Photovoltaic Panel Integration Using Phase Change Material (PCM): Review

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Photovoltaic Panel Integration Using Phase Change Material (PCM): Review

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Abstract: High operating temperature of solar photovoltaic panels induces a loss of energy output and causes structural damage, which in turn reduces the average lifespan and efficiency of photovoltaic modules. Study of various research, thermal energy storage is an effective way to collect and discharge waste heat from many thermal applications and solar photovoltaic panels. The main aim of present review is to study various photovoltaic-phase change material (PV-PCM) systems and focus on proper selection of phase changing material based on various parameter. By the study of various affecting parameters, it is found that organic phase change material contains with fins can primarily be used in the development of PV-PCM system.

Keywords: Photovoltaic Panel, Solar Efficiency, Phase change material (PCM), Heat transfer

1. Introduction

Renewable resources reduce the fuel demand, lowers system maintenance costs, and ultimately reduces energy wastage. Decrease the use of fossil fuel and increasing the use of renewable sources to get net zero emission by 2050. While demand for all other fuels declined in 2020, renewable energy was the only energy source that saw an increase in demand despite the pandemic.[1] Renewable energy consumption for electricity generation grew by 7% in 2020.[2] Prior to the exhaustion of fossil fuel supplies, all energy sectors should implement technology based on renewable energy.[3,4] The use of renewable energy appears to be the promising direction for our future.[4] Households with rooftop PV systems are referred to as prosumers since they may create electricity in addition to consuming it from the grid.[5] Prosumer existence has been shown to be a sustainable energy option.[6–8] Additionally, research has been done to see how the collectors might be integrated with other solar-powered devices to increase overall effectiveness.[9] The thermal efficiency of various solar systems is being studied by several researchers in an effort to increase heat input, performance parameter and yield rate.[9–11] It would be necessary to work on several issues at once in order to manage the growth of vitality in an orderly manner, including the economy's direction, the reduction of fossil fuel consumption, the development of human capital, and the use of sustainable energy sources in future energy frameworks.[1,12–15] Recently, the renewable energy sector has experienced rapid growth especially in solar photovoltaics and wind power. With the rapid growth of these energies in recent years, the electricity sector continues to be the most promising market for renewables. In this sector adoption rate of PV-Panel is low due to panel cost, performance, atmospheric conditions etc.[6] At a current scenario only 15–20% of the total incoming solar radiation on a PV panel can be utilized as an electricity and rest part of solar radiation reflected by the panel.[16] The reflected radiation generates heat and raises the temperature of the panel. Various factors, such as tilt angle, varying atmospheric conditions, and dust build-up, will affect the panel surface temperature.[17–22] Increasing the temperature of the photovoltaic surface will reduce the voltage drop in the photovoltaic panel, which will also affect the structural integrity. Due to the higher surface temperature, the conversion rate of photovoltaic panels is reduced by approximately 0.5%/°C above the nominal operating temperature of the panel which is 25°C defined by the industry standard.[23] Summer time temperatures vary between 40-70 degrees Celsius, causing the conversion rate to fall from average. Therefore, some techniques have been practiced on photovoltaic panels to control their temperature as minimal as possible.[24] For increasing the rate of heat transfer, the most widely used cooling technology in thermal engineering is adopted.[25][26,27]

Storing renewable energy is the best way to utilize it. Energy storage is very economical because it can reduce costs and energy consumption.[28] Even after storing energy, we are not able to fully utilize sources due to losses. Temperature-controlled heat storage systems are categorized as sensible heat storage (SHS), phase changing heat as a latent heat storage (LHS), and thermos-chemically based thermo-chemical heat storage (TCHS).

When compared to SHS & LHS systems, LHS has a higher capacity for storing heat at the same temperature rise, and on comparing LHS and TCHS gives high heat storage capacity but it is not controllable and takes too much time for the reverse process.[29,30] So latent heat storage (LHS) gives the best result for the thermal storage system, therefore, LHS is mostly used in thermal management in many applications. PCM is the best example of an LHS system. During its phase transition, PCM stored a significant amount of heat.[31] In this paper, studied PCM based photovoltaic panels (PV-PCM system).

