Evaluation on Cooling Effect on Solar PV Power Output Using Laminar H_2O Surface Method

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Abstract-The purpose of this paper is discusses the comparison of output power and efficiency between continuous cooling system, cooling system every one hour and non-cooling system of solar photovoltaic panel. The output power calculated for the continuous cooling system was 68.8 Watt, cooling system every one hour was 65.11 Watt and 59.06 Watt for non-cooling system respectively for the latitude of Universiti Malaysia Sabah (6°01'53.73''N, 116°07'14.98''E). Meanwhile, the efficiency percentage of this system was 16.7%, 14.4% and 13% respectively. The maximum temperature for continuous cooling system panel was 38.9˚C at 2 pm, cooling system every one hour was 48.2˚C at 11 am and non-cooling system was found 53.3˚C at 1 pm. Power output measurement was conducted for 10 days from 13th to 22nd March 2016. The corresponding maximum global solar radiation was 1052.9 W/m² on 17th March 2016 at 2 pm whereas the highest hourly average was 970.17 W/m²at 1 pm. Therefore, it can be concluded that generally output power for continuous cooling system is higher than non-cooling system.

Keywords Solar, Photovoltaic, Laminar surface cooling, Water Cooling, Continuous Cooling, Power Output, Temperature Effect, Kota Kinabalu, Malaysia, Tropical.

1. Introduction

Solar photovoltaic (PV) system is likely known and generally used in electric power applications such as solar farm. This is because when the solar PV is exposed to the global solar radiation it will not cause harm to any environmental even it produce direct current electrical energy. But the environmental factors such as solar radiation and temperature will affect the operation performance of the PV panels thus can influence the power output produce. The efficiency of PV not only strongly be influenced by solar radiation, but also hinge on the operating temperature of PV panels [1].

The characterization of PV module is mostly analyzed under the standard test conditions (STC: 100m W/cm^2 irradiation, 25°C module temperature, and AM 1.5 global spectrum). A main factor for the PV conversion process is the temperature of the solar PV module [2]. Electricity generation capacity of PV module is affected by the temperature, when the temperature of solar PV module increased, current slightly increased but voltage is decreased [3]. They have a tendency to generate higher voltage as the temperature falls and vice versa to lose voltage in high temperatures.

Measurement of the electrical production of PV components has already been normalized to a large scope [4].The main cause for decreasing the electrical efficiency of the PV module is the increasing of temperature to solar radiation [5]. The efficiency of the solar PV module increased when the temperature of the solar PV module decreasing [6].The temperature of PV module is one of the main parameters for evaluating the long period production of PV module and yearly amounts of electrical energy production [7]. Solar PV modules temperature has an influential effect on its operation [8].Normally for every single 1°C increase of PV module temperature, there is a ~0.45% reduce of PV module efficiency for crystalline silicon. Mostly solar PV module absorbed solar radiation but not converted to electricity but cause to increase the temperature and decreasing the electrical efficiency [9].

To increase the electrical efficiency, the solar PV module had to be cooled by eliminating the extra heat from the solar cell. The typical solar PV panel cooling procedures are by water cooling, air cooling, and heat pipe cooling [10]. Established a thermal model of an integrated PV/T water cooled system and proved with experimental results [6]. An experimental study to differentiate the performance of a PV system combined with a cooling system containing of a thin film of water flow on the top surface of the PV module with supplementary system to use the hot water formed by the system [11]. The outcome of the combined system showed that this system achieved to increase power output efficiency and decreased the temperature. Experiments were conducted with and without cooling system. Without cooling system, the temperature of the solar PV module was high and solar cells only reach an efficiency about 8-9%. When the solar PV module was run an active cooling system condition, the temperature reduced obviously leading to an increase in an efficiency level of solar PV cells between 12% and 14%. During an operation of the solar PV module, only about 15% of solar radiation is transformed to electricity and the remaining are changed to heat. The electrical efficiency level will drop when the temperature of the solar PV module is higher. Reducing the temperature of solar PV module can enhance the electrical efficiency. A hybrid PV/T solar system found that by cooled the solar PV panel with water almost 50% of the solar cells output power increases [12]. A hybrid PV/T solar system where water and air were both was considered as cooling agents [13]. Water used as a cooling agent to raise the solar PV module efficiency [14]. With the cooling system, it showed that the solar PV module produces more energy than non-cooling system. By using water, the solar cells temperature dropped by 8˚C and the solar PV module efficiency increase by 3%. Water as coolant for cooling system is the solution for the solar cells with high temperature problem with the least quantity of water and energy.

