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Innovative methods of cooling solar panel: A concise review

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Abstract. This article surveys the various mechanisms of suppressing the killing heat in the electrical performance when a high solar irradiance strikes the surface of the solar panel. In addressing this killing heat, suitable technologies of cooling (active and passive) must be adopted to checkmate the abrupt temperature increase in the solar panel. The theoretical and experimental results of previous studies were critically reviewed. The study suggests that the efficiency of solar panel can be improved beyond 45 % provided a suitable cooling technology can be adopted during the design and installation.

1. Introduction

Energy remains one of the criteria of judging the economic buoyancy of a country, state, community and humankind[1–4]. In recent time, researchers across the fields have been applying the interdisciplinary approaches in providing greener energy from renewable sources that will be sustainable to man and his organic habitat[5–7]. In addition, solar energy from the sun is a source of



electricity is gaining fast attention due to its ability to illuminate the earth seamlessly and cost-effectiveness over hydro, thermal, wind, tide, and fossil fuel inclusive [8,9]. Solar energy (renewable energy) is void of toxic waste; meanwhile, this toxic by-product is the trademark of fossil fuels such as greenhouse gases, carbon (iv) oxide, Sulphur (iv) oxide and nitrogen (iv) oxide. Surprisingly, with the level of harms, fossil fuel does to man's habitat and his health, a large number of countries still depends on fossil fuel in generating their energy[10].

Therefore, the future of solar energy remains steady and glittering because of the latest advancement in photovoltaic, solar concentrators, thermal energy collectors and discovery of new semiconductors and nanomaterials. Practically, photovoltaic remains the promising technology of converting solar energy to electricity as compared over solar concentrators and thermal energy collectors. In recent time, researchers noticed misbehaviour in the performance of solar panel specifically when it exceeds its operating temperature, which may lead to either low efficiency or destruction of the solar panel if certain precautions are not taken observed. Nevertheless, scientists have come with various cooling methods of making a solar panel to perform optimum as shown in Figure 1.

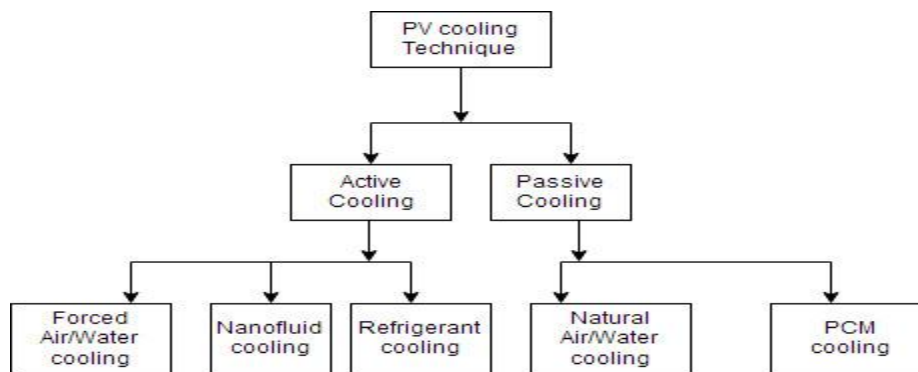


Figure 1: Schematic diagram of photovoltaic cooling methods [10]

2. Types of cooling methods

There are two types of cooling methods of improving the maximum power output and the efficiency of PV modules: active and passive cooling.

Active cooling techniques use energy either from the PV solar modules or from the external energy source to provide a cooling effect for the photovoltaic panels such as Forced air, nanofluid and refrigerant cooling as depicted in Figure 1[11]. While passive cooling methods adopt the natural, cooling means such as convection and conduction to extract heat from the solar PV panel such as natural air, natural water and PCM cooling concerning Figure 1[12]

2.1. Water method of cooling

Water is naturally known as a cooling agent for both domestic and industrial purposes like a steam power plant, refineries, chemical plant and the internal combustion engine. Furthermore, it is neither toxic nor expensive, and its storage heat capacity is high[13]. Impact of water in cooling the PV module during hot climatically condition has been studied [13]. A model was developed alongside experimental analysis for comparison and the model proved the efficacy of water in cooling PV module surface temperature to about 20 % and this assist in the increase of efficiency of PV module to about 10 % [14]. [14]carried out an investigation on the performance of P-V-T water collectors and it was observed that the efficiency of the P-V module increases at a decrease in temperature. Further

observation showed that a drop in temperature is not linear with the increase in mass of flow rate [14]. The investigation of [15] show that the water in the winding tube improved the efficiency of the PV by 25 % over Glycol cooled, water-ethylene glycerol mixture cooled and non-cooled P-V. Also, the adoption of the micro-channel absorber with the hydraulic diameter of 0.667 mm resulted into 30 % improvement in the power output. In order to improve the rate of heat transfer, [16] suggested micro-channel absorber made up of the hydraulic diameter of 0.667mm. Moreover, [13] in Figure 2, compared the efficiency of cooled PV (with its back designed to hold water) with a non-cooled PV panel. The result of their work revealed that the cooled PV have 2.8 % over the non-cooled PV.