2. Research Background

Solar PV panel efficiency mainly decreases due to high surface temperature. For better performance of PV panel, temperature should be low or in the range of working temperature by the cooling of the panel. Air-based, water-based, heat pipe and PCM based cooling are the main techniques for the cooling.[32–36] Most of researchers are using PV-PCM for cooling to get better performance of the system. The first experimental test by Huang et al. in which a building-integrated solar panel with RT25 PCM mounted system with and fins to maximize thermal capacity. It was found that the 30mm PCM layer decreases the front surface heat from 45℃ to below 35℃, and the 20mm layer thickness maintains below 36.4℃.[37] Many researchers were used this as a reference, for study and using same approach for different types of PCMs and different climates/weather conditions and all are reported that PV-PCM system effectively reduce the surface temperature of PV panel.

Nada et al. experimented on building an integrated photovoltaic panel with PCM RT55 and 2% Al_2O_3 nanoparticles to improve the overall thermal conductivity of PCM. The experiment shows the overall, daily average efficiency improved by 7.1%.[38] Abdollahi et al. used a zigzag vessel consists of composed oil and Boehmite to increase the heat transfer area. Nasrin concludes that oil with nano capsulated PCM is more effective than composed oil only.[39] Soares et al. compare horizontal, vertical, and normal aligned thermal energy storage. Movable TES with PCM RT22HC, he got that energy produced by the reference panel is greater than the horizontal and vertical.[40] Kumar et al. used nano PCM's of Cu, SiC, and Calcium Carbonate in PV-PCM technology. Experiment shows that temperature drops of 4-5℃ occur and 4.3% performance enhancement.[41] Rajvikram et al. did experimental work for two days with organic PCM OM29; it was found that average conversion efficiency increased up to 24.4% and an average temperature drop of 10.35℃.[42] Savvakis et al. compared two experimental setups in the Mediterranean climate and a copper tube as external fins. Comparing results of PV with RT27 PCM and PV with RT31 PCM, it was found that energy generation of RT27 & RT31 PCM panel increases by 4.19% & 4.24%, respectively, and conversion efficiency increased from 2.86% to 4.19%.[43] Mahdi et al. used multiple PCM, RT35, RT26 + RT42 layer, and RT26, RT35, + RT42, all layered PCM arranged in heat flow direction according to their melting temperature ascendingly; due to this melting time of PCM increased up to 18% and thermal efficiency up to 33%.[44] Shastry et al. compared three standard PV panels, PCM with PVT and PVT with PCM and aluminum metal matrix. PVT with PCM increases thermal efficiency from 6.4% to 42%, and metal matrix PVT with PCM shows a 7.1%-48.5%.[45] Adibpour et al. used a sun-tracking solar panel with PC29 PCM, results show that the increase of average efficiency by 4.6% to 6.8%, and an average temperature drops of 9.1℃.[46] Sudhakar et al. used OM35 PCM at the back side of the panel and used a water channel, top to bottom continuous flow, bottom to continuous top flow, and periodic water flow to enhance the heat transfer rate. It was found that top to continuous bottom flow to give better results compared to others; the average temperature drops up to 5.4℃ and electrical efficiency improved up to 12.4%.[47] Mauricio et al. used a hybrid solar module with PCM RT35 it was found that temperature drop of 10-17℃ and 7.43% electrical efficiency enhancement per day. The result shows that 20.45% more energy is extracted from solar radiation by the hybrid panel than the traditional panel.[48] Chavan et al. compared two panels with standard PV panels, first PV with PCM (Petroleum jelly) stored in a triangular fins container, and another a PVPCM system with water supply in copper pipes to enhance heat transfer rate. it was found that the 8.10% heat reduction in PVT-PCM system compared to standard panel and 4.06% higher electrical power in water-based PVT-PCM system compared to the standard one.[49] Sharma et al. compared water-cooling-based PV panel and PCM-mounted PV panel with the standard panel. It was observed that the PV-PCM system gives better results compared to another one and electrical efficiency increased 7.95%, to 10.2% based on location basis.[50] Kumar et al. used paraffin wax with 0.5% TiO_2 nano-PCM, it was found that PV with nano PCM enhances panel efficiency up to 2.1% and gives a temperature drop of 13℃.[51] Singh et al. used $CaC_{l2.6}H_2O$ (Calcium Hexahydrate) PCM-filled container attached at the back side of the PV module. It was found that temperature drop from 64.4℃ to 46.4℃ at January and from 77.1℃ to 53.8℃ at June. Electrical generation increased by 6.2% on daily basis in January and 8.3% daily basis in June.[52] Abdulmunem et al. analyzed the effect of tilt angle (0˚ to 90˚) on Paraffin PCM mounted PV panel. It was found that with tilting panel (90˚ to 0˚) melting time of PCM increased, showing the temperature drop from 0.4% to 12% [53]. All these researches are summarized in Table (1) with all relevant data and information. By above study it is clear that by using PV-PCM system improve PV panel performance.

