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IMPROVED PERFORMANCE FOR SOLAR PHOTOVOLTAIC CELLS BY VARIOUS COOLING METHODS- A REVIEW

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ABSTRACT

The need of energy increases with mankind evolution and technology updating. The rapidly decrease in fossil fuel sources and pollution increase, initiated research for renewable energy sources. Solar panel is an important device consists of number of photovoltaic cells. The performance of a photovoltaic cell (PV) not only depends on the irradiance of the light but also depends on the temperature of the place where it is installed. By experimentation it is noticed with an increase in operating temperature, the efficiency of a photovoltaic solar cell decreases nearly. Due to increase in ambient temperature, open circuit voltage decreases, fill factor, generated power, overall efficiency etc. sharply. Large number of researchers has been conducted investigating a range of methods that can be employed to provide thermal management for PV systems. This review paper represents an indication of several active and passive cooling ways such as air cooling , water cooling, heat pipe cooling, cooling by phase change materials, cooling by nanofluid fins, geographical position etc. briefly to improve the PV cell performance economically.

KEYWORDS: Cooling method, Nanofluid, PV cells, Phase Change Material.

1. INTRODUCTION

Globally adopted renewable energy source is a solar energy that can be utilized in various applications such as, electricity generation through special optical solar cells, also known as Photovoltaic (PV) cells or thermal management using thermal collectors like solar air heater, solar water heater. PV cell is an important source to utilize the solar energy. It helps to directly convert the solar radiation into electricity which can be utilized to power household appliances. In actual during the operation of the PV cell, only around 15% of solar radiation is converted to electricity with the rest converted to heat. This heat energy increases the cell temperature, which therefore leads to drop in its electrical efficiency. Increase in cell temperature causes a reduction in open circuit voltage (Voc) that leads to reduction in the electrical efficiency.

The manufacturer generally specifies a temperature degradation coefficient and a maximum operating temperature for the cell. Cost of photovoltaic installations is mostly dependent on the Photovoltaic array area. Therefore, in order to improve the cost effectiveness of PV array powered systems, electric power generated by the PV array should be efficiently utilized. Also at high temperatures, the light induced degradation of a PV module gets accelerated Therefore deterioration in the performance of a PV module can be minimized if it is operated at lower temperatures, which can be achieved by dissipating heat, associated with it. The thermal energy associated with the PV module can be taken away by flowing a cold fluid (usually air or water) on the top of the module. The heat extracted out by the fluid can also be utilized in several ways like water and air heating .Such types of systems are known as hybrid photovoltaic thermal (PV/T) system. Hence by reducing the temperature of PV module its electrical efficiency can be boosted.

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2. PHOTOVOLTAIC CELL THEORY

A photovoltaic cell or solar cell is like electrical device which has tendency to convert light energy directly into electrical energy by photovoltaic effect. When light rays falls on a photovoltaic (PV) cell, it may be absorbed, reflected, or pass right through it. The PV cell is made up of semiconductor material, which has some properties of metals and some properties of insulators. When light is absorbed by a semiconductor, photons of light can transfer their energy to electrons, allowing the electrons to flow through the material as electrical current. PV cell modules can be aggregated together to make an array that is sized to the specific application. Generally most of the commercial PV cells are made from silicon, and come in three general types: mono crystalline, multi crystalline, and amorphous. Mono crystalline cells are made using silicon wafers cut from a single, cylindrical crystal of silicon. Mono crystalline cells are the most efficient, with approximately 15% efficiency (defined as the fraction of the sun's energy that is converted to electrical power), but is also one of the most expensive to produce.

Factors that affect the solar photovoltaic efficiency:

The electrical efficiency of solar cell generates photovoltaic (PV) cell is adversely affected by the significant increase of cell operating temperature during absorption of solar radiation**.** The output obtained by PV system depends on several factor such as

- Solar radiation
- Operating temperature of PV panel

3. OVERHEATING EFFECT ON PV EFFICIENCY

Solar cells (PV Cell) absorb up to 80% of the incident solar radiation, however only small part of the absorbed incident energy is converted into electricity depending on the conversion efficiency of the PV cell technology used. The remaining energy is releases as heat and the PV module can reach temperatures as high as 50ºC above ambient. This happens because PV cells convert a certain wavelength of the incoming irradiation that contributes to the direct conversion of light into electricity, while the rest is dissipated as heat.

