Cooling System for Solar Photovoltaic Panel -A review

[1]P. V. Ghanekar, [2]V. D. Patil, [3] P. A. Tekale, [4]S. B. Kokate, [5]M. P. Kumbhare

[1, 2, 3, 4] Under Graduate Students, [5]Assistant Professor

[1, 2, 3, 4, 5]Department of Mechanical Engineering,

[1, 2, 3, 4, 5]A.B.M,S.P's Anantrao Pawar College of Engineering and Research, Pune, India.

Abstract : This work is devoted to improving the electrical efficiency by reducing the rate of thermal energy of a photovoltaic/thermal system (PV/T). The temperature of solar cell is increased by the absorbed solar radiation that is not converted into electricity, causing a decrease in their electrical efficiency. In hybrid photovoltaic thermal (PVT) solar systems, the reduction of PV module temperature can be combined with useful PCM heating. Therefore, hybrid PVT systems can simultaneously provide electrical and thermal energy, achieving a higher energy conversion rate of the absorbed solar radiation. A PCM jacket were connected to the PV panel to extract the extra amount of heat from the PV cell and improving the efficiency. This study mentioned the different types of cooling technique used for PV panel cooling. A large scale of literature review on the different cooling technique and the PCM cooling technique were concentrated in this work

***Index Terms* – Solar Radiations, PV Panel, PCM, Cooling Technique.**

I. INTRODUCTION

Environmental problems due to extensive use of fossil fuels for electricity production and combustion engines have become increasingly serious on a world scale in recent years. To solve these problems, renewable energy sources have been considered as new sources of clean energy. Solar energy is one of the most important sources among the renewable energies. Generally, solar energy conversion systems can be classified into two categories: thermal systems which convert solar energy into heat and photovoltaic systems which convert solar energy to electricity. Intensive efforts are being made to reduce the cost of photovoltaic cell production and improve efficiency and narrow the gap between photovoltaic and conventional power generation methods such as steam and gas turbine power generators. Solar cell performance is affected by factors such as crystalline structure, intensity of sunlight, angle of sunlight irradiation, and surface temperature. Hybrid Photovoltaic/Thermal (PV/T) collector which combines between the collection of thermal energy and generation of electrical energy is a promising solution to achieve a better exploitation for the solar energy. PV/T collectors can produce more energy per unit surface area in comparison with PV modules and solar thermal collectors [1]. The most critical period for PV panel efficiency degradation is in regimes of highest solar irradiation levels and lowest wind air velocities [2]. The other problem that can result from the high cell temperature is the capability of reaching the full damage as a result of overheating [3]. As a result, cooling of the PV panels is a necessary task that should be taken seriously into consideration. Cooling of PV can be used for heating of a fluid at the same time so we can improve the electrical efficiency and at the same time cultivate some thermal energy. This combination gave rise of hybrid system. Many types of hybrid collectors are available, where the PV is the common part. These types like the PV/T flat plate collector, PV/T concentrator collector, and PV/T heat pipe collector. The most popular collector type in the recent years is the hybrid PV/T flat plate solar collector. The PV/T collector is composed of the PV panels, the absorbing surface which is mainly flat plate, the flow channels, working (cooling) fluid, and the storage medium if required. Each one of these components may aff ect the performance of the PV/T.

II. DIFFERENT COOLING TECHNIQUE

A several conventional cooling technique are mentioned in previous literature. Three main technique are concentrated by various literature viz. 1) air cooling, 2) water cooling, and 3) advanced cooling technique [4].