3. Phase Change Materials (PCMs)

PCM is used for latent heat storage (LHS) systems.[54]

Telks and Raymond laid the foundation of the study of phase change material.[55] PCM is a material that, depending on its temperature, undergoes a reversible phase transition. During the process, it tends to absorb or releasing heat.[56] When the temperature rises, the chemical bond between molecules breaks, resulting in a transition from one phase to another. During the phase change process, it absorbs heat from the contact surface.[57] Fig. 1 shows the thermal cycle of PCM in which phase change occur during heat addition and heat releasing process.

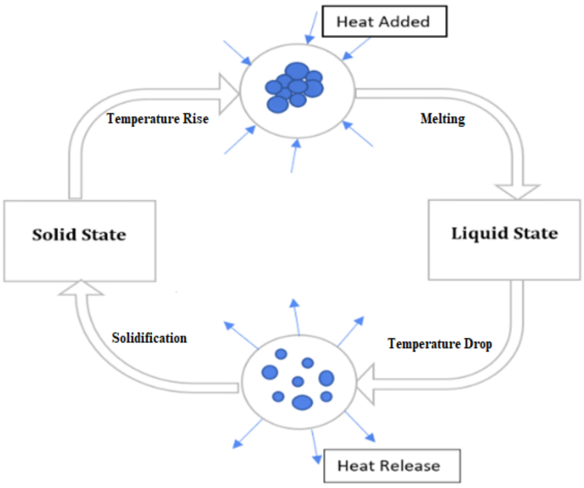

Fig. 1: Thermal cycle of PCM

3.1 Classification of PCM

PCM changes its state after attaining heat and vice versa. PCM can be classified in different ways such as according to phase transition temperature it can be divide into three types ⅰ) Low-temperature range: where PCM's phase transition temperature below 15℃, ⅱ) Mid temperature range: where phase transition temperature lies between 15-90℃, ⅲ) High-temperature range: where phase transition temperature above 90℃.[58,59] On the market, there are many distinct types of PCM available with various heat capacities, melting temperatures, and freezing temperatures. Organic, inorganic, and eutectic are the three types of PCM available.[60]

3.1.1 Organic PCM

Organic PCMs were associated with a broad variety of components includes paraffin, fatty acids, and their eutectic mixes, such as esters, and other organic substances. Due to its high heat of fusion, fluctuating stage change temperature, zero supercooling properties, lower vapor pressure, chemical inertness, and continuous conductivity, among other important properties, paraffin has been used for energy storage.[61–63] In commercial organic heat storage, paraffin wax is the most prevalent kind of paraffin. [64] These are recognized for being chemically inert and stable below 500 degrees Celsius. In addition to paraffin, the organic PCM subgroup also includes a fatty acid. They are produced by hydrolysis of plant and animal waste; therefore, fatty acids are also known as renewable PCM. In comparison to other phase transition materials, fatty acids have good chemical and thermal characteristics, negligible toxicity, melting compatibility, hence it is generally used for heat storage applications, and biodegradability.[65] They can undergo melting and freezing cycles as shown in fig.1, organic PCM were chosen for their superior thermal and physical characteristics, as well as their ease of inclusion into complex structures.[66]

