprehensive photonic approach for increasing the solar harvesting of energy and radiative cooling. A design of photonic structure was made which comprised of one-dimensional multi- layer stack and two-dimensional photonic crystals. The design allows selective reflection of radiation and heat into the ground, while solar energy transmission in the photovoltaic band (0.3–1.1μm) is achieved. It was demonstrated that when photonic structure was used with the PV system the diurnal electricity output of 99.2W/m2 was obtained. Besides nocturnal RC power of 128.5 was also generated. On comparing with the bare cell, it was found that the diurnal electric output and nocturnal RC power output were increased by 6.9% and 30.5% respectively. The potential cooling energy gained by this approach is far better than the existing RC emitters [14].

Alibakhsh Kasaeian et.al studied the impact of forced convection on the efficiency of photovoltaic systems. Eexperimentally the effects of forced convection on the PV / T system's electrical and thermal efficiencies were explored in this paper. On the revised air-cooled PV / T unit, fitted with the four fans for forced convection, a test was performed. It was concluded that the thermal efficiency improved when the air channel depth is reduced but no significant results for electrical efficiency were obtained. The increase in air thermal efficiency mass flow rate has marginally improved the electric power output of PV. The results showed that the thermal efficiency of the PV system was approx. 15-31 per cent for 0.05(m) channel depth and mass flow of air, 0.018 (kg / s) to 0.06 (kg / s). Electric efficiency was just 12-12,4 percent for the same device.

For the development, theoretical and experimental evaluation of a PV device, Roonak Daghigh, Yavar Khaledian used thermoelectric cooling-heating system. A thermoelectric set-up test was performed to reduce the compression cooling power and increase COP from 12 to 18. Peak current and voltage applied for the setup were reported respectively as 3.0043A and 12V. The total input power COP was estimated as 1. Total energy output of the PV system and energy consumption between 11:00 and 12:00 was found to be respectively 361.406 and 56.465. The average outlet water temperature and the minimum thermoelectric device cooling chamber temperature corresponding to the peak input power are 45 and 12 ° C. The temperature of the module's cold and hot sides was found to be respectively-3 and 69 ° C. It was found that the COP, running time and energy consumption was 5.4, 15000s, 7911kJ and 5.3, 16380s, 8636.8 respectively for the thermoelectric hybrid cooling system and compression cooling system. The results clearly show the upper edge of the performance of the hybrid cooling system over the compression cooling system [15].

5 Conclusion: Reviewing of various research papers leads to the conclusion that using cooling technologies as mentioned in this review paper increases thermal and electrical efficiencies of simple and the hybrid photovoltaic modules. Besides, the rate of cell degradation of the solar array w.r.t time also gets reduced on application of various cooling methods. The promising cooling methods with effective cooling effects are the use of PCM which reduce the temperature of the array by 10-15 °C. Also it has been analyzed that there is a considerable improvement in the electrical efficiency of about 3-10%. Thermoelectric cooling has a lower efficiency of conversion; Photonic crystal cooling completely removes the question of temperature but waste heat should not be used for domestic applications; compared to water cooling, forced air circulation is inefficient, even when in cold and hot conditions it is successful. In water spraying increase in efficiency was obtained and viable. In water immersion cooling temperature reduction of PV system is achieved however due to long time immersion of panel in the deionized water electrical efficiency gets reduced. Multi- concept cooling technology reduces the temperature of the module drastically and this technique is considered to be more productive and efficient because of sufficient amount of increase in power output.

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