Comparison of prediction methods of PV/T nanofluid and nano-PCM system using a measured dataset and artificial neural network

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A R T I C L E   I N F O

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A B S T R A C T

In this paper, a Photovoltaic/Thermal (PV/T) system was proposed, built and tested. Three various types of cooling were proposed: tank filled with water and water flows through the cooling pipes, tank filled with PCM and water flows through the cooling pipes, and tank filled with PCM/nano-SiC and nanofluid (water-SiC) flows through the cooling pipes. The three proposed systems results were compared with conventional PV. According to the results, it was found that nano-PCM and nanofluid improved the electrical current from 3.69 A to 4.04, and the electrical efficiency from 8.07\% to 13.32\%, compared with conventional PV. In addition, three Artificial Neural Network (ANN), MLP, SOFM and SVM methods were implemented using the experimental results. The results indicate that the output of the network is in good agreement with the experimental results and published works.

1. Introduction

Under the current climate change situation, many countries are seeking more sustainable and environmentally friendly technologies. This is to eventually replace fossil fuels and transform the industrialised world and combat climate change (Edenhofer et al., 2011a). Renewable energies have been growing rapidly over the last two decades (Edenhofer et al., 2011b), and more applications are being introduced to the markets, depending on the resource (i.e. wind, solar, geo-thermal). Solar energy has shown tremendous results and favourability among residential users; due to their lightweight, low-emission nature and availability of the sun across the globe, every day (De Vries et al., 2007). Solar energy applications cover photovoltaics (PV) and solar thermal collectors (Islam et al., 2010). PV panels convert light into electricity and processes involving no mechanical parts, therefore no noise. Similarly, solar collectors produce thermal energy through use of tubes with working fluids within (i.e. water/air/nanofluid), thus making solar energy the most suitable choice for many residential and industrial entities. Further innovation was established with hybrid photovoltaic/thermal (PV/T) systems, which combine the two technologies to enhance their performance and save space and installation costs (Al-Waeli et al., 2017a). Photovoltaic panels lose a part of their efficiency due to a drop in the open circuit voltage, which is caused by an increase in cell temperature. Therefore, it is important to apply a cooling scheme, which creates the motive to attach solar collectors to the back of these panels to absorb their heat. In doing so, the PV panel will maintain its voltage over time, and the thermal collector will have a higher thermal output, due to absorbing the cell temperature. This is system classified based on the working fluid it depends on. Innovative designs propose using nanofluids and Phase Change Material (PCM). Various experiments and simulation studies have been conducted to different configurations of the hybrid system (Ghadiri et al., 2015; Khanjari et al., 2016; Ciesiński et al., 2016). One simulation method is to use Artificial Neural Network (ANN) to study and predict the performance of PV/Ts (Kalanli et al., 2017). Artificial neural networks are designed to mimic human brain functions/processes in computers, such as pattern recognition and learning (Singh et al., 2001). These networks rely on real data input and a pre-specified function, set by the programmer to produce the desired results. The algorithms of these networks can change their own instructions to improve performance and adaptability (Grossi and Buscema, 2007). This paper presents a novel design configuration of the hybrid PV/T system, using nanofluid and nano-phase change material, and evaluates its performance using artificial neural networks.

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2. Literature review

Combining both nanofluid and PCM for PV/T requires a distinct understanding of both systems; this is due to the complexity this combination may introduce.

Photovoltaic thermal (PV/T) units may vary in the configuration depending on the working fluid; simpler configurations can be achieved when using air-based PV/T systems, and more sophisticated designs are created with nanofluid-based PV/T systems. For those systems, a heat exchanger separating the nanofluid and water or thermal output must be placed. This is to have nanofluid in a closed loop with the collector to achieve the cooling of the collector, simultaneously providing cooling to the nanofluid itself by transferring its heat to water. A special container for the nanofluid is made with limited capacity and a larger container for water, as output, should also be installed. Insulation is essential in such entities as it will protect the produced thermal energy and the temperature of the PV panel as well (Al-Waeli et al., 2017b).

This type of system mainly counts on the nanofluid’s ability to absorb heat within the pipes; this depends mainly on its thermophysical characteristics. Devendiran and Amirtham (2016) conducted a review of different preparation techniques of metal and metal oxides nanofluids, along with their effect on the physical and chemical characteristics. A detailed description of thermal conductivity enhancement for various types of nanofluids along with their thermo-physical and heat transfer properties was presented as well (Devendiran and Amirtham, 2016). Bajestan et al. (2016) investigated the effect of the TiO$_2$-water nanofluid on the laminar convective heat transfer by numerically modelling the experimental tests. The authors found a 21% enhancement of the heat transfer coefficient on average. The study also investigates the effects of the nanoparticle concentration of TiO$_2$, which was found to have a directly proportional relationship with the convective heat transfer coefficient, as opposed to the particle size, which has shown an opposite effect (Bajestan et al., 2016). Adriana (2017) studied the thermophysical properties of three oxide-based nanofluids. The results obtained showed a variety of features for those nanofluids, which are accredited to the addition of nanoparticles. This was accompanied by an enhancement in thermal conductivity of at least 12%.