3.1.2 Inorganic PCM

Inorganic PCMs have a higher heat conductivity and storage capacity (about double that of organic PCMs). Salt hydrates and metals are two standard classifications.[67,68] The phase change in salt hydrates, which includes the disappearance of a significant amount of water, is essentially comparable to the thermal process of melting in other substances. Nucleating chemicals were blended with salt hydrates to overcome the limited nucleating capacity problem, which results in substantial supercooling.[69] Despite these disadvantages, salt hydrates were often recognized as ideal materials for TES applications due to their high latent heat, and a proper phase transition temperature, and substantial cost-effectiveness and profitability.[70] Metals are also seen in inorganic PCMs. Metal alloys with high melting points range 400–1000°C have been used in extremely high-temperature systems.[71] They can be used in integrated PV module in the form of high-temperature PCMs.

3.1.3 Eutectic PCM

It is a combination of two PCM's, such as Organic-inorganic[72], organic-organic[73], inorganic-inorganic. The features of eutectics are remarkable. Eutectic mixtures' melting and freezing temperatures are often lower than their components' melting and freezing temperatures.[74] During the phase transformation process, it does not break down into its components. The most frequent type of eutectic PCM is inorganic-inorganic eutectics. Recent studies have focused on organic-inorganic and organic-organic variants.[75]

3.2 Selection parameters of PCM

The PCM, a crucial component in designing of the latent heat storage unit (LHSU).[76] The selection parameter of a particular PCM to LHSU depends on the PCM's thermal, physical, chemical, kinetic, and economical properties. Since no one substance has all the desired properties for the best heat storage medium, it is essential to make the best use of available materials, and at the same time, do everything possible to effectively compensate for the physical characteristics existing in the system design. Therefore, the selection of suitable PCM is the important task and barrier for researchers. PCM selection is based on the need and depends upon various parameters[77–83)]

i. **Thermal Properties:** Thermal properties are primary selection properties, so high energy storage density, high thermal conductivity, desired melting, and freezing temperature should be considered.

ii. **Physical Properties:** PCMs are dependent on the PV systems collectively. High-density PCM should be selected for low container volume. But density variation of material should be low to reduce the change in physical structure.

iii. **Chemical Properties:** Properties of PCMs should not degrade early on the freezing/melting cycle. It should not possess any corrosive effects with containers and PCMs should be chemically stable. It should not toxic and explosive in nature..

iv. **Kinetic Properties:** High nucleation rates and crystal growth rates. i.e., at the thermodynamic freezing point, the melt should crystallize. And heat transfer rate especially in isothermal conditions should be effective.

v. **Economical:** Material must be cost-effective and easily available in abundant quantity.

For thermal management, PCM is used in many applications like PCM walls to maintain building temperature, smart textiles, solar energy storage, food industry, space application, electronics, automotive industry, etc.[11,84–88)] According to study in decades many types of research done on PV panel surface cooling with the help of different types of PCM but still didn't getting any satisfactory result.

4. PV-PCM system

By the study of several types of research, it is found that PV module efficiency can be enhanced by attaching heat storage material (PCM) to increase the system's thermal capacity and by lowering the temperature of the rear surface for PV modules.

i. To increase the thermal capacity of the system PCM filled containers or heat pipes are used. In present study mainly focused PV-PCM system. By use of PCM with a proper heat storage property, chemically stability, non-corrosive, and shows the better performance in a repeated number of cycles of operation. The thermal conductivity of PCM can be increased by adding some additives into it such as low-cost metal powders and nano-PCM PV-PCM setup should be simple structured and keeping in mind that this hybridization should not increase total costs of the system.

ii. Surface overheating can be reduced by using water flow through the rear surface. Surface cooling of the panel through naturally flow of air but it's not sufficient, to lower the more solar heat's access temperature, continuous water circulation is created at the backside of the PV using metal pipes (mostly copper tubes) that serve as a heat exchanger. And also, for increasing heat transfer rate metallic fins can use in the container.

