Thermal Management Solutions using PCM for Photovoltaic Panels: A Critical Review of Performance

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Abstract: Solar photovoltaic (PV) panels are widely utilized worldwide to convert solar energy into electricity. However, the efficiency of these panels decreases as the temperature rises above the optimal working temperature of 25°C, resulting in a drop in efficiency of up to 0.4-0.65% per degree Celsius, depending on the type of solar cells. To maintain high productivity, cooling solutions for solar PV panels are essential. There are two main cooling methods: active cooling, which involves externally powered devices, and passive cooling, which includes the use of phase change materials (PCMs). Numerous experimental and simulation studies have explored the use of organic, inorganic, or eutectic PCMs. The use of PCM-based solar PV cooling systems has been shown to significantly enhance the conversion efficiency of PV panels.

Keywords: Photovoltaic; Thermal management; PCM

1. Introduction

Power generation from renewable energy is preferred due to environmental issues and rapidly exhaustion of other resources. Power demand in the world is growing three times faster than any other energy sector. Solar energy is the third highest contributor after hydropower and wind power. World electricity generation from solar energy reaches to 1.4 trillion kWh in between 2015 to 2040 [1].

1.1 Effect of Temperature on PV panel

In their experimental and simulation research, many scientists have uncovered the detrimental impact of elevated surface temperatures on the power output and efficiency of photovoltaic (PV) panels. This phenomenon arises from the reverse flow of ions within the solar cell. Agarwal, A. *et al.* presented the effect of panel temperature on voltage and current output. The simulation results shows that the efficiency of the panel decreases as temperature increases. They suggested the use of PCM as passive cooling for PV [2]. Tiwari, G. N. *et al.* founds similar results. Fig. 2.2. shows that as by increasing the cell temperature of the module, efficiency will decrease. Vice-versa of this is also applicable to the PV modules[3].

2. Thermal Management of PV panels

Thermal management or regulation or cooling of PV

panels are broadly classified on the basis of external electric power used or not used. There are of mainly two types, i.e. Active & Passive cooling. Active cooling used the external electric power like for forced flow of air or water requires fan and pump respectively. But passive cooling need not to require any external electric power. In passive cooling flow of fluid naturally takes place due to density difference or syphon effect. Cooling of PV panels by means of phase change material (PCM) is a passive approach which is widely used now a days. Fig. shows the different PV panel cooling techniques used by many researchers in recent years [4-8].

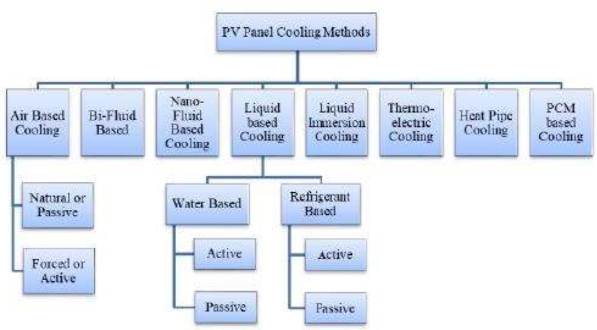

Fig.1 Different types of PV panel cooling techniques

3. PCM incorporated PV System

Many researchers modified the simple PV module by incorporating PCM at back side in a box. They compare operating data for a modified PV-PCM system with Reference PV.

Klugmann-Radziemska and Wcisło-Kucharek experimented with a modified PV module using a 2 cm-thick layer of 42-44 paraffin, which was water-cooled. They found that this modification reduced the surface temperature of the PV module by 7 K for over 5 hours[9].

In an outdoor experiment, three PV panels were tested: one as a reference and two equipped with phase change materials (PCMs) - paraffin wax (melting at 46.7 °C) and beeswax (melting at 51 °C). The experiment showed that the PV-PCM system maintained lower temperatures than the reference panel throughout the day. The electrical efficiency for PV panels with PCM ranged from 7.0% to 7.8%, while for panels without PCM, it ranged from 6.1% to 6.5%. Notably, the study concluded that beeswax exhibited superior heat-absorbing capabilities compared to paraffin wax[10].

The BIPV-PCM (Inorganic glauber salt, melting point 32 °C) system is analysed experimentally (installed on facades of the room) with BIPV in the month of May. The thermal and electrical behaviour of BIPV module is investigated for with and without PCM as shown in Fig. 2.5. The performance results show that the BIPV- PCMs electrical efficiency is improved by 10% and surface temperature is decreased by 8 °C as compared with simple BIPV system. Also both the systems generated maximum power for east orientation. [11].

Klugmann-Radziemska et al. tested the voltage and current characteristics of the solar cell on a specially design test stand for with and without using the PCM layer. They applied PCM (RT22 for module1 & Ceresine for module2) layers on rear surface of PV modules and efficiency was calculated as 10.5% (module1), 10.15% (module2) for a modified modules and 10.8% (module1), 10.6% (module2) for a modules without PCM material for the same conditions [12].

Luo, Z. et al. design a PV-PCM arrangement for thermal regulation of photovoltaic panels. They applied form stable paraffin composite PCM (ZDJN-28)/EG with high thermal conductivity. The experimental results shows that the temperature of PV-PCM panel kept below 50 °C for 200 minutes and average output power increased by 7.28 % in heating practice. They also established a numerical simulation model by FLUENT software to simulate the change in temperature process for the PV-PCM panel along with different material densities and concluded that the higher density PCM achieves better thermal regulation [13].

