Research on Different Types of Cooling System on Ground Mounted Solar Photovoltaic System for Electrical Output Enhancement

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Abstract. Solar photovoltaic (PV) can be used to generate power by using semiconductor materials to convert solar energy into electricity. In Malaysia, solar PV technology plays a significant role in increasing renewable energy generation capacity target at 20% by 2025. Malaysia’s strategic location at the equator makes it possible to achieve this target. However, several challenges need to be mitigated when implementing this technology, among others is the effect of temperature on solar PV system performance. Solar PV panel is currently rated at a range of efficiency between 13% to 20%. The efficiency of the PV panel is affected by temperature where the PV power and efficiency decrease at the rate of -0.5%/°C and -0.05%/°C respectively as the ambient temperature increases. This study aims to evaluate the effectiveness of different types of PV cooling systems in reducing the solar PV panel temperature. In this study, the PV systems were retrofitted by two types of cooling system which are passive cooling and active cooling systems. The results of panel temperatures were measured against the control system without the cooling mechanism. The research was conducted in real operating condition with direct sunlight. Active cooling system reduced the temperature of the PV system and improved the electrical output by 4.9% while the best passive cooling system improved the output by 3%. Factors contributing to the results are also discussed in this paper.

Keywords: Solar PV, photovoltaic, solar cooling, temperature, passive, active

1. Introduction
Malaysia aims to achieve 20% of renewable energy generation capacity by 2025 [1]. As an alternative energy resource, renewable energy provides a greener solution in replacing fossil fuel to meet the energy demand. Solar, in particular, poses the biggest prospect of renewable energy for Malaysia to venture into with the advantage of its location in the equator. Malaysia’s hot and sunny weather all
year round makes it a high potential for solar power generation [3]. The estimated potential capacity of solar energy in Malaysia can reach up to 6,500 MW [4]. The Energy Commission (EC) of Malaysia on the other hand has begun the bidding process for the Large Scale Solar (LSS) scheme since 2016. LSS is considered as a transparent mechanism for awarding LSS projects to achieve the government’s renewable energy target [5].

In solar PV technology, there are several factors that may reduce PV system performance, for instance, dirty solar panels, cloud cover, sun intensity, relative humidity, and heat buildup on the solar PV cell. The increase in PV panel temperature when it absorbs the solar radiation reduces the efficiency of the PV cells in generating electricity. Although the efficiency loss might be viewed as miniscule by some, when it comes to large scale solar farms, this may translate to large sum of revenue loss.

In the current solar PV panel market, the range of efficiency of the panel is rated between 13-20% under Standard Test Condition (STC) [2]. The solar PV output is dependent on the panel operating temperature and the irradiance level [6]. The operating temperature of a solar PV under the STC is typically 25 °C to maintain the efficiency of the panel. Therefore, the efficiency of the PV panel will decrease if the operating temperature continues to increase. Every 1 °C increase on a 25 °C operating temperature will have a reduction in electrical power output of the solar PV panel up to 0.5% [7].

In this particular study, the cooling systems have been classified accordingly as stated by Sainthiya and Beniwal [8] which separate into two different cooling techniques which are passive and active cooling systems. The passive cooling system operates without external power consumption while the active cooling system requires external power to operate the cooling mechanism of the system. Abdolzadeh and Ameri [9] have carried out an active cooling experimental study by spraying water over the solar PV cells using a water pumping system which was able to achieve up to 23 °C temperature reduction. Hernandez [10] has performed an experiment on passive cooling by installing aluminium alloy heatsinks with a 40 mm thin fins attached to the rear side of the solar PV panels and proved a maximum temperature reduction of 10 °C.

This paper presents a study on different types of cooling technology in reducing the solar PV panel temperature using both active and passive cooling techniques. Previous studies have conducted similar research using outdoor experiment approach. However, most of these studies are lab-scales, utilizing rather small PV panels with capacity of less then 100 Wp and PV panel area of less then 0.5 m². In this paper, cooling technologies were retrofitted on 10 commercial ground-mounted solar PV panels, each with capacity of 370 Wp and 1.9 m² effective area, that are exposed to natural sunlight to mimick actual PV system operation in Large Scale Solar farms.

2. Design and methods

In this study, a total of 3.7 kWp grid-connected, ground mounted solar PV systems were used. Each system consists of two PV panels rated at 370 Wp each and were connected to a micro-inverter to convert direct current (DC) output of the PV panel into alternate current (AC) which is the current mode for the grid. The system also consists of a monitoring and data acquisition system which is a data logger that was connected with thermocouples attached on the rear side of the solar PV panels. Table 1 shows the list of equipment used in the experiment. The PV panels used have the temperature coefficient of power equals to -0.39% / K which means each increment of K (or °C) of the PV cells will reduce the electrical power produced by 0.39%. The thermocouples were attached using tapes to
the back of the PV panel, right in the middle, sandwiched between the PV panel and the cooling system.

