Indonesian Journal of Electrical Engineering and Computer Science
Vol. 7, No. 2, August 2017, pp. 492 ~ 499
DOI: 10.11591/ijeecs.v7.i2.pp492-499

Thermal and Electrical Study for PV Panel with Cooling System

Z Syafiqah[1], YM Irwan[2], NAM Amin[3], M Irwanto[4], WZ Leow[5] and AR Amelia[6]
[1,2,4,5,6]Centre of Excellence for Renewable Energy, School of Electrical System Engineering, Universiti Malaysia Perlis (UniMAP), Malaysia
[2]Centre for Diploma Studies, Universiti Malaysia Perlis (UniMAP), Malaysia
[3]School of Mechatronic Engineering, Universiti Malaysia Perlis (UniMAP), Malaysia
[4]Department of Electrical Engineering, Medan Institute of Technology, Indonesia

Abstract

Paper presents an investigation on photovoltaic (PV) panel with a direct-current (DC) fan cooling system. The DC fan cooling system was installed at the back of PV panel in order to reduce its operating temperature. The performance of PV panel can be affected with the increase of its operating temperature. Therefore, with the aid of the DC fan cooling system, it can enhance the performance by raise the output power generated. However, DC fan cooling system is considered as an active cooling system, whereby it consumes input power in operating it. The thermal behavior of PV panel with different DC fan speeds were observed by using a computational fluid dynamic (CFD) software. From the temperature obtained, acurrent-Voltage (I-V) and power-voltage (P-V) can be formed by using PSPICE due to examine its electrical performance. As the DC fan speed increases, the power input to operate it also increase. Hence, it is crucial to find the optimum speed so that the power generated by PV panel that can be saved is high.

Keywords: *DC fan cooling system, ANSYS CFX, cooling effect, PV panel*

1. Introduction

With increasing mankind's population, what are the next reliable energy sources that will replace the depletion of fossil fuels? Renewable energy sources are becoming more popular as it does not emit greenhouse gases like non-renewable energy. Solar energy seems as the most efficient way to obtain electrical energy as the radiation continuously showered on earth by the sun shows that the sun is the primary sources of renewable energy. PV system is used to convert solar radiation into electricity that can be used to power household application. It is an environmental clean source of energy which available almost every part in the world.

However, when the temperature of PV cell increase, the power generated will decrease. This is due to change properties of the PV cell material. PV cells are made from semiconductor materials, which have the ability to move an electron from low energy (bound) state to a higher (free) energy state when absorbing lights. The required amount of energy to move an electron from bound state to free state is known as band gap. With the increase of PV cell temperature, the band gap will decrease, hence, leading to a slight increase of short-circuit current (I_{SC}) but significant decrease in open-circuit voltage (V_{oc}) [1]. The ideal operating for PV cell is at high irradiance with a low temperature based on [2].

Temperature affects how electricity flows by changing speed of electron travel. During the actual operation of PV panel, the operating temperature can reach 60 °C to 80 °C under high irradiance condition. When PV cell temperature increase, V_{oc} will decrease at rate of 0.1 %/°C, while I_{sc} increase slightly with temperature [3]. Many researchers [4-7] proved that rise in PV cell temperature will decrease its efficiency. In addition, Irwan [8] reported that the energy production from the PV aray is not high as expected due to the effect of high temperature. Therefore, a cooling system is important because it can help to decrease the operating temperature, hence improving the output power generated. Cooling systems have been proposed [9-11]. It shows that with cooling system, it enhances the power generated.

There were 2 types of PV cooling, which are active cooling (consumes energy) and passive cooling (use natural convection to extract heat) [12]. Active cooling can be considered as a method that continuously consumes power in order to reduce PV panel temperature. Most

Received May 10, 2017; Revised July 13, 2017; Accepted July 28, 2017

of the active cooling system was based on air and water cooling. Generally, active cooling methods help in enhancing the output power generated, but when power consumption is considered, the question arises if the cooling system is worth it. Hence, this paper is focused into the optimization of DC fan speed for PV panel cooling. This is as to ensure that the selected speed will helps to reduce as much temperature, but consume less power, hence increase the power generated.

