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Cooling Techniques Forphotovoltaic Module For Improving Its Conversionefficiency: A Review

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ABSTRACT:- PV cells are semiconductor devices that have the ability to convert the energy available in both dispersed and concentrated solar radiation into direct current (DC) electricity. Conversion of solar energy into electricity through PV cells is achieved at different efficiency ratings varying between 7 and 40% and determined primarily by the type of semiconductor material from which the cells are manufactured. Photovoltaic module converts the incoming solar radiation into heat and electric energy. The electrical efficiency of photovoltaic (PV) cell is adversely affected by the significant increase of cell operating temperature during absorption of solar radiation. The efficiency of photovoltaic modules decreases with heating and also the photovoltaic cells will exhibit long-term degradation if the temperature exceeds a certain limit, so there has been solution to this problem. Due to this heating feature of photovoltaic modules it is likely to produce heat energy also from PV modules. Such systems are called as both a photovoltaic and thermal systems. Many researchers have been conducted investigating a range of methods that can be employed to provide thermal management for PV systems. Among various designs, a simple pipe was placed on PV module as a spiral heat exchanger in order to provide active cooling, to actively cool the PV cells a parallel array of ducts with inlet/outlet manifold designed for uniform airflow distribution was attached to the back of the PV panel, systems utilizing air, liquid, phase change materials (PCMs) and thermoelectric (TE) devices are used for cooling of PV cells. However, when the module was operated under active cooling condition, the temperature dropped significantly leading to an increase in efficiency of solar cells to between 12% and 14%. This paper provides a comprehensive review of various methods listed in the literature and discusses various design and operating parameters influencing the cooling capacity for PV systems leading to an enhanced performance of PV systems.Cooling Techniques for Photovoltaic Module for Improving its Conversion Efficiency: A Review

Key words: *photovoltaic modules, cooling techniques for photovoltaic cell, solar energy, hybrid hotovoltaic system.*

I. INTRODUCTION

Solar energy is one of the most widely adopted renewable energy source that can be utilized in various applications such as, thermal management using thermal collectors or electricity generation through special optical solar cells, also known as Photovoltaic (PV) cells..PV cell is one of the most popular renewable energy products. It can directly convert the solar radiation into electricity which can be utilized to power household appliances. However during the operation of the PV cell, only around 15% of solar radiation is converted to electricity with the rest converted to heat. The energy converted into heat increases the cell temperature, which consequently leads to drop in its electrical efficiency. Increment in cell temperature causes significant reduction in open circuit voltage (Voc) that leads to reduction in the electrical efficiency. The cell manufacturer generally specifies a temperature degradation coefficient and a maximum operating temperature for the cell. The cost of photovoltaic installations is mostly dependent on the PV 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 relatively lower temperatures, which can be achieved by extracting out the extra 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 thermal energy extracted out by the fluid can also be utilized in several ways. Sometimes, the thermal energy extracted from the PV module can also be utilized for low temperature applications e.g. water and air heating .Such types of systems are known as hybrid photovoltaic thermal (PV/T) system .Therefore, decreasing the temperature of PV module can boost the electrical efficiency.

II. PHOTOVOLTAIC CELL THEORY

Solar or photovoltaic (PV) cells are made of semiconducting materials that can convert sunlight directly into electricity. When sunlight strikes the cells, it dislodges and liberates electrons within the material which then move to produce a direct electrical current (DC).PV cells are combined to make modules that are encased in glass or clear plastic. Modules can be aggregated together to make an array that is sized to the specific application. Most commercial PV cells are made from silicon, and come in three general types: monocrystalline, multicrystalline, and amorphous. Single crystal or monocrystalline cells are made using silicon wafers cut from a single, cylindrical crystal of silicon. This type of PV cell is 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. They are identifiable as having individual cells shaped like circles or rectangles.

III. OVERHEATING EFFECT ON PV EFFICIENCY

PV cells 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 remainder energy is dissipated as heat and the PV module can reach temperatures as high as 40ºC above ambient. This is due the fact that 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. The limited efficiency is associated with the band-gap energy of the semiconductor material. Crystalline silicon pv cells can utilize the entire visible spectrum plus some part of the infrared spectrum. The energy of the infrared spectrum, as well as the longer wavelength radiation are not sufficient to excite electrons in the semiconductor material to cause current flow. On contrary, higher energy radiation is capable of producing current flow; however, much of this energy is similarly unusable. Consequently, radiations with high and low energies are not usable by the PV cell for electricity generation, and instead are dissipated at the cell as thermal energy. For crystalline silicon PV cells, a drop in the electrical power output of about 0.2-0.5% was reported for every 1°C rise in the PV module temperature principally due to the temperature dependence of the open-circuit voltage of the cell depending on the PV technology. Such property of PV cells is known as the Temperature Coefficient of the PV cell.

Therefore main obstacles that face 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 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 Tm are kept constant. The maximum power output from the solar cells decreases as the cell temperature increases, as can be seen in Fig.1. This indicates that heating of the PV panels can affect the output of the panels significantly.

