Thermal Models for Evaporative Cooling on Photovoltaic Panel Attached with a Wetted Salo Fabric

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Abstract. Photovoltaic (PV) panel efficiency is dropped when an operating temperature has increased. An evaporative cooling by attaching a wetted Salo fabric at the back surface of the panel has been used to resolve this problem. This paper presents thermal models, which will be used as a design tool to improve the panel efficiency on the actual photovoltaic panel, to predict the back surface temperature of the photovoltaic panel. Two cases are investigated: (i) plain photovoltaic and (ii) photovoltaic with cooling device. An experiment is setup to validate the thermal models by using photovoltaic model, which made from an aluminium attached with a silicone heater, to represent for an actual photovoltaic panel. The experiment is tested in the controlled condition room. The results from the thermal models are nearly predict the back surface temperature compared with the experimental data. It shows that the temperature difference of back surface temperature between uncooling and cooling cases is 24.5°C.

1. Introduction

Photovoltaic panel (PV) is widely used for power generation in many countries. It has been founded that some parameters effect to the panel efficiency such as temperature, humidity, and dust [1-2]. Some researchers reported that rise of 1°C of the panel temperature, the panel efficiency will drop by 0.5%. Therefore, cooling of photovoltaic panel is required to maintain their efficiency. Many cooling techniques are investigated. There can be mainly divided in two techniques; active cooling and passive cooling. Active cooling is more effective than passive cooling, but it required an additional electrical power to supply a cooling device [3-4]. On the other hand, passive cooling does not require an electrical cooling device and use natural energy. There are some techniques such as using heat spreaders [5-6], phase change material (PCMs) [7], and evaporative cooling. All of these techniques are installed the cooling device at the back of photovoltaic panel to decrease the panel temperature.

Several researchers choose an evaporative cooling technique because cooling materials are affordable (i.e. fabric or clay), low initial cost, and easy maintenance. M. Chandrasekar et al. [8] studied evaporative cooling by using cotton wick attached at the back of PV panel. They can reduce the panel temperature by 20°C. Z. A. Haidar et al. [9] investigated the evaporative cooling by installing pieces of fabric at the back panel. They can decrease the panel temperature by 22°C. A.H. Alami [10] developed the synthesis clay as an evaporative cooling device and attached with the PV panel. He can decrease the panel temperature by 18°C. From the previous literature review, it can see that reduction of the photovoltaic panel temperature by using evaporative cooling is effective compared with other techniques.
In this research will investigate the temperature reduction from evaporative cooling by using a wetted Salo fabric attached at the back panel. Salo fabric is chosen in this research because of its great ability to absorb and evaporate water when wetted. Thermal models have been developed to predict the temperature at various points as a means to be used as a design tool for the application. An experiment has been tested to validate the thermal models by using photovoltaic model, which made from flat plate aluminium and attached with silicone heater to simulate as the solar irradiation. The test will separate in two cases, one is plain photovoltaic model and another is photovoltaic with cooling device model, and the test will be held in the controlled condition room for 180 minutes. The results will show an effect of evaporative cooling by using a Salo fabric attached on the back surface temperature.

2. Theoretical formulation
Normally, photovoltaic panel has received heat from the sun at the front panel, then the heat will transfer out to an ambient in two ways; front panel and back panel by effect of convection and radiation. If the panel has been installed an evaporative cooling device, the evaporation will additionally affect at the back panel too. To estimate the effect of heat transfer on the panel temperature, the thermal models are developed based on the energy equation.

\[
\rho C_p \frac{dT}{dt} = k \frac{\partial^2 T}{\partial x^2} \quad (1)
\]

There are several assumptions for the model: (i) heat transfers in one direction from the front panel to the back panel, (ii) temperature distribution on the model becomes steady-state, (iii) properties of fabric are replaced by using properties of water, and (iv) ambient condition is constant. Based on these assumptions, thermal resistances network of both the plain photovoltaic panel and the photovoltaic panel with cooling device can be constructed as shown in figures 1 and figures 2, respectively.

