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RESEARCH ARTICLE

TRENDS OF HYBRID EARTH-AIR-PIPE (EAP) PHOTOVOLTAIC COOLING SYSTEM FOR EFFICIENCY IMPROVEMENT: A REVIEW

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ABSTRACT

Photovoltaic technologies have received great attention during the last decade and is widely used around the globe. The technology gave a good solution to energy supply-demand concern, under the condition that it is under a viable economic preposition for its implementation. The geographical location of a solar module affects amongst others the efficiency of the solar panel due to temperature variation and weather effect. High operating temperature cause loss of efficiency and consequently increases the operating cost of a solar farm. A number of innovative approaches to mitigate the high operating temperature is available and are categorized as active or passive cooling system. In this paper, a review of cooling methods with an emphasize on EAP hybrid cooling systems is made. At the end of the review, it is found that an innovative approach to further explore EAP PV cooling system as a solution to loss of efficiency due to high temperature is highly necessary and essential for the advancement of the solar energy technology.

KEYWORDS

Hole quality, drilling operation, CNC.

1. INTRODUCTION

Electricity is a form of energy that is in high demand on the planet. One of the popular techniques of renewable energy used to generate electricity is by using photovoltaic (PV) systems with solar rays as the main source of energy. Solar power is the most abundant renewable resource on our planet. In spite of this abundance, only 0.04% of the basic power used by humans comes directly from solar sources because harvesting solar energy using a photovoltaic (PV) panel costs more than burning fossil fuels [1]. Thus, it is important to ensure that a PV system operates in an efficient form as possible. There are many factors that affects the feasibility of a solar PV system; amongst others, PV cell technology, operating conditions and component selection [2].

There are three factors affecting the solar panel performance, which are solar radiations, ambient temperature and wind speed [3]. Solar radiation is radiant energy emitted by the sun, particularly electromagnetic energy. Ambient temperature refers to the current air temperature. Wind speed is a fundamental atmospheric quantity caused by air moving from high to low pressure. Studies have shown that the Solar PV generally operates in the lower temperature threshold [4]. Ensuring that the surface temperature of the solar panel is within its optimum operating temperature range is important to achieve higher efficiency and maximizing production output of a system. Proper cooling can improve the electrical efficiency, and decrease the rate of cell degradation over time, resulting in maximization of the life span of photovoltaic modules. Furthermore, the excessive heat removed by the cooling system can be used in domestic, commercial or industrial applications [5]. Al-Rousan et al [1] investigated the effect of radiation conditions to output parameters such as the voltage, current, output power and efficiency. Their work shows that the efficiency of solar PV able to attain better efficiency of 47% in cooled environment [5]. One factor which noticeably influence solar PV efficiency is the solar panel surface temperature [4]. Considering and efficient Solar PV system, the cost payback time can be reduced to 12.1 years, compared to 15 years of the baseline of a similar system without a cooling system [6].

2. SOLAR PV PANEL COOLING METHOD

Without a cooling system, the solar panel surface temperature of the solar panel operates in high temperature and can caused the efficiency to drop at around 8% - 9% efficiency. However, when the module is operated under active cooling condition, the surface temperature is significantly reduced and leads to an increase in the solar cells efficiency at 12% - 14% [4].

To achieve higher electrical efficiency, the PV module should be cooled by extracting the extra heat from the cell assembly in some way. The module should be combined with a heat exchange mechanism using fluid stream like air or water at its rear or front surface. The thermo physical properties of water are established as a good selection [7] compared to other cooling agent. The working temperature in a solar PV panel can be categorised into two types of cooling; active and passive cooling [6].

2.1 Active cooling of Solar PV

Active cooling involves method that uses energy to achieve, such as; using forced air via the means of a blower to reduce the solar panel temperature [8, 9] and spraying cold water on the solar panel surface [7,12,10,16,15].

