GSJ: Volume 9, Issue 4, April 2021, Online: ISSN 2320-9186
www.globalscientificjournal.com

Solar PV Cell Cooling with cool water circulation system

Design of closed-loop cool water re-circulatory system

Winston Woon Lee Meng (*Author*)

Lee Lian Seng (Final Year Research Project)
PSB Academy Pte Ltd
School of Engineering and Technology

Abstract: This report proposes a set of closed loop water circulation as cooling system to cool the surface of photovoltaic panel. The cooling was conveyed by typical heat exchanger (Radiator). Conclusive field test results obtained through the cooling system had shown the reduction of surface temperature of PV cells which in turn increased power efficiency of solar panel. This was a very crucial finding that established closed loop water circulation cooling system able to increase the power by about 0.45W and power efficiency increase up to 7.76%. Experimental results indicated that the PV solar panel performance of a closed loop water circulation system was able to perform better as compared to opened loop system.

Keywords—Solar energy;Solar energy conversion; Photovoltaic cell ;watercontrol system;closed loop water cooling; automations; thermostat; thermocouple-sensors; solar PV; sustainable solar power

1.0 INTRODUCTION

Solar energy refers to the thermal radiant energy of the sun, manifested as solar light. With the depletion of fossil fuels, solar energy has become an important part of energy source and has been continuously developed. The use of solar energy has two methods: photoelectric conversion with PV cells and photo thermal conversion with Flat Plate panels. Currently, it is common to generate electricity or provide energy through photovoltaic cells (PV cells). It is one of the most important renewable energy sources and a sustainable energy solution. However, the overheat issue of solar PV panels is an important factor that is affecting the energy efficiency and service life of the solar panels.

The energy efficiency of solar panel is defined as the capacity of the usable electricity that can be converted when sunlight interacts with thin film or silicon battery cell inside a solar panel. In a standard test condition, the theoretical maximum conversion efficiency of single junction photovoltaic cell is 33.7% based on the Shockley Quezer limit (William 1961). For the efficiency of multi-junction photovoltaic cells, the conversion efficiency is much higher than single junction photovoltaic cells and its highest conversion efficiency exceeds 60% based on theoretical calculation (Allen 2006).
A four-junction solar cell with full sunlight concentration had energy conversion efficiency of up to 45.7% (NREL 2014) based on research information from the Energy Department's National Renewable Energy Laboratory at Dec 2014. Even with this configuration, more than half of the solar energy is still not converted into electricity, but into heat, affecting the battery lifetime of solar panel. Generally, it is known that the conversion efficiency of photovoltaic cells and its operation is directly related to the temperature. This means that when the PV surface temperature is high or heated by strong direct sunlight the efficiency reduces tremendously. According to the research study from Schafer, the efficiency decreases by approximately 0.4% per degree Celsius for crystalline Si solar cells when temperature rises. In the case of amorphous Si solar cells, the efficiency decreases by approximately 0.1% per degree Celsius increment (Schafer 2012). In addition, after the solar cells reach the upper operating temperature limit, the aging rate of crystalline silicon cells will be doubled for every 10-degree Celsius increment of cells temperature (Linxiao 2016). Operating temperature is therefore a key parameter to be considered in design of photovoltaic system. As such, manufacturers will recommend the best operating temperature range of the solar panel. When it is operating beyond the indicated range, in the short term it will cause the efficiency to drop, or an irreversible damage to the solar cells.

This project is intended to investigate the solar panel efficiency with temperature and design of the water circulation system for the cooling of solar panels.

2.0 Solar Panel & Application Theory

The principle that a solar cell can convert light energy into electrical energy is applied to the photovoltaic effect of the semiconductor. The photovoltaic effect generally means that when a photon is incident on a diode element having a PN junction, the voltage of the output power can be generated at the electrodes at both ends of the diode. This process mainly involves photon emission. The electron-hole pair is electrons and holes in the semiconductor which are separated by the built-in electric field known as the PN junction. These electrons and the holes are drifted in opposite directions generating an output to the load by the electrodes at both ends, forming a photocurrent on the loop (Energy 2015).

When the solar panel receives sunlight, the surface temperature will also increase. Under the influence of temperature, the efficiency of the solar panel will decrease. Figure 1 Solar cell V-P relationship diagram (Calebe, 2017) explains the effect of temperature on solar panel power and voltage.

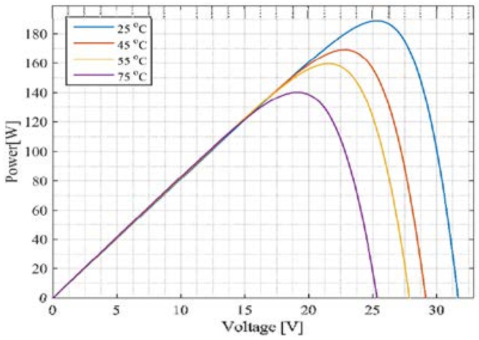

Figure1 Dependence of the Photovoltaic power output on panel operating temperature (Calebe 2017).

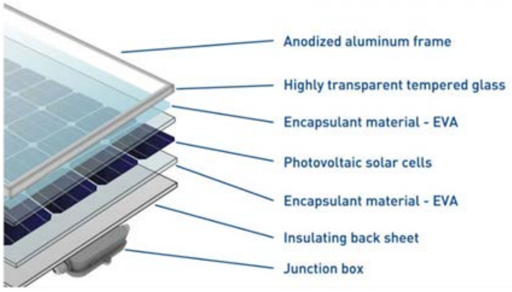

Figure 2 Solar Panel Structure (Ecoprogetti 2018)

Figure 2 shows the basic construction of the solar cell module, which is self-explanatory. The temperature rise causes the solar power generation efficiency to decrease, and the heat dissipation method can achieve a certain effect. The heat transfer mechanism includes heat conduction, convection, and radiation is the key experimental approach to reduce PV surface temperature. The water-cooling method mainly achieves through heat dissipation process by conduction and convection.

In the energy conversion of solar panels, the electric power is the product of the voltage and current, and the formula is as follows,

Electric Power (P) is the power consumed per second.

