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Effect of Active Water Cooling on the Performance of PV Module Using Steel Channels

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Abstract: Pakistan, a country well-known for some of the highest sun-shine-hours/insolation in the world, yet facing many energy crises. In order to check the feasibility of solar energy harnessing, we come up for the first time with a simple cooling technique for solar panels in the climate of Sahiwal (one of the largest cities in Pakistan). The objective of current research is not only to justify the solar energy scope but also to support and promote its utilization to get-rid of fossil fuel dependence for household needs. One of the beauties of this research is the application of simple cooling channels that can be manufactured locally without any complexity. Data was recorded for the month of May 2018 using a polycrystalline PV panel. A reference panel was also investigated to compare the performance with the said cooling methodology. A series of experimentation showed a maximum temperature drop of 27.5°C, at an irradiance of 895 W/m², when compared with a reference PV panel. This resulted in 1.61 % increase in overall efficiency of the PV module, thus proving the proposed technique effective. The performance ratio increased as high as 12.85 %.

Keywords: Active Cooling Technique, Photovoltaic Performance, Green and Alternative Energy Scope

1. Introduction

Among all the renewable energy sources, solar energy is the most promising one. The abundance of silicon and the availability of its resources, both make it a strong competition among all sustainable energy sources [1]. But the major issue of PV panel is its low efficiency that even decreases further due to overheating because of excessive temperature [2]. In addition to higher temperatures, several other environmental factors like wind, dust, and moisture also proves to hinders the PV performance [3-5]. Therefore, in order to control the PV modules thermals, some cooling tactics have already been applied.

Cooling techniques are classified as active and passive. Active cooling technique encircles the application of pumps, blowers, fans or any device that requires external power to work. On other side passive cooling methodology doesn't involve any kind of pump, fan or external energy source. Literature review emphasis more on active cooling techniques and summarizes work done on passive cooling techniques.

In an active cooling scheme proposed by L. Dorobanțu et al, [6], a perforated tube was installed at the top of the panel. This tube was equipped with 25 holes each of 1.5 mm in diameter. A thin water film was generated by flowing water from the perforated tube with flow rate of 2 lit/min. The water temperature recorded at inlet was 25°C. The experimentation was carried out at University of Politechnica of Bucharest and data was collected over a span of four months. Solar radiation was observed between 840-1000 W/m2, with the panel faced south at 350° tilt angle. Maximum increase in overall efficiency was reported as 8.4% with maximum temperature difference of 7-8°C between front and back side of the panel.

H. Bahaidarah et al,[7] reported a methodology of active cooling technique by taking a 230 watts mono-crystalline panel. PV module was equipped with cooling water flow at rear side with ports for inlet and outlet of water. Water was stored in an insulated tank connecting with the cooling panel by PVC pipes. A pump of 0.5 hp was used to circulate water to cool PV panel. A bypass system was also used to ensure a maximum pressure of 6 psi, alongside with flow rate of 3.6 L/min. Experimentation was carried out throughout the day with solar radiation of 710-979 W/m2, average ambient temperature of 20°C, and average wind speed of 1.5m/s. The module reflected 20% reduction in temperature that leads to 9% increase in relative efficiency compared to the standard one.

An active cooling technique was applied on a concentrated photovoltaic system (CPV) by Bin Du et al,[8]. A concentrated mono-crystalline module of 100 W with length and width of 1.08 m and 0.14 m respectively was taken under consideration. In order to control thermals, an aluminum sheet of thickness 2.5 m was attached on rear side, containing two pipes with an internal and external diameter of 10 mm and 13 mm. Experimentation was carried out at Southeast University, China, through the span of a day with maximum solar radiation of 1019 W/m2. Readings were taken with the interval of one hour. A massive 4.7-5.2 times increase in overall efficiency was reported when compared to a simple non-cooled module. Average wind speed of 0.25 m/s was recorded on experiment day.