A forced air cooling normally use air as the cooling agent driven by a fan or a blower to the heat exchanger area normally located at the back of the solar panel. This will increase the heat exchange effect at the cost of external energy requirement to power the fan/blower. It also complicates the system as it requires additional control system as well as maintenance work. An example of an active cooling system using air as the cooling agent is discussed in detail by Teo et al., 2012 [8]. The study was designed to investigate the thermal and electrical performances of the PV system with variation air temperature. The system was installed on the roof top of the EA building at the National University of Singapore. With active cooling, the temperature of module increases 1.4 °C for every 100 W/m^2 increment of solar irradiation. A control PV system without active cooling shows a higher increase of temperature at 1.8°C for every 100 W/m^2. The maximum temperature recorded was as high as 68°C while the efficiency drops down to 8.6%. An axial blower was used to cool the PV module, the surface temperature of the module is maintained at 38°C and the electrical efficiency were also kept around 12.5% [8]. Normally, a forced air cooling is also used with other type of cooling such as water cooling or conductive cooling to increase its overall effectiveness [9].

In a water-cooled solar PV system, the cooling heat exchanger is attached to the rear side of the module and equipped with an inlet / outlet port for the water flow. The cooling water is stored in an insulated tank connected to the PV/T system through PVC (Polyvinyl Chloride) pipes. A water pump (0.5 HP) is used to circulate the water through the collector [7]. With this technique, the operating temperature of the module dropped significantly to about 20% and an increase of 9% in the electrical efficiency was observed. The advantage of the water spray-based cooling techniques is that it could be applied simultaneously over the front and backside of PV panel surfaces which will finally result in higher performance and a more efficient reduction rate of the PV panel operating temperature [10].

Water-cooling on a micro-generation system at two levels of irradiation (high and low) investigated by Zilli et al, 2018 [11] shows that the use of the cooling system at a high level of irradiation resulted in a 12.26% relative increase in power and a 12.17% relative increase in efficiency. At a low irradiation level, the relative power and efficiency increased by 8.48% and 9.09%, respectively. The cooling system had a significant effect on the power and efficiency of the studied photovoltaic panel.

Recently, researchers have come out with multiple innovation to increase the effectiveness of a water cooled system. Floating photovoltaic is an innovative system where the solar photovoltaic arrays were installed over water bodies using floating mechanism [12]. The power generation results from the combination of PV plant technology and floating technology increases the power capacity, efficiency and cost [13] as this method replaces the installation of photovoltaic power plants over valuable land. The floating PV plant consists of a Pontoon or separate floats, mooring system, solar panels and cables. According to their study, having this effective cover up from the pontoon and the PV panels on the reservoirs resulted in reduction of water evaporation from the reservoir. This technology could benefit arid climatic region such as part of Australia, Africa and the middle east with recent studies suggests that up to 40% of open reservoir's water could be lost during evaporation [14].

To solve the problem of low power production output due to temperature increase and dust accumulation, Abdullah et al, 2018 [15] designed a self-cleaning and self-cooling PV system with feedback control. The control system is achieved by means of programmable logic controller (PLC) and frequency inverter (FI). A two subsystem exist where one is for controlling the temperature of the solar panel and another to clean up the PV surface by using pressurized water. The system has successfully increased the pilot plant energy output by 34% and the efficiency by 26%.

Ebaid et al, 2018 [16] Investigates the use of Nanofluid in solar PV cooling. They suggest nanofluids as an alternative cooling medium as it suggest enhanced cooling of PV with the presence of nanoparticles compared to plain water. Their experimental results showed that the nanofluid cooled PV cell fwrvcaused a higher decrease in the average PV cell temperature compared with the cooled cell with water and without any cooling.

2.2 Passive cooling approach

Passive cooling techniques for PV applications are in general less complicated, reliable and low cost compared to an active cooling technique [17] as it does not require additional energy for its cooling operation. However, this approach is less efficient than active cooling techniques normally associated with low cooling media flow. In a recent analysis of passive cooling techniques for PVs, it was found that there is a gap in the existing literature related to the economic and environmental aspects of the techniques.

