An experimental evaluation on revamping the productivity of solar PV panel using wind tunnel as an optimizer

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Abstract At high working temperatures, the performance of the solar photovoltaic (PV) cells will be affected. With the increase in temperature of the PV cells, the conversion of solar radiation into electrical output will be decreased. The operating temperature of the PV cells is one of the prime factors for determining its electrical conversion efficiency. In order to get the maximum electrical output from the solar PV cells, the temperature should be maintained properly. In this experimental study, the temperature of the solar PV cells was maintained by cooling both sides of the PV panel simultaneously. The front surface of the PV panel is sprayed with a thin film of pot water and the rear side is attached with a fabricated duct that was connected into a wind tunnel blower. The mass flow rate of the moist air from the wind tunnel to the rear side of the PV is ranged between 0.1m/s to 0.5m/s. The performance characteristics of both the commercially available PV panel and the experimental PV panel (PVT Clay pipe panel) were compared. The results show that the PVT clay pipe panel has an electrical efficiency of about 11.72%, whereas the commercially available PV panel has only 9.77%. Also, the overall efficiency of the experimental PVT panel is 65.55% respectively.

Key words: solar PV panel, clay pipe, wind tunnel, pot water, moist air, electrical efficiency

1. Introduction
Photovoltaic system is the utmost important device of energy converter, which is directly converts the solar energy into electrical energy without any mechanism [1,2,3]. However, The PV panel is generally produced low amount of electricity, the majority of solar irradiation is converted into heat [4]. Hence, only 13-20% of the solar irradiation converted into electricity, the residual of solar energy gets as a heat [5]. finally, the PV results get elevates the panel temperature [6]. Increase in cell temperature, their efficiency will decrease around 0.4% - 0.5% [7]. In order to overcome this problem, either to reduce PV panel temperature or maintaining operating cell temperature. When the cell temperature decreases, the efficiency of PV panel will increase [8]. Therefore, following researchers have accomplished many methods to improving PV panel efficiency like, water cooling, air cooling, pcm etc. [9] George Popovic et al. Presents the improved on photovoltaic panel efficiency by the way of temperature reduction. The panel temperature was reduced by the air-cooled heat sinks, it was high thermal conductivity material. The efficiency of the cooling was examined for different configuration of the heat sink. The result shows that, a maintained average temperature of solar PV panel.
[10] Zeyad A. Haidar an experimental investigates that, the rear surface of PV panel heat was absorbed by evaporative cooling effect. The rear surface of PV panel was maintained on wet condition by the water, it was collected from the water tank by the gravitational force. This method was very effective and also reduced more than 20% panel temperature, hereby, the electrical efficiency was achieved around 14% compared than the reference PV panel.

[11] Dhritiman Adhya, experimentally proved that, the PV panel was cooled by the distilled water as a coolant fluid. However, an aluminum pipe was mounted on rear surface of the PV panel. The coolant fluid flow through the mounted pipe line, it was extracting the accumulate the heat at rear side of the PV panel. This phenomenon would decrease the temperature level up to 33.1% and an efficiency increased about 18% of power output.

[12] Farag Mahel Mohammed proposed, an enhancing the efficiency of PV panel with the combination of water flow double glazing system and dual axis tracker has been implemented at hot climatic condition. However, the combined PV panel temperature was maintained around 40°C when ambient temperature exceeds up to 50°C, also increased a maximum efficiency about 12.7%.

[13] Haitham M. Bahaidarah experimentally investigates that, a hybrid PV system was designed to flow active water cooling on back side of PV surface. This active cooling method has been significantly reduced operating temperature around 20%. Furthermore, this water-cooling method is simultaneously produced hot water and electrical energy. The results show that an electrical efficiency achieved about 9% at 900W/m2 irradiation level.

[14] Calebe Abrenhosa Matias examined the performance of power generation equipped with cooling and without cooling systems. The experiment shows that, the cooling of panel was decreased operating temperature during the peak hour. The water is supplied on over surface of the PV panel. The supplied water flow increased power output about 77Wh and also gained 24% total energy.

[15] DjamilaNebbali investigates an increasing the efficiency of solar PV panel by the use of pulsed ambient air through the fan. An electrical efficiency achieved around 71% under the radiation of 2000W/m2 and 50°C air temperature.

