

Thermal and electrical management of photovoltaic panels using phase change materials – A review



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ABSTRACT

Thermal and electrical management of the PV systems integrated with Phase Change Materials has been discussed in this article. The main aim of this review article is to provide the current status of PV-PCM technology along with the research gaps and challenges being faced by this technology. A comprehensive literature review elaborating different aspects of this technology, such as system development, performance evaluation, PCM selection, heat transfer enhancement, simulation, and application in practice is presented. Cost incurred due to inclusion of PCM into PV system is also discussed in detail in this article. Major findings of the current review are that PV panel peak temperature can be reduced up to 20 °C with an increase in electrical conversion efficiency up to 5% by using PCM. At an average, ~ 2.6 kg of PCM is needed per meter square of the PV panel area to reduce the one-degree temperature of the PV panel during peak hours. The current review concludes that PV-PCM cooling system is not yet commercialized because of technological challenges, high system cost, and availability of appropriate PCMs. However, PV-PCM systems are still in the research phase, with great scope for practical applications. Suggestions for the future work along with current challenges are also presented.

1. Introduction

The electrical conversion efficiency of PV cell is significantly affected due to the surface temperature of the PV panel [1]. A 1.0 °C increase in a typical PV cell surface temperature normally reduces the conversion efficiency by 0.08–0.1%, reducing power output by 0.45% over the nominal cell operating temperature of 25 °C [2]. Therefore the cooling of the PV panels becomes vital to remove the excessive heat generated by solar cells. The main aim of using thermal regulation techniques in PV panels is to bring down the temperature of the solar cells at a value which is as low as possible and close to Standard Test Conditions (STC) to increase the efficiency [3]. Cooling techniques are also observed helpful to increase the life of the solar cells as the thermal stresses are reduced due to cooling [4].

1.1. Passive and active PV cooling techniques

Various PV cooling techniques have been investigated and explored in past, including passive techniques and active techniques as summarized in Fig. 1 [2]. These include air based, liquid-based and PCM based PV cooling systems. All these cooling techniques can be used

actively and passively. In active techniques, excess heat generated by PV panel is removed by circulating air or water through PV panel. Circulating air or water acts as heat transfer fluid carrying heat away from the PV panel. Active heat removal systems commonly use pumps or blowers to maintain a flow of heat transfer fluid on the front or back of the PV panel for cooling purpose [1,5]. Active systems are observed efficient in removing excess heat from PV panel leading to higher PV efficiency compared to the passive systems. However, extra or parasitic power consumption and system maintenance costs are the key issues with active techniques [6]. Passive cooling systems are based on the techniques that don't use pumps or blower for the circulation of the heat transfer fluid through the PV panel rather depend on natural convection, conduction and radiation heat transfer mechanisms. The main advantage of using passive cooling techniques is that they don't require any parasitic energy for their operation and the maintenance cost is either zero or very low. A variety of passive cooling techniques has been reported for the cooling of PV panel. Most commonly used are air cooling and water cooling [7] while the simplest one is conductive passive cooling [7,8]. Researchers around the globe are working on innovative passive cooling techniques for PV panels that don't need any extra energy and the maintenance cost is very low.

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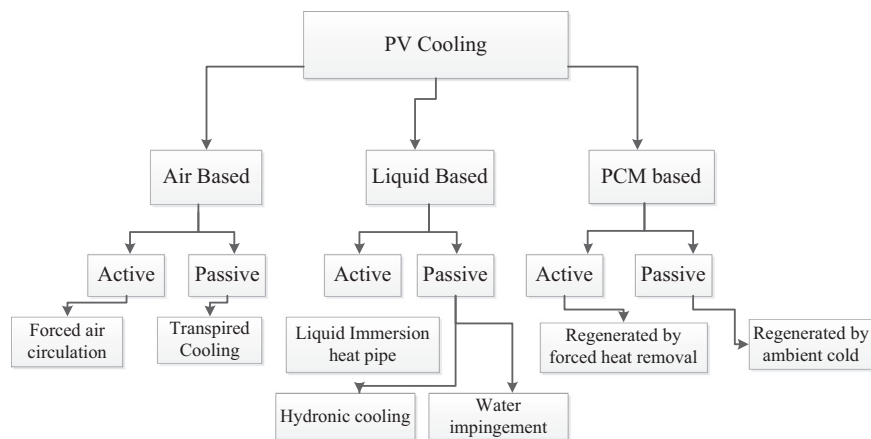


Fig. 1. Commonly used PV cooling techniques. [2].

