The Improvement on the Efficiency of Photovoltaic Module using Water Cooling

Wan Ariff Fadhil Bin Wan Abdullah1*, Chew Sue Ping1, Razanah Nabila Binti Radzuan1, Anis Shahida Niza Binti Mokhtar1

1 Department of Electrical And Electronics Engineering, Faculty of Engineering, Universiti Pertahanan Nasional Malaysia, Kem Perdana Sungai Besi, 57000, Kuala Lumpur, Malaysia.
*E-mail: wanarifffadhil@gmail.com

Abstract. This study denotes an effective design for thermal regulating by integrating the water-cooling system on photovoltaic (PV) panel. The efficiency of the PV module will reduce the increasing temperature on the panel. Thus, the focus of this study is to improve the efficiency of the PV module by maintaining a low operating temperature. A modification on the rear part of the PV panel is executed by integrating the water-cooling system by using copper pipe. This study is conducted to compare the effects of the PV panel when it is tested in different circumstances, such as with and without water-cooling system as well as a variation of water flow rates at constant solar irradiance. Comparative analyses are performed by conducting I-V and P-V curve as well as temperature test where both tests take these different conditions into account. The study exhibits that the utilisation of water-cooling system will result to a reduced rear temperature of the PV panel. The efficiency of the PV panel has also experienced an increase of 3% for 300 l/h flow rates compared to the one without water-cooling system. The increase of flow rates of the water-cooling system will reduce the rear temperature of the PV panel. In other words, a more massive reduction of temperature on the PV panel with 16°C is detected when the water-cooling system is utilised up to 300 l/h flow rates in 60 minutes duration at 350 W/m² solar irradiance.

1. Introduction

Solar energy systems fundamentally have no environmental impacts or any ecological consequences which made the system as a renewable and attainable energy source. However, the performance of the photovoltaic systems is still influenced by the type of cells and environmental factors [1]. For instance, the intensity of the ultraviolet ray, humidity and high ambient temperature will eventually be degrading the performance of the cells, thus affecting the system efficiency of the PV module [2]. Hence, the implementation of a cooling system is essential with the aim to reduce the operating temperature.

Based on Yu et al., the better operation performances is shown through water cooling technique rather than PV systems with airflow cooling technique [3]. Majorly there are three techniques of the water-cooling method. It consists of water spraying, water channel cooling and water immersion cooling [4]. However, the efficiency of the PV system is affected overtime during cloudy days when applying the immersion cooling method.
A study by Salih et al. related to an active cooling technique where a constant flow rate of forced water spraying is applied on top of the PV array surface. The results of the investigation shown that the PV output power is enhanced significantly by water spraying over the PV panels [5]. However, this method leads to non-uniformity to the distribution of the PV temperature. A numerical model has been developed by Bahaidarah et al. [6] to evaluate a PV solar water-cooled hybrid system. The results obtained from the tested system shows an increase in PV efficiency of 9% and a decreasing by 20% of the operating panel temperature. Furthermore, An analytical model was developed by Tiwari et al. [7] to examine the effect of flowing water in the PV solar system. The experimental shown a result of increment to the thermal efficiency from 24% to 58%. There was an investigation related to a variation of heat-absorbing pipe designs for back surface cooling by S. Bhattacharjee et al. where PVC pipe and copper pipe is chosen for the experiment. Based on the results of the experiment, circular spiral-shaped semi flattened shows the highest increment in efficiency after cooling by 4.32% and increase the maximum panel power by 16.77% that is from 22.60 to 26.39 W [8].

