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Artificial neural network modeling of a photovoltaic-thermal evaporator of solar assisted heat pumps

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ABSTRACT

In this work, the artificial neural network model was developed to predict the energy performance of a photovoltaic-thermal evaporator used in solar assisted heat pumps. The experiments were carried out under the meteorological conditions of Coimbatore city (latitude of 10.98°N and longitude of 76.96°E) in India. The energy performance parameters of a photovoltaic-thermal evaporator such as, evaporator heat gain, solar energy input ratio, photovoltaic efficiency and photovoltaic panel temperature were observed with reference to four ambient parameters such as, solar intensity, ambient temperature, ambient wind velocity and ambient relative humidity. The experimental results were used as training data for the network. The multilayer feed forward network is optimized to 4-15-4 configuration for predicting the energy performance of the photovoltaic-thermal evaporator. Analysis of variance was carried out to identify the significant ambient parameter influencing the energy performance of photovoltaic-thermal evaporators. The network predictions are found to be closer to the experimental values with the maximum fraction of absolute variance values, minimum root mean square errors and minimum coefficient of variance values. The analysis of variance results confirmed that solar intensity and ambient temperature are the most influencing parameters affecting the energy performance of photovoltaic-thermal evaporators.

1. Introduction

Photovoltaic energy conversion was widely used for electricity generation [1]. The photovoltaic cells have low conversion efficiencies around 10–20% due to its increase in cell temperature. The remaining 80–90% of the energy is exhausted to the surroundings [2]. The photovoltaic-thermal (PV-T) hybrid technology was initiated by Kern and Russell [3] during the year 1978. Later, many research investigations have been reported on PV-T hybrid collectors, which were comprehensively reviewed by Chow [4]. The solar illumination falls on the photovoltaic-thermal (PV-T) collectors is converted into electricity by the photovoltaic cells and the remaining portion of thermal energy was absorbed by the circulating fluid [5]. The PV-T hybrid collectors have improved the photovoltaic conversion efficiency by absorbing the generated heat from photovoltaic cells and maintain the cell temperature around 25 °C [6].

Many research investigations have reported the thermodynamic performance of PV-T collectors by theoretically and experimentally with air, water and refrigerant as the working fluids [7–18]. Dubey et al. [7] have developed analytical equations to estimate the electrical and thermal performance of PV-T hybrid air collectors. Agrawal and Tiwari [8] developed a micro-channel based PV-T collector using air as working fluid and its energy and exergy performance was estimated theoretically for four different locations in India. In a recent work, Assoa and Menezo [9] theoretically simulated the dynamic performance of a PV-T collector using air as the working fluid and compared with experimental results. Another investigation has reported the theoretical energy performance simulation of PV-T air collectors and compared with experimental results [10]. The thermal energy conversion efficiency of the air based PV-T collectors are low due to its poor thermodynamic properties, which results in poor heat transfer coefficients. To overcome these drawbacks, liquid based solar collectors have been

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developed. Many research investigations have been reported with water as a working fluid in PV-T collectors to improve its overall efficiency [11–16]. Dubey and Tiwari [11] have developed a thermal model for predicting the performance of a PV-T based water collectors. Their results confirmed that theoretically predicted results are closer to experimental results. Corbin and Zhai [12] have investigated the thermodynamic performance of a PV-T collector (using water as working fluid) using a computational fluid dynamics and validated with experimental results. Fudholi et al. [13] made theoretical simulations of three types PV-T water collectors and reported with the maximum photovoltaic efficiency of 13.8% and thermal efficiency of 54.6%. Chow et al. [14] developed a dynamic simulation model of a building integrated photovoltaic water heating system and validated with experimental results. Ziapour et al. [15] theoretically compared the energy performance of four types of PV-T collectors using water as the working fluid under the meteorological conditions of Iran. However, the scope of water based PV-T collectors are limited due to the continuous increase in water temperature over the operational period, freezing of water during lean and off sunshine hours in the severely cold winter weather conditions, corrosion and scale formation effects in the tubes of the PV-T collectors. The limitations associated with water based collectors are eliminated using refrigerant as working fluids. The phase change heat transfer coefficients of the refrigerants are significantly higher when compared to the single phase flow working fluids (such as, air and water) and also overcome the drawbacks with air and water as working fluids. Ji et al. [16] made a theoretical simulation of a PV-T collector (using refrigerant as working fluid) used in a heat pump and validated with experimental results. Further, the dynamic performance simulation model of a PV-T collector was developed and validated with experimental results [17]. In a recent investigation, Shan et al. [18] theoretically simulated the energy performance of a PV-T hybrid collector (using R410A as a working fluid) under the meteorological conditions of Nanjing, China. Their results confirmed that refrigerant based collectors performed better than air and water based collectors.