Bashir et al, [9] investigated the effect of water based solar panel cooling in the climate of Taxila, Pakistan. Two types of PV panels namely mono and poly-crystalline were used. Their results showed an increase in overall performance of PV panels.

An indoor testing was carried out on two 50W mono-crystalline panels by Y.M.Irwan et al,[10]. The cooling process in this attempt used a DC water pump to spray water directly on the surface of the panel. Testing was carried out at four different radiation levels i.e. 413 W/m2, 620 W/m2, 821 W/m2, and1016 W/m2. On comparison with standard panel, it was observed that performance difference increases as the radiation goes on increasing. The maximum temperature difference recorded was 23.17°C at irradiance of 1016 W/m2. In another technique proposed by S. Nizetic et al,[11], monocrystalline module was tested with water spraying system on the front side with nozzle system. Pressure of 4.8 bar was maintained in the pipeline with corresponding flow rate of 225 Lit/h. Experimentation was carried out for 3-hours in mediterrariane climate. The ambient temperature during test was recorded as 27-30°C. Results were compared with a standard module and maximum power recorded as 35 watts (13.9%) and 41.2 watts (15.9%) W for standard and cooled module respectively.

Active cooling technique with the application of micro channels was proposed by Ali et al,[12]. Experimental module was developed with 4 mm thick aluminum sheet that contained micro channels of 1x1 mm. Rated power of module was 35 W, in addition CFD simulation was also accomplished to predict the thermal behavior. For flow rate of 3 LPM, maximum temperature drop was recorded as 15°C which led 14% improvement in relative efficiency. A good agreement was found between CFD and actual experimentation.

Nanofluids are of profound importance when talking about heat transfer applications[13], and their usage in cooling PV module is not an exception. Abu-Rahmeh, TM [14] made an attempt to use Nanofluids i.e. TiO2-water with grain size of 30-50 nm, in order to cool PV module. For experimentation 4 PV modules were taken under consideration. First two modules were cooled by the aid of nanofluid and water, while the third module had aluminum fins attached at the rear side, and fourth one considered for reference purpose. A copper tube 6 mm in diameter and 3 m in length was used for the flow of nanofluid and water. Air cooled scheme contained 24 aluminum fins (395 mm in length, 20 mm in height and thickness of 2 mm) attached vertically at rear side of PV module. A constant flow rate of both water and nanofluid (0.1313 L/s) was ensured by the application of pump throughout experimentation. Reading was observed after every 5-minute interval. Nanofluids proved the maximum relative increase in performance of 5.37% when compared with the reference one.

Application of Nanofluids cooling on a larger scale was observed by M. Chandrasekar et al,[15]. A number of monocrystalline panels were used with each having area of 600x600 mm. Total area covered by the cells was 3456 cm2 spanning on 18 rows and 4 columns. Panels were faced south at 15-degree tilt angle. Cotton wick structures were developed at the back side of the module in a ring fashion with each of 7 mm diameter and dipped in water and Nanofluids containing Al2O3 and CuO from free end. The capillary effect was produced using these cotton wick structures. The best results were found with water, 30% reduction in the temperatures leading to 15.61% increase in power output compared to the reference one. The application of Nanofluids was not proved to be as effective as water in this case mainly due to the capillary effect.

Similar approaches were adopted by number of researchers using Nanofluids as test fluid [16-21]. All these studies reported the better efficiency of nanofluids both in active and passive methodologies, thus proving their potential for PV panel cooling.

Other schemes involve PCMs (Phase Change Materials) as heat carriers for cooling of PV panels [22-25]. PCMs proved to be effective remedy in these studies, especially in passive cooling approaches their results were much promising then water and air. In short both approaches i.e. active or passive, worked to some extend to mitigate the higher temperatures in PV modules thus increasing their performance [26-28].

The present investigation addresses a simple yet effective passive cooling technique. Experimentation of proposed methodology is carried out at Department of Mechanical Engineering, COMSTAS University Islamabad, Sahiwal Campus for the month of May 2018.