Volumetric flow rates are the volume of fluid which passes through a given surface per unit time. Flowrates often measure in litres per hour (l/h) or cubic meter per second (m³/s). As the tube water velocity increases, it will increase the tube side heat coefficient, which will maximise the heat transfer to the water and the PV panel cooling [9]. There was a study by Zhu et al. about thermal and electrical performance for different flow rates between air and water cooling at the amorphous-silicon PV module. It was stated that for water-cooled PV panels, electrical efficiency will not significantly affect by flow rate. Still, on the other hand, it has a major effect on thermal efficiency [10]. However, setting a higher water flow rate will increase the investment cost and pump power [11]. An investigation by A.W. Kandeal et al. has valid the numerical result which reveals the enhancement of the overall system performance by the water flow rate and the best flow rate that is possible about between 180l/h and 300 l/h [12]. Plain water has a high relative specific heat capacity compared to most other common fluid which is 4.2 J/(g.K) at 20°C [9]. Eventually, despite the pros and cons of each fluid for the cooling system, the chosen fluid that is often used is water as it is easier to obtain, use and much cheaper [13].

The decrement in the temperature of the PV module can be recovered through the utilisation of the cooling system to the PV system. Thus, this paper aim to apply the cooling mechanism of water cooling techniques to prove the increment in the efficiency of the PV module. The results of the experiment will prove a higher efficiency of PV panels performance can be achieved through water cooling methods.

2. Methodology

2.1 Experimental setup for temperature testing on PV Module
An indoor experimental setup is conducted as illustrated in figure 1 is executed to conduct the temperature measurements on the PV module. A polycrystalline silicon PV module with a total area of 420 x 320mm is used for the experiment and is placed horizontally facing the halogen lamp directly. Designed copper pipe is used as the back-panel cooling system with the usage of a pump to circulate the water through the pipe.

![Figure 1. The schematic diagram of the experiment setup](image-url)
The data of the PV panel temperature that are under the environmental condition will be then compared with a PV panel with the considered designated cooling system. The copper pipes are utilised to reduce the heat and the temperature mainly on the back of the PV module through heat exchanging by flowing water as the medium. Data Acquisition (DAQ) HIOKI LR8432-20 Heat Flow Logger equipment is used to record the temperature of the PV panel that has been measured by the Type K thermocouples. Each of the data is taken for 1 hour, with a time interval of 5 minutes. Cooling filament that been used in this experiment is type L copper with spacing. The designation of the copper pipe is shown in figure 2.

![Water-cooling filament](image)

**Figure 2.** Water-cooling filament

### 2.2 Experimental results

The PV module is connected by the respective terminals with the solar simulator to obtain the voltage and current for the P-V and I-V curve test results. Various of measurement point's sets are connected with the potentiometer, which is the variable load resistor which can be rotated starting from 0 Ω up to 1kΩ. The potentiometer is rotated slowly to obtain a smoother graph of the P-V and I-V curve that has been interpreted from the solar simulator. Open circuit voltage (V\text{OC}) and short circuit current (I\text{SC}) are parallelly and serially connected respectively by a multimeter for the measurement of the initial reading after a stable state condition of the temperature is achieved. When it is connected to a load, I\text{SC} was measured meanwhile when it is not connected to any load, V\text{OC} is measured.

### 3. Results and Discussion

#### 3.1 Thermal measurement

**3.1.1 Comparison of thermal measurement at the front and rear sides of the PV panel.**

![Temperature measurement](image)

**Figure 3.** Temperature measurement of PV panel at solar irradiance of 350 W/m².
Figure 3 displays the thermal measurement readings of the PV panel when conducted at a solar irradiance of 350 W/m². Solar irradiance is measured using a solar meter. The temperature measurements of the PV panel were recorded up to the last 60 minutes with 5-minute intervals once the halogen light was turned on. Based on the observation on the graph above from, the temperature between the front and rear sides of the PV panel has a slightly different. The temperature of the rear side of the PV panel recorded the highest temperature. The maximum value for the front is 59.4°C, and the rear temperature has risen to 60°C. The high temperature at the rear surface of the PV panel can cause the photovoltaic cell to be degraded and lead to the reduction of power output and efficiency of the PV panel.