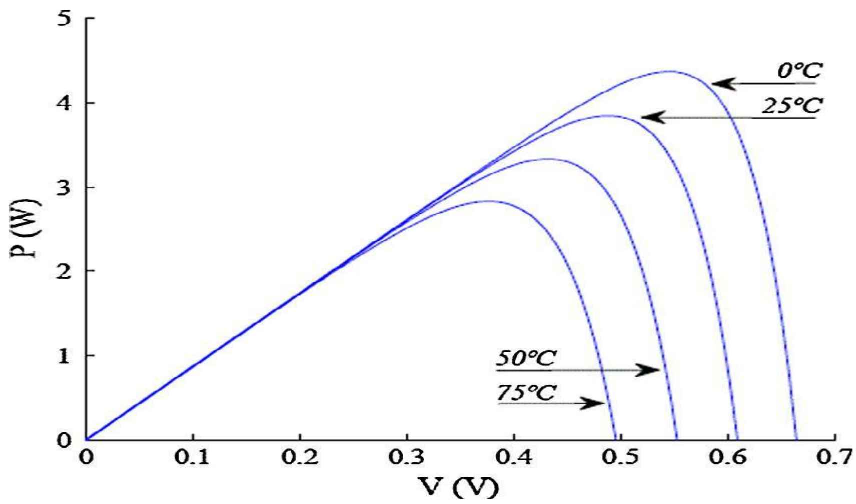

Figure: 1 P–V Characteristics as a Function of the Module Temperature

IV. COOLING TECHNIQUES

Various methods can be employed to achieve cooling of PV systems such as liquid-based, Air-based, heat pipe-based, PCM-based. However, the optimum cooling solution is critically dependent on several factors

such as, PV technology employed, types of concentrators geometries and weather conditions at which the system is installed.Passive cooling mechanisms refer to technologies used to extract and/or minimize heat absorption from/of the PV panel without additional power consumption. The mechanism implies transporting heat from where it is generated and dissipating it to the environment .Wide varieties of passive cooling options are available, simplest forms involve application of solids of high thermal conductivity metals, such as aluminum and copper, or an array of fins or other extruded surfaces to enhance heat transfer to the ambient . More complex systems involve the use of phase change materials (PCMs) and various methods for natural circulation, in addition to the use of heat pipes that are able to transfer heat efficiently through a boiling-condensing process.On the other hand, active cooling systems comprise of heat extraction utilizing devices such as fans to force air or pump water to the panels to extract away the heat
.These systems are powered using energy to affect some kind of heat transfer usually by convection and conduction. Although an active system consumes power, they are commonly used in situations where the added efficiency to the panels is greater than the energy demanded to power the system, examples include solar power plants in deserts. These systems may also be used in situations where some additional benefit can be achieved, such as waste heat recovery for domestic water heating.

For both passive and active cooling systems the commonly used cooling mediums are air and water. However, the thermal properties of air make it less efficient as a coolant medium. Therefore, air cooling is not well suited to the extraction of thermal energy from the PV absorber at hot regions. Water cooling on the other hand, permits operation at much higher temperature levels and allows waste heat recovery to be employed more efficiently. Hence, air cooling is less favorable option in many cases.

V. HYBRID PHOTOVOLTAIC SYSTEMS

Hybrid Photovoltaic/Thermal (PV/T) solar system is one of the most popular methods for cooling the photovoltaic panels now a day. The hybrid system consists of a solar photovoltaic panels combined with a cooling system. The cooling agent i.e. water or air is circulated around the PV panels for cooling the solar cells, such that the warm water or air leaving the panels may be used for domestic applications such as domestic heating. Akbarzadeh and Wadowski designed a hybrid PV/T solar system and found that cooling the solar photovoltaic panel with water increases the solar cells output power by almost 50%. They also found that cooling the solar photovoltaic panel does not allow the solar cells surface temperature to rise above 46℃ when exposed to solar radiation for a period of 4h. Chaniotakis designed a hybrid PV/T solar system where water and air were both investigated in the combined system as cooling agents. The water-based cooling system was found to increase the solar cells performance higher than the air based cooling systemTang et al. designed a novel micro-heat pipe array for solar panels cooling that consists of an evaporator section and a condenser section. The input heat from the sun vaporizes the liquid inside the evaporator section and then the vapor passes through the condenser section and finally the condenser section is cooled down using either air In order to enhance the heat transfer from the PV module, thereby effectively reducing the operating temperature and improving the efficiency of the PV module, Prasad and Saini artificially increased the roughness of absorber plate and wall of the channel. However, increased roughness of wall and absorber incurred a pressure drop penalty and, therefore, required a higher pumping power.Garg et al. presented a study of a PV/T air hybrid system, where the system included a plane booster and a flat plat collector mounted with PV module so that the effective absorption area of PV module can be significantly augmented. An optimization study of the absorber geometry for solar air heating collector was investigated by Pottler. Naphon carried out a study on the performance and entropy generation of the double pass solar air heater with longitudinal fins. This study showed that the thermal efficiency of PV module increases with increasing flow rate, as the heat transfer coefficient increases with increased Reynold number. Tonui and Tripanagnostopoulos also reported a study that an improvement of heat extraction can be achieved by low cost modifications of the channels of PV/T air system. Sopian et al. presented a steady state simulation on single and double pass combined PV/T-air collector. The simulation results indicated that the double pass PV/T collector has superior performance during the operation.