Power (P) = Voltage (V) x Current (I)

The heat required for heating water is

$$H = m*S*\Delta T$$

Where,

H is the heat,
m is the mass,
S is the specific heat capacity,
ΔT is the temperature difference.

The water specific heat is 1 calorie/gram°C.
Unit conversion for 1 cal = 4.18J and 1 watt = 1 Joule/s

For the increment of power efficiency, it is defined as

Power Efficiency (%) = (Power with Cooling-Power Without Cooling)/(Power Without Cooling)×100%

3.0 Water Cooling Technique Study

Basically, there are three types of cooling method in use. Most cooling techniques adopted some form of heat exchanger to cool the surface of PV cell and others use liquid immersion cooling.

3.1 Heat Exchanger Cooling

Heat exchanger cooling mainly means that the cooling medium is not in direct contact with photovoltaic (PV) panels, but continuously circulating the cooling medium through the interior of the heat exchanger, then the cooling medium transfers the heat to the heat sink and releases the heat to the external environment. Wilson experiment was able to achieve panel temperature cooling to 32°C and the efficiency was improved by 12.8% (Wilson, 2009).

3.2. Surface Cooling

Surface Cooling refers to spraying the cooling medium on the surface of the photovoltaic panel or directly contacting the surface of the PV panel with the cooling medium. The heat of the surface of PV panel will be removed by convective heat transfer, thus cooling the panel and removing some silt on the surface of battery. This method also reduces the reflection loss by 2% to 3.6% theoretically (Tina 2009).

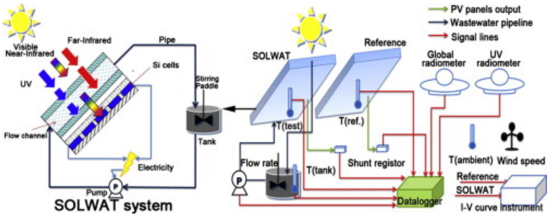

Figure 3 SOLWAT System (Wang 2014)

An experimental study was conducted by Wang and his team on the photovoltaic & photo-catalytic mixed water treatment system SOLWAT. The SOLWAT system as shown in Figure 3 uses wastewater to flow through the PV surface, and uses solar photo-catalytic technology to treat the wastewater while cooling the photovoltaic module. The experimental results showed that the temperature of the SOLWAT system PV module was reduced by about 20°C compared with the reference system.

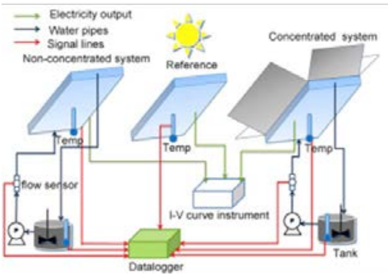

Figure 4 SODIS system with 3 kinds of PV Modules (Yiping 2015)

Unlike the SOLWAT, the SODIS (solar water disinfection system) circuit is arranged in 3 groups such as concentrated, non-concentrated, and reference PV modules as shown in Figure 4. This arrangement is to study the differences of power performance among all the battery condition under the same water flowing method. Based on the experimental results shown in Figure 5 and 6, the temperature of non-concentrated battery is about 15°C different from the reference component temperature. The temperature of concentrated battery is comparable with reference component, but the maximum output power and circuit current are greater than the reference component by about 20W (Yiping 2015).

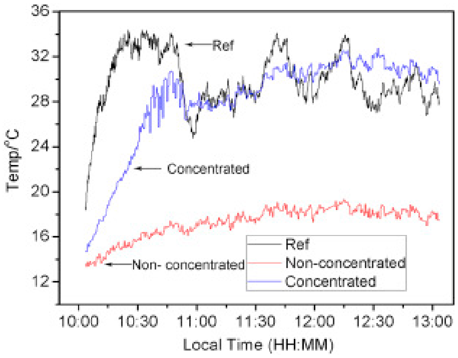

Figure 5 Time VS Temp Graph (Yiping 2015)

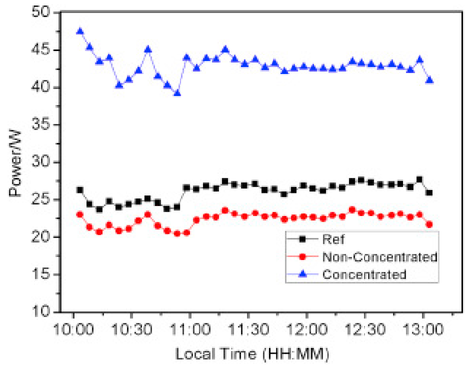

Figure 6 Time VS Power Graph (Yiping 2015)

2.3 Liquid Immersion Cooling

Liquid immersion cooling refers to immersing the PV cells in a static or circulating cooling medium, thus the cooling medium is directly in contact with the cells and both the front and rear sides of the cells can be cooled at the same time with cooling medium.

Rosa and Mehrotra studied the performance of cells under different immersion depths, as shown in Figure 8. Mehrotra also found in the experiment that the maximum conversion efficiency of 17.85% occurred when the immersion depth was 1cm.

Figure 8 Panel immersed in water (Mehrotra 2014)

4.0 Solar Panel Cooling Techniques

Currently, there are several kinds of cooling techniques in the engineering field to develop and improve the energy technology. In this project, the objective is to design a solar PV cooling with cool water circulation. Basically, there are 3 types of solar panel water cooling techniques adopted by most research and study.

1. Water is sprayed on the Solar PV cell surface to cool the cell continuously or intermittently throughout the daylight.

2. Water films are created by a line of nozzles which allows water to flow across the cell**.**

3. A closed loop cycle method that water is present on surface of solar panel

4.1 Closed Loop Water Circulation Design

Figure 9 is the 3D drawing of the designed system in isometric view and side view with solar panel, glass cover, radiator, water storage tank, water pump, structural stand & piping. This arrangement forms the closed loop water circulation design for solar panel cooling system.