Solar cooling system technology seems to be an encouraging alternative to the conventional electrical. The most important benefits of solar cooling systems concern the reduction of maximum loads for electricity utilities, the use of none ozone consumption effect refrigerants, the reduction of main energy utilization and reduced global warming effect [15,16]. The existing technologies in the market for cooling fabrication using solar thermal energy are: absorption machines, solid and liquid desiccant and solid adsorption. The greatest commercially technologically advanced for solar cooling technologies are the absorption systems [17]. The implementation and achievability of these systems in different field were also been described. Solar cooling systems such as solar absorption cooling systems count up about 59% were used in Europe [17,18]. As for hot and humid areas, the solar intensity is higher and thus solar energy can be used as a reference for power sources.

2. Experimental Methodology

Kota Kinabalu, the capital city located in the west coast of Sabah in East Malaysia with the latitude of 5.9714°N and longitude 116.0953°E. The experimental work was carried out at the Universiti Malaysia Sabah, Kota Kinabalu at exact location of 6.0367°N, 116.1186°E, similar to the work carried out in [19,20], and the measurement was taken for 10 days from 13th of March till 22nd of March 2016, and from 06:00 till 18:00. A 50 Watt mono-crystalline photovoltaic panel module SPM050-M was used in this research. LI-200 pyranometer was used to measure the amount of global solar radiation, Fluke 179 True RMS Multimeter to measure the temperature of solar PV module, open circuit voltage and short circuit current, and HoldPeak HP-720 Infrared Thermometer was used to measure the ambient temperature of solar PV module and digital thermometer to measure the environment temperature and also humidity.

The tilt angle for the solar panel was inclined at the 15° facing south following the work in [21,22]. The experimental setup of PV module is shown in Figure 1. In this research, three similar panels were used to run a simultaneous three experimental conditions: non-cooling system, cooling system every one hour gap and continuous cooling system. The cooling of PV module is attached to the top side of the module and furnished with inlet and outlet port of the water to flow in the solar PV module. The specification of the solar PV module is given on the Table 1. The water is kept in an insulated tank linked to the hose through the Polyvinly Chloride pipes. A water pump model AS 1000 is used to flow the water over the collector. A bypass system which adjusted the pressure by pumping the water back and forth to the insulated tank. The water flows over the collector, release the heat from the solar PV module and produces warm water which is measured using thermocouples attached at the back of the solar PV module of cooling system.

Table 1. Specification of solar panel module

Parameters	Value
Module Types Maximum power (Pmp) Open Circuit Voltage (Voc) Maximum Power Voltage Maximum System Voltage Maximum Power Current (Imp) Short Circuit Current (Isc) Series Fuse Fire rating Minimum field wiring	50 Watt Monocrystalline 50 Wp 21.82 V 18.22 V DC1000 V 2.8 A 3.06 A 12 A Class C 14 AWG / 2.5 mm sq, STC (AM 1.5, 1000 W/m², 25 ˚C

Fig. 1. Experimental setup of cooling system.

Fig. 2. Experimentalsetup of non-cooling system.

The output V_{oc} and I_{sc} of the solar PV panel recorded every hour from the Fluke 179 True RMS Multimeter. Then, the power output for the solar PV panel was calculated using the following equation.

$$P_{out} = V_{oc} \times I_{sc} \quad (1)$$

The power output was calculated using the Eq. (3.11) and then the efficiency ratio and percentage of the solar PV panel was investigated with the following equation.

$$\text{Efficiency ratio, } \eta = P_{max} / Irr (W/m^2) \times A (m^2) \quad (2)$$

Hence, the efficiency percentage was calculated with the following equation.

$$\text{Efficiency percentage, } \% = \text{Efficiency ratio} \times 100 \quad (3)$$

Besides that, to measure the global solar radiation in unit of W/m^2, the LI-200 pyranometer was used. Humidity (%) and environment temperature (°C) measured using digital thermometer. Module surface temperature for front was measured using HoldPeak HP-720 Infrared Thermometer. Meanwhile, temperature for back module using a thermocouple thermometer and the value recorded in the Fluke 179 True RMS Multimeter.

