KKU ENGINEERING JOURNAL 2016;43(S1):47-51 Research Article

KKU Engineering Journal

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Performance study of solar panels with cooling systems at low ambient temperature

Ittipol Hindee, Gridsada Lampongchat and Nuchida Suwapaet*

Bio-Energy and Renewable Resources Research Unit, Faculty of Engineering, Mahasarakham University, Kamrieng, Kantarawichai, Maha Sarakham 44150, Thailand.

Received April 2016
Accepted June 2016

Abstract

Solar panel temperature affects its conversion performance, which decreasing at high panel temperature. A water cooling system was designed and tested during winter at Maha Sarakham, Thailand when the ambient temperature was approximately 25°C in February. It was found that the front panel cooling system with the lowest panel temperature led to the best overall performance. Interestingly, even though the no cooling system had the highest panel temperature, it performed better than the back panel cooling system. Reduction of panel temperature increased output voltage but conversely reduced output current. In conclusion, the cooling system had little effect at ~25 °C ambient temperature and ~1000W/m^2 solar radiation. Even though the ambient temperature is low, solar panel temperature still affects the output voltage in a way that consequently reduces the overall solar panel performance**.**

Keywords: Solar panel, Cooling system, Ambient temperature

1. Introduction

Photovoltaic devices or solar cells covert solar radiation to electrical power and are used widely as a replacement for thermal power. Thai energy consumption is increasing every year [1] and using renewable energy to produce electricity is a growing trend. Recently, many solar farms generate electricity and sell it to government [1]. However, with the low efficiency of only 15-20% of solar energy converted to electrical power, the investment seems not appealing to investors, so researchers are trying to improve solar panel system performance worldwide.

Factors that cause solar panels to perform poorly are shading, dust and high working temperature [2-7]. Attempts to reduce the panel temperature include several types of coolant as well as cooling location selections. Water is one of the coolant options either on front panels [6-8] or back of the panels using water [9] or air ducts [10]. In all cases, the results showed that temperature reduction increased performance with water and air ducts giving similar results.

Water has many advantages as a coolant for solar panel systems not only reducing working temperature, but also could clean dust from the front surface [6, 8]. Waster cooling water can be reused for washing, watering plants and other general purposes. Therefore, we studied solar panel performance after applying water cooling systems to evaluate results during winter in Maha Sarakham, Thailand.

2. Methodology

We constructed cooling systems for solar panels of two types (1) back and (2) front panel cooling systems. The back panel cooling system had a water container attached at the back of the panel. Water was pumped into container and was kept there to absorb heat. The front panel system had water spray nozzles installed on top of the inclined solar panel. Water was sprayed over the surface to cool down the panel temperature.

The experimental setup (Figure 1) consisted of no cooling system (NCS), back panel cooling system (BPCS) and front panel cooling system (FPCS). The BPCS and the FPCS were connected for minimal water usage. Water would be passed first through the BPCS then through the FPCS. A water filter was included in the design because we aimed to be able to use any available water, i.e. irrigation water, fish farm water or river water, as coolant. Also for the FPCS, it is necessary to use clean water otherwise the spray nozzles maybe clogged. Moreover, the space underneath the panel was used effectively for the water filter system.

The solar panels were inclined 16° from the horizontal facing south which is the best position for irradiation in Maha Sarakham at ~16°N [11]. The experiments were run for 10 days in February, 2016 at Faculty of Engineering, Mahasarakham University (16.245751°N, 103.253785°E) from 9 am – 3.05 pm.

*Corresponding author. Tel.: +6686 868 2998; +66 4375 4316
Email address: Nuchida.s@msu.ac.th
doi: 10.14456/kkuenj.2016.67

Figure 1 Experimental systems

The panels were assembled with the cooling systems. The height above the ground of each set was 850 mm at front and 1000 mm at rear. It allowed enough space for small water filter system. The BPCS water container under the panel was made of 5 mm thick acrylic and 560 mm in width, 612 mm in length, and 50 mm in height. There were 5 water inlets at the top of the container. Water was drained out at the bottom of the container via 2 outlets. Then, used water would flow through a water filter which sit underneath the panel frame and pumped to the FPCS to be sprayed from 12 180-degree nozzles that placed 40 mm apart. The front surface of panel would be covered with thin film of water. After absorbing heat, water was collected and drained out to another filter. The final filtered water could be used for cleaning and other general purposes.

