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REVIEW ON COOLING TECHNIQUE FOR ENHANCING THE EFFICIENCY OF SOLAR PHOTOVOLTAIC SYSTEM

Manish Pawar[1], Prof. Surendra Agarwal[2]

[1]*PG Scholar, Surabhi Satyam Group of Institute, Bhopal.*
[2]*Head, Mechanical Engineering Department, Surabhi Satyam Group of Institute, Bhopal*

Abstract: A solar photovoltaic system is a device which converts energy from the sun directly into electricity. The solar PV module's power output strongly depends upon the solar irradiation falling on it. As the intensity of solar radiation decreases, the power of the module decreases almost linearly as the solar irradiation available throughout the day is not constant. A valuable amount of solar radiation falling on photovoltaic system gets converted into heat hence reducing the efficiency of the system. So there is a need to improve efficiency of the system by employing cooling technique for reducing the temperature of the panel.

Keyword: Photovoltaic cooling, Phase change material, Fill factor, open circuit current, short circuit current.

1. Introduction

Recently the energy demands in our country are fulfilled by fossil fuel and non renewable energy sources which are depleting at a very fast rate. Hence the solution for the problem of energy demand can be made from renewable energy sources. Since, use of energy has become an integral part of our life and at the same time it should be economical and environment friendly and socially acceptable. The current trends in energy consumption are neither secure nor sustainable. Green house gases such as CO_2 trap heat and make the planet warmer which leads to melting of ice and increase in sea level. Solar energy is one of the clean and inexhaustible sources of energy with no carbon-di-oxide emission and zero waste generation. An effort have been made for proper and maximum utilization of vast solar resource using photovoltaic but the efficiency of the photovoltaic system or solar panel is still very low. As the significant amount of solar irradiation gets converted in to heat energy which not only reduces electricity generation but also reduces the life of solar panel. The efficiency of the solar panel fall by 0.5% for every 1^{o}C rise in solar cell temperature.**[1]** The major issue related to the efficiency of solar photovoltaic cell is the temperature as the sun shine mostly in equatorial region where sun rays comes directly to earth. But due to the temperature rise the photovoltaic system becomes inefficient. **[2]** The other factors affecting the efficiency of solar photovoltaic system are cable thickness, charge controller, shading inverter and battery which can be balanced as per our need easily. The various parameter which affects the temperature of the solar photovoltaic system are in-solation received, wind speed over the PV panel, direction of flow of wind and ambient temperature. As solar radiation falling on the PV panel, wind speed and ambient temperature are not under human control. Hence research is focused on either to develop a new material which is not much affected by temperature or to reduce the temperature of the solar panel according to our need without adding much to the system cost.

One of the techniques for maintaining the temperature of PV system is sprinkling the water over the panel or back of the panel which consumes a lot of water if not used by pump or if pump is used it will consumes electricity. Another technique is the use of ventilated PV panel but this technique suffers from poor heat transfer and inefficient cooling. Further it becomes more ineffective if the temperature is too high, also heat stored in the panel cannot be effectively stored and reused which can reduce the system cost and raising the efficiency of solar panel.

One more step toward cooling the PV system or maintaining the panel temperature is by placing the duct below the panel and air/ water is allowed to pass through this duct which will carry out the heat of PV system thereby cooling the cell and increasing the efficiency of the panel. It has been observed that for water heating thermal efficiency varies from 50-67% while that for air heating thermal efficiency varies from 17-51%. **[3]** A double pass photovoltaic thermal solar collector suitable for solar drying application. Hence, the photovoltaic, thermal and combined photovoltaic thermal efficiencies can be obtained. This will increase the efficiencies of the collector. **[4]**

Phase Change Material (PCM) is one of the better solutions having more heat capacity than water and air based system. The heat stored in the PCM can be utilized in the night without significant heat loss and also it can be used in air conditioning or water heating which will increase the overall efficiency of the system.

2. Principle of Solar Photovoltaic

A basic solar PV panel contains a semiconductor material covered by protective glass connected to a load. When sunlight hits the semiconductor, electrons become excited. These excited electrons are separated by an internal field inherent in the semiconductor and collected into an external circuit generating electricity. When light shines on a solar cell photovoltage is generated. The generated voltage across the solar cell drives the current in external circuit and therefore can deliver power. In order to collect energy of a photon in the form of electrical energy through solar cells following action must be taken (a) increase in potential energy of carriers, and (b) separation of carrier. Task (a) is performed efficiently by semi-conductor material. In order to perform task (b) asymmetry in semi-conductor device is required. Asymmetry should be such that the generated electron hole pairs should get separated from each other [5].

