Experimental investigation of the performance of a hybrid photovoltaic/thermal solar system using aluminium cooling plate with straight and helical channels


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This paper presents a field study for the performance of photovoltaic thermal (PVT) system that use aluminium cooling plate with straight and helical channels during July 2016. Three systems each of 0.37 m² commercial poly-crystalline PV panels have been installed at the faculty of engineering at Shoubra, Benha University, Cairo, Egypt (30.1°N Latitude). Two of the systems are cooled using straight and helical channels with dimensions of 10 x 10 mm² and compared with the uncooled panel. The results showed that an increase in average electrical efficiency of 17.7% to 38.4% with relative to uncooled panels for flow rate range of 0.25 to 1 L/min. The corresponding average thermal efficiency increases from 31.6% to 47.2% for straight channels and 34.6% to 57.9% for helical configuration. While the corresponding average exergy efficiency increases from 11.1% to 12.9% for straight channels and 11.5% to 13.5% for helical arrangement. The associated water pumping power in both configurations does not exceed 3.3% of the converted electrical power while the increase in the obtained electrical power is of 30% with relative uncooled cell power.

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1. Introduction

Photovoltaic (PV) system is one of highly electric energy quality and cleanliness renewable energy in the world. On the other side, low efficiency and high cost of photovoltaic power generation restrict the development of solar photovoltaic industry. Commercial PV electrical conversion efficiency is of 6–15% and this output power decreases by 0.2–0.5% per 1 K increase in temperature module (Huang et al., 2013). Enhancing the overall efficiency or utility of solar energy collection by developing a hybrid photovoltaic/thermal solar collector has been investigated by many researchers (Singh and Othman, 2009; Hovel, 1977; Vorobiev, 2006; Mittelman et al., 2007; Coventry, 2005; Najafi and Woodbury, 2013; Ma et al., 2015; Eicker, 2003). Ma et al. (2015) showed that the thermal regulation of a PV system is of great role. The absorbed heat that elevates cell temperature can be removed using passive and active approaches. Active is also referred to photovoltaic/thermal collector, PV/T, and it utilizes both electrical and heat energies of the system. Eicker (2003) presented that most PV facades are built these days as certain walls in front of thermally insulated buildings with air ducts behind PV cells to decrease building cooling loads. This approach enhances heat dissipation rates, leading to higher PV performance rates. Active ventilation with PV facades allows a reduction of cell operating temperatures of 18 K, resulting in an increase of 8% in electrical energy output at air velocity of about 2 m/s (Krauter, 2004). van Helden et al. (2004) showed that total efficiency of PVT modules is higher than the sum of the efficiencies of separate PV and solar thermal systems. Also, through the higher combined yield PVT can contribute to the reduction in the consumption of fossil fuels in the built environment in a more cost-effective way. Helmers et al. (2014) presented an energy balance model for concentrating photovoltaic and thermal (CPVT) systems. The influence of the operating temperature and concentration ratio on the electrical and thermal performances of the CPVT system are discussed. It is shown that high concentration reduces the thermal losses considerably and increases the electrical efficiency. At concentration ratios above 300, the system operates with an overall efficiency of 75% at temperatures up to 160 °C.

The air-type product design provides a simple and economical solution to PV cooling, and the air can be heated to different temperature levels through forced or natural flow. Forced circulation is more efficient than natural circulation owing to better convective and conductive heat transfer, but the required fan power reduces the net electricity gain. Inducing airflow in underneath cavity

