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Solar PV system with pulsating heat pipe cooling

E. Roslan, I. Hassim
Department of Mechanical, College of Engineering, Universiti Tenaga Nasional, Malaysia

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ABSTRACT

Malaysia is blessed with high irradiance, making it suitable for solar photovoltaic installation for electricity generation. However, due to the broad wavelength of the solar irradiance, not all wavelength can be converted to electricity due to the limitation of the materials used for the photovoltaic. The infrared radiation absorbed produces heat, and coupled with high surrounding temperature, increases the temperature of the photovoltaic panel thus decreasing it efficiency. This paper presents the study of the effect of attaching pulsating heat pipe at the back of solar panel as a means of passive cooling. Pulsating heat pipe is a recent discovery in the heat pipe industry, introduced in 1996 by Akachi but has not been used for the purpose of cooling solar panels. This study shows the maximum difference between 5 Celsius between the pulsating heat pipe cooled panel and the reference panel without any cooling, resulting in 0.77% increase in electrical output efficiency.

Corresponding Author:

Mohd Eqwan bin Mohd Roslan,
Department of Mechanical, College of Engineering
Universiti Tenaga Nasional,
Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia.
Email: eqwan@uniten.edu.my

1. INTRODUCTION

Since the introduction of feed-in tariff (FiT) in Malaysia, a total 564MW of Renewable Energy capacity has been installed under the FiT scheme, where 375.96MW or 66.7% of the installed capacity is from solar PV [1]. This can be attributed to the abundance of solar irradiance, due the location of Malaysia on the equator [2]. Solar photovoltaic (PV) panels are used to convert the energy from the sun into electricity. However, only small percentage of the energy from the sun can be converted into electricity and 80% cannot be converted [3]. This energy not converted into electricity will heat up the PV panels, which can reduce the efficiency of the panel, which is estimated to be an average decrease of 0.25-0.5%/°C depending on the type of cell material used [4]. Based on a study of Chander et. al., the effect of the temperature on solar PV cells can be seen [5].

Figure 1 shows the comparison of the power output of solar cells at 25, 40, 50 and 60°C. It can be seen that the cell with the lowest temperature produces the highest output power and vice versa. Due to this impact, numerous studies have been done to lower the operating temperature of PV cells to harness its full potential. There are several categories of cooling methods tested, which was reviewed by Siecker et. al. [6]. The methods reviewed were water spraying, heat sink, forced water circulation, phase change material, water immersion cooling, transparent coating, forced air circulation and thermoelectric cooling. A study by Thaib et al. shows that using beeswax to limit temperature rise of building integrated PV increases it electrical output efficiency by approximately 1% [7]. A numerical simulation of PV cooling was done by [8] and showed a promising 18% improvement in electrical power generated using a single turn pulsating heat pipe [8]. An experimental study by Elminshawy et al. shows that coupling PV panel with cooled air using earth-to-air heat exchanger lowers the panel temperature by up to 24.5% and giving up to 22.98% increase of electrical efficiency [9]. The large scale application potential was shown by Castanheira et al., by the demonstration project of cooling existing PV power plants in Lisbon Portugal, where an increase of up to 12% of annual energy production was seen [10].

This paper presents the result of testing a cooling method using pulsating heat pipe (PHP). A pulsating heat pipe, also known as oscillating heat pipe (OHP), is a heat pipe partially filled with a suitable working fluid naturally distributed in the form of a liquid- vapor slug-plug system[11]. It was first proposed by Akachi in the early 1990s [12][13]. Figure 2 shows the typical schematic of a pulsating heat pipe.

A PHP operates when the evaporation side receives heat, the fluid in the capillary moves due to the uneven distribution of bubble and slugs in the tube and this movement transports the heat to the condenser [14]. However, the direction of movement is difficult to predict and research are being done in this area [14].

This project explores the potential of applying PHP for solar PV cooling, with the assumption that it can help increase the efficiency of the panel. The effect on the panel efficiency will be observed.

