Enhancement of Electrical and Thermal Performance by Cooling of Solar PV Systems

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***Abstract*: In this article, the comparative analysis of different heat transfer mediums and mechanisms are discussed in the context of cooling solar photovoltaic (PV) systems. Cooling is done through active and passive methods. Various researchers in recent years investigate air, water, nanofluids and phase change materials or combination among these. The overall thermo-electric performance of photovoltaic/thermal hybrid systems and concentrated PV systems depends on the effective thermal management of PV panels. Cooling of PV panels is beneficial to improve the overall performance and productive life of PV systems.**

***Index Terms*: Nanofluid, phase change material, Solar photovoltaics, parabolic dish.**

I. INTRODUCTION

Utilization of solar energy for the various thermo-electrical needs is most beneficial to reserve the available fossil resources for some more periods. Such renewable energy systems are not only preserving the precious fossil fuels but also leaves the environment clean and safe. Solar thermal and photovoltaic collectors are used effectively to harness solar energy. PV technology is most useful to deploy almost all parts of the country. In case of low radiation areas, the concentration of solar rays is possible and in high solar intensity areas, there combined PV and heating type solar energy systems can be deployed to utilize the available solar energy effectively. Concentrated solar collectors are employed to operate the concentrated PV/T collectors. The electrical output of the solar PV is significantly affected by the panel temperature on sunny days. Hybrid solar thermal and PV systems are beneficial to provide electrical and process heating. Building integrated PV (BIPV) is one of the methods of deploying PV systems in the building envelopes. For such systems, the cooling is to be provided to improve the human comfort inside the building.

The solar PV industry has been gained a momentum of growth due to the readiness and suitability for real-time applications. Hybrid solar PV and thermal (PV/T) are producing optimum energy and exergy performance due to the heat recovery and cooling of PV panels and subsequent improvement PV power output. The factors that affect the PV performance are solar irradiation, panel temperature, moisture and humidity of air, dust, wind velocity and ambient temperature. The standard test conditions (STC) and nominal operating cell temperature (NOCT) are given in Table 1. However, the panel temperature on sunny days in the equator region reaches to a peak of 70°C. Such extreme temperature leads to local hotspot and poor currents. Hence, the panel temperature above 45°C leads to degradation of electrical performance and panel life.

Table 1. STC and NOCT conditions of a typical PV panel

Parameters	STC	NOCT
Solar radiation (W/m^2)	1000	800
Ambient temperature (°C)	25	20
Air-Mass	1.5	---
Wind speed (m/s)	---	1
Panel temperature (°C)	25	45

Cell temperature of the PV panel is calculated by the given formula.

$$T_{cell} = T_{amb} + \frac{(NOCT - 25°C) I_c}{800 W/m^2} \quad (1)$$

Where I_c is solar radiation on a module (W/m^2).

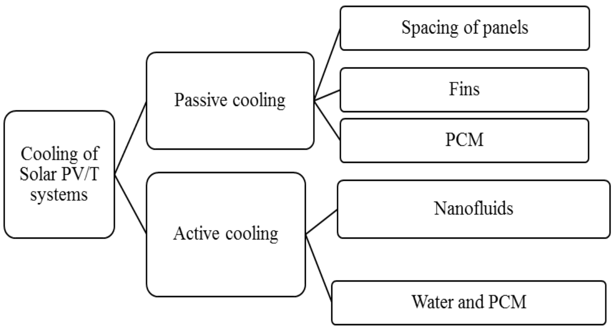

Figure 2. Different cooling methods of Solar PV/T

Open circuit voltage, short circuit current, fill factor and efficiency are determined at STC. The outdoor conditions are highly fluctuating in nature. Application of different nanofluids in solar systems is solar stills and solar collector. However, the researcher must focus on the safety concern of using nanofluids. Cooling of solar PV panels is not only increasing the electrical performance but also improves the productive life of PV panels due to operation at the permissible temperature range.

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In active systems, the cooling medium involves blower or pump to supply the cooling medium with external power. In passive systems, the cooling is natural and there are no mechanical systems used in the PV systems and no additional power or work involved. Active systems are having a trade-off between the power consumed by the active system and the improved power output from the PV system.