Once an electron-hole pair is generated within the junction (depletion layer), both carriers will be acted upon by the built-in electric field. Since the field directed from n top side, it will cause the holes to be swept quickly toward the n side. Once out of the junction region, these carriers became a part of the majority carrier in the respective regions and diffuse away from the junction region as their concentration near the junction has increased. This addition of excess majority charge carrier on each side of the junction, results in a voltage across external terminals of the junction. If a load is connected across these terminals, the photon generated current will flow this external circuit. This current will be proportional to the number of electron hole pairs generated, which in turn, depends on the intensity of illumination. Thus, an illuminated p-n junction becomes a photovoltaic cell with positive terminals on p side. [6]

Solar panel works best in certain weather condition, but since the weather is always changing and as engineers are installing solar panel all over the world in different climate region, most panels do not operating under ideal conditions. The solar panels available in India are European manufactured according to their standards which are not suitable to Indian conditions. European summers can be considered as Indian winters and it is required to manufacture solar panels suitable to Indian conditions. It has been found that with increase in temperature there is a drop in voltage and efficiency [5].

3. Effect of temperature on Photovoltaic system

PV cells absorb 80% of incident solar radiation, but they do not fully convert it into electricity. The remainder portion of sun's radiation increases solar cell temperature up to 40°C above atmospheric temperature.[7] The reason behind the low conversion efficiency of solar cell, it can convert a range of definite range of solar spectrum of light into electricity and rest of the incident solar radiation is converted into heat.[8] The output power of a solar PV module also depends on the temperature at which the module is operating. The module temperature is normally higher than ambient temperature. The module temperature could be up to 20°C to 30°C higher than ambient temperature, depending on conditions such as radiation intensity, wind speed etc. The various parameters of a solar PV module include Short Circuit Current (Isc), Open Circuit Voltage (Voc), Fill Factor (FF), Efficiency (η), Peak Power (Pm), Series Resistance (Rs) and Shunt Resistance(Rsh). The short circuit current, Isc, is the maximum current produced by a solar PV module when its terminal is shorted. The open circuit voltage, Voc, is the maximum voltage that can be obtained from a solar PV module when its terminal is left open. The increased cell temperature results in an increase in the short circuit current and decrease in open circuit voltage. Decrease in open circuit voltage is more prominent than short circuit current. Therefore, overall, the power output and efficiency of the solar cell and module decreases.

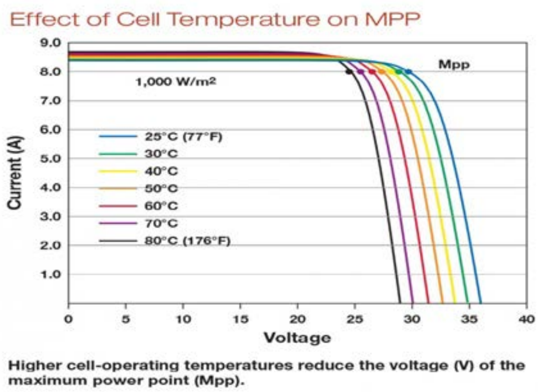

Fig.3.1 Effect of cell temperature on Maximum Power Point Tracking

4. Overview of Conventional PV cooling technique

(a) Air cooling: This techniques uses air for cooling the panel which include natural ventilation and forced ventilation. Natural ventilation uses ambient air flow to reduce PV panel temperature. Heat transfer can also be increased by adding fins to the panels. The drawback of this technique is the fluctuation of PV cell temperature and and very high temperature in summer season during peak in-solation. Forced ventilation removes the heat from the solar panel by forcing airflow at the front and rear of the PV panel. Although it consumes significant amount of fan power.[9] found that the electrical power output increases upto 8%.

(b) Water based cooling: Water based cooling techniques includes active cooling and passive cooling. Passive cooling technique is based on cooling the panel without use of pump. It is found as an effective measure for cooling PV cell having good thermal contact between the collector and PV. Whereas active cooling includes the usage of pump for increasing the velocity of water flow which increases volumetric flow per unit volume means increase in power consumption. S Krauter found that by increasing the velocity of water flow the efficiency of the panel increases upto 8-9% along with reduction in reflection losses.[10]

(c) Liquid immersion cooling: This technique removes heat from the PV panel by immersing them in a dielectric liquid in an elongated tube. The refractive index of such liquid is chosen so that it can concentrate the solar radiation on to the PV cell. While using this technique we can maintain panel temperature in the range of 30 - 45^{o}C.