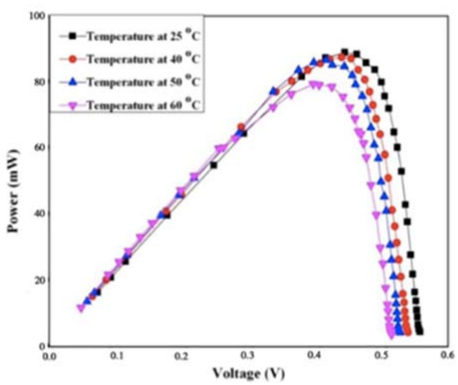

Figure 1. P-V characteristic of mono-Si solar cell with temperature [5]

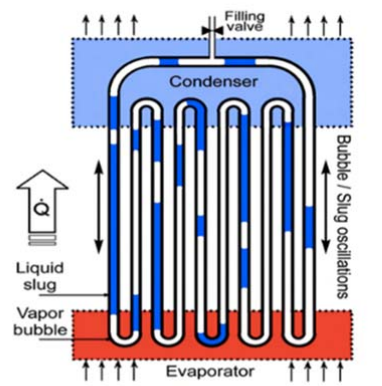

Figure 2. Typical pulsating heat pipe [15]

2. RESEARCH METHOD

Study is done by first designing the prototype, followed by its fabrication. Then, a suitable site is selected to conduct the experiment. The experiment was then set up and data is collected, followed by data analysis and a report is written at the end of the study.

Figure 1 shows the outline of the methodology for this study, followed by the explanation for each step of the process.

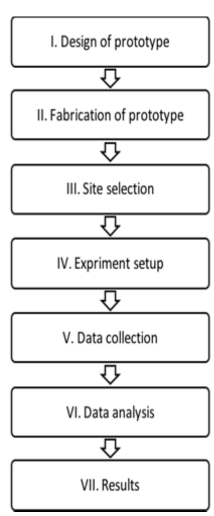

Figure 1. Methodology of study

A sketch of the prototype was made using CREO Parametric, adding 200mm of height from the top of the panel. This additional is to be made a consideration when applying this cooling method in an array, where more space is needed for installation. The dimensions of the assembled system is as in Figure 4 below:

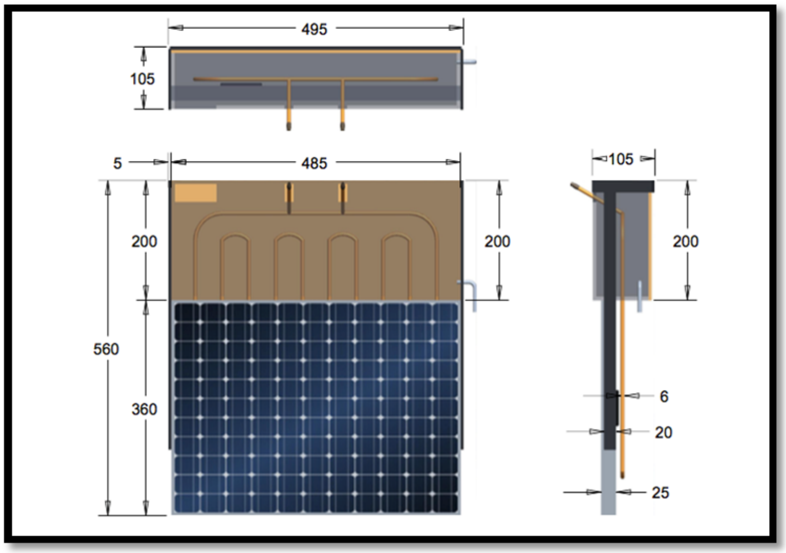

Figure 2. Multiview drawing of the prototype design

2.2. Fabrication of Prototype

After the prototype drawing has been confirmed, then, the selection of the material to be used should be selected. Some of the key factors that need to be included in the selection of the material to be used for prototype production are weather resistant materials, heavy-duty materials and economical materials. Table 1 below summarizes the components, material types and the description of the selected materials of the cooling system.

Table 1. Components and materials for prototype fabrication

Components	Material Type	Descriptions
Chamber	Clear Acrylic Sheet	High impact strength Low crazing rate Resist sunlight damage and wrinkles Transparent view
Support bracket	Steel	Rigid Good weldability Good formability Strong
Heat pipe	Copper Tube	Corrosion resistance Machinability High level of heat transfer

After the material to be used has been determined, the next step is the fabrication process. Several tools were used such as copper tube bender, cutter and welder. Figure 5 shows the completed prototype. The storage tank acts as a chamber to release heat. In this study, the heat is released passively but is required, water can be flowed through the exposed pipe in the acrylic chamber.