Hasan, A. et al. have analysed the energy performance of a PV-PCM arrangement in hot climate throughout the year. The PCM (RT-42) shows the less cooling effect in peak cool and hot months because of its incomplete solidification and melting, respectively. They also investigated that the PV-PCM system increases the annual electrical energy by 5.9 % in the hot weather conditions [14].

Mahamudul, H. *et al.* have carried out numerical analysis and experimental investigation on the PV-PCM arrangement as shown in Fig. 2.7 and concluded that if 0.02 m thick PCM layer of RT35 is used for cooling purpose with a panel, then the temperature of the panel is decreased by 10°C and remains unchanged for of 4–6 hours. They also validate it by comparing the other researcher's findings [15].

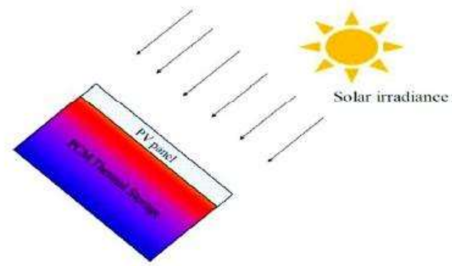

Fig. 2 PV-PCM system working principle [26]

Stropnik, R. and Stritih, U. have compared the results carried out by an experiment with simulation (on TRYNSIS software) through modification of the PV module using PCM RT28HC. The experimental results shows that the maximum and average temperature difference between with and without PCM arrangement was founds to be 35.6 °C and 14.4 °C respectively. Also with the help of simulation, they found increment in performance, compared to the conventional PV module [16].

Rajaram R. and Sivakumar D.B. have investigated experimentally the effect of PCM (Cobalt Sulphate Heptahydrate) attached behind PV panel on their performance. The results shows that the PV-PCM arrangement keep the panel's functioning temperature under 40°C for two hours at a constant solar radiation of 1000 W/m^2, also increased the performance by 5.02% and power output by 7.92% [17].

Biwol, P. *et al.* have focused mainly on heat and mass transfer CFD modelling of PV-PCM system for h_i=5 W/m^{2}K, h_e=10 W/m^{2}K and E = 1000 W/m^2. Results shows that the inclusion of PCM behind the panel can hold the panel's operational temperature below 40°C for two hours [18].

Huang, M. J. *et al.* has successfully developed and validated experimentally a numerical PV/PCM model. They concluded that, to keep the surface temperature of the PV/PCM arrangement at 25 °C, the transition temperature of PCM should be greater than ambient temperature and lower by optimum temperature [19].

Hassan, A. *et al.* experimentally compared the results of front PV surface temperature and voltage output for with and without PCM used at the hot climate of UAE. A temperature fall of 12 °C was found for PV-PCM system and, also voltage gain observed.[20]

Table 1 Comparative Literature Review summary for PV-PCM systems

Ref.	Comments/Suggestions/Conclusions
[9]	2 cm thick Paraffin with water cooling suggested
[10]	Beeswax has shows better heat absorbing capacity

Ref.	Comments/Suggestions/Conclusions
[11]	Suggested east orientation in hot and humid location
[22]	Due to very thin layer of PCM, desired effect was not achieved
[13]	suggest higher density PCM for better thermal management
[14]	PCM gives less cooling in peak cold and hot months
[15]	validate results by comparing it with other researchers findings
[16]	electricity production with PV-PCM is 7.3% higher for one year
[17]	-
[50]	heat and mass transfer CFD modelling performed
[18]	suggested 13.2*4.9 cm large PCM container
[21]	C–P and salt hydrate founds financially viable in hot
[19]	Results obtained was significant for improving performance of panel

Above mentioned discussion for PV-PCM system can give a positive response about the performance enhancement of PV panels.

4. Conclusion and Future Directions

Researchers have conducted numerous experiments, simulations, and numerical analyses, producing a wealth of evidence showcasing the benefits of using PCMs in conjunction with PV panels. The studies have demonstrated that PCM-equipped PV systems effectively reduce surface temperatures, maintain operational temperatures within optimal ranges, and enhance electrical efficiency. Different PCM materials, such as paraffin wax, beeswax, and inorganic glauber salt, have been explored, each with its unique advantages. The choice of PCM material has a significant impact on performance, with beeswax and high-density PCMs often outperforming others. Moreover, various climatic conditions have been considered, including hot, cold, and fluctuating weather. In hot climates, PV-PCM systems have successfully mitigated temperature rise, leading to increased electrical energy output. For colder conditions, PCMs have sustained panel performance by preserving heat.

Overall, these findings collectively emphasize the potential of PCM integration to optimize PV panel efficiency, minimize thermal fluctuations, and enhance electrical output. These advancements are of great significance in the pursuit of more efficient and sustainable solar energy utilization.

The future of PCM-integrated PV systems holds great promise. There is potential for further material research to identify even more efficient PCMs. Additionally, optimizing PCM thickness, density, and placement within PV panels will be crucial for maximizing performance. The development of intelligent control systems that can adapt PCM usage to real-time weather conditions is another avenue for exploration. Finally, the scalability and cost-effectiveness of PCM integration in large-scale PV installations need further investigation to facilitate broader adoption and make sustainable solar energy utilization a reality.

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