Moharram et al. developed a cooling system based on water spraying of PV panels. A mathematical model has been used to determine when to start cooling of the PV panels as the temperature of the panels reaches the maximum allowable temperature (MAT). Improving the cost effectiveness of PV water pumping systems requires effective utilization of PV energy and thus over sizing should be avoided.Yao et al. have indicated a maximum power point tracking (MPPT) inverter and a variable frequency controller to improve the slip and the efficiency of the motor under low insolation conditions. They concluded that a constant optimum value of motor efficiency can be assured by adjusting the proper inverter frequency.

5.1. Air-Based Photovoltaic System

The use of forced air enhances heat extraction resulting in further improved performance of air photovoltaic systems when compared with naturally ventilated ones. Several design concepts have been illustrated by researchers with respect to air flow patterns in addition to presence of front glazing to achieve optimum performance of PV modules. However, due to low density and small heat capacity of air, improvements in the practical performance of air-based photovoltaic collectors are limited, making air less favourable option.

5.2. Liquid-Based Photovoltaic System

At high operating temperature conditions, air cooling fails to accommodate the temperature rise at the surface of PV cells causing critical drop in their conversion efficiency. Liquid cooling offers a better alternative to air cooling utilizing coolant as heat extraction medium to maintain desired operating temperature of PV cells and a more efficient utilization of thermal energy captured. Liquid-based PV collectors aresuperior to air-based ones due to higher specific heat capacity of coolants employed leading to further improved overall performance. In addition liquid-based PV collectors offer less temperature fluctuations compared to air-based PV making them more favourable. Liquid-based PV collector uses two types of liquid viz. system utilizing water and system utilizing liquid refrigerants as heat extraction fluids.

5.3. Heat Pipe-Based Photovoltaic System

Heat pipes are considered efficient heat transfer devices that combine the principles of both thermal conductivity and phase transition. A typical heat pipe consists of three sections namely, evaporator, adiabatic, and condenser sections. Heat pipes provide an ideal solution for heat removal and transmission, with one end serving as a thermal energy collector and the other end as a thermal energy dissipator. Heat pipes have been considered for thermal management applications of PV technology due to the advantages such technology provide over other cooling means such as aiding uniform temperature distribution of PV cells. Russell et.al. Developed a cooling approach for concentrated PV (CPV) systems utilizing heat pipes, to enable operation at elevated temperature and utilization of extracted heat for beneficial use. Akbarzadeh and Wadowski utilized a passive cooling approach using two heat exchangers piped together and filled with refrigerant to cool the back of the solar cells.

5.4. PCM-Based Photovoltaic System

Phase changes Materials (PCMs) are substances that are able to absorb and release large amount of energy as latent heat through a reversible isothermal process at a particular phase transition temperature. Latent heat storage using PCMs is superior to sensible heat storage due to their higher energy storage density within a smaller temperature range. These materials are classified as organics consisting of paraffin wax, and fatty acids, inorganics consisting of salt hydrates, and eutectic mixtures of organic and inorganic PCMs.As far as PV systems are concerned, conventional passive cooling techniques are unable to provide the required cooling during peak solar radiation periods leading to a deteriorated performance of PVs. Furthermore, inhomogeneous temperature profiles which affect the generation capacity of PV systems stand as a limitation in other passive cooling methods .Recently; few studies were conducted to investigate the incorporation of PCMs in PV systems to tackle the aforementioned issues.

VI. CONCLUSION

Various methods can be employed to achieve cooling action for PV systems. However, the optimum cooling solution is critically dependent on several factors such as, system arrangement, PV technology employed, types of concentrators' geometries, and weather condition at which the system is installed. Hybrid PV System offer a practical solution to increase the electrical power production from PV panels and reduce the heating loads, in addition to the recovery of heat extracted from the panels. Heat extraction from PV modules utilizing various mechanisms was presented. Various designs employing air, liquid, heat pipe, PCM and thermoelectric modules to aid cooling of PV cells were discussed along with the parameters influencing the system performance. Air cooling of PV system provides a simple technique to thermally regulate the temperature of PV cells owing to minimal use of material and low operating cost among other PV cooling technologies. On the other hand, liquid cooling offers a better alternative to air cooling utilizing coolant allowing a more efficient utilization of thermal energy captured. In addition, liquid based PVT collectors offer less temperature fluctuations compared to air-based PVT making them more favourable in aiding a homogenous temperature distribution on the surface of PV modules.

PV module with water flow exhibit lower module temperature than that without water flow leading to higher electrical efficiency. Loss of efficiency due to a raised temperature of PV arrays can be reduced by heat removal from the front surface into the water spray across the cells which absorb the heat generated by the cells during the day. It is found that spraying water over the photovoltaic cells strongly improves the system and subsystem efficiencies.

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