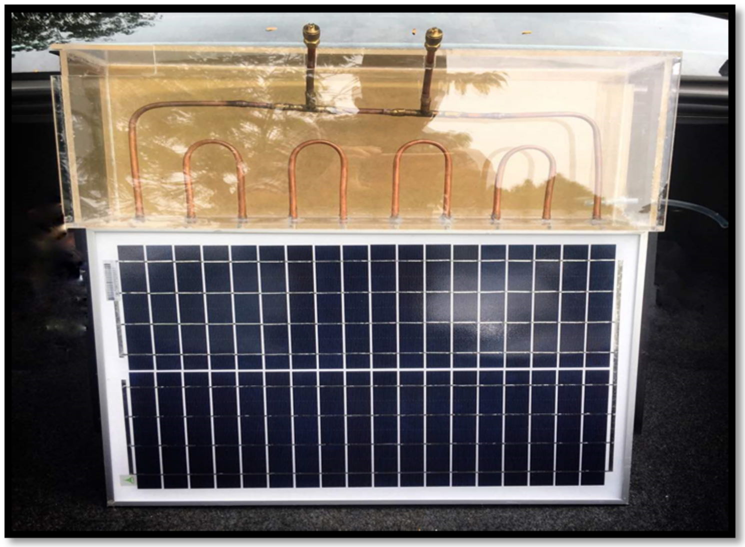

Figure 3. Front view of the prototype

Figure 5 above shows the completed assembly of the PV panel together with the pulsating heat pipe cooling system.

2.3 Site Selection

The experiment was conducted at TNB Research Kajang, due to the availability of an open area and measurement devices available.

2.4 Experiment Setup

Figure 6 shows the flow process of the experiment. To run this experiment, three types of measuring devices used are solar irradiance meter, multi-meter and current clamp meter. As the solar panel produces direct current (DC), each solar panel is connected with a 12W LED bulb as a load. Some reading will be taken using the measuring devices. Readings will be taken every 5 minutes within 1 hour of experiment. The readings are temperature of solar panel (□C), solar irradiance (W/m2), output voltage for both solar panel (V) and output current for both solar panel (A). This experiment will use two solar panels. The solar panel labelled with blue tape is a solar panel without a cooling system, while a solar panel labelled with a red tape is a solar panel with a pulsating heat pipe cooling system.

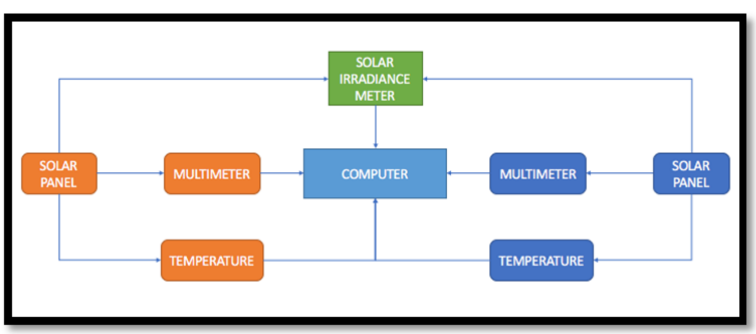

Figure 4. System connection for the experiment

2.5 Data Analysis

Using the data obtained from the meters, the electrical power output is calculated using the power formula:

$$P = I \times V$$

The system efficiency, which is the electrical power output over the solar irradiance input is calculated using:

$$\eta = \frac{P_{out}}{P_{in}} = \frac{I \times V}{E \times A} = 100$$

where:

$$I = current; V = voltage; E = solar\ irradiance; A = area\ of\ panels$$

Graphs of temperature vs. time and power output vs. time for both panels are plotted to compare the differences of the panel with and without any cooling method applied. The energy output for both panels are then calculated and compared, which is the sum of each power multiplied the time duration in hours for each time interval, or the formula:

$$E = \sum_{t=0}^{n} P \times t$$

$$t = time; n = final\ interval; P = electrical\ power\ output;$$

3. RESULTS AND ANALYSIS

The data collected is summarized in the Table 2. Table 2 shows the data recorded from the measurement devices for both panels with and without the heat pipe cooling method. The irradiance maintained below 1000 W/m2 throughout the measurement. The data was recorded from 1205 at noon until 1250 with the interval of 5 minutes. The lowest irradiance recorded was 886W/m2 occurring at 1225 and the highest was 992W/m2 occurring at 1205 and 1245. It can be seen that the general trend is that the temperature of the panel with heat pipe is lower compared to the one without.