Before starting the test, water was filtered and prepared for FPCS in the water filter tank. The test started at 9 am when the water was pumped from the water tank to the BPCS. It took about 1 minute to fill up the water container. When BPCS was filled up with water, FPCS started to spray water onto the surface. Water was kept at BPCS for 3 minutes and water was sprayed for 3 minutes at FPCS as well. Used water from FPCS would flow through water filter and stored in the clean water tank. Water from BPCS was drained out and flow through water filter and stored in the tank. The water from BPCS would be used for FPCS for the next cycle of cooling. Each cycle started every 15 minutes. The measurements of I_{SC} (short circuit current) and V_{OC} (open circuit voltage) were carried out twice for each cycle, i.e., at the start and at 5 minutes into the cycle. A multi-meter measured data which was recorded manually. Solar panel temperatures were recorded every 1 minute via thermocouple type K and a data logger (Wisco AI-2010). The sensor locations on the front surface of the panel are shown in Figure 2. Solar radiation was measured by pyranometer (Kipp & Zonen CM11). Ambient temperature and wind speed were manually recorded using thermometer and hot wire anemometer (Lutron AM-4214SD).

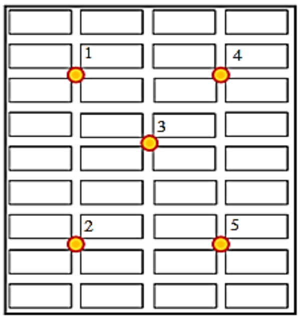

Figure 2 Temperature sensor positions on panel front surface

3. Results and discussion

The experiments were run for 10 days in February, 2016. Data of the 17th February 2016 was chosen as representative of the 10 days.

3.1 Solar radiation and ambient temperature

During the test period, the highest solar radiation of 1007 W/m^2 was at 12:05 pm and the ambient temperature increased over the whole period in the range from 22.1 – 28.2 °C with an average of 25.6 °C.

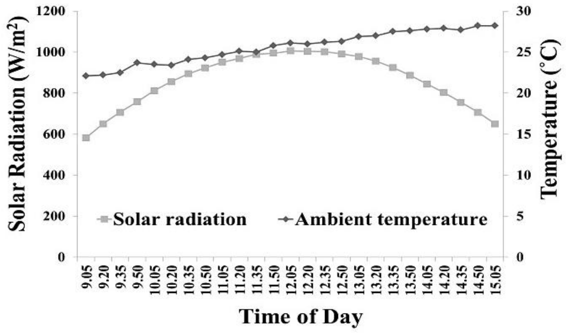

Figure 3 Solar radiation and ambient temperature during the test period

3.2 Solar panel temperature

The panel temperatures for NCS, BPCS and FPCS are shown in Figure 4. Results showed that panel temperatures of BPCS and FPCS were lower than those of NCS. The panel temperatures of BPCS and FPCS were in the range of 23.8-36.8°C and 18.5-29.7°C, respectively. Noticeably, panel temperature was close to ambient (Figure 3) for FPCS. FPCS reduced panel temperature significantly and was better than BPCS. For FPCS, the cooling water directly contacted the front surface of solar panel then absorbed heat and partly evaporated. Even though the cooling water in BPCS also contacted the back surface of the solar panel, heat actually accumulated at the front. However, BPCS still reduced the panel temperature. The highest panel temperature of 54.5 °C was measured for NCS at 12:20 pm. The solar panel temperatures of NCS tended to vary directly with solar radiation (Figure 3).

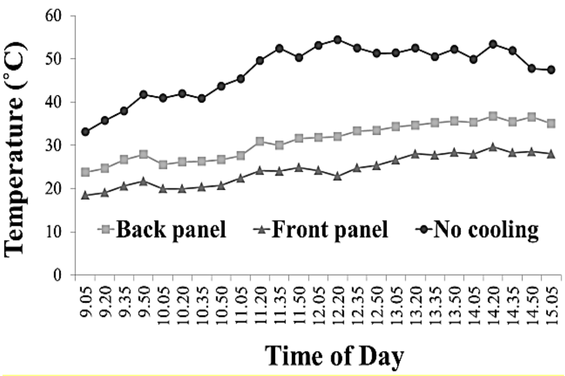

Figure 4 Solar panel temperatures for NCS, BPCS and FPCS during the test period

3.3 Open circuit voltage (V_{OC})

Figure 5 shows V_{OC} for NCS, BPCS, and FPCS. V_{OC} values decreased as panel temperatures increased for all systems. The working temperature of solar panels directly affected their voltage output, the specification (Table 1) suggest that for every 1 degree temperature increase, voltage would drop 0.1%. Both cooling systems improved the voltage output. The highest output voltages were FPCS 21.6V, BPCS 21.1V, and NCS 20.6 V. These values conform to expectations: lower temperatures lead to higher output voltage and similar to other reports [2-8].

