Study of Performance Enhancement of PVT System by Using Nano fluids

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Abstract- **The performance of PV (photovoltaic) module is strongly dependent on its surface temperature, it is necessary to study possible way for maintaining the appropriate temperature for solar panels. High solar radiation and ambient temperature lead to an elevated photovoltaic cell operating temperature, which affects its lifespan and power output adversely. To enhance the electrical performance of the PV module, different cooling techniques like air cooling, water cooling and nanofluid cooling are implemented. In the present paper, various cooling techniques with different heat collector designs and different working fluids for performance enhancement of PV system are presented.**

Index Terms- **Photovoltaic (PV) cell, Temperature Coefficient, heat collector, Minichannel, Nanofluids.**

1. INTRODUCTION

The use of renewable energy systems for real life applications has been increasing for the last few decades due to the growing concern about the global warming and environmental pollution [1]. The renewable energy sources are clean and freely available in the nature, however, the efficient utilization is still a cause of concern among the scientific and business communities. The biggest source of the renewable energies, available freely throughout the year, is the sun. A photovoltaic thermal system (PVT) consists of a common photovoltaic unit (PV) which transforms photons received by the sun into electrical energy, and a thermal collector which absorbs both remaining energy of photons and the heat generated by photovoltaic cells. Simultaneous generation of electricity and useful thermal energy makes these types of solar systems more efficient compared to a conventional PV unit with no collector. Increasing the surface temperature of the PV unit reduces the electrical efficiency of the PV unit by nearly 0.49% for each degree rise in temperature [2]. Consequently, cooling the PV unit is an effective method for improving the power output without damaging the PV unit and at the same time waste heat recovery is also achieved using PVT system. Use of het collector and nanofluids as working fluids or coolants tends to performance enhancement of the PV unit.

2. NEED FOR COOLING PV CELL

The overall performance of Si solar cell strongly depends on the environmental parameters such as light intensity, tracking angle and cell temperature etc. [9]. The efficiency of a solar cell is varied in a range 5%–18% where the lower limit is referred to the amorphous PV cells and the higher limit to the monocrystalline solar cells. The efficiency is strongly affected by the temperature and according to nominal operative cell temperature, the typical operating temperature for solar cells is about 25 °C ± 2 °C which is also depended on manufacturer specifications. The cell temperature is the key environmental parameter to decide the quality and performance of a solar cell by changing photovoltaic parameters like open circuit voltage, short circuit current, maximum power, fill factor and efficiency. In 2015, Subhash Chander et al. [9] conducted an experimentation to study the impact of temperature on performance of series and parallel connected mono-crystalline silicon solar cells. The experiment was carried out at constant light intensity 550 W/m^2 with cell temperature in the range 25–60^{o}C for single, series and parallel connected mono-Si solar cells. The performance parameters like open circuit voltage, maximum power, fill factor and efficiency are found to decrease with cell temperature while the short circuit current is observed to increase. The experimental results reveal that silicon solar cells connected in series and parallel combinations follow the Kirchhoff's laws and the temperature has a significant effect on the performance parameters of solar cell.

E. Radziemska in 2009, studied the influence of temperature and wavelength on electrical parameters of crystalline silicon solar cell and a solar module. A thick copper plate protected the solar cell from overheating, the plate working as a radiation heat sink, or also as the cell temperature stabilizer during heating it up to 80°C. A decrease of the output power (-0.65%/K) of the PV module with the temperature increase has been observed.

A.R. Amelia et al. investigated the effect temperature on Photovoltaic (PV) Panel Output Performance. Throughout simulation and experimental, there is strongly proved that the PV panel temperature plays a crucial role in output power production. Reduction in output voltage causes reduction in output power of PV panel even though the output current increases. Furthermore, the quality operation of PV panel also decreases with the increasing of PV panel temperatures.