A. Air cooling

1) Natural cooling

This technique uses ambient air flow to reduce PV panel temperature by natural ventilation. Heat transfer can further be enhanced by increasing the heat transfer area using fins and extended surface designs. The drawbacks of this system are the fluctuations in PV cell temperature and very high panel temperatures during peak insolation [5]. Yun et al. [6] studied a ventilated PV façade and found that peak temperature of PV panel was 55.5 °C in comparison to 76.7 °C for the panel without ventilation. Cuce et al. [7] were studied Effects of passive cooling on performance of silicon photovoltaic cells. Effects of passive cooling on performance parameters of silicon solar cells and aluminum heat sink were investigated, they reported that energy, exergy and power conversion efficiency of the PV cell considerably increase with the proposed cooling technique. An increase of _20% in power output of the PV cell is achieved at 800 W/m^2 radiation condition. Maximum level of cooling is observed for the intensity level of 600 W/m^2. Performance of PV cells both with and without fins increases with decreasing ambient temperature. Mojumder et al. [8] were Study of Hybrid Photovoltaic Thermal (PV/T) Solar System with Modification of Thin Metallic Sheet in the Air Channel. Model developed hybrid PVT panel by changing different shape of metallic sheets, water and air were used as the heat extraction medium. They reported that Efficiency of the PV/T system varies significantly with the variation of the shape of the metallic sheet in the air channel. Efficiency of the flat metallic sheet is the lowest, saw tooth backward and saw tooth forward shows the same efficiency and trapezoidal metallic sheet is lower than that. Popovici et al. [9] were investigated Efficiency improvement of photovoltaic panels by using air cooled heat sinks. They developed numerical approach of the reduction of temperature of the photovoltaic panels by using the air cooled heat sinks, different configurations of the heat sink, ANSYS-Fluent software used for turbulent flow. They reported that operating temperature of

PV panel reaches about 56 °C, if no ribs are used and the maximum produced power is 86% of the nominal one, using a heat sink the temperature is reduced with at least 10 °C below the value obtained in simulation. Tonui and Tripanagnostopoulos [10] were develop the Improved PV/T solar collectors with heat extraction by forced or natural air circulation. Model developed by use of a suspended thin flat metallic sheet at the middle or fins at the back wall of an air duct as heat transfer augmentations in an air-cooled photovoltaic/thermal (PV/T) solar collector. They concluded that Under natural flow, the temperature rise could reach upto about 12 ^{0}C in the early afternoon during sunny days and could induce sufficient airflow rate to effect adequate ventilation, For the forced convection with flow rate of 60 m^3/h and 15 cm channel depth, the use of fins yields an efficiency of 30% followed by the thin metallic sheet with 28% and lastly the typical with 25% for their models. The FIN type system gives higher thermal output than TMS system.

2) Forced cooling

This technique of heat removal is based on forced airflow at the front and back of the PV panels. It however consumes significant amount of fan power. Krauter et al. [11] found that active ventilation with forced convection can increase electrical output by 8%. Bhargava et al. [12] were presented Study of hybrid solar system- solar air heater combined with solar cells. Analysis of hybrid system (combination of an air heater and photovoltaic system) were investigated, they reported that the flow rate increases, then the solar cell efficiency increases, as duct depth increases, the thermal efficiency of the collector decreases.