(d) Thermoelectric cooling: This technique is based on converting additional heat generated by the panel into electricity based on peltier effect, which increase the electricity generation efficiency of PV by 8-23%

(e) Other cooling technique: From the literature it is found that by using nano fluid containing suspended metal particle increases heat transfer rate which results in cooling the panel. Sardarbaddi uses silica/water nano fluid and there is a possible increase in thermal efficiency upto 12%.[11] Gadhiri uses ferro fluid and obtains improvement upto 39% as compare to the distilled water.[12] Yun studies the influence of MgO/water nano fluid variation on solar panel and efficiency is recorded.[13]

Cooling using Phase change material: For maintaining the constant temperature of PV panel the high latent heat of the phase change material is utilized. The heat attained by the PV cell is transferred to the phase change material and further it can be used for other purposes. It has been noticed that the natural ventilation is one of the most ineffective method while forced water and air cooling are used around the world for PV panel cooling. PCM has an ability to delay the temperature rise of panel without any electricity consumption. The heat energy stored in the PCM can be further reused which enhances the efficiency of PV panel.

5. Literature Review on PV cooling technique

A.A.Al Baali identified the main factors that the effect of solar radiation and temperatures on the characteristics of a solar panel on power output of panel. The analysis reveals that there is a decrease in power output due to the increase in temperature and there is a need to maintain the panel temperature.[14]

E Radziemska shows the influence of temperature and wavelength on electrical parameters of crystalline silicon solar cell and a solar module are presented. At the experimental stand a thick copper plate protected the solar cell from overheating, the plate working as a radiation heat sink, or also as the cell temperature stabilizer during heating it up to 80°C. A decrease of the output power (−0.65%/K), of the fill-factor (−0.2%/K) and of the conversion efficiency (−0.08%/K) of the PV module with the temperature increase has been observed. The spectral characteristic of the open-circuit voltage of the single-crystalline silicon solar cell is also presented. It is shown that the radiation-rate coefficient of the short-circuit current-limit of the solar cell at 28°C is 1.2%(mW/cm^2).[15]

Skoplaki and Palyvos summaries that a solar cell has its thresholds photon energy corresponding to the particular energy band below which electricity conversion does not take place. Photons of longer wavelength do not generate electron hole pairs but only dissipate their energy as heat in the cell. Depending on the type of solar cells in use and the working conditions, a common PV module converts 4-17% of the incoming solar radiation into electricity. After deducting the reflected portion, more than 50% of the incident solar radiation is converted into heat in the cell, which leads to the extreme working cell temperature more than 30^{o}C above the ambient temperature. There can be two undesirable consequences: (i) a drop in cell efficiency and (ii) a permanent structure damage of the module if the thermal stress remains for prolonged period. [16]

T. Trupke in 2002 investigates low energy conversion efficiencies of solar cell is one of the major loss due to the thermalization of charge carrier generated by the absorption of high energy photon, which can be reduced if more than one electron hole pair is generated per incident photon. The solar panel absorbs photons with energies larger than the band gap energy E_g. The luminescence convertor is placed on the rear surface, photons with energies larger than twice the band gap shall be transmitted and absorbed by the convertor. This can be achieved by restricting the width of bands of solar cell material.[17]

The cooling performance of the PV 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.[18] The energy generated by the PCM-PV is higher than reference PV panel without PCM for 5 out of

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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. [19]

From the above literature it is very clear that due to the increase in temperature there is a reduction in efficiency and Saad Odeh suggests that the cooling of solar panel is considered as the less expensive and best technique for improving the efficiency of solar cell. Maximum research work is carried out on PV cooling is concentrated on building application such as PV façade and PV thermal hybrid system. [20,21] An arrangement of pipe fitting is used to allow water flowing under gravity on the PV module upper surface on experimentation resut shows that an increase in system output in the range of 4-10% when developed cooling technique was adopted. The major advantage of this technique are increasing cooling efficiency due to direct contact between PV module and water surface, increasing incident solar radiation on PV module due to beam refraction in water layer and maintaining PV module upper surface free of dust due to continuous flow of water. [22]

The global analysis of the PV panels using PCM on the western coast of Mexico and found that PCM is beneficial for high insolation areas with low inter seasonal climatic variation

Literature reveals that PCM based PV systems when integrated with air conditioning or water heating systems could decrease the overall system cost while making it more effective. An example of the working system utilizing PCM technology is a Japanese house which uses air to cool PV panels. A grid connected 4.2 kWp system charges the PCM installed in the building roof and ceilings which reduce the building heating and cooling loads. [23]