Irwan [13] had experimented PV panel with and without cooling using the DC brushless fan. The temperature of PV panel with DC brushless fan decrease 6.1 °C compared to PV panel without cooling system. While, the voltage, current and power had increased by 3.47 %, 29.55 % and 32.23 % respectively. Catalin [3] presented a numerical approach for temperature reduction of PV panel by using air cooled heat sinks. The numerical model was analyzed using ANSYS Fluent software for turbulent flow. Results are presented for an average temperature of PV panel. Amelia [14] had proposed working operation of DC fan controlled by PIC18F4550 microcontroller, which turn on the DC fan only when the ambient temperature reaches 35 °C. An experiment had been conducted at outdoor condition, comparing PV panel with and without DC fan. Teo [1] designed and experimented a hybrid photovoltaic/thermal (PV/T). The authors designed a parallel array of ducts with inlet/outlet manifold for uniform airflow distribution. With the cooling mechanism, the temperature dropped significantly, leads to increase of efficiency from 12 % to 14 %.

Recently, computational fluid dynamics (CFD) has been increasingly applied in the photovoltaic system, as a promising way to extend simulation capabilities of many thermal issues. Rattanasuda et al [15], focused on the suitable flow rate and optimal configuration in photovoltaic thermal (PV/T) system. Authors designed by using finite element method (FEM) to solve the CFD problem. A 4 x 4 configuration of the PV array is taken as a benchmark for comparison of the analysis of configuration with 8 x 2, 3 x 4, and 4 x 3. The analysis was done by using COMSOL MULTIPHYSICS software.

This work deals with a comparative performance study of 6 different DC fan airflow for PV air cooling system through a computational simulation. A CFD computation has been done for the DC fan airflow that flowing at the backside of the PV panel. The performance study will be based on the thermal performance by using ANSYS CFX software as well as electricity performance which is by using PSPICE software. Air cooling system is considered as an active cooling system, whereby it consumes energy to operate [1]. Therefore, it is crucial in finding a suitable DC fan speed, so that it can increase the output power generation, but at the same time does not consume much power in order to operate.Shahsavar [16] increased the DC fan mass flow rate by increasing number of DC Fans. However, the authordoes not include the power consumption by the DC fans in calculating the net electrical output for the system.

2. Methodology

A typical PV panel consists of 5 layers, which are top glass cover, Ethylene-Vinyl Acetate (EVA 1), silicon cells, EVA 2 and tedlar back sheet as shown in Figure 1. The glass used is ultra-clear, with a high transmittance rate and low iron content so that it can extract as much solar energy as possible. The PV cells are encapsulated in a layer of EVA as to stick the PV cells toward cover glass and the back encapsulating material (tedlar). The tedlar polymer layer is made of polyvinyl fluoride (PVF) which provides additional insulation and protection for the PV layer.

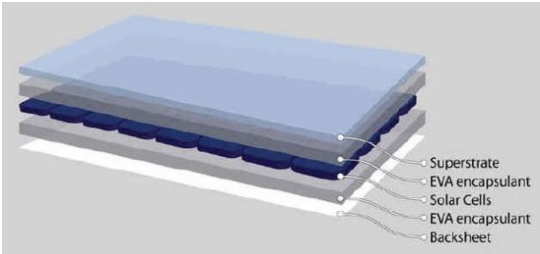


Figure 1. A typical laminated PV panel structure

The properties of the PV panel materials, such as thickness, thermal conductivity, density as well as specific heat capacity are varied, as shown in Table 1. These 5 layers are embedded in a metal frame, but the effects of it are not included in this paper. This is because, it has a low surface area compared to PV panel area, thus it has a negligible effect on the temperature response [17]. Therefore, the metal frame is not included in this simulation study since it will slightly reduce the error and simulation time. The dimension of the PV panel is 1200 mm x 540 mm x 4.5 mm.

Table 1. PV panel material properties

Layer	Thickness, (cm)	Density, (kg/m^3)	Thermal conductivity, (W/m.°C)	Specific heat capacity, (kg. °C)
Glass	0.30	3000	1.8	500
EVA 1	0.05	960	0.35	2090
PV cells	0.04	2330	148	677
EVA 2	0.05	960	0.35	2090
Tedlar	0.01	1200	0.2	1250

DC fans are installed at the back of PV panel as to reduce its operating temperature. The DC fan will act as forced air convection to cool down the PV panel. In this investigation, the unit number of DC fans installed are 2, following the research that has been done by[16], with inlet/inlet airflow combinations. The geometry model has been drawn by using Solidwork software as shown in Figure 2. The DC fans are installed at the backside of PV panel with the help of aluminum sheet, which also will act as a heat sink.