![Figure 1. Thermal model for plain photovoltaic.](image1.png)
![Figure 2. Thermal model for photovoltaic with cooling device.](image2.png)

Thermal resistances network of plain photovoltaic panel consists of the solar heat source \( Q_s \) and three thermal resistances; conduction from front panel to back panel \( (R_{cell,front}) \), convection \( (R_{conv}) \) and radiation \( (R_{rad}) \) from back panel to ambient. To solve this thermal model, the energy equations in finite difference form for each node are shown as the following equations,

**Front temperature node** \( (T_f) \):
\[
\frac{\rho C_p C_{cell}}{2} \frac{T_{f,i+1} - T_{f,i}}{\Delta t} = k_{cell} \frac{T_{b,i+1} - T_{f,i}}{x_{cell}} + q_{f}'
\]

**Back temperature node** \( (T_b) \):
\[
\frac{\rho C_p C_{cell}}{2} \frac{T_{b,i+1} - T_{b,i}}{\Delta t} = k_{cell} \frac{T_{b,i+1} - T_{b,i}}{x_{cell}} + h \left[ T_{f,i+1} - T_{amb} \right] + \sigma \varepsilon \left[ T_{b,i+1}^4 - T_{amb}^4 \right]
\]

where the superscription \( i \) and \( i+1 \) refers to present time domain and future time domain respectively. For the photovoltaic panel with cooling device, thermal resistances network is similar as the plain photovoltaic panel, but it adds a conduction from the back panel to the cooling device \( (R_{cond, w}) \) and evaporative heat source from the cooling device to ambient \( (Q_{evap}) \). The energy equations in finite difference at the back temperature and water temperature node will becomes,
Back temperature node (\(T_b\)):
\[
\frac{P_{coll}C_{coll}}{2} \frac{dT_b}{dt} + \frac{\rho_sC_{p,w}}{2} \frac{dT_b}{dt} = k_{coll} \frac{T_b^{i+1} - T_b^i}{x_{coll}} + k_w \frac{T_b^{i+1} - T_b^i}{x_w}
\] (4)

Water temperature node (\(T_w\)):
\[
\frac{\rho_wC_{p,w}x_w}{dt} - \frac{T_w^{i+1} - T_w^i}{x_w} = k_w \frac{T_w^{i+1} - T_w^i}{x_w} + h\left[\left(T_w^{i+1} - T_{amb}\right)\right] + \sigma e_w \left[c\left(T_w^{i+1}\right)^2 - C_{amb}\right] + q_f^w
\] (5)

All the equations are rearranged in matrix form and perform an iteration to estimate for the front panel, back panel, and water temperature by using MATLAB.

3. Experimental setup

Photovoltaic model is designed to represent a common photovoltaic panel and tested in a controlled environmental chamber for repeatability. It is divided in two models; (i) plain photovoltaic model as shown in figure 3 and (ii) photovoltaic model with cooling device as shown in figure 4. The setup consists of a 150 W silicone heater to simulate the net solar irradiation. An aluminium flat plate size 160×170×3 mm., which imitate as a photovoltaic panel, is mounted with the silicone heater. A polyurethane (PU) foam size 160×170×10 mm. used as an insulator to prevent heat loss to the front panel of the model. A power supply generating electrical power is connected to the silicone heater. The photovoltaic model is installed on a support and tilt of 15° with reference to the horizontal due to the optimum tilt angle of photovoltaic installation in Thailand. Three measured devices are used; a digital multi-meter to measure the input current and voltage of the power supply, a VICTOR 816B turbine anemometer (accuracy 3%) to measure wind speed, and DIGICON (model: DP-74SD) with four channels K-type digital thermocouples (accuracy 0.4% ± 0.5°C) to measure a temperature of the photovoltaic model. Three thermocouples are attached separately at the back surface of the aluminium flat plate as shown in figure 5. The experiment is tested in the environmental room which can control temperature and humidity. The room condition is set to be 35 ± 0.2°C and 65 ± 3% relative humidity, respectively. The experiment will begin after the room is controlled at the setting condition. Input power is set at 12.5 W, which resulted in an estimated incoming heat flux from actual solar irradiation. The experiment is tested for 150 minutes, repeated 5 times, and sampling the temperature every 5 second.

![Figure 3. Plain photovoltaic model.](image)

![Figure 4. Photovoltaic model with cooling device.](image)

![Figure 5. Temperature measured point at the back surface of the photovoltaic model.](image)
4. Result and discussion

The thermal model results of photovoltaic temperature at the back surface of both cases comparing with the results from the experiment are shown in Figure 6. Noted that the uncertainties of the measurement are evaluated and also presented as bands between the dash lines. The experimental results show that back surface temperature increases rapidly and become steady at $59.3 \pm 0.2 ^\circ C$ in 45 minutes for the plain photovoltaic case. For the photovoltaic with cooling device case, back surface temperature becomes steady at $34.8 \pm 0.7 ^\circ C$ within 10 minutes and maintain that temperature for about 70 minutes. Then, it increases rapidly and become steady again at $58.0 \pm 0.2 ^\circ C$ in 125 minutes.