3. METHODS FOR COOLING OF PV CELL

Two types of cooling can be distinguished: active cooling, which consumes energy (pump, fan, etc.,) and passive cooling, which uses natural convection/conduction to enable heat extraction. Various cooling techniques are as follows [10],

Air-cooling is a nonexpensive and simple method of PV cooling. In the natural air cooling, no extra arrangement is required for cooling PV panels. However, systems with heat extraction by natural air circulation are limited in their thermal performance due to the low density, the lower volumetric heat capacity and thermal conductivity of air and measures for heat transfer augmentation are necessary. The irregular and uncontrolled nature of natural air circulation cooling method can be rectified by using forced air circulation.

In 2009, Swapnil Dubey et al. [11] developed an analytical expression for electrical efficiency of PVT hybrid air collector. Results showed that the overall electrical efficiency of the photovoltaic (PV) module can be increased by reducing the temperature of the PV module by withdrawing the thermal energy associated with the PV module. In this communication an attempt has been made to develop analytical expression for electrical efficiency of PV module with and without air flow as a function of climatic and design parameters. The annual average electrical efficiency of the PV module with and without duct is 10.41% and 9.75%, respectively.

In 2011, Sanjay Agrawal et al. [12] performed energy and exergy analysis of a hybrid micro-channel photovoltaic thermal (MCPVT) module based on proposed micro-channel solar cell thermal (MCSCT) under constant mass flow rate of air in terms of design and climatic parameter. On the basis of numerical computations, it has been observed that an overall annual thermal and exergy gains have been increased by 70.62% and 60.19% respectively for MCPVT module for Srinagar climatic conditions. Similar observations have been made for Bangalore, Jodhpur and New Delhi.

Photovoltaic–thermal (PV/T) technology refers to the integration of a PV and a conventional solar thermal collector in a single piece of equipment. Swapnil et al. [13], in 2009, evaluated the performance of partially covered flat plate water collectors connected in series using theoretical modeling. PV is used to run the DC motor, which circulates the water in a forced mode. They presented detailed analysis of thermal energy, exergy and electrical energy yield by varying the number of collectors by considering four weather conditions for five different cities (New Delhi, Bangalore, Mumbai, Srinagar, and Jodhpur) of India. Annual thermal and electrical energy yield is also evaluated for four different series and parallel combination of collectors for comparison purpose considering New Delhi conditions. It is observed that the collectors partially covered by PV module combines the production of hot water and electricity generation and it is beneficial for the users whose primary requirement is hot water production and collectors fully covered by PV is beneficial for the users whose primary requirement is electricity generation.

Ahmad Fudholi et al. [14] in 2014, performed an analysis of photovoltaic thermal (PVT) water collectors. The electrical and thermal performances of photovoltaic thermal (PVT) water collectors were determined under 500–800 W/m^2 solar radiation levels. At each solar radiation level, mass flow rates ranging from 0.011 kg/s to 0.041 kg/s were introduced. The PVT collectors were tested with respect to PV efficiency, thermal efficiency, and a combination of both (PVT efficiency). The results showed that the spiral flow absorber exhibited the highest performance at a solar radiation level of 800 W/m^2 and mass flow rate of 0.041 kg/s. This absorber produced a PVT efficiency of 68.4%, a PV efficiency of 13.8%, and a thermal efficiency of 54.6%. It also produced a primary-energy saving efficiency ranging from 79% to 91% at a mass flow rate of 0.011–0.041 kg/s.

In 2013, K.A. Moharram et al. [15] presented a mathematical model for enhancing the performance of photovoltaic panels by water cooling. The objective of the research is to minimize the amount of water and electrical energy needed for cooling of the solar panels, especially in hot arid regions, e.g., desert areas in Egypt. A cooling system has been developed based on water spraying of PV panels. A mathematical model has been used to determine when to start cooling of the PV panels as the temperature of the panels reaches the maximum allowable temperature (MAT). A cooling model has been developed to determine how long it takes to cool down the PV panels to its normal operating temperature, i.e., 35 °C, based on the proposed cooling system. Both models, the heating rate model and the cooling rate model, are validated experimentally. Based on the heating and cooling rate models, it is found that the PV panels yield the highest output energy if cooling of the panels starts when the temperature of the PV panels reaches a maximum allowable temperature (MAT) of 45 °C. The MAT is a compromise temperature between the output energy from the PV panels and the energy needed for cooling.