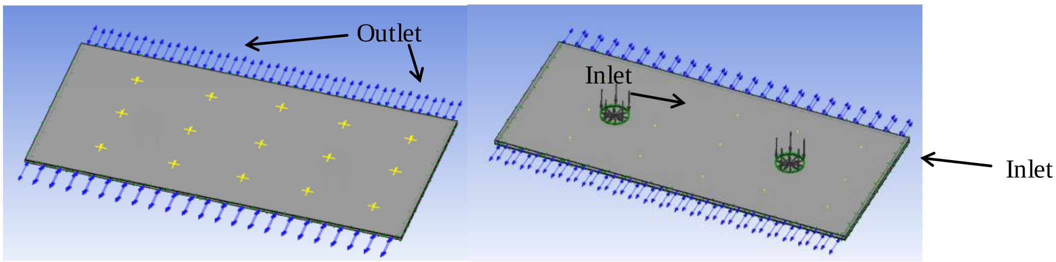


Figure 2. PV panel with air cooling system drawing (a) front view (b) backside view

The 2 holes at the backside of the PV panel, indicates the position of the DC fans. The DC fans were placed at the center as to ensure a uniform airflow distribution. The simulation was tested with 6 different DC fan speed as shown in Table 2 in order to examine its impact towards PV panel temperature. The sizes of the DC fans were also differed with the different airflow speed. The ultimate goal for this present study is to find the optimum DC fan speed in reducing the PV panel operating temperature, hence enhancing the PV panel output power generated.

Table 2. Details on the different DC fans speed

No.	Airflow in cubic feet minute (CFM)	Airflow in meter per second (m/s)	Size of DC fans (mm)	Power consumption (W)
1	8.28	1.99	50 x 50	0.72
2	17.01	2.84	60 x 60	0.96
3	25.03	3.07	70 x 70	1.08
4	35.36	3.32	80 x 80	1.92
5	61.41	4.36	92 x92	2.40
6	107.60	4.49	120 x 120	4.80

2.1. ANSYS CFX Simulation Setup

ANSYS CFX is one of the CFD packages which are capable of solving diverse and complex three-dimensional (3D) fluid flow problems. It uses Navier-Strokes equations to describe the fundamental process of momentum, mass and heat transfer [17]. ANSYS CFX uses finite volume approach to convert the governing partial differential equation into a system of discrete algebraic equations by discretizing the computational domain. The basic procedure in modeling using ANSYS CFX consists of five steps, which are creating the geometry, meshing, pre-processing, solving and post-processing (result). The geometry drawing has been drawn by using Solidwork software as shown in Figure 2. Then the 3D drawing was imported into the ANSYS Workbench for further analysis.

The geometry then was discretized into a number of small control volumes using a mesh which was generated by using ANSYS ICEM. Due to the circular shape at the air layer and aluminum sheet, tetrahedron mesh was generated as shown in Figure 3. While the rest were consists of hexahedron mesh with total skewness of 0.824. It is important to obtain a good mesh because it can affect the results accuracy [18]. The CFD analysis was solved after applying an appropriate boundary and initial conditions. The CFD analysis consists of 7 domains (including the air and aluminum sheet layer) since the PV panel air cooling system consists of 7 different layers.

