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Investigating the Effect of Active Cooling on Grid Connected Solar Power Plant in Sukkur, Sindh, Pakistan

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Abstract

Solar cells produce current by consuming photons energy, generating electron-hole pairs. Solar modules are notoriously sensitive to ambient temperature. New studies put forward shows that global warming would lead to reduced power output across the globe by the year 2100. Climate change is going to have a substantial impact on solar power output and incident sunlight is a varying quantity in terms of time and location. Sunlight is a visible electromagnetic wave that falls into the thermal wavelength category and causes the temperature of the solar cell to augment considerably. One challenge linked with solar cells is that they only capture visible light in the ultra-violet and infra-red spectrum. Higher blue and green energy photons provide higher energy than required for an electron to excite from valence band to conduction band. For hot regions like Sukkur, this problem plays a great role in impeding solar cell's performance. Another reason for the rise in temperature is Ohmic resistance inside module due to metallic current collecting lines. Hence, every single oC rise in cell temperature causes a significant power loss. Numerous studies have been shown to reduce solar panel temperature and enhance their performance. This study uses a water cooling scheme to improve the performance of poly and mono-crystalline panels. The central objective of this study is to estimate the potential surge in power yield of 849 kW solar plant installed at Sukkur IBA University, Sukkur, Pakistan by the introducing water cooling scheme. Results indicated considerable improvement in the module performance and estimated an added 10% improved power yield.

Keywords: *Photons; Thermal wavelength; PV cell temperature; passive cooling; Ohmic resistance*

1. Introduction

With the hot regions like upper Sindh, Pakistan experience higher ambient temperatures, high solar irradiance, and dry conditions. The foremost reason for higher ambient temperatures other than equatorial topography is global warming and consequent climate change. Some regions receive more

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sunlight than others because of cloud shelter, atmospheric water content, and aerosols [1]. The output of the solar module drops as operating temperature rises with the passage of day time. It is more concerning that how climate change is going to affect photovoltaic performance and how to cool PV cells properly is still a poorly studied area. The main aspect that affects solar cell performance is non-Radiative recombination [2]. Recombination takes out the electrons from the conduction band and recombines with holes that lead to a drop in power. This is because electrons do not get a chance to do external work [3]. Recombination is opposite phenomenon to generation as electron loses its energy and tries to stabilize itself in valance band again provided that as electron loses its energy in the form of heat, temperature of panel also rises. This recombination effect is directly linked with temperature, as the temperature rises this rate of recombination also raises, leading to a loss in output yield. The parameters such as open-circuit voltage *Voc*, Short circuit current *Isc*, Fill Factor (FF) and efficiency are temperature-dependent parameters [4]. The *Voc* decreases considerably and Isc increases marginally with the rise in temperature. The overall performance of solar cells decreases with an increase in temperature and also causes an increase in internal losses in the form of recombination [6]. Investigating the temperature dependence and effect on Voc and Isc is critical in the field of solar research. The diode parameters of the solar module such as ideality factor (n), series resistance (Rs), reverse saturation current (Io), and shunt resistance (Rsh) are the key factors that define the possible effect of temperature on Voc, FF, and Z of the solar cell. The solar cell p-n junction I-V characteristics can be described by the following mathematical equation [7].

$$I_f = I_{ph} - I_o \left(e^{qV_j/nKT} - 1 \right) - V_j/R_{sh} \quad (1)$$

Where

$$V_j = V_f + I_f R_s \quad (2)$$

Here, Iph represents photo generated current which is approximately equal to the short circuit current and Io is reverse saturation current. Vj is voltage dropped across the junction, n being ideality factor, T as temperature and k represents Boltzmann constant. The terminal voltage, series resistance, and shunt resistance are represented by Vf, Rs and, Rsh respectively [8-10].

$$V_{oc} = nV_T \,.\ln\left(\frac{i_p + I_o}{I_o}\right) \quad (3)$$

Where VT is voltage equivalent of temperature, i_p is photocurrent. The current-voltage characteristics of the solar module depend on temperature as Isc increases with temperature and Voc decreases due to the positive and negative temperature coefficients. The Pmax also drops with a rise in temperature as it has also a negative temperature coefficient. The overall impact would be a significant loss in the performance of solar modules due to an increase in temperature [11-13].