The majority of the conducted research studies were focused on PCM based PV cooling, where most systems used Si-poly or Si-mono PV technologies. However, most of these studies are numerical and laboratory-based study rather than a field based. Liquid based cooling technique are highly preferred, such as the liquid immersion method (water, nanofluids, etc.) or by using an air-wicks. Finally, air and radiative based passive cooling techniques are less investigated currently [18] as passive air flow are considered slow and insignificant.

A phase change material (PCM) based cooling is achieved by the thermal regulation effect caused by the PCM being solidified at lower temperature than that of the melting. It allows the solar panel to cool to a lower temperature unimpeded by the PCM effect [19]. The application of a PCM material is reasonable from a technical point of view, as it reduces the PV panel operating temperature by up to 10.26^0 C and thus increases the efficiency by up to 3.73% [20]. Another author found that the average efficiency improvement of PV-PCM systems ranges from 2% to 6%, depending from the specific geographical location [21]. Using a RT28CH PCM material, the peak PV cell temperature was reduced by about 35.6^{0}C when compared to a non-cooled PV panel [22]. Alternative material for PCM-PVs were also considered, investigation on pork fat as the potential PCM material for PV-PCM cooling was done and it was found that pork fat has almost similar characteristics compared to other PCM materials and is more reasonable from the economic point of view [23].

Water immersion method is achieved by placing the solar PV in large source of water such as lakes, dam, rivers, etc. The water absorbs and regulates the temperature of PV module causing the efficiency of the module to increase. A study conducted on water immersion method shows an average increase of 11% in efficiency [24]. It also found that the optimal depth of the water layer is between 2 cm and 4 cm in thickness. The improvement of the peak power output was about 20% on average and an efficiency improvement of between 4.0% and 4.7% was reached. Water immersion technique also used in domestics house using rainwater harvesters. On a designated day, the solar-driven rainwater cooling system is able to pump 152 l of water to PV modules. The maximum reduction in the temperature of the cells reaches 19°C and average electrical yield is increased by 8.3% [25].

Application of cotton wick structures in cooling of PV modules were done by Chandrasekar et al., 2013 [26]. The temperature of the PV module is reduced to about 45 °C when cooling is provided with cotton wick in combination with water. This corresponds to about 30% reduction in module temperature which is attributed to the moist condition prevailing at the back side of module due to dampness of the cotton wick caused by the capillary action of the wick structures. A combination of fin and cotton wick structures was also proposed and experimentally tested by Chandrasekar and Senthilkumar, 2015 [27]. They found improvement in delivering electricity by about 14% with a reduction in PV panel operating temperatures of 12%. PV (photovoltaic) modules cooled by heat spreaders in conjunction with cotton wick structures show that the maximum PV module temperature was reduced from 49.2 ^{0}C to 43.3 ^{0}C.

Air based cooling normally involves the use of a heatsink; a metal device that absorbs the heat from the solar cell and dissipates it into the surrounding air by natural or forced heat convection [4]. Heat sinks are made of materials with high thermal conductivity like aluminum or copper. They can be shaped like a flat panel below a solar cells array with fin arrays in one side, or many sides if the design allows in a single solar cell. Heat sinks are optimized by changing the geometrical shape of the fins. Study on fixed aluminum fins on the backside surface show that an increase in efficiency of about 2% was found during peak power [28].Water can also be used to cool heat sinks. In this case, more heat exchange takes place due to the higher heat capacity of water[7].The output power of a forced air cooling PV cell increased by 10% over natural air cooling and 66% with water cooling [29].