In 2012, an experimental investigation on the effect of Al_2O_3-H_2O nanofluid on the efficiency of flat-plate solar collectors was performed by Tooraj Yousefia et al. [16]. The weight fraction of nanoparticles was 0.2% and 0.4% and the particles dimension was 15 nm. The mass flow rate of nanofluid varied from 1 to 3 Lit/min. For 0.2 wt% the increased efficiency was 28.3%.

In 2014, Mohammad Sardarabadi et al. [17] experimentally studied the effects of using nanofluid as a coolant on the thermal and electrical efficiencies of a PVT (photovoltaic thermal unit). Coolant fluids in the experiments are pure water and silica (SiO_2)/water nanofluid 1% and 3% by weight (wt%). It is found that the overall energy efficiency for the case with a silica/water nanofluid of 1 wt% is increased by 3.6% compared to the case with pure water. When using the silica/water nanofluid of 3 wt%, however, the increase is 7.9%. The thermal efficiency of the PV/T collector for the two cases of 1 wt% and 3 wt% of silica/water nanofluids are increased by 7.6% and 12.8%, respectively. The total exergy of the PV/T system, with and without nanofluids, is also compared with that of the PV system with no collector. It is observed that by adding a thermal collector to a PV system, the total exergy for the three cases with pure water, 1 wt% silica/water nanofluid, and 3 wt% silica/water nanofluid is increased by 19.36%, 22.61% and 24.31%, respectively.

In 2014, Nooshin Karami et al. [18] conducted experiments to investigate the cooling performance of channels by water-based nanofluids containing small concentrations of Boehmite ($AlOOH\_xH_2O$) for the PV cell. The channels were fabricated in two different configurations as straight and helical. The straight channel consists of 23 parallel rectangular channels with a hydraulic diameter of 4.1 mm, a length of 24.5 cm, a width of 5 mm and a depth of 3.5 mm. For the helical configuration the plate was divided into four symmetrical sections which, each part contains a helical channel with a width of 5 mm, a depth of 3.5 mm and a hydraulic diameter of 4.1 mm. Results showed that the nanofluid perform better than water and caused higher decrease in the average PV cell temperature. They were about 39.70% and 53.76% for 0.1 wt.% (the best case) at flow rate of 80 ml/min for the helical and straight channel, respectively. Moreover, the highest decrease of average temperature relative to the reference temperature was observed for 0.1 wt% nanofluid concentration in both channels. This led to the highest electrical efficiency about 20.57% and 37.67% for the straight and helical channel, respectively.

In 2014, P.K.Nagarajan et al. [4] studied Nanofluids for solar collector applications. The study showed that Nanofluids are embryonic fluids that exhibit thermal properties superior than that of the conventional fluid. The application of nanofluids is to achieve the highest possible thermal properties at the smallest possible concentrations, by homogeneous dispersion and stable suspension of nanoparticles in the host fluids. Nanofluids plays vital role in various thermal applications such as automotive industries, heat exchangers, solar power generation etc. Mostly heat transfer augmentation in solar collectors is one of the key issues in energy saving, compact designs and different operational temperatures.

In 2015, an experimental study on using natural vaporization for cooling of a photovoltaic solar cell was done by Morteza Ebrahimi et al. [19]. The performance of solar cell was examined on simulated sunlight. The natural vapor encountered backside of PV cell vertically in various distribution and different mass flow rates. Also, the effect of natural vapor temperature in cooling performance was analyzed. Results indicated that the temperature of PV cell drops significantly with increasing natural vapour mass flow rate. In detail, the PV cell temperature decreased about 7 to 16 °C when flow rate reaches 1.6 to 5 gr/min. It causes increasing electrical efficiency about 12.12% to 22.9%.

Matin Ghadiri et al. [20] in 2015, performed an experimental investigation of a PVT system performance using nano ferrofluids. The fluids considered in the experiment are distilled water and a ferrofluid (Fe3O4-water) with 1% and 3% concentrations by weight (wt%). The experiments were performed in indoor conditions under two constant solar radiations (1100 W/m2 and 600 W/m2) using a solar simulator. The results show that by using a 3 wt% ferrofluid, the overall efficiency of the system improved by 45% and when an alternating magnetic field with 50 Hz frequency was applied, the overall efficiency increased to about 50% compared to that of the distilled water as coolant fluid. The overall exergy output of the system with and without ferrofluids, was also compared with that of the PV system with no collector.