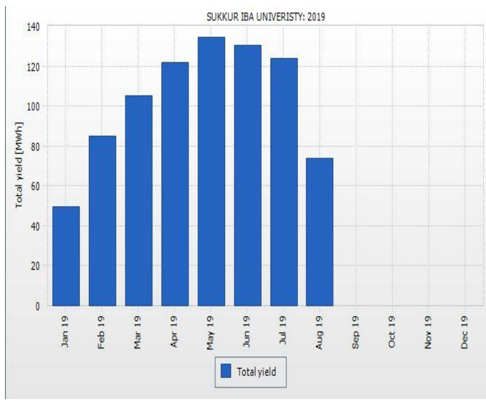

Fig 1: Total energy yield during the year 2019

Hence, this study focus on the different effects of temperature on the solar module performance and preventive water cooling technique. Experimental and numerical studies are conducted to compare and observe different behavior of I-V characteristics of the solar modules. The objective of this study is to see whether water or Radiative cooling could be a more efficient technique for solar module performance enhancement [14-17].

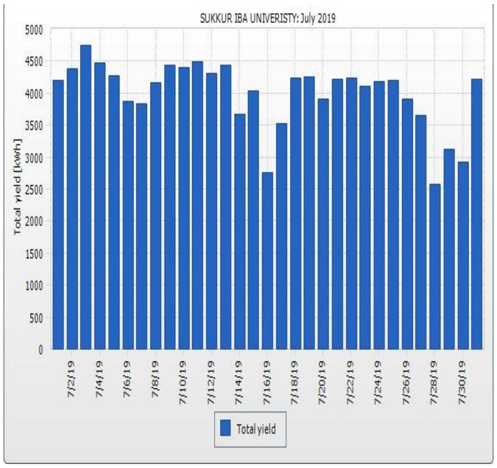

Fig 2: The power yield during the month of July

We analyzed an 849 kW solar PV plant and found that during the year 2019 the maximum power generated in May was less than 500 kW as. This power can be increased greatly with cooling techniques either by passive or active cooling [18-20].

2. Methods

The performance of a PV cell depends on the solar spectral distribution of irradiance and reference spectra. Solar cell parameters are mostly measured at standard temperature conditions (STC) [21-24]. The optical losses occur due to the reflection of glass at the front and for fixed-tilt angle latitude, clearance index, surface treatment, and refractive indices are the main factors on which optical losses depend.

2.1. Specific Module Selection

The performance of solar module can greatly be increased with different cooling methods such as water cooling, Radiative cooling, and convective cooling. This study focused on the cooling of module using water and an enhancement in the performance of the module. The cooling technique applied had a uniform cooling effect on the entire surface area of the panel. The total number of modules selected was 6. It was made sure that during cooling there should be a uniform cooling at the glass surface; however, it was not entirely possible at all.