B. Water cooling

Passive and active cooling technique are the two methods in water cooling method. It is based on PV panel cooling using water without the use of pumps. It is found eff ective for PV cooling provided good thermal contact between the PV and the collector system is ensured. Active cooling performance is improved as the water flow velocity is increased. However, increase in volumetric flow per unit time means increase in power consumption. Krauter [13] found that water flow can increase the electricity generation efficiency of the panel by 8–9% along with reducing the reflection losses. Wei et al. [14] were presented Hybrid photovoltaic and thermal solar-collector designed for natural circulation of water. They developed hybrid photovoltaic and thermal (PVT) collector technology using water as the coolant, design developments of the PVT collectors. They reported that daily thermal efficiency could reach around 40% when the initial water-temperature in the system is the same as the daily mean ambient temperature. Mehrotra et al. [15] were investigated Performance of a solar panel with water immersion cooling technique. They developed water immersion cooling technique. They concluded that Maximum efficiency of 4.76 % was obtained under1cm depth of water with the proposed design and operating conditions, depth increases, the surface temperature of the panel decreases and the electrical efficiency increases till a particular depth after which it begins to fall. Musthafa [16] were presented study Enhancing Photoelectric Conversion Efficiency of Solar Panel by Water Cooling. Model were developed to reduce the temperature of the solar cell in order to increase its electrical conversion efficiency with and without water cooling .they concluded that without cooling, the temperature of the panel was high and solar cells achieved an efficiency of 8–9%. However, when the panel was operated under water cooling condition, the temperature dropped maximally by 40C leading to an increase in efficiency of solar. Ying Wu et al. [17] presented Heat transfer characteristics and performance evaluation of water-cooled PV/T system with cooling channel above PV panel. They developed three-dimensional numerical model of water-cooled PV/T system with cooling channel above PV panel, influences of mass flow rate, cooling channel height, inlet water temperature and solar radiation intensity on heat transfer characteristics of cooling channel. they reported overall exergy efficiency of system achieves maximum at the mass flow rate of 0.003 kg/ s and cooling channel height of 5 mm, Convective heat transfer between PV panel and cooling medium is enhanced at higher mass flow rate, solar radiation intensity and lower inlet water temperature, cooling channel height, The impact of thermal exergy efficiency on total exergy is more than that of electrical exergy efficiency, which means improving the utilization of heat energy is an effective way to prom. Cooling is more eff ective by using water. The electrical and thermal efficiencies have increased to be 9.1% and 41.9% [18] respectively as a result of higher thermal properties as compared to air. In addition, researchers have used refrigerants as cooling fluids for the PV panels. In this technology evaporation coils are installed beneath the PV cells to allow for low temperature refrigerant to pass through it which will be responsible in decreasing the PV cell temperature and as a result increasing the overall efficiency of the PV/T system [19]. There were some problems that resulted by the usage of such systems like the possibility for leakage of refrigerant. Using this method, electrical and thermal efficiencies reached 12% and 50% respectively [20]. The highly promising enhancement was achieved using nanofluids. Nanofluids are simply nanoparticles that are from metals or metal oxides in the micrometer or nanometer scale that are dispersed homogeneously in the base liquid. These nanoparticles have high thermal properties that allow it to be able to enhance the thermal properties and especially the thermal conductivity of the liquid once dispersed in the base fluid. Increasing thermal conductivity can result in reduction in operating cost and attaining higher thermal efficiency and better performance. There was two ways of cooling either passive or active. For the passive cooling, there is no need for any pumping or compressing to circulate the cooling fluid and the fluid circulation occurs naturally due to gravity [3].

C. Advanced cooling technique

1) Liquid immersion cooling

The technique involves removal of heat from the PV panels by immersing them in a dielectric liquid in an elongated tube. The liquid of such a refractive index is chosen so that it can concentrate the solar radiation onto the PV cells. This technique can maintain panel temperature in range 30–45 °C [5].

2) Thermoelectric cooling

Thermoelectric cooling is based on converting additional heat generated by the panel into electricity based on Peltier eff ect. This technique can increase the electricity generation efficiency of PV by 8– 23% [21]. Borkar et al. [22] were investigated Performance Evaluation of Photovoltaic Solar Panel Using Thermoelectric Cooling. Mathematical model were developed to simulate thermoelectric system for cooling of PV panel, they reported that simulation shows at low temperature 25^o C of the PV panel there is improvement in efficiency of PV module. The detailed analysis of the model indicates that performance and life enhancement of PV module could be achieved with 25° C cooling without loss of power.

3) Use of PCM cooling

The high latent heat capacity of PCM is utilized to maintain the PV panel at a fairly constant temperature. The heat stored can later be used for space heating, water heating and other purposes. However, the initial investment with these systems is quite high. It is clear that the natural ventilation based cooling is the most ineffective method while forced water and air cooling techniques are being used around the world for PV panel cooling. PCM has an added advantage of its ability to delay the temperature rise of panel without any electricity consumption. Further, the heat stored can be reused which further enhances the system efficiency. Studies on liquid immersion cooling are lacking though it also appears promising. For thermoelectric (TE) cooling, the focus is more on increasing the electrical energy output of the panel. Lower the panel temperature, lower is the TE efficiency. M. Rajvikram et al. [23] were carried out an experiment to investigate abasement of operating temperature in solar photovoltaic panel using PCM and aluminium. This approach has been experimented naturally under direct sun rays for three months and observed results observed results of 2 days are attached. The experiment has been conducted using two 5W panels, and the results of the PV-PCM entrenched with aluminium panel is compared with naturally ventilated panel without PCM and aluminium. They concluded that, PV-PCM with aluminum sheet at the backside of panel has improved the conversion efficiency of the panel by an average of 24.4%. For an average decrease in temperature of 10.35 °C, the electrical efficiency of the panel is increased 2%. While using this proposed cooling method, the results of FLIR images show a maximum decrease in temperature of 13 °C for the Day 1 and 7.7 °C for the Day 2. Zhenpeng Li et al. [24] were presented experimental Study and performance analysis on solar photovoltaic panel integrated with phase change material were investigated, they reported that the flow rate increases, then the solar cell efficiency increases, as duct depth increases, the thermal efficiency of the collector decreases the PV/T system performance.