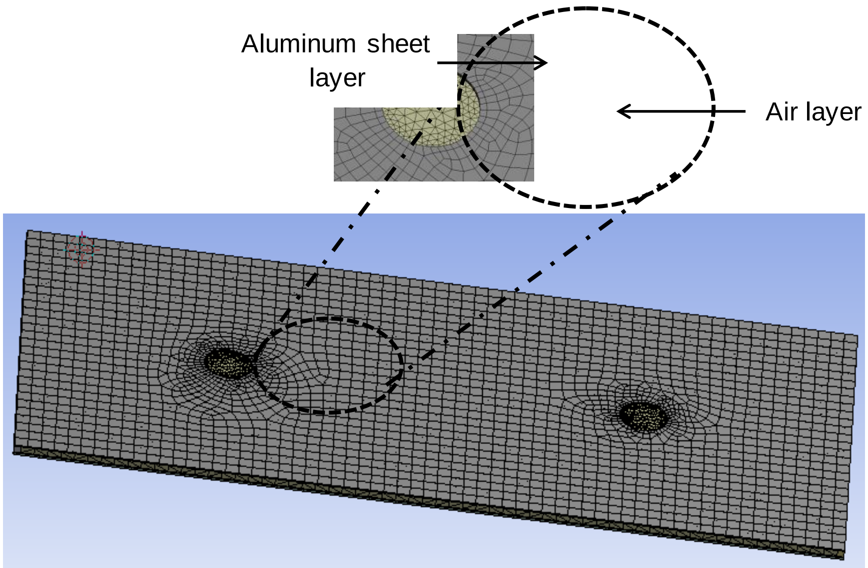


Figure 3. The mesh that has been generated for the model

The analysis of the PV panel air cooling system was done by using the finite element methods, with several assumptions. For example, all domainswere assumed to be dependent on the ambient temperature and solar radiation. The outer layer of the domains and top glass layer was assumed facing the solar radiation directly and the solar radiation was fully transmitted to the layer below.The data for ambient temperature and solar radiation weretaken from 8.00 a.m. until 6.00 p.m. While, the wind speed across the front and outer layer of PV panel was taken as v=2.53 m/s (average wind speed of Perlis [19]). Using an equation from [20], the heat transfer coefficient equation (W/m^2.K) can be calculated.

$$H = 11.4 + 5.7V \tag{1}$$

The DC fan flow was modeled by the mass flow rate boundary condition on the inlet surface of the air domain with a uniform velocity. The 2 inlets were considered as a continuous fluid with the same air characteristics and uniform speed of DC fan. The simulation was repeated with 6 different DC fan's airflow as referred to Table 2. No-slip condition was assigned at the walls in contact with the fluid in the simulation. The working fluid, which is air, was assumed to be incompressible, steady and turbulent flow. A convergence criteria of 1 x 10^{-4} was assumedfor residuals of continuity, velocity components and energy, while a second-order implicit scheme was used to approximate the transient terms.

3. Results and Discussions

This section presents and discusses the results of varying the DC fan's airflow toward the temperature distribution of PV panel and output power generated.The results were presented in terms of PV panel temperature, I_{sc}, V_{oc} and output power generated. The data were observed and analyzed by comparing the performance with different DC fan speed. This is due to investigate the optimum DC fan speed that can lower the PV panel temperature the most. There were 15 points that were plotted on silicon layer surface as to monitor its temperature as shown in Figure 2. With these, an average temperature of that layer can be obtained at any particular time. Figure 4 displays the difference of the temperature for different DC fan speed. The highest ambient temperature was recorded at 1.30 p.m. which is 36.5 °C, whereas the highest solar radiation is 1011 W/m^2 at 1.35 p.m. and 1.45 p.m.

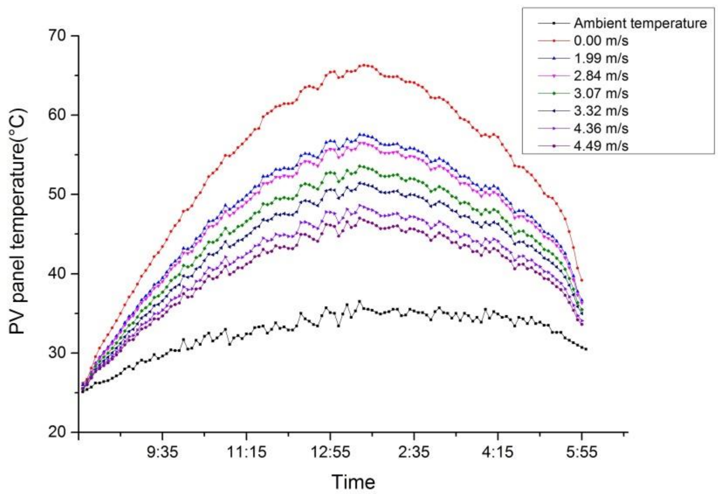
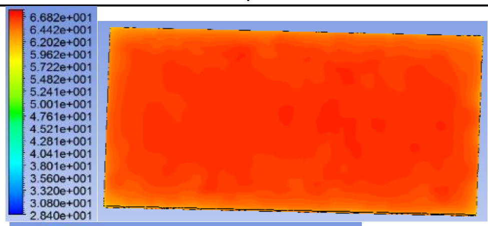
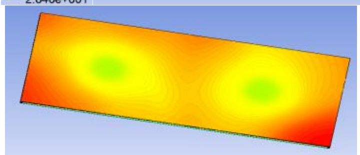
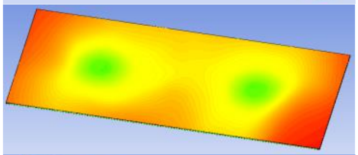
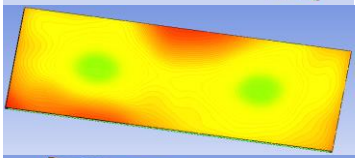
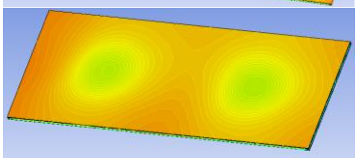
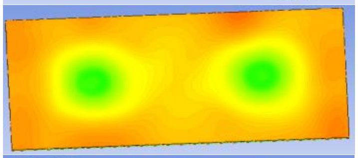
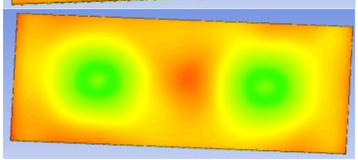