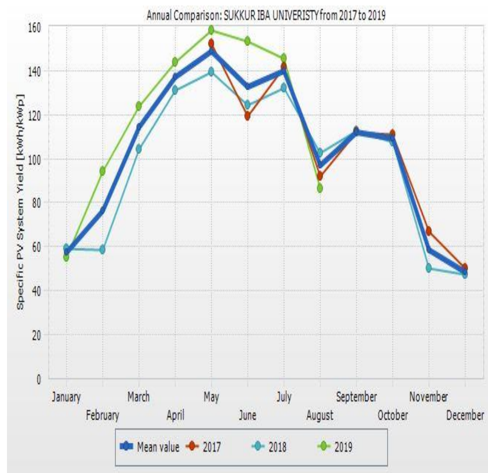

Fig 3: The total power produced in 2017-2019

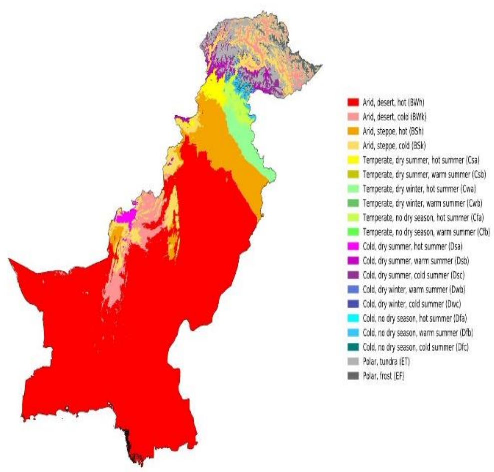

Fig 4: The climate conditions of the studied region [25]

Table 1 The climate & weather averages in Sukkur

Parameter	**Value**
High Temp	41 °C
Low Temp	30 °C
Mean Temp	35 °C
Precipitation	11.2 mm

Humidity	53%
Dew Point	24 °C
Wind	6 km/h

Table 2 The specifications of the studied PV modules.

Parameters	**Values**
Area of single panel	1.64 m^2
Tilt angle of panels (polycrystalline)	15º
Tilt angle of panels (Monocrystalline)	5º
Ideal V_{oc}	37.4 V
Ideal I_{sc}	8.63 A
Ideal power	322.76 W
Ideal V_{oc} Single cell	0.6233 V
Azimuth angle for panels understudy	41^0
Total system power	849 kW

Fig 5: The equipment used for the measurements

The equipment used for this study were Multimeter, Irradiance meter, and a digital laser thermometer. The front and backside temperatures of modules were measured when modules were covered with dust and after the dust was removed. The effect of dust shading was also observed on Voc and Isc of the module. The performance of the solar module is mostly determined by the Voc and Isc. The readings were measured during the month of July as shown in figures.

3. Results and Discussion

Isc increases with irradiance and decrease marginally with the temperature. However, the short circuit voltage decreases with rising temperature logarithmically. Voc is more sensitive to temperature than Isc. The increase in Isc due to temperature is very small approximately 0.45% per degree rise. However, the Voc drop and heat produced causing Ohmic losses to contribute to a more overall loss in performance. Hence, this study shows how much we can achieve with a simple water cooling method.

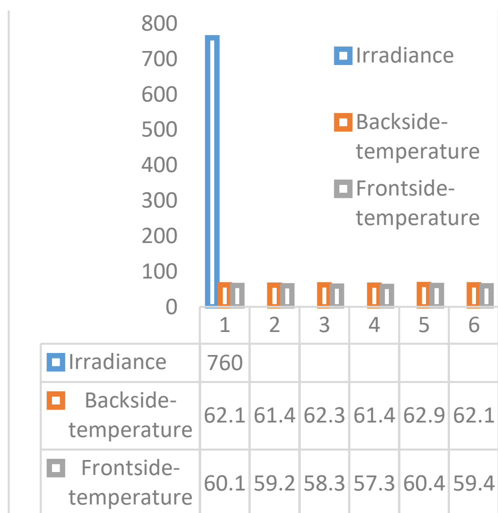

Fig 6: Front and backside temperatures of modules at higher irradiance

It was observed that the front side temperature was 1-2 degrees lesser than the backside of the module. This must be due to the glass layer at the front which does not allow all light to reflect and causing more heat at the backside of the panel. This could be also due to current collecting lines present at the backside, when current is produced and travels through backside current collecting buses it experiences more resistance compared to the front side. This higher temperature at backside of module also contributes negatively to the performance of the module. Fig. 6 indicates that temperature rises with increasing irradiance level. But in the post afternoon time when irradiance decreases but the temperature still remains higher. That rise in temperature at a lower irradiance level compared to morning.