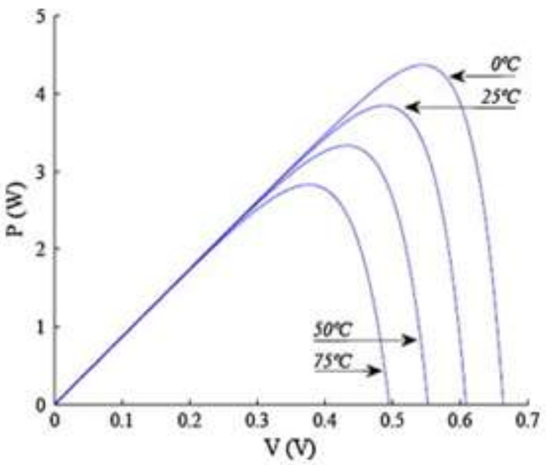

Figure 1. Effect of temperature on* P–V *characteristics

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The main drawback occurs in the operation of photovoltaic panels (PV) is overheating due to excessive solar radiation and high ambient temperatures. Overheating reduces the efficiency of the panels dramatically. The ideal *P–V* characteristics of a solar cell for a temperature variation between 0 °C and 75 °C are shown in Fig.2. The *P–V* characteristic is the relation between the electrical power output *P* of the solar cell and the output voltage, *V*, while the solar irradiance, *E*, and module temperature, T_m, are kept constant. As the cell temperature increases the maximum power output from the solar cells decreases, as can be seen in Fig. 1. The temperature coefficient of the PV panels used in this research is −0.5%/°C, which indicates that every 1 °C of temperature rise corresponds to a drop in the efficiency by 0.5%. This represent that temperature increase of the PV panels can affect the output of the panels significantly.

4. COOLING TECHNIQUES FOR PV PANEL

Two types of cooling can be distinguished: active cooling, which consumes energy (pump, fan, etc.,) and passive cooling, which uses natural convection/conduction to enable heat extraction.

Air cooling
Air is the most popular cooling component than any other materials. Air can be blown as natural or forced convection namely passive and active cooling respectively.

Water cooling
Among the liquid cooling fluids, water is the most popular fluid. Water can be used as active or passive cooling fluid easily.

Heat pipe cooling system
Generally the heat pipe includes evaporator section, adiabatic section and condenser section where evaporator section absorbs heat, condenser section rejects heat and the adiabatic section stays apart. Copper and aluminum materials are used as heat pipe wick and wall materials for -20°C to 100°C temperature range.

Nanofluid cooling system
Nanotechnology acts as a significant role to enhance the efficiency of the PV technology. In present most of the researchers focused inclination for nanofluid technology. Nanofluids consist of two pars which are based on fluid or liquid and nanosized particles or nano material. Nanofluid technology can be used for thermal collection and electrical conversion in PV cooling development. Utilization of nanofluids can enrich the PV performance significantly.

Phase change materials based cooling system
In the form of latent heat Phase changing materials (PCM) can store energy getting very small temperature difference. Thermal energy can be stored in the PV modules by means of PCM as a higher graded energy resource. PCM can store 5–14 times more energy per unit volume comparing the conventional materials like

water, concrete rock etc. In the practical life there always remains difference between the demand and the produced power. To overcome the limitations solar energy can store the thermal energy to ensure the heat availability at night time. Many researchers worked on the PCM based PV cooling technology.

Table 1. Assessment of different PV cooling solutions.