III. Literature Review

Intensive efforts are being made to reduce the cost of photovoltaic cell production and improve efficiency. Bhaskar B. Gardas et.al. [25] were studied Design of Cooling System For Photovoltaic Panel for Increasing Its Electrical Efficiency. They were obtained the aluminum fin at an irradiation of 1000 W/m² is showing maximum efficiency of 97.58 %, when water vapor is made to flow through the duct, maximum mass flow rate is for carbon dioxide and of the magnitude of 0.04559 kg/sec through the duct. Electrical efficiency drops when temperature of solar cells increases. For hydrogen, the system requires a mass flow rate of 0.00275 kg/s, which is the least of all other gas mass flow rate values & Number of fins required are 3.46. Raghuraman. [26] presented Analytical Predictions of Liquid and Air Photovoltaic/Thermal, Flat-Plate Collector Performance. They carried out one-dimensional analyses for thermal and electrical performance of both liquid and air flat-plate, photovoltaic/ thermal (PV/T) collectors. They concluded any modifications in the design of the primary insolation absorber, the solar cell, has a direct impact on the collector performance, solar cell, has a direct impact on the collector performance, Heat losses through the top cover glass to the ambient air typically are computed to be 20 percent radiative and 80 percent convective losses. Convective losses are thus clearly the dominant cover surface, For the liquid collector, heat resistance resulting from air gaps between the absorber plate and the liquid-carrying Tubes can be minimized by making the tubes an integral part of the absorber plate.

Skoplaki and Palyvos. [27] studied on the temperature dependence of photovoltaic module Electrical performance: A review of efficiency/power correlations. Operating temperature of one-sun commercial grade silicon-based solar cells/modules and its effect upon the electrical performance of photovoltaic installations they concluded that electrical efficiency and – hence – the power output of a PV module depend linearly on the operating temperature.

A. Previous work on PCM cooling

This section reviews updated literature and important studies on the PCM cooling based PV system. C. J. Ho et al. [28] tested the cooling performance of the PV with microencapsulated PCM and found that PCM with 30 °C melting temperature performed better than the one melting at 28 °C. They concluded that PCM couldn't completely solidify at night after a certain thickness thereby affecting its cooling performance. Japs et al. [29] found that the energy generated by the PCM-PV is higher than reference PV panel without PCM for 5 out of 25 days while with PCM+ graphite-PV, it was lower for all the 25 test dates studied. They found that the results of PCM used with PV are only positive in the forenoon at peak temperature hours while the daily average energy and economic yields were negative for the whole test duration. In a second research they [30] found that PCM equipped with graphite performed better than that without it as graphite enhances the conductivity of the PCM which causes rapid heat dissipation resulting in considerably improved performance. Smith et al. [31] did global analysis of the PV panels using PCM and found that PCM is beneficial for high insolation areas with low inter seasonal climatic variations. An improvement in energy output of over 6% is seen on the Western coast of Mexico and improvements of over 5% are seen in many regions. For none of the regions studied, financial benefits were able to overcome the material costs assuming an average lifetime of 25 years of PV/PCM systems. The greatest improvements in performance were found for Africa, South Asia, Australia and South and Central America as these areas receive high levels of irradiance and often experience high ambient temperatures year-round.