The ground-mounted solar PV systems were retrofitted with four (4) different types of cooling systems and one (1) control PV system with no cooling system. The cooling systems used in this study were active cooling system and three (3) passive cooling systems. The description of each system is presented in Table 2. These installations were set up on a field within TNB Research Sdn. Bhd. premise compound in Kajang, Selangor. The nearest source of shading is a 4 m tall slender palm tree, 7 m from the setup. Other than this source and the clouds, the setup is shade-free.

The configurations of the cooling systems and the equipment are illustrated in Figures 1, 2, 3 and 4. The study was carried out to measure the temperature of the solar PV panel in each system as listed in Table 2. The temperature reading was obtained by attaching thermocouples at the backside of solar PV panels. The temperature readings were then logged to the data logger with an interval of one minute. The experiment ran for six days from 24th Dec 2019. The results obtained from the thermocouples at each system were tabulated for the period and presented based on daily temperature readings and the analysis for the week. The performance of all the cooling systems was analysed and evaluated.

Table 1: Equipment and instrument used in the experiment

| Equipment/Instrument                      | Purpose                                           |
|-------------------------------------------|--------------------------------------------------|
| Monocrystalline PV panel (Hanwa Q Cell 370 Wp, Temperature Coefficient of Power -0.39 %/K) | Converts solar energy to electrical energy        |
| Micro-inverter                            | Converts direct current (DC) generated by PV panel to alternating current (AC) |
| Data logger                               | To monitor and collects data from the thermocouples |
| Thermocouple type K                       | Measures the temperature at the backside of the PV panel |

Figure 1. System 2

Figure 2. System 3
Table 2: Types and description of solar PV cooling systems tested in this study

| System ID | Types of cooling system | Description | Simplified Diagrams |
|-----------|-------------------------|-------------|---------------------|
| System 1  | Reference system        | No cooling system. | N/A |
| System 2  | Active cooling system   | Active cooling with nanofluid-based (SiC) PV/T using Split Flow Absorber with 10 Columns of Copper Tubes. Heat absorbed by the nanofluid is exchanged with water. | |
| System 3  | Passive cooling system  | Passive cooling with 31 lapping longitudinal fins (Aluminum). | |
| System 4  | Passive cooling system  | Passive cooling with 32 longitudinal fins (Aluminum). | |
| System 5  | Passive cooling system  | Passive cooling with 11 lateral fins (Aluminum). | |
3. Results and discussion

Measurements were performed from 9.00 to 6.00 pm everyday. The results of the PV panel temperature against time of the day were plotted. Figure 5 shows the temperature readings fluctuate throughout the day. There is a number of explanations towards the fluctuation, including the solar irradiance, which in this study was not diligently measured throughout the day, therefore is not presented. Another explanation is the potential shadings from nearby objects that may affect the temperature readings. However, there is a noticeable peak each day that occurred in the time interval of 11.30 am – 1.30 pm. It is deemed that these peaks are contributed by the high solar irradiance during noon.

As for the comparison for which cooling system provide the most promising result, System 2 (active cooling system) had the lowest temperature reading for the whole week. Based on Figure 5 (b) Day 2, System 2 has the lowest temperature reading which is 11.1% cooler than the reference system during the hottest time of the day. System 5 showed a promising result for a passive cooling system with 10.2% cooler than the reference system. However, Systems 3 and 4 have only a slight difference in temperature reduction with the result of 1.2% and 4.4% respectively when compared to the reference system.

The average and maximum temperature differences between all of the cooling systems installed and the reference system were plotted as shown in Figures 6 and 7. These plots proved that System 2 has the most reduction in temperature compared to other cooling systems. Maximum temperature difference is 12.5 °C which translate to 4.9% of power improvement due to temperature coefficient of power of the PV panel. System 3 has an inconsistency that occurred as the average temperature difference is sometimes lower than the reference system in the measurement period. System 5 shows the best results among the passive cooling systems with maximum temperature difference of 8 °C which translate to 3% electrical power output improvement.
The effects of shading also play a role in the temperature level of the solar PV panel. As illustrated in Figure 5 (a) Day 1 and (d) Day 4, System 2 has a significant drop in temperature reading at a certain time compared to the other cooling systems. This inconsistency of temperature drop was caused by the shading from nearby tree closest to System 2 as described in Design and Methods.

4. Conclusion

The research project was performed to analyze and evaluate the effectiveness of four solar cooling systems in reducing the temperature of ground-mounted solar PV system. Out of the four cooling technology installed, the results of this study show that the active cooling system (System 2) has a better overall performance than the other cooling systems installed with the reduction of temperature level up to 11.1% that improves the electrical power output by 4.9%. System 5 has the best results for the passive cooling system with up to 3% electrical output improvement and can be nominated as the best cooling system for retrofit on the existing solar PV system as the installation of the heat sink fin
is much easier and cost less than System 2. Furthermore, the reduction in the temperature of the solar PV panel would benefit the end-user due to the increase in the levelized cost of energy (LCOE) which will have a direct impact on reducing the overall financial cost. Some gaps and challenges were identified when conducting this study. Such challenges would be the complexity of the installation for the active cooling system (System 2) compared to the other cooling systems. Unpredictable weather conditions also have an impact on the data because it will be difficult to see the differences in temperature of each system at a low ambient temperature.

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