Figure 4. PV panel temperature with different DC fan speed

Meanwhile, the lowest ambient temperature and solar radiation is at 8.00 a.m., which are 25.1°C and 26 W/m^2 respectively. The PV panel temperature without cooling is the highest at 1.30 p.m., which is 66.2 °C. With a 1.99 m/s speed of DC fan applied to it, the PV panel temperature decrease to 57.5 °C. But, with the increasing speed of DC fan, there is an improvement in PV panel temperature. With DC fan speed of 4.49 m/s, highest PV panel temperature that has been recorded is 47.0 °C, which is almost 29.0 % decrease in temperature, compared with PV panel without cooling system (0 m/s). The PV panel temperature and contour on its surface with different DC fan speed can be seen at Table 3. PV panel without DC fan attached to it, its surface covered with red spot contours which resemble a hot surface. With the help of DC fan cooling system, the red spot contour slowly disappeared, which means the temperature of PV panel is getting lowered.However, there is not much difference in PV panel temperature at lowest ambient temperature of 25.1 °C, even though with different DC fan speed which only 0.5 °C.

Table 3. PV panel temperature and contour at highest ambient temperature

Speed of fan, m/s	PV panel temperature and contour at 36.5 °C	
	Temperature, °C	PV panel contour
0.00	66.2	
1.99	57.5	
2.84	56.5	
3.07	53.6	
3.32	51.4	
3.36	48.6	
4.49	47.0	

On the other hand, the characteristics of the PV panel based on PSPICE software are shown as in Figure 5. It displays the I-V and P-V curve for different DC fan speed at maximum ambient temperature of 36.5 °C with solar radiation of 1000 W/m^2. The V_{oc} and I_{sc} of the PV panel used in the simulation are 22.2 V and 5.78 A respectively at Standard Test Condition (STC). Even though since the PV panel temperature increases with the increasing DC fan speed, but the I_{sc} produced does not affected much. It only caused a major changes in the V_{oc}as presented in [21]. When the temperature of PV panel rises, the rate of photon generation will increase. Hence, the reverse saturation current will increase rapidly which causing the band gap to reduce [6]. The V_{oc} of PV panel without cooling system attached to it is 19.0V, while with DC fan speed of 4.49 m/s, the V_{oc} recorded is 20.0 V. It is proven that with the increment of DC fan speed, it can lowered the PV panel temperature, thus improving the V_{oc}. Apart, with the enhanced V_{oc}, the power output generated also rise as illustrated in Figure 5. The maximum output power generated is 73.24 W with DC fan speed of 4.49 m/s, compared to PV panel without cooling system only generated 66.96 W.