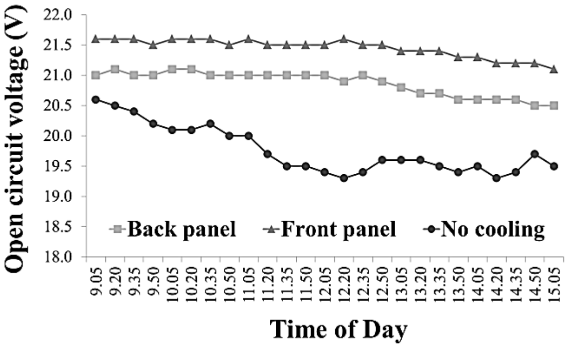

Figure 5 Open circuit voltage, V_{OC}, for NCS, BPCS, and FPCS during the test period

3.4 Short circuit current (I_{SC})

Figure 6 shows that I_{SC} for all systems trended similarly to solar radiation data in Figure 3. Even though the NCS panel temperature was the highest, it also had the highest I_{SC} value. This differs from previous results [5, 7, 12-13] which showed that I_{SC} would increase slightly when the working temperature decreased.

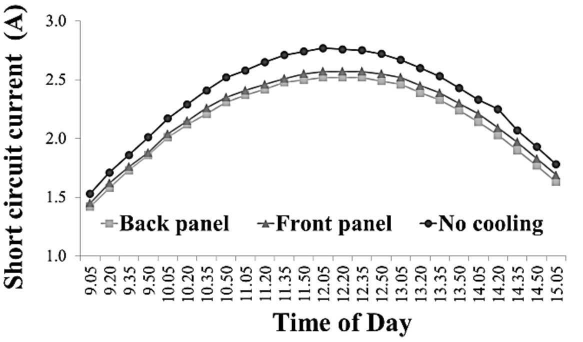

Figure 6 Short circuit output current, I_{SC}, for NCS, BPCS, and FPCS during the test period

In particular, Suwapaet et al. [7] similar NCS and FPCS systems were tested and reported an ambient temperature in the range 30.4 – 36.8 °C and the highest solar radiation was 710 W/m^2. Suwapaet et al. [7] showed that the NCS panel temperature was higher than that of FPCS while I_{SC} for NCS was lower than that of FPCS. This is possibly due to better optical performance on the front surface from water cleaning [12].

However, the I_{SC} increased with the panel temperature at ambient temperatures around 25°C, in contrast with previous work at much higher ambient temperatures [7]. The ambient temperature (T_{amb}) might be the key factor.

Table 1 Specifications of solar panel at standard test conditions (STC) [14]

STC condition measurements	
Output power (peak W)	40
Working voltage, V_{mp} (V)	17.5
Working current, I_{mp} (A)	2.29
Open voltage, V_{oc} (V)	21.5
Short circuit current , I_{sc} (A)	2.55
Fill factor (I_{mp} x V_{mp} / I_{sc} x V_{oc})	0.7309
Current temperature coefficient	+0.035%/°C
Voltage temperature coefficient	-0.33%/°C
Power temperature coefficient	-0.47%/°C

The solar panel specifications are shown in Table 1[14].Those measurements were made under standard test conditions (STC) of 1000 w/m^2 solar radiation, Air Mass 1.5 spectrum and 25°C operating temperature. During our experiments, T_{amb} was relatively low for February month in Maha Sarakham (Figure 7). In Figure 3, T_{amb} ranged from 22.1 – 28.2 °C during the test period whereas the panel temperature ranges were 18.5 – 28.0 °C for FPCS and 23.8 – 35.1 °C for BPCS.