2. Materials and Methods

Table 1 shows the module specification. Two 50W solar panels of same specification were used. One is taken as standard while the other one is equipped with the steel channels for cooling purpose. Nine rectangular channels were constructed and attached on back of PV module by using polyvinyl siloxane (known as silicone). Depth and width of each channel is 3mm and 20 mm respectively. Fig. 1 shows the steel channel used in this investigation. A distributer was used to regulate the flow into channels for proper cooling of module (see Fig. 2). In addition to that a storage tank is installed of 30 L capacity. Minimum level of head is maintained to get smooth flow of water.

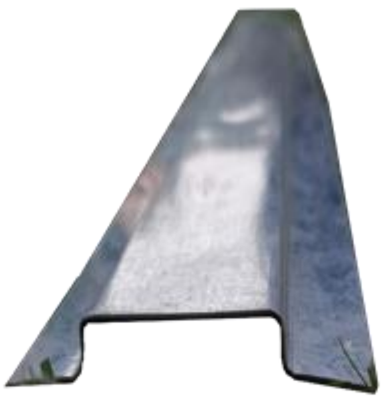

Fig. 1. Steel channel

Fig. 2. Tubes used to connect water with PV panel

Fig. 3 shows schematic of experimental setup, same water flow scheme, already proposed [29]. Modules were installed in slope of 15° facing south. For smooth flow of water, fixed water level was maintained in the tank. Butterfly valve was used to regulate and control the flow. Each outlet of distributer was fitted into the channel to ensure the water to carry heat from the panel. Solar cell temperature was measured with the help of temperature gun. Simultaneously irradiance meter (200R) and I-V curve meter (Prova-210) were used to measure irradiance and I-V curves characteristics respectively. Technical specifications of these instruments are shown in the following tables. At the start of experimentation, temperature of both panels were noted and as their temperature rises above the 35°C, water was allowed to flow at 3LPM in designed channels.

Table 1. PV module specification

Cell Type	Polycrystalline Cell
Glass type	Tempered Glass
Lamination	EVA
Maximum Power ($\boldsymbol{P_{max}}$)	50.0 W
Voltage at $\boldsymbol{P_{max}}$ ($\boldsymbol{V_{mp}}$)	17.4 V
Current at $\boldsymbol{P_{max}}$ ($\boldsymbol{I_{mp}}$)	2.89 A
Open-Circuit Voltage ($\boldsymbol{V_{oc}}$)	22.0 V
Short-Circuit Current ($\boldsymbol{I_{sc}}$)	3.03 A

Performance parameters like maximum power, fill factor, normalized output efficiency, module conversion efficiency and Performance ratio were calculated to understand the behavior of solar modules using the following equations.

Maximum Power: $Max_{power} = I_{max} \times V_{max}$

Maximum Efficiency: $\eta_p = \frac{P_{measured}}{P_{max}} \times 100$

Fill Factor: $FF = \frac{I_{max} \times V_{max}}{I_{SC} \times V_{oc}}$

Performance Ratio: $PR = \frac{Energy_{measured}}{SI \times A_{module} \times \eta_p}$

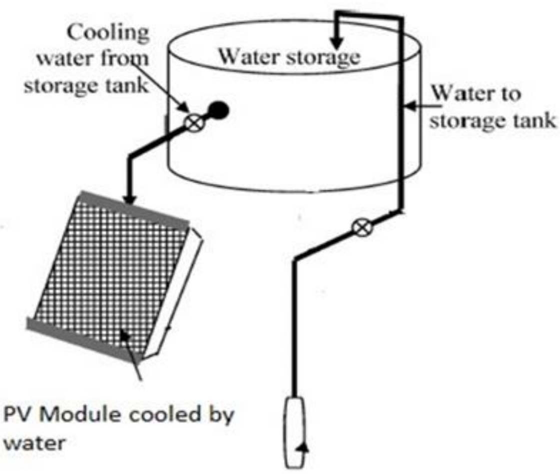

Fig 3. Experimental set-up, A schematic [29]