A free-standing photovoltaic panel with fixed aluminum fins on the backside surface as a cooling method was investigated by Mittelman et al. [18]. It was found that cooling effect successfully occurred and was especially visible for high solar insolation intensities, where a relative increase of up to 5% in electrical energy yield was observed. However, it was also noticed that the cooling effect was not efficient for lower insolation, i.e. for solar irradiation levels less than 350 W/m^2. Channel spacing and length also plays an important role in solar PV efficiency. It was found that an increase in channel spacing will cause an increase in the energy efficiency conversion from about 0.3% to 0.5%. Cooling for High Concentrator Photovoltaic (HCPV) systems shows that an optimized finned heat sinks made of aluminium able to keep a 3 mm by 3 mm cell temperature below 60 °C and 80 °C degrees under standard conditions [30].

Passive radiative cooling has been study and show that under the same atmospheric and solar conditions, PV modules able to achieve a steady-state temperature of 19.5 ^{0}C below ambient. Substantial gains in the photonic radiative cooler's performance are thus achievable by improved packaging further [31]. Broadband optical thin-film filters were used in radiative cooling [32]. The authors found that with the application of the thin-film optical filters, it was possible to boost the average reflectance in the visible and near-infrared spectrums by 3-4% (which increases the cooling rate by about 35 W/m^2).

3. EARTH AIR PIPE (EAP) COOLING

An earth air pipe (EAP) system is a common method used as a natural ventilation system to regulate the temperature inside a building both in summer or winter depending on the geographical location. The system is using geothermal energy to absorb heat during winter or to reject heat during summer by taking advantage the cool temperature under the earth. Previous studies showed that earth thermal energy have big potential in building cooling and heating system such as.

- Geothermal electricity [33, 34].
- Underground buildings (earth homes) [35].
- Earth air tunnel heat exchanger (EATHE) [36, 37].
- Ground source heat pump (GSHP) [38].

EAP techniques have been reviewed in detail by a number of researchers [39,40]. They summarized that EAP performance system is primarily affected by ground surface conditions, soil and air properties, soil moisture content, soil texture and compaction levels. In a specific location, the following properties is important in determining the overall feasibility of the EAP techniques; thermo-physical properties of soil (thermal diffusivity, density, thermal conductivity, specific heat capacity), depth of water table and bedrocks [40, 41, 42].

3.1 Thermo-physical properties of Soil

The soil thermal conductivity in turn mainly depends on dry density, degree of saturation, particle size, packing geometry and soil mineralogy etc. [39]. These factors can be classified into two groups (i) Compositional factors and (ii) Environmental factors. Mathur et al. [43] investigated the thermal performance of EAP systems by considering three different soil thermal diffusivities of 1.37×10^{-7} m^2 /s, 4.37×10^{-7} m^2 /s and 9.69×10^{-7} m^2 /s. Study shows that the soil with higher thermal diffusivity has a faster heat transfer rate and can transfer larger amount of heat through the soil.

The thermal conductivity of water-saturated sand was found to be six to eight times greater than that of air saturated packs of the same sand [40]. Various models are available to predict the thermal conductivity of soil with moisture content variation. Tong et al. [44] a model for calculating the thermal conductivity of soil by considering the effects of water content, the degree of saturation, porosity, pressure and temperature. Agrawal et al. [41] developed two identical experimental setups of EATHE system and compared the performance of dry and wet soil EATHE system and observed that the average heat transfer rate and COP of wet system increased by 24.1% and 24.0% respectively compared to the dry system.

The soil thermal conductivity increases with the increase in soil density. By increasing unit weight of soil (or mass density), the contact area in the particles increases as more soil particles are filled in a unit volume and the consequent increased contact area provides a more extensive heat flow path thus enhancing soil thermal conductivity [42].

3.2 Air flow Properties

Air properties such as temperature, flow rate, relative humidity are important parameters which affect performance of EATHE system. Various studies have been performed considering the influence of air properties on EATHE system performance [45, 46]. Rakesh et al. [46] studied the impact of ambient air temperature on the outlet air temperature of EATHE and noticed that with the increase in inlet air temperature, the outlet temperature of the air increases whereas, the amplitude decreases considerably. The increase in the velocity of air flowing in the pipe beneath the soil surface also influences the performance of an EATHE system as evident from a decrease in the total temperature difference between inlet and outlet air [47]. Considering five flow velocities viz. 0.5, 1.0, 1.5, 2 and 2.5 m/s for cooling operation.