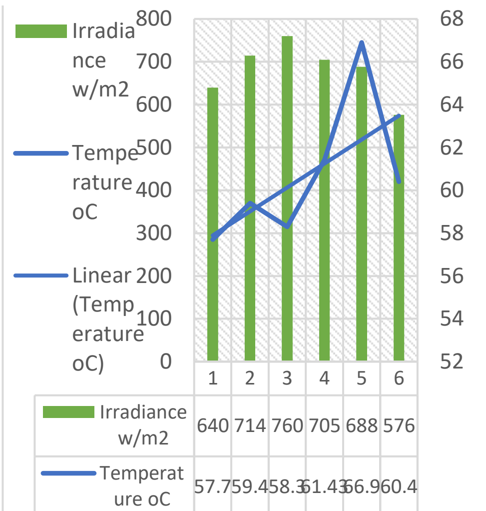

Fig 7: Irradiance vs temperature relation

Fig. 7 indicates that V_{oc} increases with increasing irradiance but at in evening time the V_{oc} decreases

The solar panels under study have all cells connected in series to add up the voltage. When cells are connected either in series or parallel fill factor does not change. However, it does change when cells are not identical by manufacturing aspect and cells are not receiving an equal amount of light. Hence, non-uniform light scattering over panel and disparity in manufacturing cause a difference in fill factor. Table 3-4 indicates that before and after cooling Voc, Isc recovers considerably. The temperature decreases with cooling and it augments with fill factor and performance of the module substantially.

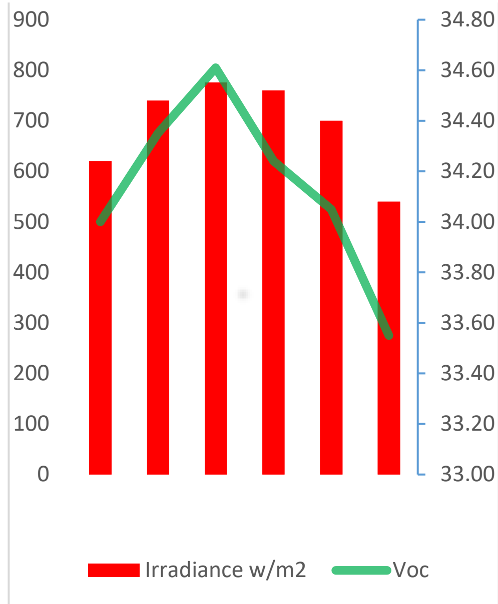

Fig 8: The behavior of Voc with irradiance

Fig. 8 clearly shows that there is a significant increase in power yield of panels after active cooling through the water. Hence, roughly speaking there can be a 55 kW increase in power yield of Sukkur IBA University's total monthly power yield. The amount of power used for active cooling is small and water consumption can also be controlled. Hence, the 45th total power increase is much higher than what it requires to run the motor for the active cooling of solar panels.

Water spray over the front surface of the module reduces reflection losses and absorbs heat accumulated inside PV panels. The power yield improvement and operating temperature reduction were higher at noon than morning or evening time

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Table 3 Before and after cooling parameters

S.no	V_{oc} (V) Before cooling	I_{sc} (A) Before cooling	Back side temperature Before cooling	Front side temperature Before cooling	Fill factor Before cooling	V_{oc} (V) After cooling	I_{sc} (A) After cooling	Front side Temperature(°C) before	Front side Temperature(°C) after	Fill factor After cooling
1	31.20	7.10	62.1	60.1	0.68	34.61	7.95	62.0	44.1	0.85
2	32.40	6.43	61.4	59.2	0.64	34.00	7.92	60.5	46.8	0.83
3	32.33	6.09	62.3	58.3	0.61	33.64	7.98	62.3	47.7	0.83
4	31.29	6.23	61.4	58.6	0.60	34.71	8.06	61.3	50.5	0.84
5	32.40	6.28	62.9	60.4	0.63	34.05	7.95	64.2	45.3	0.84
6	32.60	7.00	62.5	59.5	0.70	33.85	7.93	65.6	45.8	0.86