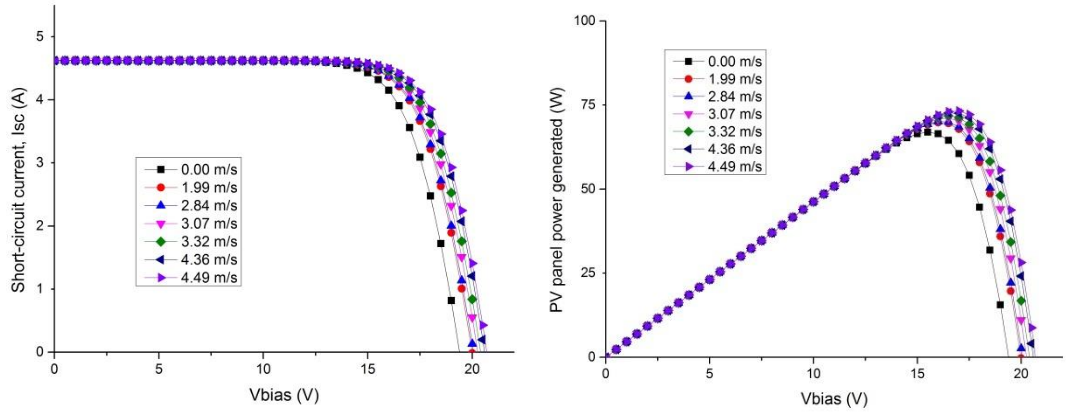


Figure 5. I-V and P-V curve for different DC fan speed

Based on the P-V curve shown in Figure 5, the output power generated by PV panel did improve with the increment of DC fan speed. However, the DC fan is considered as an active cooling system, whereby it consumes power in order to operate it. Therefore, the power consumption for each DC fan also need to be considered, as with the increasing DC fan speed, the power consumption for operating it also increases. The power consumption for each DC fan speed is presented in Table 6. Besides, Table 6 also illustrated the net power saving from PV panel after considering the power consumption by the DC fan.

Table 6. Power saving from different DC fan speed

	0 m/s	1.99 m/s	2.84 m/s	3.07 m/s	3.32 m/s	4.36 m/s	4.49 m/s
PV panel output power generated (W)	66.96	69.81	70.09	71.13	71.84	72.65	73.24
Power consumption by DC fan (W)	0.0	1.44	1.92	2.16	3.84	4.8	9.6
Net output power (W)	66.96	68.37	68.17	68.97	68.00	67.85	63.64
Net output power saving (W)	-	1.41	1.21	2.01	1.04	0.89	-3.32
Percentage of net output power saving (%)	-	2.11	1.81	3.00	1.55	1.33	-4.96

With the increasing DC fan speed, it does help improving the power generated by the PV panel. PV panel with DC fan speed of 4.49 m/s, it enhanced the power generated by 9.6 W, compared with PV panel without DC fan. Unfortunately, with the increasing DC fan speed, the power consumption of DC fan also increases. Even though PV panel with DC fan speed of 4.49 m/s generated the highest power output of 73.24 W, but the DC fan also employed the highest input power, which is 9.6 W. The power consumption of the DC fan also needs to be considered, as it operated by using the power generated by the PV panel. Hence, the selection of the DC fan speed must base on the highest output power that can be saved whereby, the DC fan does not consume much power, but it can still enhance the generation of power by the PV panel. With these characteristics, PV panel with DC fan speed of 3.07 m/s has the highest output power saving, compared to others at a particular time. Therefore, it can be said that PV panel with DC fan speed of 3.07 m/s is the optimum speed that can enhance the performance of the PV panel.

Teo [1] find out that the optimum flow rate for the hybrid PV/T system is 0.055 kg/s. Author had installed a blower at the back of 4 units of 55 W PV panel, on the roof of an EA building at the National Univesity of Singapore. It is found out that, without a cooling system, the temperature of PV panel reaches 68 °C. With the PV/T system, the temperature of PV panel reduced up to 38 °C. Unfortunately, the authordoes not focus on the output power saving, since the system is connected to a battery.

4. Conclusions

As a conclusion, this paper presents the thermal and electrical performance of PV panel with 6 different DC fan speeds. The thermal performance was done by using ANSYS CFX, whereas the electricity performance was done by using PSPICE. By using the temperature generated from the ANSYS CFX, it is used in PSPICE due to generate the I-V and P-V curve for the electrical performance. It was found out that PV panel temperature decrease with the increase of DC fan speed. Nevertheless, the power consumption of the DC fan also rise when its speed increase. Even though the highest DC fan speed can enhance the power generated by PV panel the most, but its output power saving is the lowest, since the DC fan requires the highest input power. Thus, DC fan speed of 3.07 m/s it selected as the optimum speed for the DC fan cooling system since it acquired the highest net output power saving, compared to others.

References

[1] Teo HG, Lee PS, Hawlader MN. A. An active cooling system for photovoltaic modules. *Applied Energy*. 2011; 309-315.