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located in the back of the PV modules is proposed as an effective strategy to reduce frontal surface temperatures. Computational fluid dynamics has been applied as a powerful methodology to study the cavity ventilation potential (Gan, 2009; Corbin and Zhai, 2010; Yoo and Manz, 2011). Mei et al. (2009) performed an experiment to test PV modules under various climate conditions. Back-ventilation was performed by installing a fan behind the cavity while different ventilation rates were applied. Mirzaei and Carmeliet (2015) carried out an experimental setup consists of a complete simulator for building prototype and solar radiation. The experimental setup placed inside an atmospheric wind tunnel to control wind velocity. Thermography is measured using an infrared camera to record the surface temperature of the BIPV. The effect of an underneath cavity with various cavity heights and PV arrangement is further studied. The results would be eventually useful in the development of practical guidelines for BIPV installation. Hegazy (2000) carried out an extensive investigation of the thermal, electrical, hydraulic and overall performance of four types of flat-plate PVT/air collectors. The four modes are: channel above PV, channel-below PV, single-pass channels with PV in-between, and finally the double-pass design. The numerical analysis illustrated that while channel above PV mode has the lowest performance, the other three have comparable energy yields. Also, single-pass channels with PV in-between consume the least fan power.

Tripagnagnostopoulos et al. (2002) carried out outdoors measurements on PVT with air and water collectors of different configurations. They found that 5% and 8% higher than the PV modules in production costs for PVT/air and PVT/water, respectively. Their measurements gave a range of thermal efficiency from 38% to 75% for PVT/air designs. The corresponding values are 55% to 80% for PVT/water system. The tests are performed at steady state noon-hour measurements in the University of Patra (at 38°2'N) in Greece. Nualboonrueng et al. (2013) focused on the performance of photovoltaic-thermal (PVT) systems working in Bangkok for residential applications. The results show that effect of water flow can improve the cell efficiency of PV cells. Moreover, the total energy output from the PVT collectors, which had glass covers is very significantly higher than those without design. Vivar et al. (2013) carried out the first prototype of the hybrid CPVT micro-concentrator. The prototype has been installed at the Australian National University, Canberra, Australia. The results show that the combined efficiency of the system can exceed 70%. The full day performance shows that the average electrical efficiency was 8%. The corresponding average thermal efficiency was 50%. Vivar and Everett (2014) performed a review study on actively cooled solar concentrators. The most suitable candidate fluids available in the market are assessed according to their properties and applications, with special emphasis on fluid toxicity and long-term performance. Yamada and Hirai (2016) investigated experimentally the maximization of module electrical efficiency based on global normal irradiance (GNI) rather than direct normal irradiance (DNI). The results of outdoor tests showed that the low-cost cell enhanced the generated power by factors of 1.39 and 1.63 for high-DNI and midrange-DNI conditions, respectively. Tiwari et al. (2006) estimated the overall efficiency of an unglazed PVT/air collector in India. In that study, the optimal air flow rate, duct dimensions were concluded. Also, Raman and Tiwari (2008, 2009) investigated the annual thermal and exergy efficiencies of the hybrid PVT/air system for five different Indian climate conditions. It was noticed that the exergy efficiency is 40–45% lower than the thermal efficiency under strong solar radiation. Also, the double-pass system illustrated better performance than the single-pass option. These results are similar to the findings of Sopian et al. (1996). On the other hand, Joshi and Tiwari (2007) provided an exergy analysis of an unglazed PVT/air collector for the cold climate region of India. The instantaneous energy and exergy efficiencies were found in the ranges of 55–65% and 12–15%, respectively.

Sandnes and Rekstad (2002) studied the energy performance of a PVT/water collector with c-Si solar cells pasted on polymer thermal absorber. The absorption coefficient is of 0.94 for normal incidence. The analysis found that the presence of PV cells reduces the heat absorption by about 10% of the incident radiation. Also, the glass cover decreases the optical efficiency by around 5%, and its application to low-temperature water-heating system is promising. Chow (2003) introduced an explicit dynamic model for analysing single-glazed sheet-and-tube collector performance. Through the multi-nodal finite difference scheme, the exact influences of fluctuating irradiance and dynamic auto-control device operation can be readily analysed. The steady–state energy flow analysis also reveals the importance of having good thermal contact between the encapsulated solar cells and the absorber plate, as well as between the absorber plate and the water tubing. Abdolzadeh
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