3. Result and Discussion

The production of the solar PV system is influenced by several climatic factors such as global solar radiation and ambient temperature. From the Figure 3, we can see clearly the maximum value of global solar radiation recorded throughout 10 days was 1052.9 W/m^2 on 17th March 2016 at 14:00 whereas the highest hourly average was 970.17 W/m^2 at 13:00 can be seen on Figure 3.

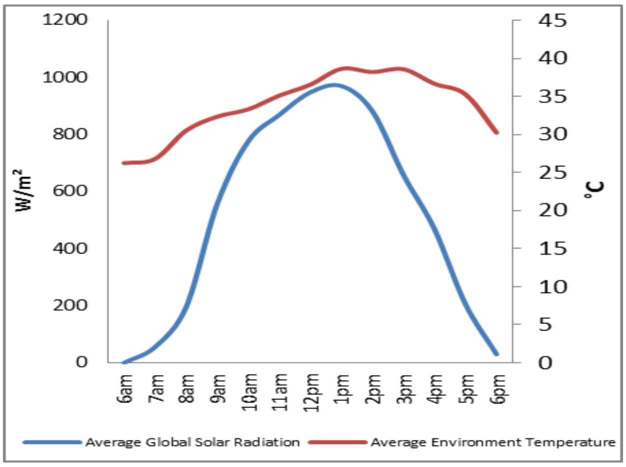

Fig. 3. Hourly average of global solar radiation and environment temperature.

The maximum hourly average environment temperature found to be 38.6˚C at 13:00 and the maximum average for global solar radiation throughout the days was 970.17 W/m^2 also at 13:00. The impact of water cooling and non-cooling system throughout the 10 days on the solar panel shows in Figure 4. The maximum hourly average temperature for continuous cooling system panel was found 38.9˚C at 14:00. The maximum hourly average temperature for cooling system every one hour was 48.2˚C at 11:00. Meanwhile, the hourly average temperature for non-cooling system was found 53.3˚C at 13:00. Continuous cooling module resulted in the decreases of the cell temperature about 14.4˚C from non-cooling module. Meanwhile, reduction between cooling system every one hour and non-cooling system was 5.1˚C. When the global solar radiation higher the temperature of module increase and the power output will decreased.

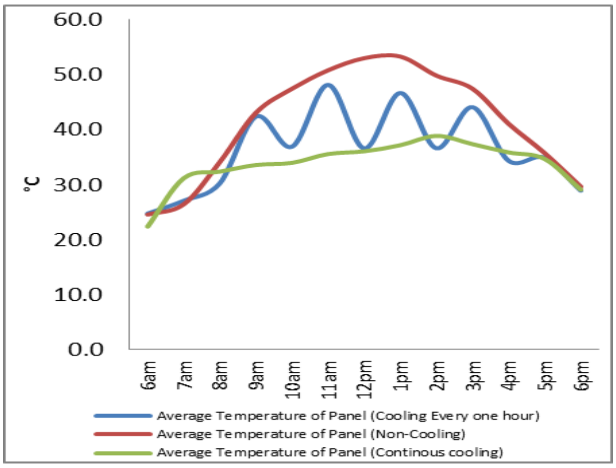

Fig. 4. Hourly average temperature of non-cooling, cooling system every one hour and continuous cooling system.

This temperature dropped resulted in enhancement in power output as shows in Figure 7. A substantial increase in the power output is detected with the water cooling system. This shows that the use of continuous water cooling can lead to significant increase in conversion efficiency and power output of PV cells hence reduce the panel temperature similar to findings reported in [23,24,25]. The hourly average maximum value for power output for non-cooling system throughout the 10 days was 59.06 Watt observed at 12:00 whereas cooling system every one hour maximum value for power output was 65.11 Watt at 12:00 and maximum value for power output continuous cooling was 68.8 Watt at 12:00 respectively. With active cooling, the increased in the average power output between every one hour cooling system and continuous cooling system was 3.69 Watt. Meanwhile, continuous cooling system and non-cooling system was increased with 9.74 Watt and every one hour cooling system and non-cooling system was increased about 6.05 Watt respectively. This result shows in Figure 7. Hence, the efficiency percentage of this system was 16.7%, 14.4% and 13% respectively.