II. AIR COOLING BY CONVECTION

A passive method of cooling of PV panels and balance of systems by air is carried out naturally without any mechanical techniques [1-3]. But, the forced convection by air cooling is required for inverters and transformers where blowers and oil coolers are practiced. The spacing between panels is playing a vital role in the cooling of panels and balance of system due to the flow of air [4]. The passing of air over the PV panels removes the heat by convection and the air passing over the panel is more effective than the air moving under the PV panels [5]. Table 2 indicates the recent researches on PV cooling by air.

Table 2. Air cooling of PV panels

Cooling system	Findings	Reference
Air	Cylindrical pin fin density of 1.22/cm^2 is optimum	[1]
Air	Wind velocity and solar radiation are major factors	[2]
Passive cooling through Aluminium fins	About 2% improvement of efficiency	[3]
BIPV	Optimum air gap of 0.1 m is used for cooling by convection of air	[4]
Air-cooled PV/T	Cooling channel above PV panels is effective when compared to cooling channels below the PV panels	[5]
Radiative cooling	Passive method of cooling with the effect of surface emissivity spectra	[6]
Thin air channels	Longitudinal staves improved the heat gained by the air	[7]

Forced convection based cooling employs blower or pump for liquids. Radiative cooling and thin air channel flow were used to remove the heat of the PV panels [6, 7].

Figure 1 indicates the cooling of rooftop and BIPV systems. Both panels are involving natural convection of air as the cooling medium.

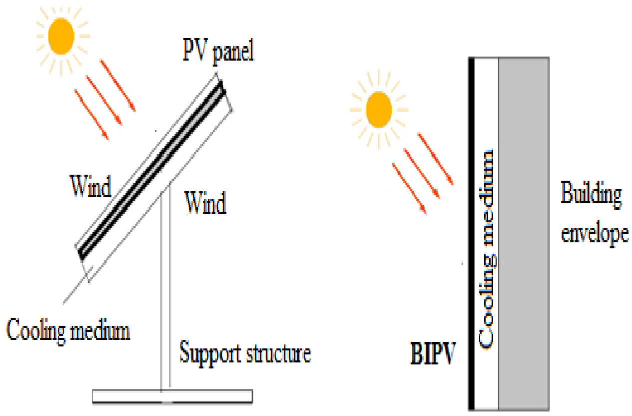

Figure 1. Cooling of PV panel by cooling medium

III. COOLING BY WATER AND NANOFLUIDS

Spraying of water is done whenever the panel reaches a high temperature around 45°C. PV panel temperature rises above 50°C during hot climates normally. This condition leads to localized heating and destructs the electrical output of the PV systems. Alumina oxide based nanofluid was used to cool the PV by 5°C [8]. Predominantly water is used for cooling of PV panels and water-based nanofluids [9, 10]. The conduction and convection heat transfer enhancement were carried out with the highly conductive nanofluids to remove the heat away as well as to utilize the heat for space heating or dryer applications. Table 3 contains the literature on PV cooling by water and nanofluids.

Table 3. Liquid cooling of PV panels

Cooling system	Findings	Reference
Al_2O_3-water nanofluid	Reduction of panel temperature by 5°C	[8]
PCM and water	Heat exchange mechanism for PCM is essential	[9]
Water nanofluids	Electrical efficiency enhancement of 12.70% at a solar irradiance of 1000 W/m^2	[10]
Hybrid PV-Photochemical collector	Overall power generation efficiency up to 25.3%	[11]
Hybrid PV and PTC	Harnessing of visible and UV and infrared rays	[12]
Hybrid PV/T collector with nanofluids	Nanofluid based PVT improved the heat transfer coefficient by 25.2% for the equal Reynolds number	[13]
Hybrid PV/T	Cooling fluid velocity of 0.5 m/s is the most beneficial by simulation studies	[14]