[16] Azadeh Kordzadeh have examined different techniques for reduce solar PV panel temperature. finally, they concluded that, the water-cooling method have to be reduced cell temperature through the pump motor. It is most effective method for increasing efficiency solar PV and also reduced cell temperature.

[17] Jie Ji designed PVT water heating system with help of natural circulation methods has been implemented. The authors have used to different mass of water and different initial temperature of water on outdoor condition. Thereby, an increasing electrical efficiency and thermal efficiency to be 10.15% and 45% respectively. The total efficiency was achieved about 52% and also recovered primary energy saving up to 65%.

[18] M. Chandrasekar improving an efficiency of solar PV panel combination with heat spreaders and cotton wicks used for controlling the cell temperature during peak hour. An electrical efficiency and thermal efficiency of PVT system results were compared with the nominal flat PV panel. The thermally regulated PV panel temperature was reduced about 12% also be increased an electrical efficiency up to 14% through this cooling methods.

In this experimental study is focused on enhancing the efficiency of solar PV panel by using pot water to reduce front surface panel temperature. In addition, the duct was designed at rear side of the PV panel to create a way to air flow on it. It was connected with the wind tunnel. By using moist air to control the released heat. Finally, the electrical efficiency and thermal efficiency were analyzed both PV and PVT panels.
Nomenclature

| Symbol | Description                          |
|--------|--------------------------------------|
| $A_p$  | PV panel surface area (m$^2$)        |
| $C_{\text{water}}$ | Specific heat of water (kJ/kg-K) |
| $A_{\text{duct}}$ | Area of the duct                      |
| $m_{\text{water}}$ | Mass of water flow (kg/sec)       |
| $\beta$ | Temperature coefficient (°C)           |
| $T_g$  | Temperature of glass cover (°C)        |
| $T_{\text{sky}}$ | Sky temperature (°C)                 |
| $U_L$  | Overall heat loss coefficient (W/m$^2$ K) |
| $h_w$  | Convective heat transfer coefficient due to wind (W/m$^2$ K) |
| $h_{\text{air}}$ | Heat transfer coefficient in air duct (W/m$^2$ K) |
| $T_{\text{inlet}}$ | Inlet water & air temperature (°C)     |
| $T_{\text{outlet}}$ | Outlet water & air temperature (°C)   |
| $\eta_{\text{ele}}$ | Electrical efficiency (%)             |
| $\eta_{\text{th}}$ | Thermal efficiency (%)                |
| $\eta_{\text{o}}$ | Overall efficiency (%)               |
| $\varepsilon$ | Emissivity of the glass cover          |
| $\sigma$ | Stefan-Boltzmaan constant (W/m$^2$K$^4$) |

2. Experimental setup

The Experimental setup consists of two identical 40W solar PV panel. Among these, one PV panel used as reference panel for comparing the electrical efficiency and another one is working panel equipped with cooling system as an evaporative cooling moist air. Here, the evaporative cooling system comprised a rectangular wind tunnel made by plexi glass with size of 3.14 m length, 0.38 m X 0.38 m square cross.
section and 9 mm thickness. Hence, the following apparatus has been used in this experiment work like,
1. wind blower 2. rectangular wind tunnel 3. clay pipes 4. Utube monometer 5. Water shower 6. PVT panel 7. reference PV panel 8. clay pot water tank 9. Pot water. Fig 1. Shows the schematic view of experimental setup.

Fig 1 clears that; the wind tunnel has been separated into two parts. The initial part of conical adaptor is built with blower and second part is made with a clay pipe with the size of 40cm length and width is 8cm. As per the reference [Ramkumar et al] the clay pipes are settled in different arrangement like align position and staggered position in 16 and 14 tubes respectively. Moreover, the clay pipes are placed at vertical position in the rectangular wind tunnel besides, one end of the wind tunnel has been directly connected into the solar PV panel. This experiment was conducted from 9 am to 5 pm during the month of February to June 2019 under the climatic condition of Chidambaram. A thin film of pot water supplied on over the front surface of the PV panel, Whereas the rear surface was made as duct to make a way to air flow. An ambient air is allowed to flow over the rectangular wind tunnel with the help of an induced air blower. The supplied air flow cross over the clay pipe to the solar PV panel. The clay pipes were filled with water and arranged in two different position. A set of sixteen clay pipes were arranged in an aligned position and another set of fourteen clay pipes where are arranged in staggered position as shown in the fig 2. Both the type of arranged pipes were tested for three pitch distances (3cm, 6cm & 9cm) and five different velocities (0.1m/s, 0.2m/s, 0.3m/s, 0.4m/s,0.5m/s) individually.