Table 2. Prove-210 meter specifications

Power P_{max}	500W
Voltage at (P_{max}) V_{max}	60V ± 1% accuracy
Current at (P_{max}) I_{max}	12A ± 1% accuracy
PV Panel Area Setting	0.001m^2-9999m^2
Standard Light Setting	10W/m^2 -1000 W/m^2
Opera. Environment	5°C-50°C

3. Results

3.1. Variation of Solar Irradiance

Experimentation was conducted in the open air, on the top of Engineering block, COMSATS university Sahiwal campus. Sunny days data was recorded. Solar irradiance was measured bi-hourly from 08:30 am to 3:00 pm for the month of May, 2018. Average solar irradiance is plotted against time in Fig. 4. It is clear from the figure that irradiance increases with the passage of time and reaches to value of 895 W/m2 and then it begins to decrease. Solar irradiance was found strong function of sun angle with solar panels.

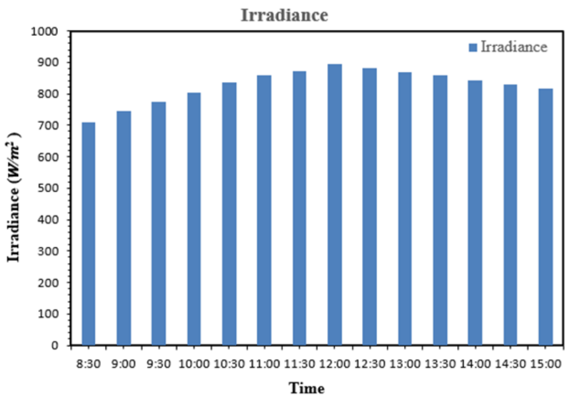

Fig 4. Variation of irradiance with time

3.2. Temperature Variations

Effect of average surface panel temperature against time is plotted in Fig. 5. As it was summer season in Sahiwal, surface panel temp of panels was above 45 ºC in the morning (sat at 8:30 am). This temperature begins to increase with the passage of time and reaches as high as 61 ºC at 1 pm. This increase in temperature is in line with the increase of solar irradiance received at the panel surface (see Fig. 6). However, in both these figures, surface temperature of solar panel equipped with cooling effect remain the same (around 35 º) at all times. This data shows the effectiveness of proposed methodology to control the thermals of solar panels. As discussed, maximum temperature difference of 27.5 ºC at 13:00 pm was calculated when reference panel temperature was compared with steel-channeled panel. Solar Irradiance measured at this time was also at its peak and was recorded to be 867 W/m2 .