S.No	Cooling Technique	Advantage	Limitation	Achieved PV panel temperature range
1.	Natural Ventilation	Zero or negligible cost input	Low conductivity and heat transfer rate	50-70^{o}C[24]
		No electricity requirement	High PV panel temperature fluctuations	
		No Maintainence	Depends on wind direction and ambient air temperature	
2.	Forced Ventilation	High heat transfer compared to natural ventilation	Heat removed can't be reused effectively	20-30^{o}C[24]
			High installation cost	
		Do not depend on ambient conditions	Consumes large amount of fan power	
			System is noisy	
3.	Liquid immersion cooling	Larger heat dissipation	Ionization of water is a problem	30-40^{o}C[24]
		Better electrical performance	Liquid ingress due to leakage	
		Less reflection losses	Salt deposition is an issue	
			Corrosion may occur so appropriate care is must	
4.	PCM	No maintenance and electricity costs	Large initial investment	25-30^{o}C[24]
		Delays panel temperature rise	Cyclic stability of the material is a concern	
		No noise issues	Poor thermal conductivity	

Table.1 comparison of various cooling technique.

6. Results and Discussion

The review suggests that literature is more focused on potential of cooling technique in the solar cells used recently. The studies are found on testing the performance of integrated designs of solar panels such as ducts behind panel passing air and water through ducts, spraying of water over panel and applying phase change material behind the panel for heat interaction The studies on determining the possible thermal benefits using PCM, resultant effects on its lifetime and year round increase in power generation efficiency are however limited. Based on the study of literature the status of research, identified research gaps along with follow-up research areas are presented and discussed in this section:

i. **Selection criteria for PCM material:** While selecting the PCM material melting temperature plays an important role from the above literature it is clear that the material having lower melting temperature will be suitable for some condition it will be difficult for them to survive at higher temperature of 35-40^{o}C. The PV system equipped with PCM material essentially requires high thermal conductivity and high heat capacity. On applying thick layer of PCM material a problem of incomplete melting and PCM leaving the surface of PV system and system becomes inefficient. The PCM material having high melting point could maintain panel at slightly higher but uniform temperature. This suggests that using multiple PCM with different melting point could be a better solution. A balance must be maintained between the PCM melting temperature, thickness and obtained efficiency.

ii. **Salt hydrates for PCM cooling:** Salt hydrates have that potential for cooling of PV panel in terms of their high thermal conductivity, large heat storage capacity and lower volume expansion. Salt hydrates serves as a strong motivation which has far better conductivity while being several times cheaper than organic PCM material.

iii. **Solidification of PCM at night:** It has been observed that there is a performance problem when PCM material solidifies in night. During solidification of the PCM heat transfer comprises of complex flow geometries and convection becomes important. Further the PCM detaches from the container wall adding resistance to heat transfer.

iv. **Flammability of the PCM:** While using paraffin and fatty acid needs to be carefully used since they are highly flammable. Since the back surface reach the temperature above 80^{o}C in high insolation areas i.e it can be used up to certain limit.

7. Conclusion

A comprehensive review of cooling techniques for photovoltaic power systems using conventional cooling technique is presented to identify the status and research gaps, while also suggesting the plausible solutions. Based on the review, the main conclusions are as follows:

i. PCM is an economical and preferred cooling technique for PV panel in India as most of the time, temperature of country is round about 26-42^{o}C and the panel temperature before applying PCM is going to be from 40-70^{o}C which will not be favorable for Panel to work. After applying PCM on Panel and heat transfer the temperature of the panel may be 30-45^{o}C which will be the best temperature for PV panels to work.

ii. Suitability of PCM for PV cooling depends on geographic location and the year round climatic condition. PCM found to be suitable for that areas of high insolation and high ambient temperature and most of the part of the country lies below Tropic of Cancer i.e, it receives good sunlight all round the year.

iii. PCM in spite of their low thermal conductivity are found to improve the efficiency of the PV panel to the greater extent as the condition found in the Indian condition is favorable.

iv. PCM of melting temperature greater than 30 found to be promising in maintaining the constant PV panel temperature as compared to the low melting PCM. The former avoid formation of hot spots by keeping the panel at uniform temperature and also ensures proper solidification in hot summer nights.

v. Focus should also be directed to developing new technique with better conductivity and removing the problem of melting and solidification to meet the challenges in PV cooling technology.

References

[1] Chandrasekar M, Rajkumar S, Valavan D. A review on the thermal regulation techniques for non-integrated flat PV modules mounted on building top. Energy Build 2015;86:692–7.