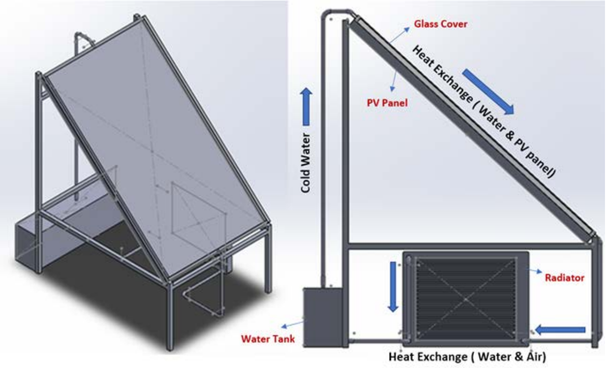

Figure 9 Isometric View and Side View of Cooling System

The working concept is by using the temperature difference of water and PV cells to conduct a heat exchange between cool water and cells where the heated water flows downward through the radiator to perform the heat exchange with surrounding air. Cooling water will then pump into the glass to cool the PV cells and return to the water tank basin.

5.0 Material Part Selection Study

5.1 Flow Rate Selection Study

Based on the study from Calebe, the result showed the power generated by the photovoltaic panel without cooling system decreases when the temperature increases. Figure 10 shows the power of panel influence by the water flow rate and a large variation of the temperature of PV panel as in Figure 11. Similarly, water flow rate condition also affect voltage result as in Figure 12 (Calebe 2017).

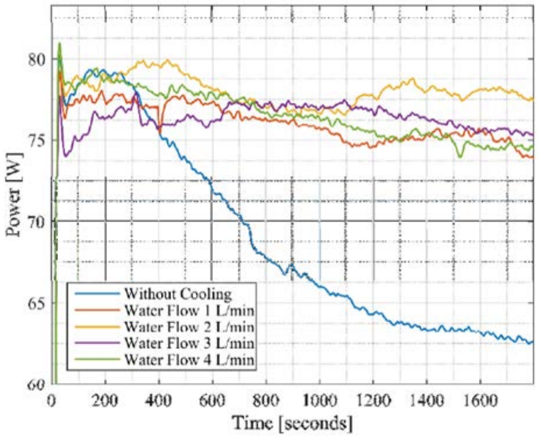

Figure 10 Result of water flow rate affecting the power performance (Calebe 2017).

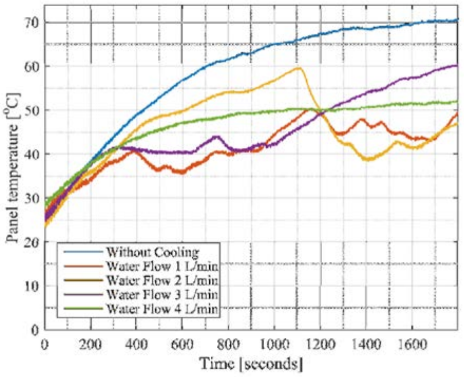

Figure 11 Result of water flow rate affecting the panel temperature (Calebe 2017).

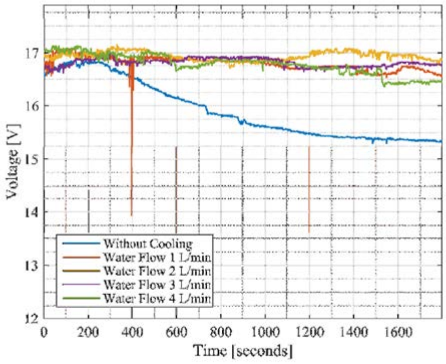

Figure 12 Result of water flow rate affecting the voltage (Calebe 2017).

From Calebe's experimental result, the maximum efficiency gain was 22.90% with water flow rate of 2 liter per minute.

Table 1 Summary of efficiency gain of the PV panel with cooling system (Calebe 2017) ==F13

Water Flow (L/min)	Energy (Wh)	Efficiency Gain (%)
Without	63.09	-
1	74.81	18.57
2	77.54	22.90
3	75.62	19.86
4	75.32	19.38

In this experiment, he set two important criteria; the pipe size and the minimum water flow rate of 2-liter per minute for the cooling circulation.

The water flow rate is calculated as

$$Q_w = 60\pi V(D/2)^2$$

Where,

Q_w is the water flow rate (m3/min).
V is the water speed (m/s).
D is the inner diameter (m).
Based on 2-liter per min, the pipe size is calculated as

$$0.002 = 60\pi(2.5)(D/2)^2$$
$$D = 4.12\times10^{-3}\ \text{m}$$
$$D = 4.12\ \text{mm}$$

From the calculation, the water flow velocity is assumed as 2.5m/s based on the standard of tap water velocity, specifically between 2 to 18.4-liter per minute for standard pipe size of 4.12 mm and 12.5 mm inner diameter respectively.

5.2 Sunlight Intensity Condition

Sunlight is electromagnetic waves. The part of the visible light ranges from red light with a wavelength of about 700nm to purple light with wavelength of about 400nm. The energy distribution of the solar spectrum is classified into 3 groups such as, the ultraviolet portion accounts for about 9%, the visible light accounts for 47%, and the remaining infrared light accounts for about 44%.

The material of the cover for the designed system is selected to be glass, as the standard absorption spectrum of the glass is around 450nm to 470nm based on Figure 13 (Justin 2015).

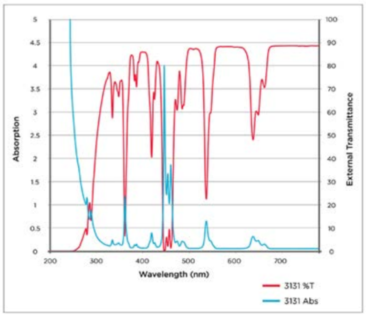

Figure 13 Glass Absorption Wavelength Chart (Justin 2015)

Apart from the glass, the system is water filled with 3mm gap for cooling purpose (based on experiment study of Mahrotra and Syran). Figure 14 shows that the absorption spectrum of visible light by water is low, thus the wavelength can reach solar cells without much disturbances (Wikipedia 2019). These two studies did not show any major energy transmission issue to the designed solar panel system.