IV. Criteria for PCM Selection

Most of the research highlights the impact of PCM on the PV performance for specific periods when the conditions are suitable for PCM i.e. high insolation and average ambient temperature. Performance under real conditions is also not well studied. The PVPCM system essentially requires higher thermal conductivity and high heat capacity PCM. However, the criteria for selecting the PCM melting temperature (m.p.) are not well defined in literature. Lower melting PCMs (around 25 °C) are able to maintain temperature of PV panels in the desired range for very short intervals and become ineffective after peak insolation hours. Increasing thickness of the lower melting PCM create problems of incomplete melting. On the other hand, high melting PCM (>30 °C) cannot maintain PV at the desired temperature of 25 °C although it can be maintained below a particular temperature for the entire duration. This essentially means that high melting PCM could maintain the panel at slightly higher but uniform temperature preventing creation of hot spots while low melting PCM could maintain the panel at low temperature at which it gives maximum efficiency but only for a limited duration. This suggests that using multiple PCM with different melting points could be a better solution. A balance must therefore be made between the PCM melting temperatures, thickness and the obtained efficiency.

Since there are so many categories of PCMs, selection of PCMs is a hot topic in this field. As suggested by some studies on PCMs for thermal energy storage [33, 34], various properties, including thermal, physical, chemical, kinetic and economic properties, should be considered to guarantee the high performance, reliability, safety, adaptability, and also low cost.

Whether PCMs can be integrated with PV module is also dependent on their user-friendliness and long-term cyclic stability. As the user is the PCM container or PV module, PCMs should have low density variation and vapor pressure thus low volume change to avoid deformation of them, as well as no corrosivity. Besides, higher mass density results in lower container volume, which is preferred in practical application. For long-term cyclic stability, on the one hand, the chemical stability of PCMs should be kept for many years. Furthermore, in a 24-h cycle, PCMs should be fully solidified at night, which requires PCMs to be no or little super-cooling, and have an adequate crystallization rate

The above requirements are basically enough for exploratory research and lab test. For practical application, PCMs should be safe and eco-friendly. For large-scale application, available and abundant source of materials cannot be ignored.

A. Types of PCM.

A different types of PCMs used for cooling of PV system is shown in figure 1. There are main three categories of the PCM viz. organic, inorganic and Eutectic [34].

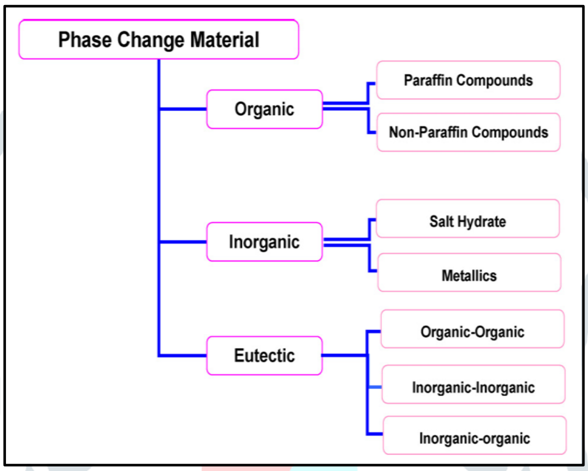

Fig. 1 PCM Classification

Table 1 shows the most used PCM materials and their melting temperature used for PV-PCM technique.

Table 1: Different PCM used for cooling of PV system by the researchers.

Category	**PCM type**
Organic	Paraffin based
	Lauric acid
	Fatty acid
	Petroleum jelly
Inorganic	$CaCl_2.6H_2O$
	$Na_2SO_4.10H_2O$
Eutectic	Capric-Lauric acid
	Capric-palmitic acid

V. Conclusion

In this paper, the state-of-the-art of PV-PCM systems is reviewed with respect to technology overview and materials selection. Attaching PCMs at the back of PV panel introduces external cooling power of PV due to the latent heat storage capacity of PCMs. The selection of a suitable kind of phase change materials could be one of the most significant barriers. Paraffin, slat hydrates, eutectics seem very good potential candidates, but each of them has strengths and weaknesses, with common problems of low thermal conductivity and liquid leakage. Pure paraffin stored in a cuboid container is still the most commonly used, with internal fins or adding nanoparticles for thermal conductivity enhancement. Almost all research only focuses on the melting process of PCMs, and neglects the solidification, which will lead to inaccurate results. Besides, the determination of the optimal phase transition temperature of PCMs should consider both the PV temperature and ambient temperature, ensuring the maximum melting fraction in day and solidification fraction at night.