![Figure 2](image)

**Figure 2.** shows the aligned and staggered position of clay pipe with different pitch distance.

3. Mathematical formulation of energy balance equation for PV & PVT panel

The energy balance equation was given below adapted from the equation [19]
The following equation describes the total energy absorbed, the top surface supplied pot water and moist air is bottom side:

\[
Q_{\text{overall}} = Q_{\text{front}}(\text{convection} + \text{radiation}) + Q_{\text{rear}}(\text{convection})
\]

\[
U_{L}A(T_{M} - T_{A}) = h_{w}A_{w}(T_{g} - T_{A}) + \sigma e(T^{4} - T^{4}_{g})A_{s}(T_{M} - T_{A}) + h_{\text{air}}A_{duc}(T_{M} - T_{\text{moist air}})
\]

(1)

The following parameters were measured influence of cooling technique like, maximum power \(P_{\text{max}}\), short circuit current \(I_{\text{sc}}\) and open circuit voltage \(V_{\text{oc}}\). This equation is given by the examine the effect of temperature on the electrical performance of PV panel:

\[
P_{\text{max}} = I_{\text{max}}V_{\text{max}} = FF \times I_{\text{SC}} \times V_{\text{OC}}
\]

(2)

The Eq. (2) shows the FF, as it is called the fill factor, which describes the ratio of maximum power obtainable of the PV module’s short circuit current \(I_{\text{sc}}\) and open circuit voltage \(V_{\text{oc}}\). The electrical efficiency \(\eta_{\text{ele}}\) is can be determined with various incident solar irradiation. It is given by:

\[
\eta_{\text{ele}} = \frac{I_{\text{max}}V_{\text{max}}}{I_{\text{SC}}V_{\text{OC}}}
\]

(3)

The effective electrical efficiency is can be determined below equation:

\[
\eta_{\text{ele}} = \eta_{r} \left[ 1 - \beta_{r}(T - T_{r}) \right]
\]

(4)

Here, \(\eta_{\text{ele}}\) denotes the electrical efficiency, \(\eta_{r}\) indicates the reference efficiency of Photovoltaic (PV) module. The coefficient of cell temperature is \(\beta = 0.0045^\circ\text{C}\) [20].

The total heat energy gained from the PVT system:

\[
Q = q_{1} + q_{2}
\]

In Eq. (5) defines the rate of heat energy absorbed by the water:

\[
q_{1} = m_{\text{water}} \cdot C_{p_{\text{water}}}(T_{\text{outlet}} - T_{\text{inlet}})
\]

(5)

Where, \(m_{\text{water}}\) denotes the mass flow rate of water and \(C_{p_{\text{water}}}\) denotes the specific heat of the water. The below equation gives the rate of heat energy absorbed by the air [21].

\[
q_{2} = m_{\text{air}} \cdot C_{p_{\text{air}}}(T_{\text{outlet}} - T_{\text{inlet}})
\]

(6)

The thermal efficiency can be calculated as the below equation; \(Q\) is denoting the gained heat energy, ‘\(G\)’ is solar irradiation and ‘\(A\)’ is the area of PVT module system.

\[
\eta_{\text{th}} = \frac{Q}{G \cdot A}
\]

(7)

Addition of Both the thermal and electrical energy determined the overall efficiency; below equation could be solve it:
4. Result and Discussion

This research work was conducted to increase the efficiency of PV panel, and wind tunnel clay pipe and pot water were used as coolant medium. These techniques a way to increase in heat transfer rate between PV panel and atmospheres. The combined pot water and wind tunnel moist air has been used to improving the efficiency of PV panel. Fig.3 represents the temperature difference between ambient temperature, wind tunnel air and pot water temperature. It was observed that, an ambient temperature gradually increased upto 41°C at peak hour at the same time a wind tunnel air and pot water temperature inversely decreased to be 32°C and 28°C respectively. A reason behind that, generally clay pot have evaporative cooling effect, which makes better performance at peak hour due to the pore holes of clay pot. And of clay pot water always been 5°C to 8°C lower than the ambient temperature [20].