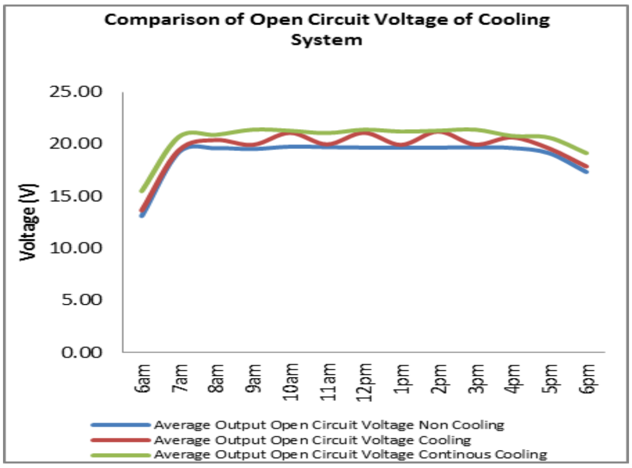

Fig. 5. Average hourly daily open circuit voltage between non-cooling, cooling system every one hour and continuous cooling system.

The highest average hourly daily open circuit voltage of the continuous cooling was 21.4 V at 9:00, cooling system every one hour was 21.22 V at 14:00 and the highest for non-cooling system was 19.77 V at 10:00. From the Figure 5, we can see clearly that the open circuit voltage for cooling system was a bit wavy at the certain time because cooling system was switch on and off every hour to see the temperature effect on the solar panel and how long it's take to cool down the solar panel when the water pump is on and water flow on the solar panel surface. Meanwhile, open circuit voltage for continuous cooling system always higher than cooling system every one hour and non-cooling system. Besides, the operating temperatures which has a negative impact on PV systems that lead to decreases in voltage and power output as discussed by [26,27].

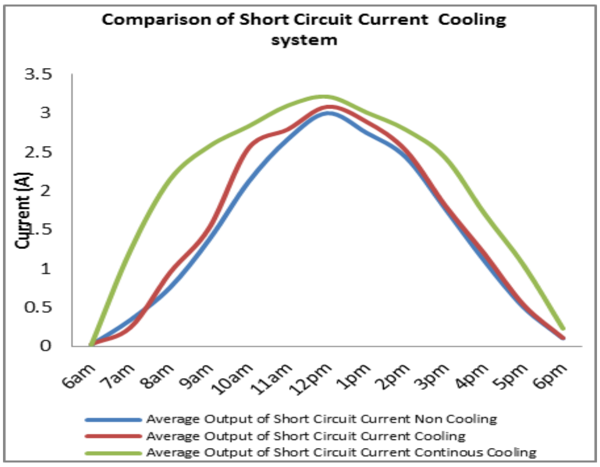

Fig. 6. Hourly average short circuit current non-cooling, cooling system every one hour and continuous cooling system.

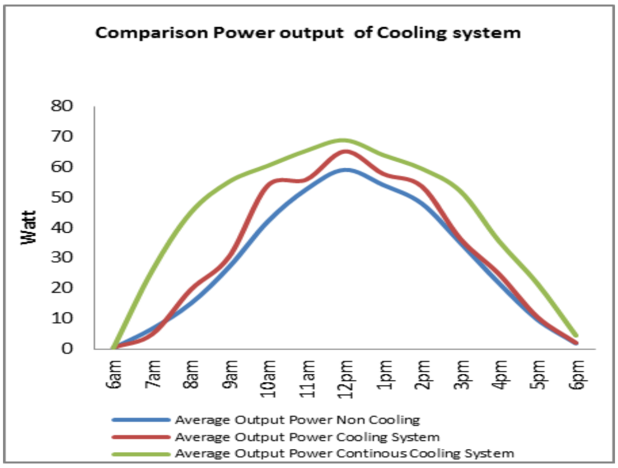

Fig. 7. Hourly average output power between non-cooling, cooling system every one hour and continuous cooling system.