Niu et al. [48] found that the air temperature drop rate was the highest at 0.5 m/s, as low velocity provides more contact time between air and pipe. Ahmed et al. [49] carried out a numerical parametric study to investigate the impact of air velocities on thermal performance of earth-pipe cooling system for four air velocities of 0.41 m/s, 1.0 m/s, 1.5 m/s and 2.0 m/s and noticed that air velocity of 1.5 m/s provided the best cooling performance.

3.3 Geometric design and pipe materials

The geometrical properties include pipe length, diameter, thick- ness etc. and thermo-physical properties include thermal conductivity, density, roughness etc. [49]. Pipe material has a little influence (negligible) on thermal performance of EATHE system [50]. Increasing the length of pipe, the difference between inlet and outlet air temperature increases up to a certain length beyond which no rise in heat transfer was evidenced [51]. At given mass flow rate, heating and cooling potential of EATHE increases with decreasing pipe diameter. [52]. Increasing the depth of EAP pipe increases the heating and cooling potential up to a certain value which is followed by insignificant increment of efficiency [50]. The spacing between pipes must be equal to or greater than thermal influence zone. Smaller spacing between pipe produces a negative impact on thermal performance of EAHE system [53]. By increasing relative roughness of pipe, the cooling/heating efficiency increases, but pumping power also increases [50].

4. HYBRID SYSTEM OF EAP AND PV MODULE COOLING

The concept of air cooling in an EAP system can be applied to cool down the PV modules temperature. Sanusi et al. [54] undertook the experimental investigation to determine the performance of EATHE in a hot and humid climate of Malaysia and observed a significant temperature drop of 6.4 °C and 6.9 °C in wet season and hot-dry season respectively. Thus, the EAP system can be coupled with an air-based cooling technique of PV modules as a hybrid system to further increase the cooling rate and overall efficiency of the solar PV system.

Jakhar et al. [55] designed an earth water heat exchanger (EWHE) for PV cooling, his simulated results show that there is an inverse relation between the pipe length and outlet temperature, no significant dependence on material and increasing the air flowrate will decrease the EWHE performance. Pairing the system to cools down PV modules shows better cooling results compared to PV cooling systems without WHE. An electrical efficiency comparison shows there is an increase in efficiency by 1.02%-1.41% [56]

Elminshawy et al. [57] suggest a novel pv cooling system involving the use of earth air heat exchangers (EAHE) systems techniques. The air is first induces thru an underground heat exchangers to pre-cools the air which is than pass thru the back of the solar pv module to regulate the temperature. Using this method, they are able to reduce the operating temperature from 55°C to 42°C at an optimum flow rate of 0.0288 m^3/s. The study is further explored by experimenting the atmospheric air at several elevated air temperature and air flow rate; 35°C-45°C and 0.0228 m^3/s – 0.0288 m^3/s. The experiments proved that a hybrid system utilizing buried heat exchanger (BHE) is a promising active cooling system [58].

5. CONCLUSION

This paper has reviewed cooling of photovoltaic, which covers active and passive cooling methods. Active cooling is more effective method of cooling, but it is costly and complexity. The water-cooling technique shows significant effect on photovoltaics efficiency. Passive cooling in photovoltaic also have potentials to be applied in large scale levels due to advances in PCM, passive air cooling and other innovative hybrids. In general, current passive cooling in photovoltaics only achieved 5% efficiency in operation which is somewhat insignificant. Recent study in EAP and its potential to be used as pre-cooling system enables higher efficiency to be achieved. A significant temperature drops of 10^{0}C is possible by using EAP/EWHE/EAHE/BHE hybrid solution. This cooling method is still in its infancy as a lot of innovative approach have yet to be discovered. Thus, it is to be concluded that a further research needs to be done to explore the potential of using EAP system as air pre-cooling to increase the efficiency of PV module cooling.

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