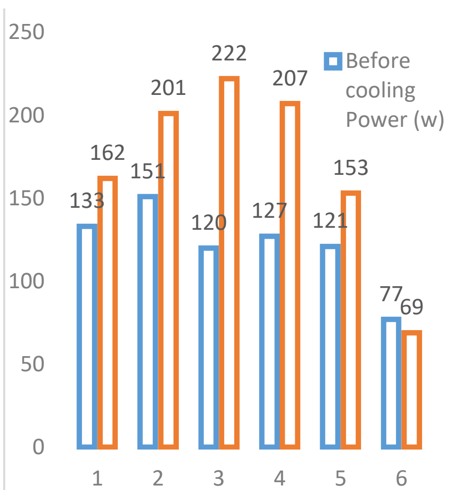

Fig 9: The difference between the power output of the module before and after the cooling

The both active and passive cooling methods are considered as suitable method in terms of Energy saving generated through solar. However, the passive cooling method is more economically viable and more effective method.

Fig. 9 &10 shows that with cooling method *Voc*, *Isc* increases, especially *Voc* improves a lot. Which contributes to the total power yield enhancement.

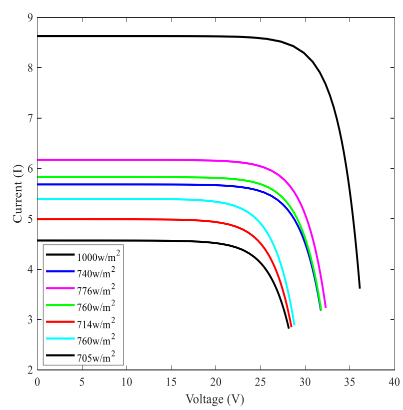

Fig 10: Illustration of power comparison before and after cooling

The major reason for the improvement in *Voc* is greatly due to the reduction in the operating temperature of the module with active cooling. The top black curve represents the ideal IV curve at 1000 w/m2, AM 1.5 and 25 0C. The middle three curves represent after cooling IV curves, which are clearly above the before cooling bottom three curves. It is evident that cooling shifts the IV curves to the top which means an improvement in the performance of the module.

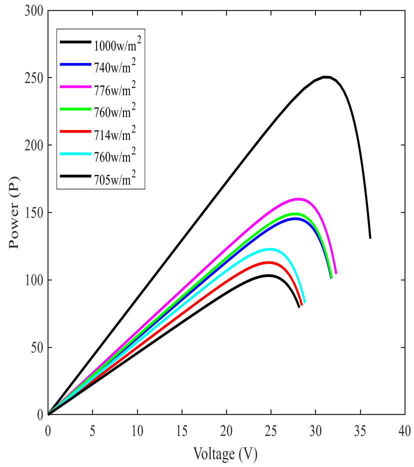

Fig 11: The power voltage curves based on experimental calculation

The power voltage curves show that after cooling curves are near to the ideal curve as shown in the black ideal curve at the top. The before cooling curves however are more shifted towards the bottom side indicating that less power was produced before cooling of the module.