The study concluded that the use of nanofluids raised the convective heat transfer coefficient, and linked such rise to the Reynolds number and the nanoparticle concentration (Adriana, 2017). An exergy analysis is fundamental when dealing with PV/T systems in order to understand and validate the nanofluids’ effect on performance before installing the systems. Hassan et al. (2016) theoretically performed an exergy life cycle analysis of nanofluid based PV/T with three variable arrangements. Furthermore, the study compares the performance of the nanofluid based PV/T to the conventional PV and PV/T systems. The life cycle exergy results indicate a higher performance in nanofluid-based PV/T systems compared to the traditional ones. The authors found the system to achieve a maximum electrical and exergetic efficiency of 12% (Hassan et al., 2016). Various studies have been conducted over the past five years or so, describing the nanofluid’s effect on the PV/T systems in terms of the overall performance and thermal output (Sardarabadi and Fard, 2016; Hjerrild et al., 2016; Sardarabadi et al., 2014; Radwan et al., 2016; An et al., 2016; Khanjari et al., 2016; Hussian et al., 2015; Manikandan and Rajan, 2016; Ghadir et al., 2015; Crisostomo et al., 2017; Rejeb et al., 2016; Michael and Iniyay, 2015).

Table 1 shows a summary to present the trends and ideas proposed for nanofluid based PV/T systems.

As for the PCM based photovoltaic thermal systems, many researchers have investigated their ability to improve the PV performance by preserving the cell temperature close to that of the ambient air temperature, as well as the capacity to store high amounts of latent heat. That coupled with various melting points, which make it compatible with different applications, renders the use of PCM very productive in solar energy applications. The nature of solar cell efficiency enhancement is also investigated. Smith et al. (2014) examined the impact of the PCM with different melting temperatures, ranging from 0°C to 50°C in order to identify the best PCM melting temperature for various locations, by implementing a one-dimensional energy balance model to simulate the system. Authors claim an enhancement in efficiency and the cooling process of the solar cell when using PCM, and that the best results were in areas that have little intra-annual climate variability and high insolation. The simulation results show a 6% increase in the annual PV energy output in Mexico and eastern Africa, and an increase of 5% for the Arabic region, Southern Asia Central and South America, and much of Africa (Smith et al., 2014). The works of Al-Imam et al. (2016) involving different PV/T designs with PCM are also present. The authors conducted an outdoors experiment of a compound parabolic concentrator (CPC) Photovoltaic Thermal PV/T system with PCM to investigate the solar energy conversion into thermal energy, thermal efficiency and total, and the element of heat storage. Furthermore, a comparison between a clear and a semi-cloudy day during the winter seasons has been drawn. The study also examines various parameters, such as useful energy, thermal and overall efficiencies, etc. The results obtained show that the thermal efficiencies for bright and semi-cloudy days are 40–50% and 40%, respectively. While the overall PV/T efficiencies achieved for sunny and semi-cloudy days are ranging between around 55–63% and 46–55%, respectively (Al-Imam et al., 2016). Elarga et al. (2016) numerically investigate the dynamic-thermal behaviour and performance of a PCM-PV system in double skin facades (DSP) in different climates (Venice, Helsinki and Abu Dhabi). This is first done by developing a physical-mathematical model, which combines codes for optical, thermal and electrical behaviour that are validated when running the simulation. The model developed is coupled to an indoor air heat balance equation to test the performance of the system for such applications. The authors claim that the system causes a monthly reduction in cooling energy demands of approximately 20–30% while the increase in the PVs’ electric energy with a peak value is around 5–8%. The peak produced power was found to be in Venice, Italy with a value of around 33 W/m$^2$ (Elarga et al., 2016). Recently, various studies have been conducted within the field of PCM/PV and PCM/PVT (Gaur et al., 2017; Browne et al., 2016; Hasan et al., 2010, 2014; Biwole et al., 2011; Kazanci et al., 2014; Qi et al., 2015; Fiorentini et al., 2015; Stropnik and Striti, 2016). Table 2 shows a summary of those studies.

Some studies have gone through different routes, for example, Karunanumurthy et al. (2012) incorporated CuO nanoparticles in paraffin PCM to improve its thermal conductivity. The experiments conducted show that dispersing nanoparticles with paraffin enhances the thermal conductivity of the PCM, which allows it to overcome the relatively low rate of heat transfer in the thermal energy storage applications (Karunanumurthy et al., 2012).

In other works, Sardarabadi et al. (2017) designed, built and performed an experimental study on a ZrO$_2$-nanofluid based PV/T collector with Paraffin-PCM. The nanofluid runs in the pipes emerged in the PCM storage tank. The use of both techniques has raised the electrical output of the PV/T by 13% over the conventional PV model (Sardarabadi et al., 2017).

On the other hand, several researchers are implementing predicting tools for PV and PV/T system performance (Singh et al., 2001; Grossi and Buscema, 2007; Al-Waeli et al., 2017b; Devendiran and Amirtham, 2016; Bajestan et al., 2016). These methods can generally be classified as follows: empirical mathematical, regression, and artificial intelligent neural network based models and finally statistical models based on time series of data.

Argiriou et al. (2012) proposed and integrated a neural controller model based on the feed forward back propagation for hydronic heating plants in buildings. Variables, such as meteorological modules, ambient temperature and solar irradiance were forecasted using the controller. These models depend on real-scale office buildings during real operating conditions. The studies show a comparison between operational results and the conventional controller in order to evaluate the

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