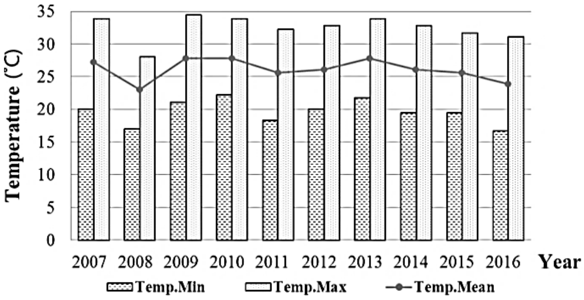

Figure 7 10 year temperature history in February in Maha Sarakham, Thailand [15]

In attempt to explain the incident, we looked at the experimental data that closed to the specification data and shown in Table 2. Solar radiation was at least 1000 w/m^2 from 11.35 am to 1.05 pm with T_{amb} from 25.0 – 26.9 °C. Results showed that NCS produced the highest I_{SC}. Thus, panel temperature reduction had no significant effect on short circuit current, I_{SC}, when T_{amb} was close to 25 °C (STC value). I_{SC} differences between FPCS and BPCS were very small. It might be due to the difference in the individual efficiency of each testing solar panel, accumulative dust at front of BPCS, or the temperature reduction affected the current production. Theoretically, when the cell temperature increases, the band gap of a semiconductor would shrink and the V_{OC} would decrease accordingly. On the other hand, more electrons could be promoted from the valence band to the conduction band and then the incident energy is more absorbed which lead to the increase of I_{SC}. Since the rate of charge carrier generation increases with cell temperature, therefore low cell temperature would result in decreasing I_{SC} [3, 16-17]. However, we will focus on this topic in our future work.

Table 2 Experimental data at solar radiation of ~ 1000 w/m^2

Time	Solar radiation	T_{amb}	NCS		BPCS		FPCS	
am/pm	W/m^2	(°C)	I_{SC} (A)	V_{OC} (V)	I_{SC} (A)	V_{OC} (V)	I_{SC} (A)	V_{OC} (V)
11:35	989	25.0	2.71	19.5	2.48	21.0	2.51	21.5
11:50	994	25.8	2.74	19.5	2.50	21.0	2.55	21.5
12:05	1005	26.1	2.77	19.4	2.52	21.0	2.57	21.5
12:20	1003	26.0	2.76	19.3	2.52	20.9	2.57	21.6
12:35	1001	26.2	2.75	19.4	2.52	21.0	2.57	21.5
12:50	990	26.3	2.72	19.6	2.49	20.9	2.55	21.5
1:05	978	26.9	2.67	19.6	2.46	20.8	2.52	21.4

3.5 Power output

Panel power output ($P = I_{mp} \times V_{mp}$) was computed from Fill Factor (Table 1), I_{SC}, and V_{OC} and shown in Figure 8. Power output from NCS, FPCS, and BPCS differed slightly with BPCS having the lowest power output. NCS and FPCS had approximately the same power output from the beginning of the test period until 11.05 am. After 11.20 am, FPCS had higher power output than NCS, even though NCS had higher I_{SC} (Figure 6), FPCS had significantly higher V_{OC} than that of NCS (Figure 5), therefore, it tended to produce more power output in overall.

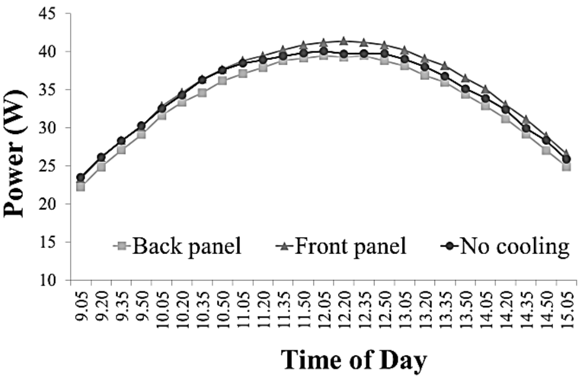

Figure 8 Power output from NCS, BPCS and FPCS during the test period

4. Conclusions

The performances of solar panel with cooling systems using water were investigated at low ambient temperature in Maha Sarakham, Thailand. Water was used to spray at front panel and to absorb heat at the back panel. We concluded that the cooling system might not be necessary at ambient temperatures close to 25 °C which typically found in the Thai winter.

Surprisingly, the no cooling system (NCS) produced power output similar to the spray cooled (FPCS) one and better than the back surface cooled (BPCS) one. Reduction of panel temperature increased output voltage but conversely resulted in lower output current. Nevertheless, FPCS, with the lowest panel temperature, showed slightly better performance than the no cooling one (NCS). Even though the ambient temperature is low, solar panel temperature still affects the output voltage in a way that consequently reduces the overall solar panel performance.

5. Acknowledgement

We would like to thank Chhaina Se, Apisak Palalert, Chadatorn Dawyan, and Jutarat Somkhunthod for their helping hands. We also thank the Mechanical Engineering Laboratory, Faculty of Engineering, Mahasarakham University for lending the pyranometer to record the solar radiation data.

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