\[ \eta_0 = \eta_{th} + \eta_{ele} \]  

(8)

Figure 3. Temperature difference of ambient temperature, Wind tunnel air and pot water
Figure 4. shows the variation of ambient temperature and solar radiation

Figure 5. shows the temperature difference between PV and PVT modules
Figure 4 shows that, the variation of ambient temperature and irradiance level range is found to be 41°C and 975W/m² respectively. At 9am to 5pm the ambient temperature and intensity of solar radiation is achieved about 32°C to 35°C and 812W/m² to 875W/m² respectively.

Hence, the experimental study is carried out, during the month of February to June 2019. Figure 5 represents the comparison between surface of reference PV panel and Working PVT panel temperature. All the temperatures were recorded by the data logger. From the initiating work the temperature difference between reference PV and working PVT panel surface is to be about 48°C and 43°C. At peak hour the reference PV and PVT panel temperature reaches up to 65°C and 53°C respectively. The maximum temperature difference between the reference PV panel surface and ambient temperature is 24°C, similarly; for the working PVT panel is about 12°C. Moreover, the back side of PVT panel surface is 8°C lower than the ambient temperature due to the wind tunnel moist airflow on it. From the graph 6,7 represents the power production and electrical efficiency of PV and PVT panel. Here, both the power output and electrical efficiency has been increased with the decrease of PVT module temperature.

![Figure 6](image_url)

**Figure 6.** Shows the variation of power production between reference PV and PVT clay pipe panel

Figure 7 clears that, electrical efficiency were compared between reference PV and PVT clay pipe panel. Both the panels should be produce same amount of energy but from the begining time of morning 8 am to 11 am, the PVT clay pipe panel electrical efficiency has been continuously degereased due to the cooling technics on it. The reason behind that, both the sides of panel were cooled before it recives the required heat to generate electricity.
Figure 7. Shows the electrical efficiency of reference PV and PVT clay pipe panel

The overall efficiency can be determined by the absorbed solar radiation of PVT module, Figure 8 shows the electrical efficiency, thermal efficiency and overall efficiency of both PV and PVT module.

Figure 8. Overall efficiency compared with electrical and thermal efficiency of PV and PVT clay pipe panel
Hence, the reference PV system can be generating only electrical energy, but the working PVT system to yield both electrical and thermal energy. Due to the sensible heat was absorbed by the pot water on PVT front surface, additionally the rear side heat was captured by the wind tunnel moist air. Hereby, the dissipated heat was recovered on front and rear side of PVT system, whereas water and moist air is used as coolant medium. Figure 8 clears that, the overall efficiency of PVT achieved about 65.5% total energy output. Which is better efficiency of compared with reference PV panel. A reason behind that both the side of PVT panel were simultaneously cooled continuously by the water and air as coolant medium. The maximum thermal efficiency of water and moist air is to be 40.82% and 13.10% respectively, the air efficiency is lower than the water efficiency due to the specific heat (Cp) of air and thermal conductivity. Which makes better cooling effect both the side of PVT panel surface.

Conclusion
The experimental study has discussed about electrical and thermal performance of PVT module system. From the obtained result shows that, the temperature of reference PV reaches upto 65°C and its electrical efficiency dropped significantly to 1.95%. similarly, the working PVT panel temperature is absorbed around 53°C only, due to the evaporative cooling effect, the temperature drop will be significantly reduced around 10°C to 12°C. At peak our, the efficiency of PV and PVT panel achieved about 9.77% and 11.72% respectively. Although, both the side of PVT panel were cooled continuously, front surface was cooled thin film of water and rear surface is cooled by wind tunnel blower moist air thereby the thermal efficiency would be reached upto 53.92%. due to the better cooling effect the overall efficiency of PVT panel is achieved about 65.55%. it is concluded that, the PVT clay pipe panel has achieved better electrical and thermal efficiency compared than the reference PV panel.

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