In 2016, Mohammad Sardarabadi et al. [21] experimentally investigated the use of metal-oxides/water nanofluids as coolants in photovoltaic thermal units (PVT). The considered nanoparticles include Aluminum-oxide (Al_2O_3), Titanium-oxide (TiO_2) and Zinc-oxide (ZnO) all dispersed in deionized water as base fluid, with 0.2% by weight (wt%). Experimental results show that theTiO_2/water and ZnO/water nanofluids present a better performance in terms of the electrical efficiency compared to that of theAl_2O_3/water nanofluid and deionized water. In terms of the thermal performance of the system, the ZnO/water nanofluid is found to have the highest thermal efficiency compared todeionized water and the other two nanofluids.

In 2017, Ali H.A. et al. [22] investigated the thermophysical properties of nanofluid composed of water and SiC nanoparticles without the use of a surfactant as a coolant for a PV/T system. It was observed that the addition of 3 wt% of these nanoparticles to water caused an increase in the resulting fluid density by up to 0.0082% and an increase of viscosity by up to 1.8%. Moreover, the thermal conductivity was enhanced by up to 8.2% for the tested temperature range of 25^0C–60^0C. The use of 3 wt% SiC nanofluid increased the electrical efficiency by up to 24.1% compared to the PV system alone, while the thermal efficiency increased by up to 100.19% compared to the use of water for cooling. The final results indicated that the total effectiveness of the PV/T nanofluid system had a higher overall efficiency of about 88.9% compared to the separate PV system.

4. COMPARISION OF COOLING METHODS

Three working fluids are reviewed in above literatures, out of which nanofluids show the highest rate of heat transfer due to their higher thermal conductivities. From overall efficiency point of view, TiO_2, Al_2O_3 and ZnO show better results. In case of silica based nanofluids, overall efficiency increases with addition of nanoparticles i.e. concentration. For water based system, energy efficiency varies from 79% to 91% for the mass flow range of 0.011 to 0.041kg/s. From design point of view, helical channelled heat collector is more efficient than the conventional straight channel heat collector.

5. MINICHANEL BASED PVT SYSTEM

Minichannel in micro technology is a channel with a hydraulic diameter ranging from 200 μm to 3mm [24]. Reducing passage hydraulic diameters provides a larger surface area per unit volume of heat exchangers for a given mass flux of fluid flowing through the channel. Hydraulic diameter is the diameter of the circular pipe (channel) and it may be taken as the depth of the channel in non-circular channels.

Need for Smaller Flow Passages

The flow passage dimensions in convective heat transfer applications have been shifting towards smaller dimensions for the following three main reasons:

(a) Heat transfer enhancement.

(b) Increased heat flux dissipation in microelectronic devices.

(c) Emergence of micro scale devices that require cooling.

However, an economic evaluation is required for the different thermal management techniques, to determine if the extra capital cost of additional arrangement is indeed outweighed by additional energy savings. Then the suitability, applicability, and impacts generated by the systems should be addressed at the environmental and social levels. It can be expected that these systems will have a relatively long payback period taking into account the initial cost of PV panels and the additional cost of the cooling arrangements. Providentially, if the thermal energy extracted from PV panels can be effectively used for space heating, ventilation, and hot water, the economic feasibility is expected to be enhanced.

6. CONCLUSIONS

In this paper an extensive review has been carried out for various methodologies used for cooling PV panels to enhance their electrical efficiency. Techniques such as air cooling, water cooling, nanofluid cooling are discussed for regulating the temperature of the photovoltaic cells. It can be concluded from this study that cooling technologies are essential in the solar circuit, in order to take maximum advantage of the solar photovoltaic cell and control the temperature rise of photovoltaic. PVT systems with nanofluids show better results than that in case of air and water. From the above literature review, it can be suggested that use of Minichannels in heat collector may enhance heat transfer rate and increase the waste heat recovery in case of PVT system.

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