3.1.2 Comparison of thermal measurement with and without water-cooling system.

Figure 4. Temperature measurement of the rear side of the PV panel with and without the usage of the copper cooling system at 350 W/m².

Figure 4 exhibits the temperature readings of the rear side of the PV panel, with for 300 l/h flow rates and without the usage of the cooling system. From the result, as seen that at the earlier minutes, the temperature of the rear side of the PV panel that was without the cooling system has risen and stayed constant at 60°C. Meanwhile, the temperature of the panel that has been integrated with the cooling system reaches its stable value of 44°C.

3.1.3 Variation of the flow rate of the water-cooling system.

Figure 5. Comparison of temperature reading of the PV panel at a different water flow rate.

Figure 5 illustrated the thermal measurement readings when different flow rates were utilised at 350 W/m² solar irradiance intensity for 60 minutes. The flow rates with the highest flow of 300 l/h have recorded the lowest temperature compared to the flow rates with 100 l/h and 200 l/h. The rear surface of
the PV panel with flow rates of 300 l/h had a lower temperature reading compared to the 100 l/h. However, both only display a slightly different temperature. In addition, the increased flow rates of water had also increased the absorption of heat transfer that resulted in an increase in thermal efficiency. With the integration of the water-cooling system, the thermal efficiency on the rear side of the PV panel increases, which caused by the continuous thermal transfer between the PV panel and the copper pipe. The maximum reading for the 300 l/h flow rates was 16℃ lower than the PV panel without the water-cooling system. The temperature gap for 200 l/h and 100 l/h flow rates level of water-cooling were 14℃ and 13℃, respectively. The graph further supports the relationship between the flow rates and the reduction of the temperature when the water-cooling system is integrated. The results indicate that the integration of the water-cooling system on the PV panel has helped the panel to attain a cooler temperature during the test compared to when the water-cooling system is not used. This simultaneously improves the performance and operation of the PV panel. Therefore, it can be concluded that the highest flow rates for the integration of the water-cooling system are 300 l/h.

3.2 I-V and P-V curve test

3.2.1 I-V curve test of PV panel with and without water-cooling system at 350 w/m² of solar irradiance intensity.

![Figure 6](image_url)

Figure 6. Comparison of IV and PV curve test for PV panel, with and without water-cooling system at solar irradiance intensity of 350 W/m².

Figure 6 (a) and (b) illustrate the IV and PV curve test result of the PV panel, with and without the water-cooling system that was carried out under 350 W/m² of solar irradiance intensity at 300 l/h water flow rates. The production of output power depends on the temperature of the PV panel. Based on the thermal measurement result, the temperature of the PV panel without water-cooling system has experienced an increase of 35℃ from the 25℃ of ambient temperature, before it becomes stable after 20 minutes as the generated maximum point power becomes 4.26 W. Meanwhile, the temperature of the PV panel with the water-cooling system has only experienced an increase of 20 ℃ from the ambient temperature before it becomes stable in the 15th minute and produces a 6.03 W of maximum power point. Therefore, the maximum point power (Pmp) has experienced an increase of 1.77 W, which is from 4.26 W to 6.03 W along with a reduced temperature of 16℃ and with the rate improvement of 111 mW/℃. The absolute electrical power conversion efficiency for the PV panel without the integration of the water-cooling system is 9.8% while the integration of the water-cooling system on PV panel has resulted in an increase of 12.8%. Thus, the overall conversion efficiency of the PV panel has experienced an improvement of 3.0% due to the integration of the water-cooling system as the cooling system.