Table 2. Measured data

Time	Solar Irradiance	Temperature	Current	Voltage	Temperature	Current	Voltage
		Without Heat Pipe			With Heat Pipe		
(Hour)	(W/m2)	(°C)	(Amp)	(V)	(°C)	(Amp)	(V)
1205	992	35	0.6	16.12	35	0.6	16.7
1210	957	40	0.73	15.59	39	0.7	16.8
1215	900	42	0.77	15.6	41	0.78	15.7
1220	887	42	0.89	15.1	39	0.89	15.8
1225	886	44	0.79	15.8	39	0.82	15.7
1230	916	48	0.82	14.9	40	0.87	15.7
1235	954	50	0.87	14.9	40	0.98	15.8
1240	989	51	0.92	14.8	44	0.99	15.9
1245	992	48	0.98	14.9	44	0.98	15.8
1250	912	49	0.97	14.8	44	0.98	15.9

The temperature difference between the two panels was calculated and plotted against the output current difference as shown in Figure 7 . It can be seen that the higher the temperature difference between the two panels, the higher the output current difference. Using linear regression, it can be seen that there is a high correlation between the two parameters, which has a coefficient of correlation (R) of 0.88 and a coefficient of determination (R2) of 0.7779. Since the input irradiance is the same for both panels, it can be concluded that the higher the temperature of the panels, the higher the output current.

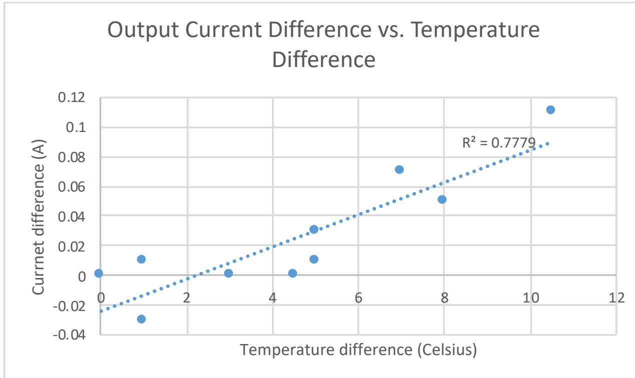

Figure 5. Graph of current difference vs. temperature difference

Table 3 shows the power output, energy output and panel efficiency calculated based on the data measured. It can be seen that throughout the time, the temperature of the panel with heat pipe cooling is consistently lower, having the minimum difference of 1 Celsius and the maximum difference of 10.5 Celsius at 1235 in the afternoon. The initial temperature difference is 0 Celsius due to the panel is exposed in the sun long enough to be affected. It can also be seen that the power output of the panel with heat pipe cooling consistently lower, with up to 2.5125W more power output or 19.45% higher at 1235 pm. The energy output throughout the measurement period is 10.562Wh for the panel without heat pipe cooling and 11.409Wh for the panel with heat pipe cooling, which is 8.025% more. However, to evaluate the overall improvements of the performance, a longer period of experiment needs to be conducted.

Table 3. Calculated output

Time	Solar Irradiance	Power input (irradiance)	Without Heat Pipe: Power output	Without Heat Pipe: Energy	Without Heat Pipe: Efficiency	With Heat Pipe: Power output	With Heat Pipe: Energy	With Heat Pipe: Efficiency	Panel Temp. Difference	Power Output Difference	Energy Output Difference
(Hour)	(W/m2)	W	W	Wh	%	W	Wh	%	(°C)	W	Wh
1205	992	173	9.672	0.81	5.584	10.02	0.835	5.785	0	0.348	0.029
1210	957	167	11.381	0.95	6.811	11.76	0.980	7.038	-1	0.379	0.032
1215	900	157	12.012	1	7.644	12.246	1.021	7.793	-1	0.234	0.020
1220	887	155	13.439	1.12	8.678	14.062	1.172	9.080	-3	0.623	0.052
1225	886	155	12.482	1.04	8.069	12.874	1.073	8.322	-5	0.392	0.033
1230	916	160	12.218	1.02	7.639	13.659	1.138	8.540	-8	1.441	0.120
1235	954	167	12.963	1.08	7.782	15.484	1.290	9.296	-10.5	2.521	0.210
1240	989	173	13.616	1.13	7.885	15.741	1.312	9.116	-7	2.125	0.177
1245	992	173	14.602	1.22	8.431	15.484	1.290	8.940	-4.5	0.882	0.074
1250	912	159	14.356	1.2	9.016	15.582	1.299	9.786	-5	1.226	0.102
Total Energy (Wh)				10.562			11.409		Difference		0.848