[2] **A.A.Al-Baali**, Improving the power of a solar panel by cooling and light concentrating, Solar & Wind Technology Vol. 3, No. 4, pp. 241 - 245, 1986.

[3] **Jai Prakash,** Transient analysis of a photovoltaic-thermal solar collector for cogeneration of electricity and hot air/water, Energy Convers. Mgmt Vol. 35, No. II, pp. 967-972, 1994.

[4] **K. Sopian,** Performance of a double pass photovoltaic thermal solar collector suitable for solar drying systems, Energy Conversion & Management 41 (2000) 353-365.

[5] **Chetan Singh Solanki,** Solar Photovoltaic Fundamentals, Technology and Application, 2nd edition, PHI Learning Pvt. Ltd. Published 2009.

[6] **Blaine F. Parker**, Derivation of efficiency and loss factors for solar air heaters, Solar Energy Vol. 26, pp. 27-32.

[7] W.G.J. Van Helden, R.J.C. van Zolingen, H.A. Zondag, PV thermal systems: PV panels supplying renewable electricity and heat, Prog. Photovolt.: Res. Appl. 12 (2004) 415–426.

[8] A. Luque, S. Hegedus, Handbook of Photovoltaic Science and Engineering, John Wiley & Sons, 2011.

[9] Krauter S, Araujo RG, Schroer S, Hanitsch R, Salhi MJ, Triebel C. Combined photovoltaic and solar thermal systems for facade integration and building insulation. Sol Energy 1999; 67:239–48.

[10] Krauter S. Increased electrical yield via water flow over the front of photovoltaic panels. Sol Energy Mater Sol Cells 2004;82:131.

[11] Sardarabadi M, Passandideh-Fard M, Zeinali HS. Experimental investigation of the effects of silica/water nanofluid on PV/T (photovoltaic thermal units). Energy 2014;66:264–72.

[12] Ghadiri M, Sardarabadi M, Pasandideh-fard M, Moghadam AJ. Experimental investigation of a PVT system performance using nano ferrofluids. Energy Convers Manag 2015;103:468–76.

www.irjeas.org, ISSN(O): 2322-0821, ISSN(P): 2394-9910, Volume 5 Issue 4, Oct 2017-Dec 2017, Page 01-06
[13] Yun GY, Evoy MM, Steemers K. Design and overall energy performance of a ventilated photovoltaic façade. Sol Energy 2007;81:383–94

[14] **A.A.Al-Baali**, Improving the power of a solar panel by cooling and light concentrating, Solar & Wind Technology Vol. 3, No. 4, pp. 241 - 245, 1986.

[15] **E Radziemska**, The effect of temperature on the power drop in crystalline silicon solar cells, Volume 28, Issue 1, January 2003, Pages 1–12

[16] Skoplaki E, Palyvos JA. On the temperature dependence of photovoltaic module electrical performance. A review of efficiency/power correlations. Sol Energy 2009;83:614–24.

[17] T Trupke, Improving solar cell efficiencies by down-conversion of high-energy photons, Journal of Applied Physics, Volume 92, 3.

[18] Ho CJ, Chou WL, Lai CM. Thermal and electrical performance of a water-surface floating PV integrated with a water-saturated MEPCM layer. Energy Convers Manag 2015;89:862–72.

[19] Japs E, Peters S, Sonnenrein G, Krauter S. Energy-economic comparison of photovoltaic modules equipped with a layer of conventional and improved phase change material. In: Proceedings of the 40th IEEE Photovoltaic Specialist Conference (PVSC), Denver CO (USA) pp. 1348–52; 2014.

[20] Brinkworth, J., Cross, M., Marshall, H., and Hongxing, Y., Thermal Regulation of Photovoltaic Cladding, *Solar Energy*, vol. 61, pp. 169–178, 1997.

[21] Tripanagnostopoulos, Y., Souliotis, M., Battisti, R., and Corrado, A., Application Aspects of Hybrid PVT/Air Solar Systems, *Euro-Sun 2004*, vol. 1, pp.744–753, Freiburg, Germany, 2004.

[22] Saad Odeh, Improving Photovoltaic Module Efficiency Using Water Cooling, Taylor & Francis, Heat Transfer Engineering, 30:6, 499-505.

[23] Hestnes Anne Grete. Solar Energy Houses: Strategies, Technologies. Publisher Earthscan; 2003, [ISBN 1902916433].

[24] Darkwa JDD, Kokogiannakis JG. Thermal management systems for photovolatics installations. Sol Energy 2013;97:238–54.