The maximum power output from the solar PV module changed with the increasing of intensity of global solar radiation and the temperature of the solar PV panel. Moreover, the efficiency of solar cell is also greatly affected by the amount of solar irradiance as mentioned in [28]. The outcome of the solar PV panel also influenced by on the number of cells in the module, types and surface area of the cells. All modules are evaluated by manufacturers in expressions of their peak power (Wp) under standard test conditions such as irradiance of 1000W/m^2, air mass 1.5 and the cell temperature 25 ˚C.

In general, water cooling system produce higher power output and have a good potential in providing electricity similar to the suggestion in [29,30].

4. Conclusion

The performance of the power output between continuous cooling system, cooling system every one hour and non-cooling system was analyzed. From the data obtained, it can be summarized that the cooling system works more efficiently than non-cooling system but continuous cooling system is more efficient than cooling system every one hour. Therefore, the maximum power output for continuous cooling system was 68.8 Watt, cooling system every one hour was 65.11 Watt and 59.06 Watt for non-cooling system, respectively.

References

[1] S. Chokmaviroj, R. Wattanapong and Y. Suchart, “Performance of A 500 kWp Grid Connected Photovoltaic System At Mae Hong Son Province, Thailand, Renewable Energy, vol. 31, No.1, pp. 19-28, 2006.

[2] E. Skoplaki, J. A. Palyvos, “On the temperature dependence of photovoltaic module electrical performance: a review of efficiency/power correlations”, Solar Energy, vol. 83, No. 5, pp. 614–624, 2009.

[3] S. Rustemli, F. Dincer, “Modeling of photovoltaic panel and examining effects of temperature in Matlab/Simulink”, Elektronika Ir Elektrotechnika (Journal of Electronics and Electrical Engineering), vol. 3, No. 109, pp. 35–40, 2011.

[4] J.J Bloem, “Evaluation of a PV-integrated building application in a well-controlled outdoor test environment”, Building and Environment, vol. 43, No. 2, pp. 205–216, 2008.

[5] A. Tiwari, M. S. Sodha, “Performance evaluation of hybrid PV/thermal water/air heating system: a parametric study”, Renewable Energy, vol. 31, No.15 pp. 2460–2474, 2006.

[6] A. Tiwari, M. S. Sodha, “Performance evaluation of solar PV/T system: an experimental validation”, Solar Energy, vol. 80, No. 7, pp. 751–759, 2006.

[7] P. Trinuruk, C. Sorapipatana, D. Chenvidhya, “Estimating operating cell temperature of BIPV modules in Thailand”, Renewable Energy, vol. 34, No. 11, pp. 2515–2523, 2009.

[8] D. F. Butay, M. T. Miller, “Maximum peak power tracker: a solar application”, Worcester Polytechnic Institute (WPI) Degree of Bachelor of Science, 2008.

[9] M. Mattei, G. Notton, C. Cristofari, M. Muselli, P. Poggi, “Calculation of the polycrystalline PV module temperature using a simple method of energy balance”, Renewable Energy, vol. 31, No. 4, pp. 553–567, 2006.

[10] K. Araki, H. Uozumi, and M. Yamaguchi, “A Simple Passively Cooling Structure and Its Heat Analysis for 500x Concentrator PV Module”, Proceeding of the 29th IEEE Photovoltaic Specialist Conference, pp. 1568-1571, 2002.

[11] R. Hosseini, N. Hosseini, H. Khorasanizadeh, “An Experimental Study of Combining a Photovoltaic System with a Heating system”, World Renewable Energy Congress, Sweden, 8-13 May 2011.

[12] J. A. Akbarzadeh, and T. Wadowski, “Heat-pipe-based cooling systems for photovoltaic cells under concentrated solar radiation”, Applied Thermal Engineering, vol. 16, No. 1, pp. 81–87, 1996.

[13] E. Chaniotakis, “Modelling and analysis of water cooled photovoltaics” M.Sc. thesis, Faculty of Energy System and Environment, Department of Mechanical Engineering, University of Strathclyde, Glasgow, Scotland, 2001.