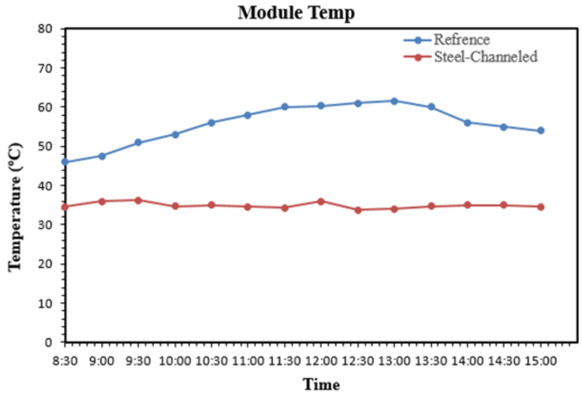

Fig 5. Variation of solar panel temperature with time

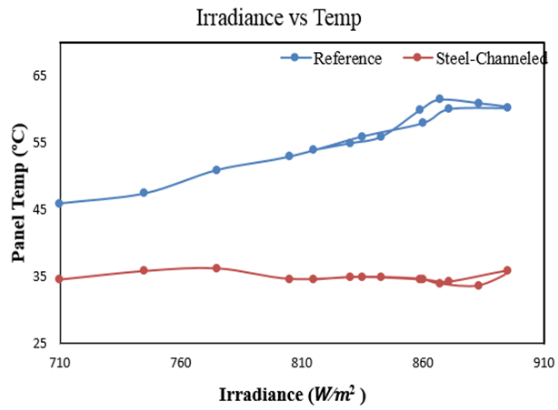

Fig 6. Variation of panels temperature with irradiance

Table 3. Irradiance meter 200R specifications

Irradiance	Values
Display range	0-1500 W/m^2
Measurement range	100-1250 W/m^2
Resolution	1 W/m^2
Temperature	Values
Display range	-30°C- +125°C
Measurement range	-30°C- +125°C
Resolution	1°
Inclinometer	Values
Display range	0-90°C

3.3. Variation in Efficiency Related Parameters

Figure 7-10 shows the variation of efficiency, power output and performance ratio for both steel channeled and reference panel. In addition, effect of irradiance on power output for both panels is analyzed here.t is obvious that efficiency and output power begin to increase, reaches a maximum value and then begin to decrease. In all these figures, panel with cooling outperformed over reference panel.

In the start of experimentation around 8:30 am, minimum power output 29.6 W and 31.96 W was measured for reference and steel-channeled solar panel. As the solar irradiance increased with the passage of day, both modules showed increasing trend. Again, this increasing trend is more dominant in steel-channeled module because of continuous heat removal. Maximum power output recorded as 36 watts for reference and 39.85 watts for steel-channeled module. However, an increase of 12.85 % in power output was measured when compared the performance of steel-channeled panel with reference panel.

Similar argument is given for variation in efficiency, where steel-channeled panel provided 1.61 % increase in overall efficiency at 13:00 in comparison to reference panel. Effect of irradiance variation with power output for both panels is presented in Fig. 10. Steel-channeled panel showed a linear increase in power output with increase of irradiance. This shows that thermals of this panel were controlled well by the applied cooling technique. On the other hand, reference panel struggled in increasing its power output and this negative effect went on increasing by increasing solar intensity.

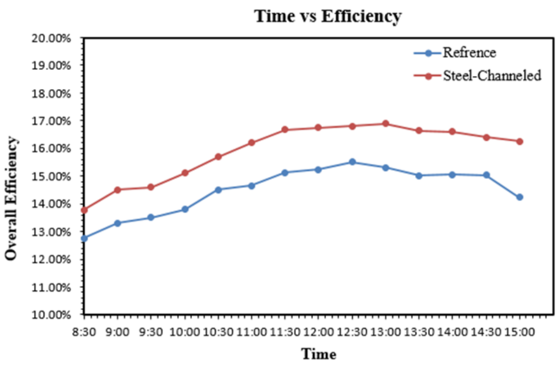

Fig 7. Measurement of efficiency with time.

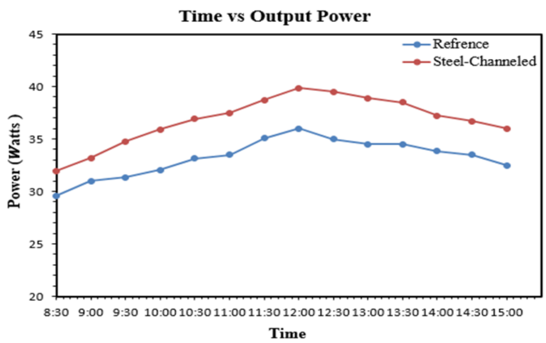

Fig 8. Variation of power output with time

3.4. Comparison of Fill Factor

Fill -factor (FF) in solar cells is defined as the ratio of maximum obtainable power to the product of the open-circuit voltage and short-circuit current. It basically measures the squareness of the IV-curve. Using IV-curve meter, fill factor for both reference and steel-channeled PV panel was recorded. An average value of fill factor is presented in Fig. 11. It can be seen that steel-channeled PV panel performed better over reference panel with no cooling effect.