Figure 8 shows the electrical power output of both panels against time. It can be seen that the panel with heat pipe is continuously producing more power compared to the one without. It can also be seen that the highest difference of power output occurs at 1235, which is also the time at which the temperature difference is the highest, although the temperature is not the highest recorded. The highest panel temperature recorded is 51 Celsius at 1240, for the panel without heat pipe.

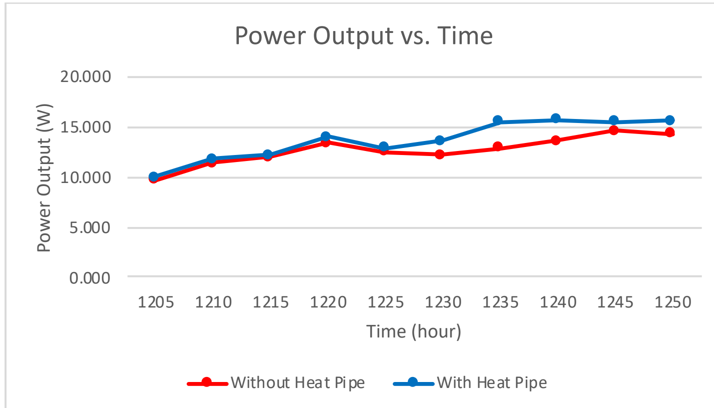

Figure 6. Graph of power output over time

Figure 9 shows the graph of panel efficiency against time. It can be seen that the panel with heat pipe is consistently higher in efficiency compared to the one without. The highest difference in efficiency also occurs at 1235, which is the time at which the temperature difference is the highest between the two panels. Although the temperature is higher at the time, it can also be noted that the irradiance is also high, recorded to be above 900W/m2, so a higher input power is available.

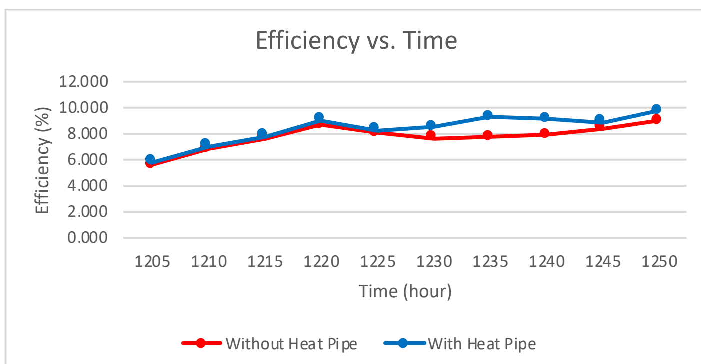

Figure 7. Graph of panel efficiency over time

4. CONCLUSION

This paper has presented the result of incorporating pulsating heat pipe on the back plate of a solar PV panel. The addition of pulsating heat does increase the performance output of the solar panel, with up to 19.45% more electrical power output and 8.025% energy produced. The temperature of the panel is lowered up to 10.5 Celsius. If the cost can be kept small compared to the overall cost of PV installation, there is potential of lowering the payback period of solar PV projects and increasing the return of investment. However, a lot more design work needs to be done and also the production method if the cooling method is to be applied at commercial scale. To better study the improvement offered by the pulsating heat pipe, a controlled environment is needed, which can give a controlled irradiance, ambient temperature and wind speed, at which one parameter can be manipulated at one time while the others are kept constant. This study looks at the output in the real-life environment. Using pulsating heat pipe requires no pumps for moving fluid, so it requires no external energy.

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