The efficiency of the panel depends on panel surface temperature; more surface temperature drops can create a more effective PV-PCM system with great output. The findings of the research mentioned above indicate that PCM is effective for efficiency enhancement. Such systems are financially feasible in medium temperature and sun irradiation environments, as well as with the lowest PCM combination and pollution-free operation with minimal space requirements.

Most of the current research has concentrated on the use of organic PCM. Organic PCM gave better results than other PCM due to its excellent property but it has also some disadvantaged, such as low thermal conductivity they are slightly costlier than inorganic. So, the problem of low thermal conductivity can be overcome by adding some additives to it. Whereas inorganic PCM has good thermal conductivity and is cheaper than organic PCM but they are not stable for a repeated number of cycles. Therefore, organic PCM is the better option with some improvement.

Various types of PCM with different melting points, used by researchers [39-44,46-53,89–94)] to cooling of the PV panel are shown in Fig. 2, and with the help of Fig.2 it is observed that 45% of the published research have used PCMs with a melting point in the range of 25 °C - 35 °C. In 40% research PCMs with a melting point above 35 °C have been used while only 15% of the research have been used PCM with a melting point generally below 25 °C. PCMs with a melting point generally above 40 °C, are preferably used for the very hot and dry climate.

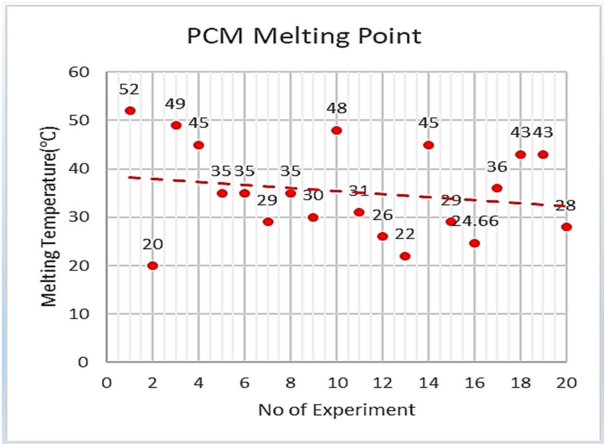

Fig. 2 PCM melting point used by researchers

The major issue and limitation of PCM are its low thermal conductivity. Organic PCM that has been most widely used by researchers around 65% shown in Fig. 3, for thermal regulation and management of PV panels has very low thermal conductivity. Eutectic PCM is using around 20% and inorganic PM is using around 15% for PV-PCM system.

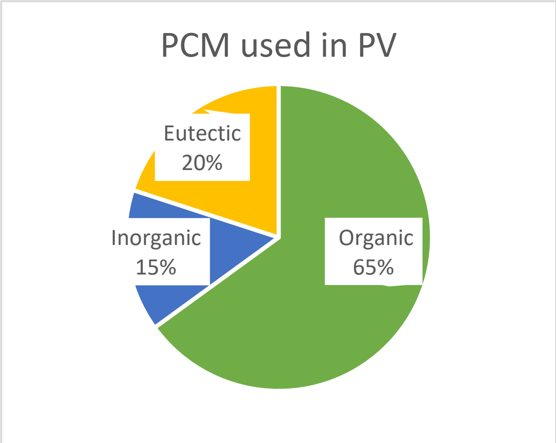

Fig. 3 Type of PCM used for PV cooling

5. Conclusion and Future Outlook

In the present work studied different types of PCM integrated with PV panel. It is found that performance and electrical efficiency increases of PV panel by using PCM with less energy consumption. There are various types of PCM has been studied. The result shown that organic PCM has a better performance compared with other PCMs. The future research aspects need, to use PCMs in different areas and study the effects on various solar and electrical performance parameter.