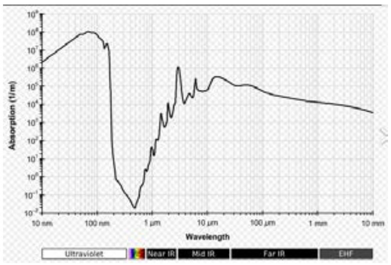

Figure 14 Water Absorption Wavelength Chart (Wikipedia 2019)

6.0 Model Part Assembly

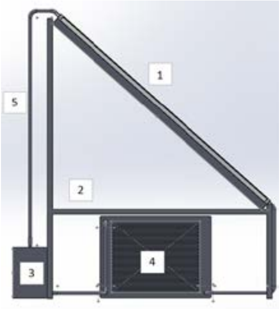

Figure 15 Side View of Design Assembly

Figure 15 illustrates the various components with description.

Section 1 - Glass Cover is silicon sealed with waterproof seal.

Section 2 – Rig structure and framework for Panel mount.

Section 3 – Suitable size water tank.

Section 4 - Radiator (heat exchanger).

Section 5 – Standard size pipe joints, elbow and adapters.

6.0 Model simulation and test condition

6.1 Test condition

Table 2 shows the test condition for all the four set of tests to reflect a fair comparison and observation as possible.

Table 2 – testing parameters of the experiments

Items	Condition
Ambient Temperature	32°C ~34°C
Water Flow Rate	3liter/min
Testing Time	12:00 - 14:00
Resistor	50 ohm
Solar Panel Power (Specification)	10W

6.2 Test 1

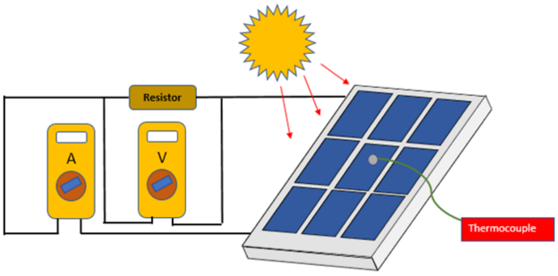

Figure 16 Schematic Diagram of Test 1

6.6.1 Test 1 Result (Before applied the resistor)

Test 1 was started by measuring the open circuit voltage (VOC) and Short Circuit Current (ISC) to prove that the solar panel is good in quality according to the product specification. Figure 18 & Figure 19 are the results of the open circuit voltage and short circuit current of the testing solar panels.

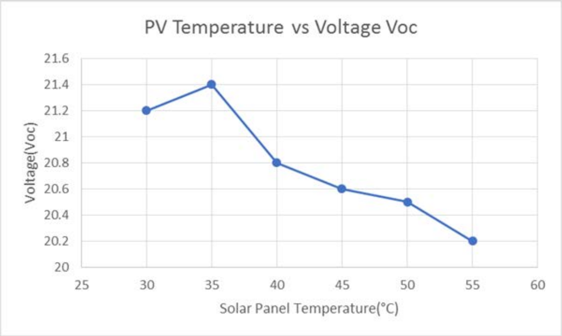

Figure 17 Voltage VOC Performance of the testing solar panel

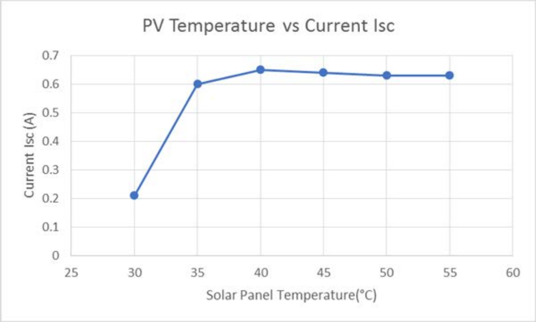

Figure 18 Current ISC Performance of the testing solar panel

From the Figure 17 and 18 result, the solar panel with almost similar product specifications of maximum VOC of the result was 21.5V and maximum ISC was 0.65A which were comparable with product specification 21.6V of VOC and 0.62A of ISC. The results also show that the VOC magnitude decreases when the solar panel temperature rises, but the ISC retains similar performance as temperature rises.

6.6.2 Test 1 Result (After applied the resistor)

The performance of solar panel can be validated with a 50 ohm no load condition attached in the circuit, as shown in Figure 16 to ascertain the maximum power.

Figure 17 and 18 show that the voltage and current decreases when the panel temperature rises. The voltage dropped 1.35V and the current dropped 0.02A when the PV panel temperature was increased 28°C.