[2] Skoplaki E, Palyvos JA. The temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlation. *Solar Energy*. 2009; 614-624,

[3] Catalin GP, Sebastian VH, Theodor DM, Nelu-Cristian C. Efficiency Improvement of Photovoltaic Panels by Using Air Cooled Heat Sinks. *Energy Procedia*. 2016; 425-432.

[4] Fesharaki VJ, Dehghani M, Fesharaki JJ. *The effect of temperature on photovoltaic cell efficiency.*Proceedings of the 1st International Conference on ETEC. 2011.

[5] Borkar DS, Prayagi SV, Gotmare J. Performance Evaluation of Photovoltaic Solar Panel Using Thermoelectric Cooling.*International Journal of Engineering Research.* 2014; 3: 536-539.

[6] Fontenault B. Active Forced Convection Photovoltaic/Thermal Efficiency Optimization Analysis. *Rensselaer Polytechnic Institute Hartford*. 2012.

[7] Sobhan D. Evaluating the Radiation and Temperature Effect on Photovoltaic Systems. *Buletin of Electrical Engineering and Informatics*. 2015; 4(1): 1-6.

[8] Irwan Y.M., Syafiqah Z., Amelia A.R., Irwanto M., Leow W.Z., Ibrahim S. Design the Balance of System for Low Load Application. *Indonesian Journal of Electrical Engineering and Computer Science.* 2016; 4(2): 279-285.

[9] Krauters S. Increased Electrical Yield Via Water Flow Over the Front of Photovoltaic Panels. *Solar Enegery Materials & Solar Cells*.2004; 82.

[10] Royne A, Dey CJ, Mills DR. Cooling of Photovoltaics Cells Under Concentrated Illumination: A Critical Review*Solar Energy Materials & Solar Cells*. 2005; 86: 451-483.

[11] Daghigh R, Ruslan MH, Sopian K. Advance in Liquid Based Photovoltaics/Thermal (PV/T) Collectors. *Renewable and Sustainable Energy Reviews.*2011; 4: 4156-4170.

[12] Kumar R, Rosen MA. A Critical Review of Photovoltaic-Thermal Solar Collectors for Air Heating.*Applied Energy*. 201; 88: 3603-3614.

[13] Irwan YM, Leow WZ, Irwanto M, Fareq M, SIS, Hassan, Safwati I, Amelia AR. *Comparison of Solar Panel Cooling System by Using DC Brushless Fan and DC Water.* Journal of Physics: Conference Series 622. 2015; 1-10.

[14] Amelia AR, Irwan YM, Irwanto M, Leow WZ, Gomesh N, Safwati I, Anuar MAM. Cooling on Photovoltaic Panel Using Forced Air Convection Induced by DC Fan. *International Journal of Electrical and Computer Engineering*. 2016; 2; 526-534.

[15] Rattanasuda N, Kamonpan EH, Chumpolrat, Tongpool S, Jiraphong P, Sirimongkhol J. Finite element method for computational fluid dynamics to design photovoltaic thermal (PV/T) system configuration. *Solar Energy Materials & Solar Cell.* 2011; 95: 390-393.

[16] Shahsavar A, Ameri M. Experimental Investigation and Modelling of a Direct-Coupled PV/T Air Collector. *Solar Energy*. 2010; 84: 1938-1958.

[17] Ruifeng Q, Dedy N, Benjain RC, Mannan MS. Numerical Simulations of LNG Vapor Dispersion in Brayton Fire Training Field Test With ANSYS CFX. *Journal of Hazardous Materials*. 2010; 183: 51-61.

[18] Versteeg HK, Malalasekera W. An Introduction to Computational Fluid Dynamics: The Finite Volume Method, 2nded, Prentice Hall. 2007.

[19] Leow WZ, Irwan YM, Asri M, Irwanto M, Amelia AR, Syafiqah Z. Investigation of Solar Panel Performance Based on Different Wind Velocity Using ANSYS. *Indonesian Journal of Electrical and Computer Science.* 2016; 1(3): 456-463.

[20] Ali T. Performance Evaluation of PV Module by Dynamic Thermal Model.*Journal of Power Technologies*. 2013; 93: 111-121,

[21] Davud MT. Restores in the Photoelectric Parameters of the Aging Silicon Solar Cells by Thermal Annealing and Ultrasonic Treatment. *WALIA Journal.* 2014; 30: 63-68.