References

[1] Zondag, H. A., de Vries, D. W., van Steenhoven, A. A., van Helden, W. G., & van Zolingen, R. J. (1999, July). Thermal and electrical yield of a combi-panel. In Proceedings of ISES Bi-annual Conference on CD-ROM.

[2] Nizetic, S., Grubisic-Cabo, F., Marinic-Kragic, I., & Papadopoulos, A. M. (2016). Experimental and numerical investigation of a backside convective cooling mechanism on photovoltaic panels. Energy, 111, 211-225.

[3] Odeh, S., & Behnia, M. (2009). Improving photovoltaic module efficiency using water cooling. Heat Transfer Engineering, 30(6), 499-505.

[4] Chandrasekar, M., Rajkumar, S., & Valavan, D. (2015). A review on the thermal regulation techniques for non integrated flat PV modules mounted on building top. Energy and Buildings, 86, 692-697.

[5] Du, D., Darkwa, J., & Kokogiannakis, G. (2013). Thermal management systems for photovoltaics (PV) installations: a critical review. Solar Energy, 97, 238-254.
[6] Yun, G. Y., McEvoy, M., & Steemers, K. (2007). Design and overall energy performance of a ventilated photovoltaic façade. Solar Energy, 81(3), 383-394.
[7] Cuce, Erdem, Tulin Bali, and Suphi Anil Sekucoglu. "Effects of passive cooling on performance of silicon photovoltaic cells." International Journal of Low-Carbon Technologies 6, no. 4 (2011): 299-308.
[8] Mojumder, Md Sadman Sakib, M. M. Uddin, I. Alam, and H. K. Enam. "Study of hybrid photovoltaic thermal (PV/T) solar system with modification of thin metallic sheet in the air channel." J. Energy Technol. Policy 3 (2011): 47-55.
[9] Popovici, Cătălin George, Sebastian Valeriu Hudişteanu, Theodor Dorin Mateescu, and Nelu-Cristian Chereches. "Efficiency improvement of photovoltaic panels by using air cooled heat sinks." Energy Procedia 85 (2016): 425-432.
[10] Tonui, J. K., and Y. Tripanagnostopoulos. "Improved PV/T solar collectors with heat extraction by forced or natural air circulation." Renewable energy 32, no. 4 (2007): 623-637.
[11] Krauter, S., Araújo, R. G., Schroer, S., Hanitsch, R., Salhi, M. J., Triebel, C., & Lemoine, R. (1999). Combined photovoltaic and solar thermal systems for facade integration and building insulation. Solar Energy, 67(4-6), 239-248.
[12] Bhargava, Ashok Kumar, H. P. Garg, and Ram Kumar Agarwal. "Study of a hybrid solar system—solar air heater combined with solar cells." Energy Conversion and Management 31, no. 5 (1991): 471-479.
[13] Krauter, S. (2004). Increased electrical yield via water flow over the front of photovoltaic panels. Solar energy materials and solar cells, 82(1-2), 131-137.
[14] He, Wei, Tin-Tai Chow, Jie Ji, Jianping Lu, Gang Pei, and Lok-shun Chan. "Hybrid photovoltaic and thermal solar-collector designed for natural circulation of water." Applied energy 83, no. 3 (2006): 199-210.
[15] Mehrotra, Saurabh, Pratish Rawat, Mary Debbarma, and K. Sudhakar. "Performance of a solar panel with water immersion cooling technique." International Journal of Science, Environment and Technology 3, no. 3 (2014): 1161-1172.
[16] Musthafa, M. Mohamed. "Enhancing photoelectric conversion efficiency of solar panel by water cooling." Fundamentals of Renewable Energy and Applications 5 (2015): 166.
[17] Wu, Shuang-Ying, Chen Chen, and Lan Xiao. "Heat transfer characteristics and performance evaluation of water-cooled PV/T system with cooling channel above PV panel." Renewable Energy 125 (2018): 936-946.