PV/T for power generation	Power generating efficiency is 18.37%	[15]
Hybrid PV/T	Maximum exergy efficiency achieved for a water flow rate of 0.003 kg/s. A height of the cooling channel is 5 mm.	[16]
Concentrated PV with PCM	Temperature of concentrated PV with PCM is 25°C lower than the PV without PCM	[17-20]
PVT cooling by automated water system	Around 33% improved combined thermal and electrical performance	[21]
PV/T with water jet collision	Thermal efficiency of PV/T is 81%	[22]
PV/T	Ohmic shunts are prone to panel temperature above 45°C	[23]
Pulsating heat pipe in hybrid PV	There is 18% improved electrical output due to pulsating heat pipes.	[24]

Hybrid solar PV and thermal systems have been investigated with the nanofluids and the size of the cooling channels [11-20]. The automated water-cooling system improved the overall thermal and electrical performance of hybrid PVT is around 33% [21]. The collision of water improved the cooling performance of PV panels and resulted thermal efficiency of 81% [22]. Ohmic shunts are prone to panel temperature above 45°C [23]. Pulsating heat pipes in the hybrid PV system improved the electrical performance by 33% [24].

IV. EFFECT OF PCM

Use of PCM for thermal management of PV systems is recently investigated by several researchers for thermal management of PV systems. However, utilization of PCM in the electronic cooling is investigated by several researchers recently. The use of PCM beneath PV panels absorbs the heat of the panels during the day time and releases the heat to the ambient during the night time. This heat transfer is normally passive cooling without any external force. The forced cooling may be used for the sunniest days to release the stored heat of PCM. Heat exchange into and away from the PCM is a complicated mechanism and the process is to be enhanced with the fins into the PCM and the heat exchange tubes inside the PCM [17-19]. Table 4 indicates a few recent types of research on PCM for cooling of PV panels. PCM is successfully used in solar thermal collectors for process heating [25-27]. PCM is used as storage and energy conversion materials in solar thermal as well as electrical collectors.

Table 4. PCM based cooling of PV panels

Cooling system	Findings	Reference
Water and PCM for PVT	Thermal storage capacity of PCM are to be maintained not only to remove the heat of PV panel effectively but also to supply the heat to process heating.	[9]
Concentrated PV with PCM	Temperature of concentrated PV with PCM is 25°C lower than the PV without PCM with the help of fins in the PCM side	[17]
PV with PCM	There is 5% electrical energy efficiency for a reduction of 20°C panel peak temperature	[18]
PV with an integrated PCM	5°C temperature rise is observed for each 100 W/m^2 increase in solar insolation. A PCM with a melting point of 5°C higher than ambient temperature produced optimum PV performance.	[19]
Solar collector with PCM	PCM ensures the uniform heat output after sunshine	[25-27]

PCM should have an appropriate melting point well within the desirable operating temperature of PV panels. Selection of PCM is to be non-reactive to the PV panel materials with long-term stability at the outdoor weather conditions. Most of PCM are lack of thermal conductivity to hinder the actual performance at the real-time. Higher latent heat and a little higher melting temperature to the average local temperature is one of the most useful criteria to absorb the heat at the day and release at the nigh. The heat recovery is an added benefit to improve the overall productivity of the PV systems. Heat recovery ensures the safe operation of PV systems as well as cogeneration. Simultaneous electrical and thermal power from PVT is the effective utilization of available solar energy. For every ten degrees rise in temperature of the panel, the ohmic resistance is usually increases twice. For the silicon solar cells, there will be a 0.1% drop in cell efficiency for every one-degree temperature rise of the PV panel.

V. CONCLUSIONS

Natural or forced air cooling of panels using fins, forced cooling by water, the spray of water over the panels, use of PCM layers beneath the panels are found helpful to maintain the panel well below the maximum operating temperature.

The optimal spacing of PV arrays are most influencing factor to maintain the panel closer to the operating range of PC panels. The combined effect of heat pipe and PCM proves better heat removal and utilization.

The use of nanomaterials substantially increases the efficiency of the PV system with effective cooling through improved thermal conductivity, specific heat and heat transfer properties. Thermal conductivity enhancement methods of PCM and proper design of PV panel back cover is vital to obtain the full functionality of the PCM in solar PV systems.

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