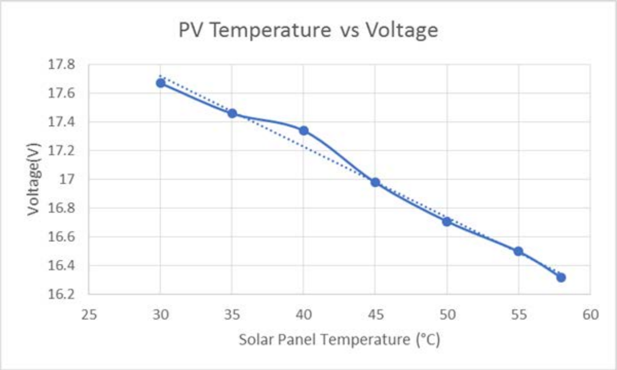

Figure 19 Voltage Performance of the testing solar panel with 50ohm resistor

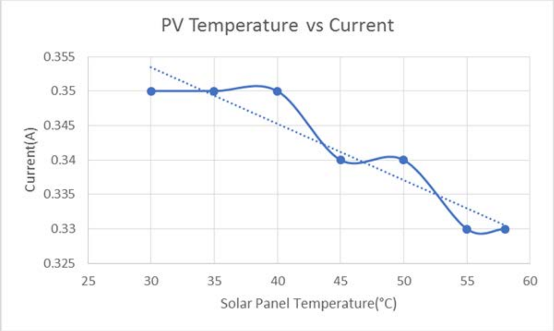

Figure 20 Current Performance of the testing solar panel with 50ohm resistor

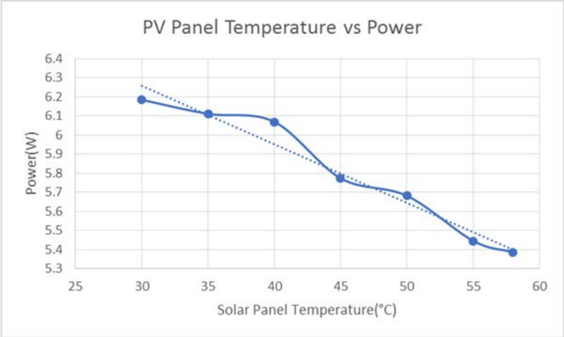

Figure 21 Power Performance of the testing solar panel with 50ohm resistor

From Figure 21 result calculated with Figure 19 and Figure 20, the solar panel power decreases when the PV temperature increases. The overall result of test 1 proved that the solar panel temperature is an important factor. It affects the power generation and the cooling system is required to control the temperature.

In addition, the results of PV temperature against the time period was also recorded in test 1 as shown in Figure 22. The solar panel temperature was raised to 58°C within 6 minutes and fluctuated at 58±5°C due to cloud blockage during the experiment.

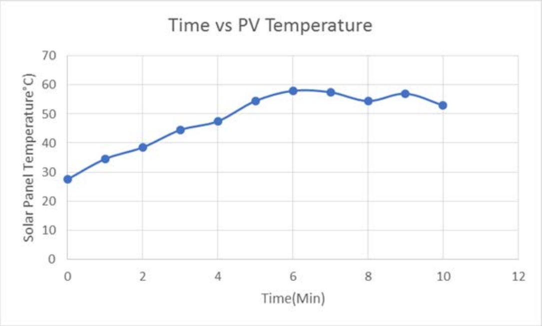

Figure 22 PV temperature increment against time

6.3 Test 2

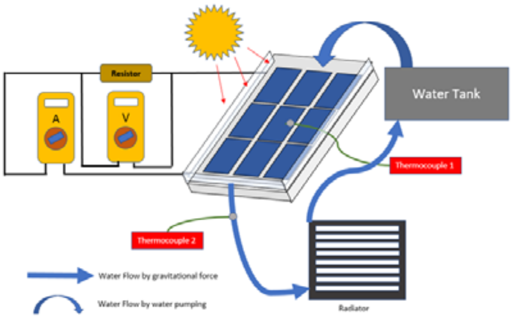

Figure 23 Schematic Diagram of Test 2

Test 2 Results (Open Loop Water Cooling)

From the result of Voltage performance in test 1, the water cooling was set to start when the solar panel temperature reached 45°C, as it was the main target temperature in this experiment and investigation.

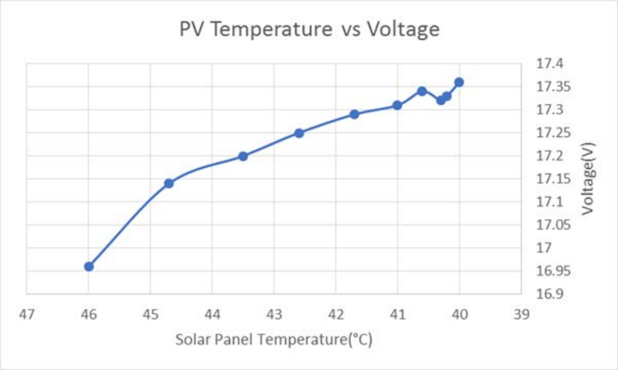

Figure 24 Voltage performances against PV temperature with water cooling

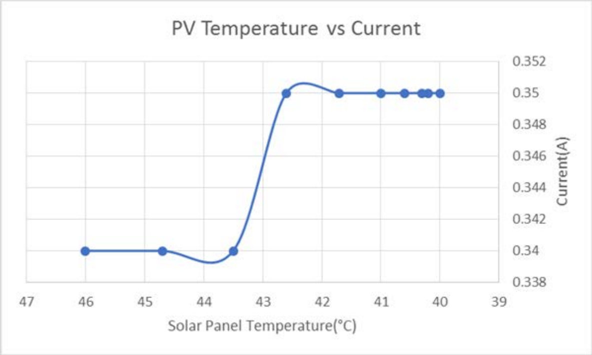

Figure 25 Current performances against PV temperature with water cooling

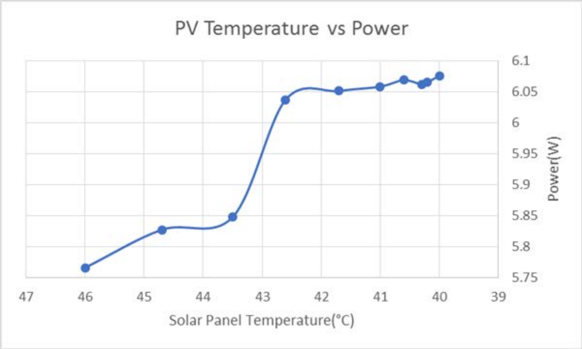

Figure 26 Power performances against PV temperature with water cooling

The water cooling was applied at 46°C on the solar panel, the results of Figure 24, 25 & 26 showed that the voltage, current & the power were increased when the temperature was decreased to a lower level. However, the water-cooling system was able to lower the solar panel temperature to 40°C with an ambient temperature of 32°C in this experiment.

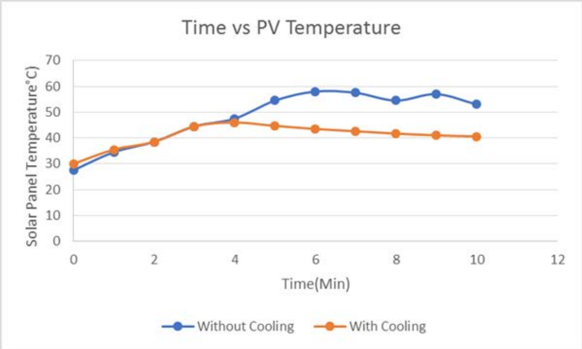

Figure 27 Effect of the water cooling on the PV panel

Although the PV panel temperature was only cooled to 40°C, the water cooling effectively lowered the temperature by 6°C and there was a difference of temperature of 18°C lower as compared to the temperature of 10 minutes without cooling as shown in Figure 27.