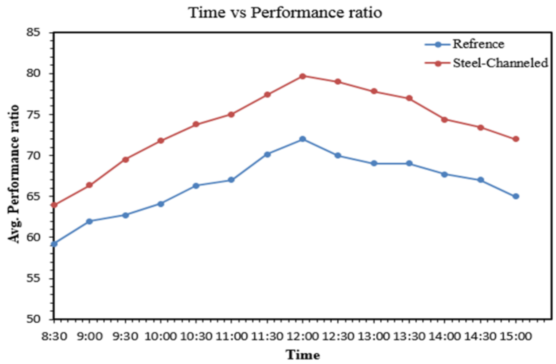

Fig 9. Variation of performance ratio with time.

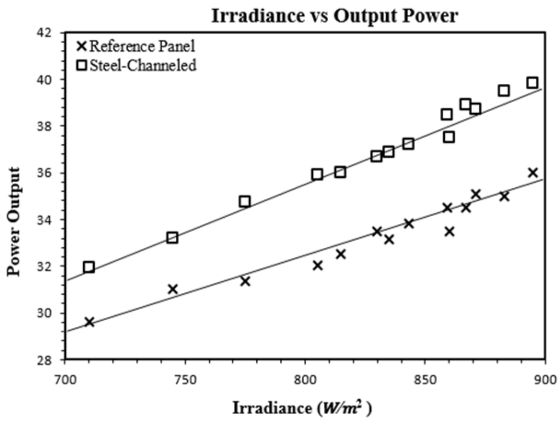

Fig 10. Comparison of power output with irradiance.

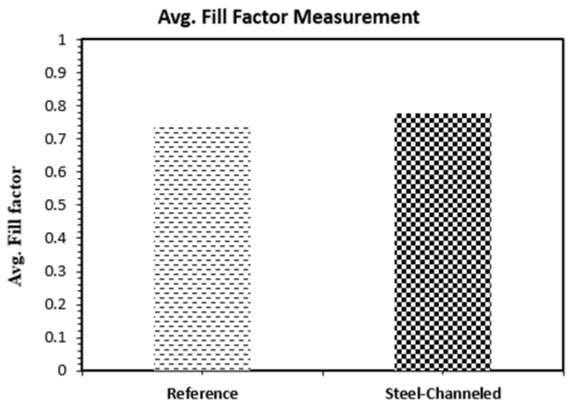

Fig 11. Comparison of fill-factor.

4. Discussion and Conclusions

Effect of water-based cooling was investigated on the performance of photovoltaic panel using steel channels on its rear side. Data was recorded for the month of May, 2018. Results showed high effectiveness of cooling technique as panel temperature dropped as high as 27.5 ºC when compared with reference solar panel. This resulted in increase in all performance related parameters: i.e. power output, efficiency and performance ratio. Overall efficiency was recorded to be 16.99 % for steel channeled panel while for reference panel it was measure to be 15.38 %. Similarly, power output enhances to 12.85 % for steel channeled PV panel. This research not only shows the strong potential of solar energy in areas like Sahiwal, Pakistan, but it also made an attempt to improve the PV panel performance panel. Further research can be carried out to find out the optimum water flow rate and to find more suitable material for channels for water circulation.

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Conceptualization, Muhammad Jarrar Awan and Hafiz Muhammad Ali;
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Investigation, Rana Shamaim Hassan and Khizer Ali Sultan;
Resources, Muhammad Ahsan Nawaz;
Data curation, Muhammad Jarrar Awan, Aamir Rasool, Khizer Ali Sultan and Muhammad Faizan Younas.;
Writing—original draft preparation: Muhammad Faizan Younas, Muhammad Abubaker;
Writing—review and editing: Hafiz Muhammad Ali and Muhammad Abubaker;
Visualization, Muhammad Faizan Younas;
Supervision: Muhammad Abubaker;
Funding acquisition: Muhammad Jarrar Awan, Rana Shamaim Hassan, Aamir Rasool and Khizer Ali Sultan

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