[14] A. Kluth, “Using water as a coolant to increase solar panel efficiency”, California State science fair, California, USA, April 2008.

[15] Sözen Adnan, Özalp Mehmet, Arcaklioğlu Erol. Prospects for utilisation of solar driven ejector-absorption cooling system in Turkey”, Applied Thermal Engineering, vol. 24, No. 7, pp. 1019-1035, 2004.

[16] X. G. Casals, “Solar absorption cooling in Spain: perspectives and outcomes from the simulation of recent installations”, Renewable Energy, vol. 31, No. 9, pp. 1371–1389, 2006.

[17] H. M. Henning, “Solar assisted air conditioning of buildings – an overview”, Applied Thermal Engineering, vol. 27, No. 10, pp. 1734–1749, 2007.

[18] C. A. Balaras, G. Grossman, H. M. Henning, A. Carlos, I. Ferreira, E. Podesser, “Solar air conditioning in Europe an overview”, Renewable Sustain Energy Rev, vol. 11, No. 2, pp. 299–314, 2007.

[19] K. Sukarno, A. S. Abd Hamid, J. Dayou, M. Z. H. Makmud and M. S. Sarjadi, “Measurement of global solar radiation in Kota Kinabalu Malaysia”, ARPN Journal of Engineering and Applied Science, vol. 10, No. 15, pp. 6467-6471, 2015.

[20] K. Sukarno, A. S. Abd Hamid, J. H. W. Chang, F. P. Chee and J. Dayou, "Comparison of Power Output between Fixed and Perpendicular Solar Photovoltaic Panel in Tropical Climate Region", Advanced Science Letters, vol. 23, No. 2, pp. 1259–1263, 2017.

[21] L. Y. G. Seng, Lalchand and G. M. S. Lin, “Economical, environmental and technical analysis of building integrated photovoltaic systems in Malaysia”, Energy Policy, vol. 36, No. 6, pp. 2130-42, 2008.

[22] D. H. W. Li and T. N. T. Lam, “Determining the optimum tilt angle and orientation for solar energy collection based on measured solar radiance data”, International Journal Photoenergy, Vol. 2007, Article ID 85402, 9 pages, 20 September 2007.

[23] T. Nehari, M. Benlekkam and D. Nehari, “The effect of inclination on the passive cooling of the solar PV panel by using phase change material”, International Journal of Renewable Energy Research, vol. 6, No. 1, pp. 1434-1441, 2016.

[24] V. Suresh, S. Naviynkumar and V. Kirubakaran, “Improved power output of PV system by low cost evaporative cooling technology”, International Conference on Green Computing, Communication and Conservation of Energy, Chennai, India. 12-14 December 2013.

[25] A. Pradhan and S. K. S Parashar, “Water cooling method to improe efficiency of photovoltaic module”, International Conference on Signal Processing, Communication, Power and Embedded System, Paralakhemundi, India, 3-5 October 2016.

[26] A. Belhamadia, M, Mansor and M. A. Younis, “A study on wind and solar energy potentials in Malaysia”, International Journal of Renewable Energy Research, vol. 4, No. 4, pp. 1043-1048, 2014.

[27] A. K. Tripathi, M. Aruna and C. S. N. Murthy, “Output power loss of photovoltaic panel due to dust and temperature”, International of Renewable Energy Research, vol. 7, No.1, pp. 439-442, 2017.

[28] R. Arshad, S. Tariq, M. U. Niaz and M. Jamil, “Improvement in solar panel efficiency using solar concentration by simple mirrors and by cooling”, International Conference on Roboticsand Emerging Allied Technologies in Engineering, Islamabad, Pakistan, 22-24 April 2014.

[29] G. Colt, “Performance evaluation of a PV panel by rear surface water active cooling”, International Conference on Applied and Theoretical Electricity, Craiova, Romania, 6- 8 October 2016.

[30] C. S. Sreejith, P. Rajesh and M. R. Unni, “Experimental study on efficiency enhancement of PV systems with combined effect of cooling and maximum power point tracking”, International Conference on Inventive Computation Technologies, Coimbatore, India, 26-27 August 2016.