6.4 Test 3

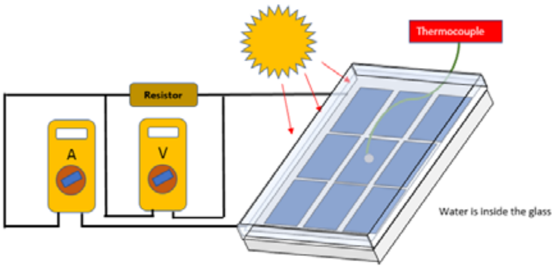

Figure 28 Schematic Diagram of Test 3

6.6.4 Test 3 Result

Test 3 as shown in Figure 28 was to study the relationship of water temperature and power generated by solar panel with an enclosed water gap in between. The glass cover was fully filled with water and placed under the sun with similar condition of test 1 but without water cooling.

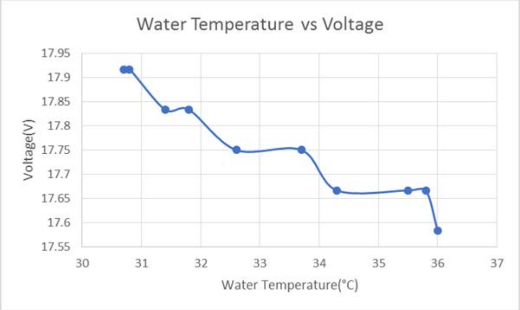

Figure 29 Voltage Performance against to the water temperature

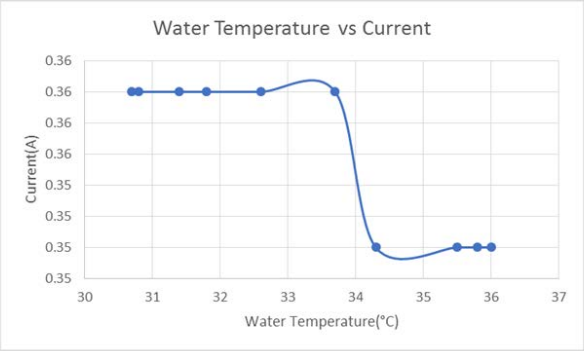

Figure 30 Current Performance against to the water temperature

From the results as shown in Figure 29, 30 & 31, the voltages, current and power were all decreased when the water temperature increased. This scenario indicated that it had the same trend as test 1 result and reflected the weakness of the solar panel as temperature increase.

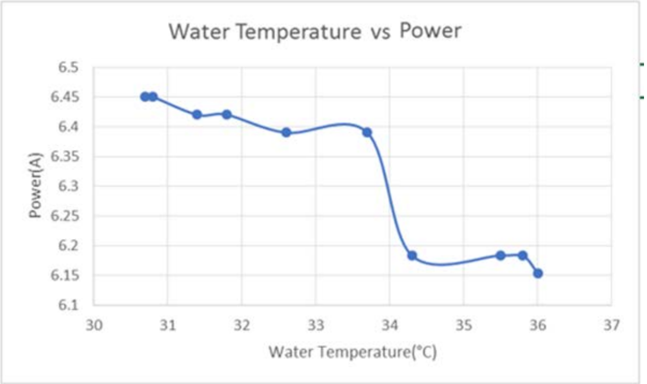

Figure 31 Power Performance against to the water temperature

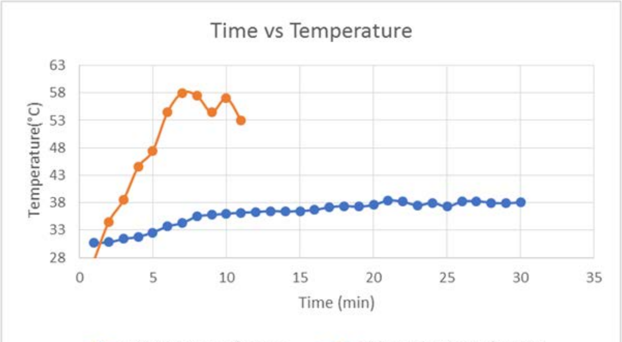

Figure 32 Comparison of temperature trend between with and without glass & water

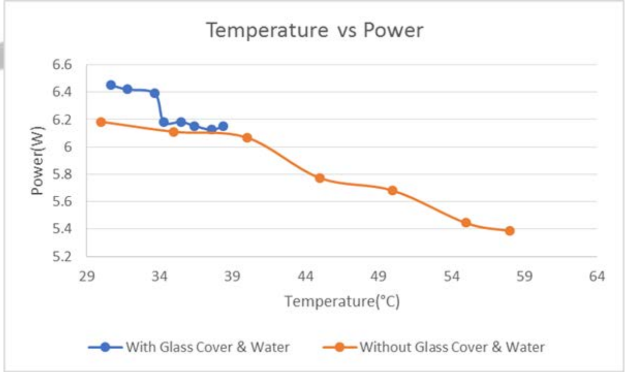

Figure 33 Comparison of power trend between with and without glass & water

By comparing the temperature performance between the conditions with and without glass and water, the data presented that the solar panel temperature (Condition without glass and water) increased faster than the water temperature (Condition with glass and water). The increment of solar panel was about 4.35°C/min and water temperature was 0.53°C/min in a 10 minutes period study. This explained that the heat absorption rate of the solar panel was faster than water due to black body effect. For purpose of confirmation, the water was left under the sun for another 20 minutes. It was observed that the water temperature fluctuated between 36°C to 38°C which needed more energy to raise the temperature as water has a much higher specific heat capacity.

At the same time, the power generated under the condition of test 3 was higher than the power generated under the condition of test 1. Based on Figure 33, test 3 condition can generate 0.27W more power than test 1 in the maximum power comparison. Referring to the average power generated, test 3 conditions were able to generate 0.45W of power more than the test 1 condition. This result indicated that the solar panel with the installation of glass cover & closed loop water cooling system was able to generate more power without water flowing.