1.2. PCM based PV cooling system

Phase Change Material (PCM) based thermal regulation of PV panel falls under the category of the passive cooling technique [5]. Research in PCM based cooling systems are gaining interest as the excess heat generated by PV is absorbed by PCM without using any heat transfer fluid or moving part. In PCM based cooling systems excess heat generated by the PV panel is absorbed by PCM passively during sunshine hours when PCM is in the solid state. The absorbed heat is rejected to the ambient during non-sunshine hours when the ambient conditions are much cooler [9] turning PCM from the liquid state back to the solid state. PCMs are organic or inorganic in nature that undergoes a reversible phase change. PCM undergo melting phase if the absorbing surface temperature is more than the melting point of the PCM and vice versa and keep the absorbing surface temperature close to the melting point [10]. PCM based cooling of PV panels have gained interest since the year 2010 and most of the quality literature was published during the 2015–2017 while the first study was published in the year 2004 [11] by Dublin Institute of Technology. The published literature about PV-PCM has shown that PCM can effectively reduce the temperature of the PV panels up to 10 °C to 20 °C improving the electrical conversion efficiency up to 3–5% [8,12] but its economic viability is still under research phase. Availability of the PCM with required thermal and chemical properties with suitable price is also an issue as PCM is not commercially available in most of the countries. PV-PCM systems with numerous benefits, issues, and challenges offer further research opportunities for the researchers around the globe as PCMs not only reduce the temperature of PV panel but also provide thermal energy storage option for further utilization. Therefore the main aim of this article is to give the readers and researchers answers to the following questions that can arise related to the PV-PCM technology:

- What is a PV-PCM technology? How much temperature of the PV panel can be lowered using PCM? How much mass of the PCM is needed to lower the PV temperature of PV panel?
- What should be the melting point of the PCM for PV cooling application? PCM should be organic or inorganic? Heat collected by the PCM from PV panel can be further utilized or not? What issues may arise if PV is integrated with PCM? What is the procedure to integrate PCM with PV panel?
- And finally, whether PV-PCM is economically feasible technology or not?

Therefore, sections in the current article are formulated in a way to answer the above-mentioned questions and provide a deep understanding of PV-PCM systems for academic researchers and implementation resource persons. PV-PCM system working principle is

explained in Section 2 while the scholarly articles published on PV-PCM systems are analyzed and discussed in Section 3. Theoretical and experimental studies are also summarized in Section 3. The effectiveness of PCM for thermal and electrical regulation of PV panels is discussed and analyzed in detail in the Section 4. PCM encapsulation techniques are elaborated in Section 5. Types of PCM along with the criteria to choose PCM for PV applications are discussed in Section 6. Heat transfer enhancement practices and their effect on PV-PCM system output have been discussed in Section 7. Indicators to access the performance of the PV-PCM system is discussed in Section 8 while the economic viability of the PV-PCM systems is elaborated in Section 9. Key issues and challenges with the PV-PCM system are discussed in Section 10 while conclusions are presented in Section 11.

2. PV-PCM working principle

PV panels integrated with the PCM storage is a hybrid technology in which PV panel and PCM are integrated into a single component to achieve the higher electrical conversion efficiency and lower PV surface temperature. A typical PV-PCM system is shown in Fig. 2. It consists of a PV panel and PCM encapsulated in a suitable capsulation material and attached at the back side of the PV panel. In PV-PCM systems, PCM storage acts as a heat sink for PV panel, especially during sunshine hours, when the operating temperature of the PV panel is higher than the melting point of the PCM. PCM starts absorbing excess heat from PV panel keeping the temperature of the PV panel close to its melting temperature without any external energy input. Excess heat absorbed by PCM changes its phase from a solid state to liquid state at a certain temperature known as the melting point of the PCM. PCM keeps on absorbing the PV heat until the PCM is converted to the liquid phase. The liquefied PCM gets solidified again as the surrounding temperature and the PV surface temperature falls below the melting point of the PCM. Excess heat absorbed by the PCM from PV panel is released to the surrounding converting PCM back into the solid state. PCM solidification process normally occurs during non-sun shine hours when PV panel is not receiving any solar radiation. In this way, PV panel is cooled passively and electricity conversion efficiency is enhanced without using any parasitic energy from PV panel.

3. PV-PCM published scholarly literature

In this section, experimental and theoretical literature related to the PV-PCM is analyzed and discussed. It is analyzed when and where the PV-PCM topic got the attention of the scientists. Universities, groups, and individuals working on the PV-PCM topic are also discussed. Later in the same section theoretical and experimental studies published on PV-PCM topic are analyzed and discussed in brief along with their

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