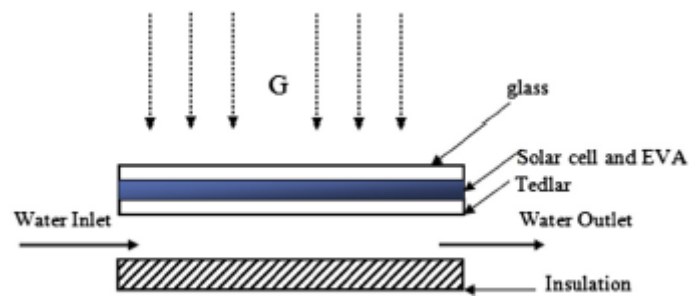


Figure: 2 Set-up of water-cooled PV/T [13]

2.2. Air method of cooling

Air-cooling as a medium of providing a cooling effect to the PV module is attracting the attention of researchers due to free accessibility, reduced cost and straightforward application. Qureshi et al. reported that the efficiency of PV would increase progressively if a wind of low velocity could be directed to blow away the heat build-up in the front and back of the solar PV [17]. Also, [18] work on PVT air model has revealed that the combination of glazing and fin would improve the efficiency of the PVT significantly. Interestingly, [19] modelled mechanism of heat extraction in the natural, forced and fitted it with experimental data. Hence, the comparison between glazed- PV and non-glazed PV was examined. Results again concurred that glazed and force circulation enhanced the performance of the PV because of fast thermal dissipation. The experimental work of [20] showed that the efficiency of the solar panel with a fan in the right side of Figure 3 is 2 % above the efficiency of the solar panel without a fan at the left side Figure 3 specifically at 970 W/m^2 .



Figure 3: Solar panel with and without cooling fan[20]

2.3. Phase change material method of cooling

In 1977, Stultz and Wen began exploring the use of PCM to cool photovoltaic systems [21] and through their studies discovered that the usefulness of PCM method could be improved via enhancing its thermal conductivity to allow the absorption of more heat from the PV module [21]. Although initial studies on the phase change material were carried out in 1977, significant research and development investigations on the usefulness of phase change material in cooling began a decade ago. In recent time, [22] developed paraffin based RT40 PCM to enhance the efficiency of a photovoltaic installed in the extremely hot climate of United Arab Emirates. Also, a combined thermal transfer model was developed and fitted with experimental data to assess paraffin based RT40 PCM performance. The work of [25] indicates that the melting and solidification of PCM determines to a degree its ability to cool PV. This is observed in the PCM's lesser cooling capacity in cool months compared to hotter months; evidence that further bolsters the use of phase change material- photovoltaic thermal (PCM-PVT) in more humid climates as it will improve the electrical yield by 5.9%. [23] investigated a PCM based PVT with a metal fin configuration in an absorber where three paraffin based PCM (RT35, RT27 and Waksol A) filled up to 85% of the volume of an absorber. The result of the study showed significant temperature reduction while using the RT27 and internal fin.

A comparative indoor study of PCM-PVT (capric palmitic PCM), PVT-Water and non-cooled PV collector carried out by [24] in which a stainless steel container with copper tubing was devised to pass water and PCM. The study indicated that the heat storage capacity of PCM-PVT is under given conditions is substantially higher than that of PVT-Water. [25] conducted a comparison study of PCM1-PVT (eutectic mixture of capric palmitic acid), PCM2-PVT (Salt hydrate $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$) and a non-cooled PV collector under two distinct climates (as hot as Vihari, Pakistan and as cold as Dublin, Ireland) in which the back of a PV with internal fins were attached with a metallic PCM container [22]. Experimentation with non-cooled PV, commercial paraffin based PCM RT28 (one with a thermal conductivity of 2.4 W/mK and another with 0.19 W/mK) was conducted by [26] The thermal conductivity of paraffin can be manipulated using

expanded graphite. The study showed that phase change material with higher thermal conductivity would achieve a higher thermal reduction and power yield. Similar work was also carried out to compare the impacts of pure PCM (0.18 W/mK) and combined PCM (made up of 70% PCM, 20% copper, and 10% graphite; with 95.38 W/mK) on the electrical and thermal behaviour of PV modules. The study revealed proportionality of thermal conductivity to electrical performance, the electrical efficiency of the combined and pure PCM increased by an average of 3 % and 5.8 %.