6.5 Test 4

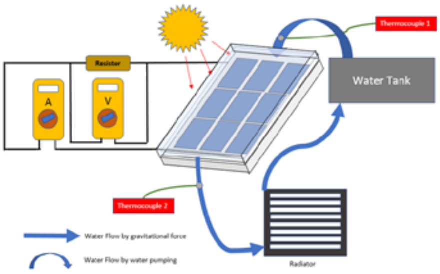

Figure 34 Schematic Diagram of Test 4

Test 4 Result (Closed Loop Water Cooling)

Test 4 was to run the test of closed loop water cooling to cool the PV panel temperature. However, the water temperature on the solar panel was not raised to the desired temperature as defined in test 2. In test 3, the water temperature only achieved around 38°C within 30 minutes, limited by the 40 °C radiator. Therefore, a simulation of the cooling system was conducted by using the heated water to study the temperature changes when the water was flowing.

Figure 35 presented the water temperature changes at both input and output position. Figure 36 indicated the heated water with 52.8°C was cooled to 39.5°C in 15 minutes. This is a significant observation for Test 4 postulating similar results with Test 3.

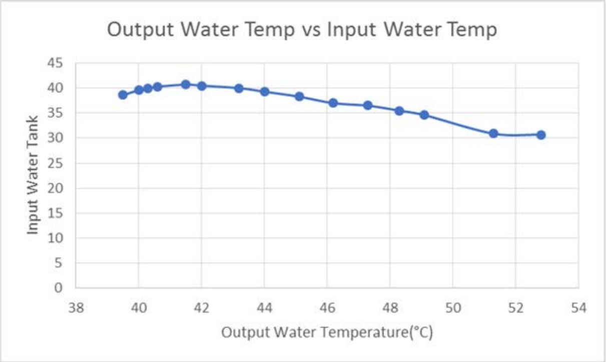

Figure 35 Relationship between output & input water temperature

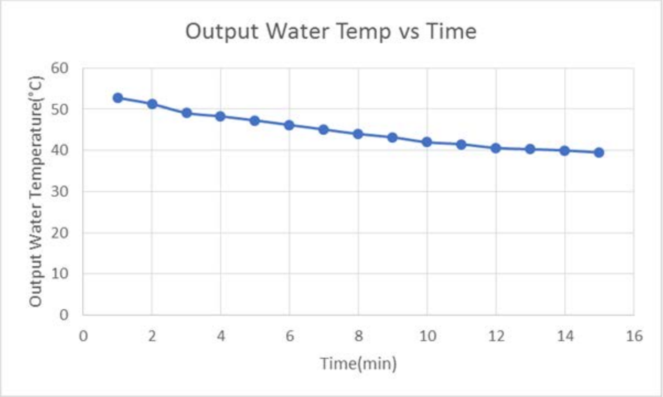

Figure 36 Effect of water cooling against time change

6.6 Result and Data Analysis

6.6.6 Overall Result Summary

Table 3 – overall efficiency results of experiments

Test No	Condition	Average Power(W)	Power Effciency(%)
Test 1	Without Cooling System	5.81	0.00
Test 2	Open Loop Cooling System	6.00	3.32
Test 3	With Glass Cover & Water	6.26	7.76
Test 4	Closed Loop Cooling System	NA	NA

Table 3 indicated the summary of power analysis results gathered from the 4 tests. From the table, the opened loop cooling system and the project designed system were able to generate average power more than 6 watt when applied a 50ohm resistor. Both experiments (Test 3 & 4) had convincingly proven that the PV power efficiency improved significantly with water cooling system.

7.0 Conclusion

In conclusion, this study showed that the designed system successfully achieved the desired cooling effect on the solar panel. During the study, the results proved that the power generation was directly affected by the temperature of PV cells and sunlight intensity. In the initial condition, the photovoltaic panel without cooling system produced average 5.81W and after using the open loop water circulation cooling system with water flow rate 3 liter/min, the power generated by the panel was increased to 6W and gained 3.32% in power efficiency. For the closed loop water circulation cooling system, the solar panel can generate 6.26W of power and achieved a much higher power efficiency of 7.76% when the water statically remained on the solar panel for 30 minutes. This experiment reinforced the proof of concept that a closed loop water circulation cooling system can be deployed on PV cells to improve power efficiency. A closed loop water circulation cooling system can also prevent dust contamination that may otherwise block sunlight and reduce light reflection from the surface of PV panel.

8. Acknowledgement

I would like to express my utmost gratitude to the people who have contributed me with the opportunity towards completing this Research paper. A special acknowledgement goes to my final year student Mr. Lai Lian Seng who believed in my innovative idea and had thoroughly conducted an outstanding investigation. At the same time, I am thankful to my module leader, Dr Lim Chong Lai, who had been very supportive of this research project and urged me to publish this research finding.

9 REFERENCES

Allen B., Christiana H., Douglas K., Sarah K., Duncan M., David S., Jeffrey G., Stuart B., Keith G., Michael H., Dan A., Mark W., & Keith E. (2006). 50% Efficient Solar Cell Architectures and Designs, Hawaii: IEEE.

Calebe A.M., Licínio M.S., Aylton J. A., Wesley P.C. (2017). Increasing photovoltaic panel power through water cooling technique. [Online]. Available at: https://teee.eu/index.php/TEEE/article/download/90/59 [Accessed 15 Dec 2018]

Ecoprogetti (2018) The Structure of A Photovoltaic Module [Online]. Available at: https://ecoprogetti.com/the-structure-of-photovoltaic-module/ [Accessed 14 Dec 2018]

Energy Education (2015). Photovoltaic Effect. [Online]. Available at: https://energyeducation.ca/encyclopedia/Photovoltaic_effect [Accessed 04 Jan 2019]

Energy Gov (2019) Solar Water Heaters [Online]. Available at: https://www.energy.gov/energysaver/water-heating/solar-water-heaters [Accessed 02 Feb 2019]

Gaur A. (2014). Performance of a-Si thin film PV modules with and without water flow: An experimental validation. In: Yan JY. Applied Energy, pp.184-191.