[18] Faninger, G. (2000). Combined solar–biomass district heating in Austria. Solar Energy, 69(6), 425-435.
[19] Qiu, Z., Zhao, X., Li, P., Zhang, X., Ali, S., & Tan, J. (2015). Theoretical investigation of the energy performance of a novel MPCM (Microencapsulated Phase Change Material) slurry based PV/T module. Energy, 87, 686-698.
[20] Ji, J., He, H., Chow, T., Pei, G., He, W., & Liu, K. (2009). Distributed dynamic modeling and experimental study of PV evaporator in a PV/T solar-assisted heat pump. International Journal of Heat and Mass Transfer, 52(5-6), 1365-1373.
[21] Van Sark, W. G. J. H. M. (2011). Feasibility of photovoltaic–thermoelectric hybrid modules. Applied Energy, 88(8), 2785-2790.
[22] Borkar, Dinesh S., Sunil V. Prayagi, and Jayashree Gotmare. "Performance evaluation of photovoltaic solar panel using thermoelectric cooling." International Journal of Engineering Research 3, no. 9 (2014): 536-539.
[23] Rajvikram, M., S. Leoponraj, S. Ramkumar, H. Akshaya, and A. Dheeraj. "Experimental investigation on the abasement of operating temperature in solar photovoltaic panel using PCM and aluminium." Solar Energy 188 (2019): 327-338.
[24] Li, Zhenpeng, Tao Ma, Jiaxin Zhao, Aotian Song, and Yuanda Cheng. "Experimental study and performance analysis on solar photovoltaic panel integrated with phase change material." Energy 178 (2019): 471-486.
[25] Gardas, Bhaskar B., and M. V. Tendolkar. "Design of cooling system for photovoltaic panel for increasing its electrical efficiency." International J Mechanical Prod Engineering 1 (2012): 63-67.
[26] Raghuraman, Pattabiraman. "Analytical predictions of liquid and air photovoltaic/thermal, flat-plate collector performance." Journal of solar energy engineering 103, no. 4 (1981): 291-298.
[27] Skoplaki, Elisa, and John A. Palyvos. "On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlations." Solar energy 83, no. 5 (2009): 614-624.
[28] Ho, C. J., Chou, W. L., & Lai, C. M. (2015). Thermal and electrical performance of a water-surface floating PV integrated with a water-saturated MEPCM layer. Energy Conversion and Management, 89, 862-872.
[29] Japs, E., Peters, S., Sonnenrein, G., & Krauter, S. (2014, June). Energy-economic comparison of photovoltaic modules equipped with a layer of conventional and improved phase-change material. In 2014 IEEE 40th Photovoltaic Specialist Conference (PVSC) (pp. 1348-1352). IEEE.
[30] Japs, E., Sonnenrein, G., Steube, J., Vrabec, J., Kenig, E., & Krauter, S. (2013, September). Technical investigation of a photovoltaic module with integrated improved phase change material. In Proceedings of the 28th European photovoltaic solar energy conference and exhibition, Paris, Frankreich (Vol. 28, pp. 500-502).
[31] Smith, C. J., Forster, P. M., & Crook, R. (2014). Global analysis of photovoltaic energy output enhanced by phase change material cooling. Applied energy, 126, 21-28.
[32] Sarbu, I., & Sebarchievici, C. (2018). A comprehensive review of thermal energy storage. Sustainability, 10(1), 191.
[33] Hausler, T., & Rogass, H. (2000, May). Latent heat storage on photovoltaic. In Sixteenth European Photovoltaic Solar Energy Conference, Glasgow, UK (pp. 2265-2267).
[34] Li, Z., Ma, T., Zhao, J., Song, A., & Cheng, Y. (2019). Experimental study and performance analysis on solar photovoltaic panel integrated with phase change material. Energy, 178, 471-486.