2.4. Nano-liquid method of cooling

The science of nano-liquid comprises the fluid and the redefined features of the solute. This nanotechnology portrays a leeway of enhancing the thermal conductivity of the nano-liquid the features of the base fluid. The investigation of [27] revealed that Al_2O_3 water nano liquid of 0.5 % has the capacity to improve the convection current in the dual pipe heat exchanger with little drop in pressure. In the same manner, [28] adopted Al_2O_3 , CuO and TiO_2 nano-fluids of varied concentrations to cool the solar panel, but surprisingly, Al_2O_3 nanoparticle significantly improved the power output of the solar panel. In addition, the efficiency of the solar panel was improved by 30 % when carbon nanotube and $AgSiO_2$ (silver silica) were properly combined [29]. Further, the suitability of CuO , SiC , and Al_2O_3 in improving the efficiency of the solar panel was carried out with the advanced simulator, such that, the simulator presented SiC as nanofluid of choice for a better efficiency [30]. Also, a scientific comparison was examined between Bohemite-water and water as heat extractor in PVT. The outcome made Bohemite and water a good candidate over water in improving the power put of PVT. In recent time, [31] studied the impact of concentration, water and nanoparticles on the electrical and thermal productivity of the PV. [10] reported that copper-water nanoparticle was preferred to copper-ethylene glycol in terms of electrical and thermal efficiency. Cross-examination of various cooling methods such as forced air, natural, SiO_2 -water, water and Fe_3O_4 has shown that nano-liquid (SiO_2 -water) was the best cooling candidate. More importantly, the experimental result of 13 % efficiency and 16 °C drop in PV temperature that was achieved by [32] has indicated nanofluid as a good coolant over water-PVT and Uncooled-PV. Therefore, this nanofluid technology is a solution to checkmate the arbitrary temperature rise in the solar panel (that is under a high concentration of irradiance) due to its surface area sensitivity to heat dispel.

2.5. Refrigerant method of cooling

Scientists in space heating have developed a gaseous refrigerant that is capable of operating at low pressure, low temperature and sucking out the killing heat in the photovoltaic panel [10]. Gaseous refrigerant remains a leeway in enhancing the efficiency of PVT to as far as 13.4 % and the coefficient of performance (COP) to 8.3 [33]. The comparison of Honbing et al. [34] between a PV module with R13a refrigerant and a non-R13a module revealed that an R13a improved the efficiency of the module by 1.9 % over a non-R13a PV module. [35] applied a MATLAB tool to fit his model with the experimental data he got during sunshine hours. The result showed 86.29 % efficiency and 7.09 coefficient of performance. In subsequent time, [36] suggested R410a as the refrigerant to cool the solar panel. Therefore, [37] validated a theoretical model that studied the impact of irradiance, evaporator temperature on the thermal and electrical output with experimental data harvested in China from the R410a refrigerant-based PV module. Further, an efficiency of 69.7 % and 4.7 COP were recorded when an enhanced micro-channel (that allows vapour to escape and permits free flow) with a small area of the cross-section was attached to the PV panel. In addition, a mini-channel sucker with low surface area attached to PVT gave an efficiency of 45 % and the coefficient of performance of 4.9. Technically and economically, water spraying is preferred to refrigerant-based cooling. However, in terms of thermal dissipation is more suitable than water-based cooling [38].

Table 1: Efficiency of various cooling methods

Cooling technology	material	Efficiency (%)
Air	Mono pass sheet and fin	13.75 [39]
Water	Cylindrical aluminium	6-14.2 [40]
Phase change material	Water-PCM-PVT	53 [41]
Nano liquid	Titanium(iv) oxide	13.62 [32]
Refrigerant	R22 refrigerant	45 [42]

Conclusion

This study has vividly shown how the abrupt rise in temperature of PV panel specifically under high solar radiation can be reduced to favour its maximum power output and efficiency in Table 1 via the active and passive methods of cooling. In addition, the study has pointed out that, the choice of cooling method depends on its cost-effectiveness, climatic condition and the end use of the retrieved heat energy. Conclusively, Table 1 has shown that more improvement on the phase change material and refrigerant are needed to make them suitable technology of improving the efficiency of solar panel beyond 45 %.

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