![Figure 6. Thermal model and experimental results for plain photovoltaic and photovoltaic with cooling device.](image)

From the figure 6, the thermal models of both two cases can nearly predict the back surface temperature profile on the photovoltaic model compared with the experiment results. However, they have some limitations; (i) heat loss to the front surface is assumed to be 25% of the heat source ($Q_s$), and (ii) no evaporation on the Salo fabric if humidity of the fabric is lower than 22%RH in case of the photovoltaic with cooling device. It is possible to use them to predict the back surface temperature on an actual photovoltaic panel which approximately required 4 or 5 hours to generate an electrical power. Moreover, they can estimate amount of water need for evaporation and a cooling time in case of photovoltaic panel with cooling device. Thus, they can be used as a design tool for installing the cooling device on the actual photovoltaic panel in various conditions.

The experiment results showed that an average difference temperature between the uncooling and cooling cases is $24.5 ^\circ C$. Noted that the wetted Salo fabric can decrease the surface temperature to even below the ambient temperature. Thus, it confirms that this cooling technique will be useful to improve the panel efficiency. However, when the fabric begins dry, the surface temperature rises up and become steady again. Still, the surface temperature of the photovoltaic attached with dry fabric is lower than the plain photovoltaic. In this experiment, although attaching the dry fabric at the back surface will increase a system thermal resistance, an emissivity ($\varepsilon$) of the dry Salo fabric is greater than the aluminium which increase the radiative heat transfer on the back surface of photovoltaic attached with dry fabric. This results in the slightly decrease in the temperature of the photovoltaic attached with the dry fabric model compared with that of the plain photovoltaic model.

The major limitation of this cooling technique is that the surface temperature can be maintained at low temperature only while the fabric is wetted. When the fabric becomes to dry, the surface temperature will increase and the panel efficiency will drop to be the same as the plain photovoltaic model. To resolve this problem, a thicker Salo fabric or a higher porosity fabric may be used to increase the amount of water absorbed within the fabric. If the fabric has more water, the cooling time will be longer. Alternatively, to further extend the cooling period, a water supply system should be designed to keep the fabric wetting and cooling the surface temperature all the time.
5. Conclusion

Thermal models of a photovoltaic (PV) panel with and without a Salo fabric evaporative cooling have been developed and validated with the experiment. The thermal models can nearly predict the back surface temperature profile compared with the experiment results. Thus, it is possible to use these thermal models as a design tool on the actual photovoltaic panel. In this study, using a wetted Salo fabric as an evaporative cooling device for a photovoltaic model is effective as it can decrease the back surface of the photovoltaic model by 24.5 ºC. However, this cooling technique cannot reduce the photovoltaic model temperature all the time due to a lack of water for evaporation. Therefore, in a future work, a water supply system should be designed to keep the fabric wetting and decrease the back surface temperature all the time.

6. References

[1] Rahman M M, Hasanuzzaman M and Rahim N A 2015 Effects of various parameters on PV-module power and efficiency Energy Conversion and Management 103 348-358.
[2] Elbreki A, Alghoul M, Al-Shamani A, Ammar A A, Vegani B, M.Aboghra A, Sopian K 2016 The role of climatic-design-operational parameters on combined PV/T collector performance A critical review. Renewable and Sustainable Energy Reviews 57 602-647.
[3] Krauter S 2004 Increased electrical yield via water flow over the front of photovoltaic panels. Solar Energy Materials and Solar Cells 82(1-2) 131-137.
[4] Mazón-Hernández R, García-Cascales J R, Vera-García F, Káiser A S, and Zamora B 2013 Improving the Electrical Parameters of a Photovoltaic Panel by Means of an Induced or Forced Air Stream International Journal of Photoenergy 1-10.
[5] Ahmed I 2018 Enhancement the Performance of PV Panel by Using Fins as Heat Sink Engineering and Technology Journal 36 798-805.
[6] Chen H, Chen X, Li S, and Ding H 2014 Numerical study on the electrical performance of photovoltaic panel with passive cooling of natural ventilation International Journal of Smart Grid and Clean Energy 395-400
[7] Khaled M, Hachem F, Gad El-Rab M, and Ramadan M 2015 Cooling photovoltaic cells using phase change materials – Experiments and economical study.
[8] Chandrasekar M, Suresh S, Senthilkumar T, and Ganesh karthikeyan M 2013 Passive cooling of standalone flat PV module with cotton wick structures Energy Conversion and Management 71 43-50.
[9] Haidar Z A, Orfi J, and Kanessamkandi Z. 2018 Experimental investigation of evaporative cooling for enhancing photovoltaic panels efficiency Results in Physics 11 690-697.
[10] Alami A H 2014 Effects of evaporative cooling on efficiency of photovoltaic modules Energy Conversion and Management 77 668-679.