Advances of Solar PV System Output Improvement through Cooling Technologies in Malaysia

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Abstract. Solar photovoltaic (PV) panel is the most widely used renewable energy technology in Malaysia due to constant irradiation throughout the year as the country is located near the equator. According to the current state of the Malaysian weather, the ambient temperature is around 25°C and can go up to 30°C. The electrical efficiency of a PV panel is sensitive towards temperature where it is known that the power and efficiency decrease at the rate of ±0.5%/°C and ±0.05%/°C respectively as the ambient temperature increases [1]. This paper discusses the cooling of solar PV technologies, the methodologies of the cooling system and its effectiveness. Generally, the effectiveness of the studies conducted were derived from the solar PV panel temperature reduction and solar PV electricity power output increment. This paper elaborates the trend of methodologies for cooling of solar PV in Malaysian climate. The methodologies that were used by the researchers vary according to the specific objectives which can be categorized as active cooling and/or passive cooling. The gaps of the studies were also identified alongside with the possible solutions to mitigate the problems.

1. Introduction

Increase in the world population reflects a rapid increase in the utilization of energy. Conventional method in meeting the energy demand is through fossil fuels. However, this possesses several problems such as it is non-renewable and emits harmful green-house gases. Renewable energy has then tried to make its way as an alternative energy resources, replacing fossil fuels. Solar energy is the most interesting and promising source of renewable energy with a huge potential in meeting the energy demand. Malaysia in particular is located at the equator which means it receives constant amount of solar energy throughout the year thus making solar photovoltaics (PV) the most widely practiced renewable technology. Most commercial PV modules uses silicon as its materials. The PV modules can be classified according to the type of crystals such as amorphous silicon, polycrystalline silicon and monocrystalline silicon. PV panels work by converting solar radiation that are incident over the panel into direct current (DC) which will then passes through inverter to convert it into alternating current (AC). The current must be converted to AC as AC can be transported over long distances due to its frequency. The electricity is then used for self-consumption, stored in a battery system or injected into the grid.
The efficiency of PV panel is very limited which is approximately around 15% - 20% [1]. This efficiency is sensitive towards temperature. When solar radiation hits the PV panel, it generates electricity and absorbs heat. This heat increases the temperature of the panel which in turns effects the panels’ efficiency. PV output power is dependent on panel operating temperature and radiation incidence [2]. To maintain the efficiency of the panel, the panel must operate at the operating temperature under the Standard Test Condition (STC) or typically 25°C. Continuous increase in temperature results in the decrease of efficiency of PV panel. Different type of panels has different drops in efficiency, where for every 25oC increase in temperature, there is a 0.25% efficiency drop in amorphous cell and 0.4%-0.5% drops for crystalline cells [3].

In order to reduce the solar PV temperature increment, various methods can be deployed to achieve the STC and maximum PV efficiency. One of the methods is through cooling mechanism. Solar cooling techniques can be categorised into two distinguish categories which are passive cooling and active cooling. Active cooling can be regarded as methods that continuously consume power in order to cool the PV module. For examples, front water cooling and fan-forced cooling system. Opposite of active cooling is passive cooling which does not involve any consumption of power such as pump or fan. Typically, passive cooling can be classified into three main groups which are, air passive cooling, water passive cooling and conductive cooling. Although there is a wide range of solar cooling methods, active cooling water pumping cooling system is the most opted cooling mechanism for solar cooling in developing countries [4].

Throughout the years, several papers have been published regarding the cooling system for PV, including reviews on cooling technologies that are used globally [5]. According to Sainthiya H. and Beniwal, N. S. [4], active cooling is the most opted cooling mechanism for solar cooling in developing countries. This paper provides an overview of the cooling system for both passive and active cooling methods focusing its application in Malaysian climate.

2. Passive cooling technologies
Passive cooling extracts heat without any power consumption. There is a wide range of passive cooling technologies that are available nowadays with the simplest forms such as installing PV on rooftop and allow the natural air convection on the backside of the panels or the integration of materials with high thermal conductivity such as metals (aluminium, copper, etc.) or even biological methods such as planting trees under the PV ground-mounted structure where these plants acted as heat-sink. Table 1 refers to passive cooling technologies that have been studied specifically in Malaysia. Sheikh, et. al. [6] submerged the solar PV panel in fresh water as part of its cooling system. figure 1 illustrates another example of a passive cooling method, which is the biological method using Java tree plants, planted under the PV panels as heat sink which translate into almost 3% increase of annual energy generation.

| Ref. | Method                                                                 | Performance improvement                  |
|------|------------------------------------------------------------------------|------------------------------------------|
| [6]  | Submerging solar panel at all times featuring gravity and fresh water pipe | 47% increase in daily electric power produced |
| [7]  | Planting Java tree under PV mounting structure that acts like heat sink | 2.77% increase in annual energy generation |
Figure 1. Biological method of passive cooling by placing Java tree under PV modules [7]

3. Active cooling technologies

Active cooling system requires additional powers to extract heat from solar PV. Additional power is for pumps or fans that promote full circulation of heat sink, either on top or bottom of the PV panel. Both forced air flow and liquid flow induced by the pumps or fans create a more uniform temperature reduction on the PV panel. Due to constant consumption of power, the benefit of active cooling is considered from its efficient thermal energy harvest, instead of the electrical output. Table 2 refers to active cooling technologies that have been studied specifically in Malaysia.