Technology	Features	Advantages	Disadvantages
Photovoltaic/Thermal hybrid solar system (PVT air cooling)	-Forced air circulation more efficient than natural (for building integration BIPVT) -More effective in cold climatic conditions -Many designs possible	-Simple technology -Air readily available -Increased overall efficiency -Economically viable -Less corrosion risk	-Lower efficiency than water cooling -Lower mass flow rates and PV temperature reduction -Blowers required for forced air circulation
Photovoltaic/Thermal hybrid solar system (PVT water	-Effectively increases electrical efficiency -More efficient on bottom side than on top side	-Increased overall efficiency -Higher conversion efficiency to electric	-High initial cost -Lower system life -Possible freezing in cold climatic conditions

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cooling)	-Temperature control by mass flow rate variation -Other liquids may be used	energy -Hot water used for domestic applications -Lower space requirement than for separate systems	-Electricityconsumption for pumping power -Possible leakage, fouling, Possible corrosion
PV/Phase Change Materials (PV-PCM cooling)	-Heat from PV panel is stored during PCM melting -Absorptive capabilities of material degrade over time -Compatibility, maintenance-free and high cooling capacity	-Store large heat amounts at small temperature change -System may operate during off-sunshine hours -Phase-change occurs at a constant temperature - Heat absorbed can be used	-Low thermal conductivity of PCM in its solid state -Some PCMs are toxic and have fire safety issue. -Disposal problem after end of life cycle. -Segregation reduces active volume for heat storage.
PV/Heat Pipes (HP-PV cooling)	-More complex design -Improved thermal output -Corrosion issues influence -Pipe material	-Very high heat fluxes -Passive heat exchange -Heat transfer across long distances -Easy to integrate	-High cost -Difficult tomanufacture -Generation of non condensable gas -Leakage of working agent
PV/Nano-fluids (PVT-NFs)	-Improved thermal output -Enhance heat transfer / heat removal -Sedimentation of Nano particles may be a problem	-Nano-fluids are available -Higher thermal efficiency	-Incipient technology -Influences not determined -Nano-particles high cost

5. LITRETURE REVIEW

Cooling Method	Reference	Information
Air Cooling	[1] 2013	-Experimented on the performance of micro channel solar cell using two fluids as air and water. The density and viscosity of air was 1.185 kgm^{-3} and 1.831x 10^{-5} respectively. The experiment was completed in a constant temperature 22°C and 1 atmospheric pressure. It was considered water and air flow rate about 88 ml/min and 4.20 l /min respectively to obtain maximum power output growth as 1.61 W.
Air Cooling	[2] 2012	-A comparative analysis of different types of PVT air collectors. -Unglazed, glazed and standard hybrid PVT air systems are analyzed in real climate conditions
Air Cooling	[3] 2015	Study on most influencing parameters: solar radiation intensity, mass flow rate of air, optimum channel depth Glazing improves thermal efficiency to 50-70%, but the electrical one remains at 10-12%
Air Cooling	[4] 2011	-Conducted experiments which result in increase of exergy efficiency from 9.8 to 11.1% by varying the wind speed from 0 to 10 m/s. -They found the optimized ambient temperature, solar irradiance and wind velocity for 300 K, 700 Wm^{-2} and $1ms^{-1}$ respectively
Air Cooling	[5] 2016	-Investigate to determine PV module position effect on thermal and electrical performances. -Result show that maximum thermal and electrical performance for distance between PV module and cover of 3 cm and 5 cm, respectively -Analysis of variance demonstrates the superiority of hybrid PVT over