3.1 Numerical results

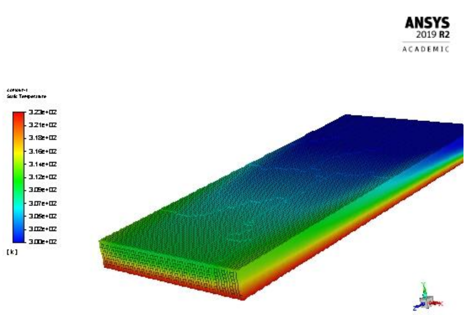

Fig 12: Temperature contours of solar glass surface after water cooling

Fig. 12 indicates that the glass surface temperature reduces unevenly with the water cooling method. Even though temperature distribution is not smooth but operating temperature falls with increasing Reynolds number as concluded from the numerical simulations. The maximum cooling was achieved at Reynolds number 15 and minimum at 5. Furthermore, the operating temperature was achieved below the desired value with a higher Reynolds number. The temperature at top of the module is much lower compared to the bottom of glass. This is due to water is sprayed from the top and it absorbs some of the heat while reaching the bottom of the module. The variation of contours in figure 12 indicate the validity of results as in practice it is observed that there is always variable temperature distribution across Solar plate surfaces.

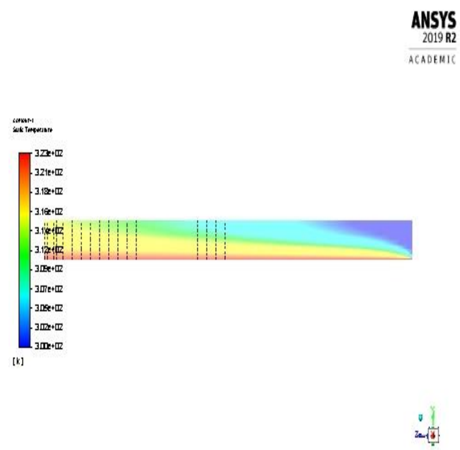

Fig 13: The Temperature distribution in the frontal plane

Fig. 13 indicates that the temperature of the module reduces the maximum from the point where the water starts flowing downwards. The water cooling does not cool operating temperature below 25 0 C. The overall module temperature drop using numerical technique was around 23 0 C.

4. Conclusion

This study shows the power yield of the solar plant greatly reduces due to the dust and rise in operating temperature. The temperature rise after 2 pm is higher and the irradiance level continues to decrease after 1 pm. The rise in temperature, reduction in irradiance level and no tracking cause great loss in total power yield of the plant. During the study, it was observed that the backside temperature was higher than the front side. Backside temperature also leads to resistance in backside metallic current collection points. Temperature relation with irradiance was not entirely linear due to wind effect and changing environment such as clouds. Several other effects cause non-linear behavior of temperature with irradiance. However, Voc increases with irradiance and reduces when irradiance decreases.

The power yield graph clearly illustrates that power improves greatly with passive cooling. The VI curve shows that after cooling VI curves are more close to the ideal IV curve. Which means after cooling power yield is significant increases. The rain greatly improved the 849 kW solar plant. Before rain 849 kW produced a maximum 550 kW. However, after rain, the maximum power yield reached the 605 kW mark. Hence, there were almost 55 kWs enhancements in the performance of the solar plant. On average 2.2 tons of CO2 has been avoided by the 849 kW plant. If this plant is regularly cleaned and cooled than the maximum yield might reach 650 kW. The total energy yield for the month of September was higher than 4000 kWh through the highest outcome is expected is in the month of May and June. It is therefore suggested that regular cleaning and cooling of the module installed at Sukkur IBA University will surely boost total yield.

Solar panels are constructed by connecting solar cells in array form. There are more than 15 different categories of solar cells are designed until now and most of them are not commercialized yet due to different reasons, such as stability issues and efficiency issues while different techniques are being applied to improve the stability or efficiencies of solar cells [26,27]. Rise in temperature is one of the major issues in stability of thin film solar cells. However in this paper, experimental work is totally based on conventional silicon solar cells. This research can further be conducted on thin films solar cells to improve the stability and efficiency which are the main barrier in commercializing of thin film solar cell.

5. Future Recommendations

1. Find the heating rate and cooling rate of PV panels.
2. Determine optimized flow rate for optimized reduced operating temperature.

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