Among others are Edaris, et. al. [8] who have studied the effects of water spray on PV panel and Zulkefli, et. al. [9] who performed experiment of thin water film on PV panel as well. Figure 2 shows what Edaris, et. al. [8] has performed during their experiment, while figure 3 describes the improvement of such setup towards the reduction of PV panel temperature. As seen in the figure, the temperature is significantly reduced with water spraying/cooling. There is also studies of forced airflow as performed by Farhana, et. al. [11] where up to 12 ºC of PV panel temperature can be achieved. Last but not least, the use of chemical in the lights of phase change material (PCM) and glycol are also preferred to improve the liquid-induced cooling system. This was performed by Al-Waeli, et. al. [12] and Daud et. al.[13].
### Table 2. List of active cooling system studied in Malaysia

| Ref. | Method | Performance improvement | Temperature aspects |
|------|--------|-------------------------|---------------------|
|      |        |                         | Temperature of PV module | Temperature reduction |
|      |        |                         | Bottom PV module temperature: 54 – 63 °C (without cooling), 38–41 °C (with cooling) | 22 °C (in PV module temperature) |
|      |        |                         | Average PV module temperature compared to ambient T: 70% higher (without cooling), 30% higher (with cooling) | 12 °C or 40% (in PV module temperature) |
|      |        |                         | N/A | N/A |
|      |        |                         | N/A | N/A |
|      |        |                         | N/A | N/A |
|      |        |                         | N/A | N/A |

#### Note
- Edaris, Z.L et. al (2018)
- Farhana, Z et. al (2012)
- Daud, M.M.M et. al (2012)
- Zulkefli, M.Z et.al (2018)
- Al-Waeli, A.H.A et.al (2018)

#### Figure 2. Front water surface cooling experimental setup – sideview [8]
4. The future of solar cooling in Malaysian solar farm landscape

Malaysia has recently opened tender for RM 2 billion for the large scale solar (LSS) scheme in February 2019 [14]. This is the third time such offer has being offered by the government. In this third time, the government has increased the quota for each developer from 30 MW during LSS 2, to 100 MW. Although lower electricity tariff may be achieved from this quota increment, however, more challenges will need to be addressed. This includes the operating temperature of the solar PV panels, especially when there are huge number of them installed. Based on the literature, the temperature of the PV panel can go up to 70 °C in Malaysian weather. LSS farm is prone to higher PV panel temperature due to the arrangements of the panels and the geographical and local weather reasons. On the other hand, to cater degradation and power loss, LSS farms are usually overdesigned up to 25\% larger. This is a typical exercise and indeed this requires serious additional costs to cover such overdesign.

Solar PV cooling technologies will be able to assist in mitigating these issues, through the followings:

1. Focus will be to install the cooling system in hotspot areas, regions in the LSS farm where high operating temperature is detected. This will indeed urge the technology to be in the form of retrofit, where the cooling system can be easily installed and can be transferred and re-installed as and when necessary, depending on the hotspot in the LSS farms. The cooling system will need to be light and mobile, and also robust to cater the need to reduce temperature in large areas.

2. Introduction of cooling system at certain areas in LSS farms will be able to increase the annual energy generation. This will ultimately match the benefit of overdesign as mentioned previously, and in turns, reduce the need of the latter. Studies of techno-economic analysis and comparison between the two still lack and should be performed.

Looking into technical-wise, active cooling shows substantial improvement in terms of temperature reduction and increment in PV output performance. Nevertheless, the power requirement and the comprehensive setup for active cooling may hinder industry players to implement such technology in bulk for their LSS farms. Passive cooling may be the best method as most of the technologies of passive cooling is light in weight and smaller in size compared to active cooling, although the PV power output improvement is not as good as active cooling. Based on the literature reviewed, robust study on various cooling design still lack variety in Malaysia.

On the other hand, another possible and feasible passive cooling method that can be considered in Malaysia that has not being discussed in this paper is floating solar PV. While it is preferred for many other reasons, for example reducing land use, reducing water evaporation where it is installed, floating solar PV can effectively reduce the operating temperature of the PV panel. A number of pilot scale floating solar PV systems have been installed in Malaysia – in Sg Labu, Sepang and Seri Manjung, where TNB Research has actively involved in. Studies on the effectiveness of such cooling method are still on going.
Studies and experiments that have been discussed in this paper indicate that considerable PV output improvement can be achieved through both active and passive cooling. Nonetheless, these studies were performed at lab scale and may not be representative for larger scale. LSS farms, for example, have a lot of other parameters that may affect the cooling system, compare to the ones tested in lab scale. These parameters include the PV layout and arrangement, land topography and even the huge number of PV panels itself. The impact of solar PV cooling in Malaysia should further be studied at a larger scale, at least at pilot size. This will allow the technology to further advance and will be able to be implemented in LSS farms in Malaysia.

Sections, subsections and subsubsections

5. Conclusions

This paper discusses the recent studies of cooling mechanism to regulate the PV temperature and ultimately enhance the performance of the PV system, focusing the research and implementation in Malaysian climate. This discussion shows that active cooling has substantial effects to decrease the PV working temperature, although most studies that were performed required a comprehensive setup of system for such cooling mechanism, including extra power requirement. On the other hand, passive cooling, although provide minimum PV performance improvement, stands as a promising solution for large scale solar farm as this system requires minimum setup and less cost compared to active cooling. More designs of solar cooling, be it active or passive, needs to be further explored for Malaysian climate. The current trend of solar cooling in Malaysia lacks competition; designs and methods available or presented are limited, while large scale solar farms key players are not strategically exposed to such technologies. Another setback found from this discussion is that these studies were performed at lab scale and are yet to be proven effective at larger scale. Pilot scale plants for these technologies are required, especially to study the responses such system in larger scale and to lure industry players towards its benefits

Acknowledgments

The research project is part of a larger research activity funded by TNB Research through Seeding Fund, R-C-SF-0336-19-003-1. The authors would like to express sincere gratitude to personnel involved in this research project, directly or indirectly.

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