Han XY., Wang Q., Zheng J., Qu J. (2015). Thermal Analysis of Direct Liquid-Immersed Solar Receiver for High Concentrating Photovoltaic System. [Online]. Available at: http://dx.doi.org/10.1155/2015/321350 [Accessed 15 Dec 2018]

Justine G. (2015). Optical Properties of Glass: How Light and Glass Interact. [Online]. Available at: http://www.koppglass.com/blog/optical-properties-of-glass-how-light-and-glass-interact/ [Accessed 18 Dec 2018]

K.A.M., Hamdy A. K., Saeb A., and Hisham E. (2013). Enhancing the performance of photovoltaic panels by water cooling. In: Ayman M. Bahaa-Eldin, Yoohansen Yehya Eid, Hany Hasanien, Emad Hegazi, and Adel Helmy Salem. Ain Shams Engineering Journal, pp.869-877.
Kamaruzzaman S., Ali H.A.A., Husam A.H., and Ali N.A.S. (2018). Advances in High Efficiency Photovoltaic Thermal Solar Collectors. [Online]. Available at: https://www.researchgate.net/profile/Penerbit_Akademia_Baru/publication/327793003_Advances_in_High_Efficiency_Photovoltaic_Thermal_Solar_Collectors/links/5ba4cff9a6fdccd3cb67d3f2/Advances-in-High-Efficiency-Photovoltaic-Thermal-Solar-Collectors.pdf?origin=publication_detail [Accessed 11 Dec 2018]

Linxiao Z., Aaswath R., Ken X.W., Marc A.A., and Shanhui F., (2016). Radiative Cooling Of Solar Cells. [Online]. Available at: https://www.researchgate.net/profile/Linxiao_Zhu/publication/268982422_Radiative_cooling_of_solar_cells/links/56eedaff08ae4b8b5e753bfe/Radiative-cooling-of-solar-cells.pdf?origin=publication_detail [Accessed 15 Dec 2018]

Liu Zhisheng & Hong Rusheng (2009). High Efficiency of solar cells. [Online]. Available at: https://ejournal.stpi.narl.org.tw/sd/download?source=9807/9807-08.pdf&vlId=2E40C1C0-5FA2-4B27-BC42-2C2BCB262877&nd=0&ds=0 [Accessed 15 Dec 2018]

M.Rosa-Clot, P.Rosa-Clot, G.M Tina, and P.F.Scandura. (2009). Submerged photovoltaic solar panel: SP2, In: Soteris K. Renewable Energy, pp.1862-1865.

Mehrotra S., Pratish R., Mary D., and K.Sudhakar. (2014). Performance of a Solar Panel with Water Immersion Cooling Technique. In: Dr. Mehmet Akbaba, Dr. Frede Blaabjerg, Professor Ibrahim Dincer and Dr. T. Nejat Veziroglu. International Journal of Science Environment and Technology, pp.1161-1172.
Morteza A. and Mohamad A., (2009). Improving the effectiveness of a photovoltaic water pumping system by spraying water over the front of photovoltaic cells, In: Soteris K. Renewable Energy, pp.91-96.

National Renewable Energy Laboratory (NREL)., (2014), NREL demonstrates 45.7% efficiency for concentrator solar cell. [Online]. Available at: https://phys.org/news/2014-12-nrel-efficiency-solar-cell.html [Accessed 15 Dec 2018]

PG Nikhil and M PRemalatha, (2012). Performance enhancement of solar module by cooling: An experimental investigation, In: Dr. Mehmet Akbaba, Dr. Frede Blaabjerg, Professor Ibrahim Dincer and Dr. T. Nejat Veziroglu. International Journal of Science Environment and Technology, pp.73-82.

Saad Odeh and M.Behnia, (2009). Improving Photovoltaic Module Efficiency Using Water Cooling, In: Afshin J. Ghajar. Heat Transfer Engineering, pp.499-505.

Sayran A.Abdulgafar, Omar S.omar and Kamil M.Yousif, (2014). Improving The Efficiency of Polycrystalline Solar Panel Via Water Immersion Method, International Journal of Innovative Research in Science, Engineering and Technology, pp.8127-8132.

Schafer J., (2012). Device And Method For Cooling Solar Cells By Means Of A Flowing Cooling Medium, Patent Application Publication.

Tina Giuseppe Marco, Marco Rosa-Clot, Paolo Rosa-Clot, Pier Francesco Scandura, (2009). Optical and thermal behavior of submerged photovoltaic solar panel: SP2, In: Soteris K. Renewable Energy, pp.1862-1865

Wang Zhen, Yiping Wang, Marta Vivar, Manuel Fuentes, Li Zhu, Lianwei Qin, (2014). Photovoltaic and photocatalytic performance study of SOLWAT system for the degradation of Methylene Blue, Acid Red 26 and 4-Chlorophenol, In: Yan JY. Applied Energy, pp.1 -10.

Wikipedia, (2019). Electromagnetic absorption by water. [Online]. Available at: https://en.wikipedia.org/wiki/Electromagnetic_absorption_by_water [Accessed 02 Feb 2019]

William Shockley and Hans J.Queisser, (1961). Detailed Balance Limit of Efficiency of p-n Junction Solar Cells. Journal of Applied Physic.
Wilson E., (2009). Theoretical and operational thermal performance of a 'wet' crystalline silicon PV module under Jamaican conditions, In: Soteris K. Renewable Energy, pp.1655-1660.

WU S.Y., and Xiong C.G., (2014). Passive Cooling Technology for Photovoltaic Panels for Domestic Houses, International Journal of Low-Carbon Technologies, pp.118-126.

Yiping Wang, YanChao Jin, Qunwu Huang, Li Zhu, Marta Vivar, Lianwei Qin, Yong Sun, Yong Cui, and Lingyun Cui, (2015). Photovoltaic and disinfection performance study of a hybrid photovoltaic-solar water disinfection system, In: Henrik.L. Energy, pp.757 -764