There are certain limits to utilizing other PCM, such as supercooling, phase segregation, lack of thermal stability, corrosion effect with some metals, and also, they are a little poisonous. But PCM can store a large amount of excess heat on the panel surface which will help to improve panel efficiency. Concluding remarks of this study as:

- Organic PCM can overcome the disadvantages as compared to the other PCM-based method.
- Organic PCM shows the promising role in improvement of performance of PV panel.
- The PV-PCM can effectively reduce the average surface temperature of PV systems.
- The heat transmission rate is also increased when fins are installed in PCM containers. To make a cost-effective setup, aluminium containers with aluminium fins are mostly used.
- External cooling sources, such as forced flow water supply through tubes, provide greater cooling results.

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Inclusion:

Table 1 Summary table of above research on PV-PCM technology

S.N.	PCM Considered	Melting Temperature (°C)	Latent heat (KJ/Kg)	Type of PCM	Result	Reference
1.	Paraffin wax + 0.5% TiO_2	52	140	Eutectic	Temperature drops of 13°C and daily efficiency increased up to 2.1%	51)
2.	RT20	20	155	Organic	Electrical efficiency increased in January at Jaipur up to 7.95% and at Dwarahat Uttarakhand up to 10.2%	50)
3.	Paraffin	46.9°C-59°C	154.4	Organic	Temperature drops from 0.4% to 12% and tilt of system increased melting time of PCM	53)
4.	White petroleum jelly	36°C-60°C	-	Inorganic	Electrical efficiency increased up to 4.24% and temperature reduction 8.10%	49)
5.	RT35	35	160	Organic	Electrical efficiency increased up to 7.43%/day and temperature drop from 10°C to 17°C	48)
6.	OM35	35	197	Organic	Electrical efficiency increased 12.4% and avg. temperature drop of 5.4°C	47)
7.	PC29	29	188	Organic	Avg. efficiency increased 4.6%, and avg. temperature drop of 9.1°C	46)
8.	RT26, RT35, RT42	26,35,42	180,160,165	Organic	PCM melting time increased 18%, Thermal management duration increased 33%	44)
9.	$CaCl_2.6H_2O$	30	191	Inorganic	Temperature drops from 64.4°C to 46.4°C in January and 77.1°C to 53.8°C in June. Electrical efficiency increased from 9.5% to 10.5%	52)
10.	OM47	48	196	Organic	Thermal efficiency by PVTPCM setup increased from 6.5% to 42% and PVTPCM with matrix increased from 7.1% to 48.5%	89)
11.	RT27, RT31	25-28,27-31	179,165	Organic	Conversion efficiency increased up to 2.86% to 4.19%	43)
12.	Composed Oil (Coconut oil, Sunflower oil), Boehmite nano powder	25-26	308	Eutectic	Only oil efficiency enhancement 21.19%,26.88%,29.24% and by adding Boehmite nano powder efficiency increased to 44.74%,46.63%,48.23%	39)
13.	RT22HC	22	190	Organic	Reference PV panel give more energy output than vertical & horizontal.	40)
14.	Nano PCM's of CU, SIC and Calcium Carbonate	36-60	-	Inorganic	Surface temperature DROP FROM 48.6 to 45 and average efficiency of panel increased up to 4.3%.	41)
15.	OM29	29	229	Organic	Avg. panel temperature drop 10.35°C, Avg. conversion efficiency increased to 24%	42)
16.	Capric–lauric acid	24.66	172	Eutectic	C-L maintains highest temperature deviation of 18°C	90)
17.	Waksol wax	32-36	162	Organic	Effect of crystallization – less cavity formed during solidification	91)
18	Parafina Merck	43	130	Organic	lower the temperature of the module by 7 K	92)
19	GR40	43	82	Eutectic	GR40 is not effective in thermal control.	93)
20	ZDJN-28	28	204.5	Organic	By applying this pcm in panel it increases average panel power by 7.28%.	94)