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		standard PV system.
Water Cooling	[6] 2016	-Test carried out on the PVT and thermal (PVTT) collectors for module as well as observed electrical power difference between PVTT and PVT nearly 185 and 159 W in summer and winter respectively.
Water Cooling	[7] 2009	-Experimented for water cooled PV technology utilizing halogen lamp bulbs and dc water pump. It was obtained maximum power output was 19.87 W due to the reduction of 5 to 23 ˚C temperature.
Water Cooling	[8] 2015	-Water glazed PV/T system, with roll-bond flat plate aluminum absorber. -Model developed to evaluate performance of PV/T collectors show enhancements in electrical efficiency.
Water Cooling	[9] 2016	-Investigate to maximize the energy conversion by optimizing flow rate. -Extracted energy increased by 7.82%, thermal efficiency decreased between 5.54% and 7.34% using connecting pipes.
Water Cooling	[10] 2017	-Experimented in Multiple-channel heat sink for concentrated PV cells. -PV cell temperature rises to 91.4°C and flow rate at 0.6 m/s optimized conversion efficiency to 31.8% and net power to 4064 W.
Heat Pipe Method	[11]2012	-Emphasize on the heat pipe cooling system of Concentrating Photovoltaic (CPV) Cells. Copper/water heat pipe by natural convection with aluminum fins.
Heat Pipe Method	[12]2010	-used heat pipe array for solar panel cooling technology with air-cooling system. They compared the proposed system with the ordinary solar panel where the efficiency differed nearly 2.6%.
Heat Pipe Method	[13]2014	-Experiment carried to reduce the operating temperature of the PV panel using finned heat pipe technology
Heat Pipe Method	[14] 2016	-Wickless heat pipe compared with wire-meshed heat pipe -Thermal efficiency on wickless heat pipe and wire-meshed heat pipewas 52.8% and 51.5%, respectively
Nanofluid Cooling System	[15]2016	-studied on the nanofluid based PV cooling system comparing the separate channel (D-1) with the double pass design (D-2). on the nanofluid based PV cooling technology utilizing the straight and helical channels.
Nanofluid Cooling System	[16]2016	-Experimented on the performance of a solar thermal collector utilizing the magnetic nanoparticles to form an array structure. They found the optimum instantaneous efficiency and heat loss coefficient using magnetic nanoparticles for 0.742 and 8.41 respectively.
Nanofluid Cooling System	[17]2014	-Used dilute nanoparticle suspensions to increase the efficacy of the CPV/T system fixing 62ºC nanofluid outlet temperature of the silicon solar cell.
Nanofluid Cooling System	[18]2017	-Suggested use of nanofluid (water + Cu) more efficient than water in all cases. -Yearly enhancements of 4.35% thermal and 1.49% electrical
Nanofluid Cooling System	[19]2018	-Compared to no cooling and water cooling, by using 4 wt% nanofluid (with turbulent flow) the power output of the panel increased by 35% and 10% . Exergy efficiency was higher by 50% and 30%
PCM Based Cooling System	[20]2016	-Experiments on ZnO/water nanofluid (0.2 wt%) and paraffin wax PCM/Nanofluid increased PVT thermal energy output by 48%
PCM Based Cooling System	[21]2017	-Pure and combined PCM enhances electrical performance of PV panel. Combined PCM increased electrical efficiency by an average of 5.8%.
PCM Based Cooling System	[22]2017	-Investigation show that the maximum temperature reduction for simple water based and PCMPVT arrangements were found to be around 47 and 53% respectively. Gain of 2% in electrical efficiency achieved with paraffin (RT 30).
PCM Based Cooling System	[23]2017	-Analysis among three PV prototypes using pure PCM (White petroleum jelly), without PCM and combined PCM (white petroleum jelly, copper,

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	and graphite) to observe the thermal behavior and electrical characteristics of the PV panels.

6. CONCLUSION

For optimum utilization of solar energy, photovoltaic devices (PV Cell) are important component due to the present energy scenario in all over the world. In this modern time, the improvement of PV efficiency has become an innovative issue for the real time application. This paper represents highlight some experimental work carried out to improve the efficiency of solar photovoltaic cells with the help of various effective cooling methods. The optimum cooling solution also depends on quite a lot of issues for instance system procedure, engaged methodology, geometric concentration, atmospheric circumstance, solar irradiance, temperature effect etc. Out of Several technologies here we discussed air, water, heat pipe, nanofluid and PCM cooling method to extract heat from the PV solar modules.

Some general conclusions are briefly mentioned:

- PV Cell power output, and consequently the conversion efficiency, decreases with increasing operational temperature and, therefore, cooling technologies may be employed.
- PVT air cooling is the simplest solution and is very effective for space heating applications in the cold regions.
- PVT water cooling with channel(s) below PV module is most efficient, but freezing during cold seasons may limit their applications. Forced circulation of liquids is more efficient that of air, but the required pumping power is also higher for liquids than for air. Natural circulation is more economical, but less efficient, for both air and water.
- Air is readily available everywhere, while water usage may be restricted.
- Hybrid PVT systems may decrease, optimize and control the PV panel temperature, improve the overall energy conversion efficiency, as well as minimize the space required.
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- PCM increase the electrical efficiency, maintain constant lower temperature and store energy for night time applications, however, material properties may degrade over time.
- Nanofluids clearly improve thermal output of the system, but technology is still under development and influences of material characteristics are not yet completely determined.

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