4. Conclusion

This study presents an experimental investigation to improve the performance of the PV panel by integrating the water-cooling system. The utilisation of water has seen to significantly reduce the
temperature of the PV panel. Therefore, it has resulted in an increase of power output with the rate improvement of 111 mW/°C once the water-cooling system was integrated on the rear surface of the PV panel. The usage of water as the cooling agent has also resulted in increased efficiency of the PV panel of 3% and become more efficient compared to the panel without the water-cooling system. Besides, the flow rates of the water-cooling system significantly affect the temperature rise on the PV panel. The 300 l/h of water flow rates have displayed the best performance in reducing the temperature and improving the efficiency of the PV panel. Ergo, increasing the water flow rates reduces the temperature of the PV panel, which later results to an increase of output power. It is proven that the utilisation of water as a cooling system is significant in reducing the temperature of the PV panel. Thus, the main objective of the experiment has been achieved.

5. References

[1] B. M. Zilli et al., "Performance and effect of water-cooling on a microgeneration system of photovoltaic solar energy in Paraná Brazil," J. Clean. Prod., vol. 192, pp. 477–485, 2018, doi: 10.1016/j.jclepro.2018.04.241.

[2] Tariq Ahmed Hamdi, Roshen & Abdulhadi, Sanan & Kazem, Hussein A & Chaichan, Miqdam. (2018). Humidity impact on photovoltaic cells performance: A review.

[3] Yu M, Diallo TMO, Zhao X, Zhou J, Du Z, Ji J, Cheng Y. Analytical study of impact of the wick's fractal parameters on the heat transfer capacity of a novel microchannel loop heat pipe. Energy 2018;158:746–59.

[4] Krauter Stefan. Increased electrical yield via water flow over the front of photovoltaic panels. Sol Energy Mater Sol Cells 2004;82:131–7.

[5] S. M. Salih, O. I. Abd, and K. W. Abid, "Performance enhancement of PV array based on water spraying technique," Int. J. Sustain. Green Energy, vol. 4, pp. 8–13, 2015, doi: doi: 10.11648/j.ijrse.s.2015040301.12.

[6] H. Bahaidarah, A. Subhan, P. Gandhidasan, and S. Rehman, "Performance evaluation of a PV (photovoltaic) module by back surface water cooling for hot climatic conditions," Energy, vol. 59, pp. 445–453, 2013, doi: 10.1016/j.energy.2013.07.050.

[7] A. Tiwari and M. S. Sodha, "Performance evaluation of solar PV/T system: An experimental validation," Sol. Energy, vol. 80, no. 7, pp. 751–759, 2006, doi: 10.1016/j.solener.2005.07.006.

[8] S. Bhattacharjee et al., "An investigational back surface cooling approach with different designs of heat-absorbing pipe for PV/T system," Int. J. Energy Res., vol. 42, no. 5, pp. 1921–1933, 2018, doi: 10.1002/er.3977.

[9] P. G. Charalambous, G. G. Maidment, S. A. Kalogirou, and K. Yiakoumetti, “Photovoltaic thermal (PV/T) collectors: A review,” Appl. Therm. Eng., vol. 27, no. 2–3, pp. 275–286, 2007, doi: 10.1016/j.applthermaleng.2006.06.007.

[10] Q. Zhu and L. Si, "Electrical outputs and thermal outputs of water/air cooled amorphous–silicon photovoltaic modules," vol. 8, pp. 83–88, 2012.

[11] A. Hassan, "Phase Change Materials for Thermal Regulation of Building Integrated Photovoltaics," 2010, doi: 10.21427/D7461W.

[12] A. W. Kandeal et al., "Photovoltaics performance improvement using different cooling methodologies: A state-of-art review," J. Clean. Prod., vol. 273, p. 122772, 2020, doi: 10.1016/j.jclepro.2020.122772.

[13] T. Chinamhora, G. Cheng, Y. Tham, and W. Irshad, "PV panel cooling system for Malaysian climate conditions," Int. Conf. Energy Sustain. Karachi, Pakistan, no. April, 2013.

Acknowledgments

The authors gratefully acknowledge the Department of Electrical and Electronics Engineering Faculty of Engineering and Centre of Research Management and Innovation, Universiti Pertahanan Nasional Malaysia, Kuala Lumpur.