The PV-T hybrid collectors using refrigerant as working fluid was successfully integrated with heat pumps for performance enhancement [19–24]. The refrigerant undergoes phase change from liquid to vapor by absorbing the solar and ambient energy sources from surroundings. Many investigators have developed different configurations of PV-TE for solar assisted heat pumps and its thermodynamic performance was investigated theoretically and experimentally. In a theoretical simulation, Xu et al. [19] predicted the energy performance of a solar photovoltaic-thermal heat pump (SPV-THP) using a modified aluminum extruded tube photovoltaic-thermal evaporator (PV-TE). Their results concluded that, the modified aluminum extruded tube PV-TE improved the energy performance of a SPV-THP. Further, the energy performance of a SPV-THP (using low concentrating PV-TE) for water heating applications was experimentally investigated [20]. In their work, the parabolic concentrates were used to improve tracking of solar illuminations. A micro photovoltaic panel covered with vacuum glass tube was developed in another work for heat pump applications and its performance was investigated experimentally [21]. The energy performance of a PV-TE covered with a glass plate was experimentally investigated during winter climates [22]. An improved electrical and thermal energy performance was reported in their work. Further, the energy performance of a SPV-THP integrated with heat pipe was experimentally investigated under the meteorological conditions of Hong Kong, China [23]. It was reported that the heat pipe assisted PV-TE has higher energy efficiency in the range between 62% and 82%. Zhang et al. [24] developed a heat pipe assisted PV-TE water heater and experimentally investigated its energy performance under the meteorological conditions of Shanghai, China.

The brief literature review on PV-T collectors confirmed that many research investigations have reported with air, water and refrigerant as working fluids [7–24]. The performance of PV-T collectors reported in the literature was investigated by conventional methods either by theoretical or by experimental approach. Theoretical simulations of PV-T heat exchangers using analytical correlations involve more assumptions, which are not strictly valid. Modeling of two phase flow characteristics of refrigerants in the PV-TE will become complicated due to the non-linear phase change behavior of refrigerant mixtures (in the case of using refrigerant mixtures in heat pumps) is the other drawback with empirical correlations [25]. The major influencing parameters such as, degree of refrigerant super-heating at the evaporator outlet, evaporator temperature, pressure drop and heat losses in the PV-TE are assumed as constant in the case of theoretical simulations. But in actual experiments, these parameters are highly fluctuating with reference to ambient conditions. The experimental methods are expensive and time consuming due to its initial investment required for developing an experimental setup and year-round experimental trial to monitor its performance. The ANN (artificial neural networks) model based on experimental results overcomes the above limitations and establishes the nonlinear relationship between the input and the output variables based on the set of training data [26]. The ANN modeling involves the changes in system operating parameters with reference to ambient fluctuations by extracting the required information as training data, which has not required system descriptions [27]. Many researchers have reported the comprehensive reviews on applications of ANN for modeling of solar photovoltaic systems [28], energy systems [29], heat exchangers [30] and for refrigeration and air conditioning units [31]. The review studies confirmed that ANN approach is suitable for modeling of thermal systems with good accuracy.

The cited literature review confirmed that, there is no specific work reported on ANN modeling of PV-TE used in SPV-THP. Hence, the main objective of this work is to develop an ANN (multilayer feed forward network model) model for predicting the energy performance parameters of a PV-TE, such as evaporator heat gain, solar energy input ratio, photovoltaic panel efficiency and panel surface temperature with reference to four ambient parameters such as, solar intensity, ambient temperature, ambient wind velocity and ambient relative humidity. The ANN predicted results are compared against the experimental results for validation. ANOVA (Analysis of variance) was carried out to identify the significant ambient parameter influencing the energy performance of a PV-TE. The energy performance parameters of a PV-TE have been simulated for three levels using ANN. Moreover, brief description on the use of ANOVA to identify the significant ambient parameter influencing the energy performance of PV-TE is presented.

2. Experiments

The experimental observations were made under the meteorological conditions of Coimbatore city in India, during the months between January 2014 and March 2014.

2.1. Experimental setup

The schematic view of a SPV-THP experimental setup is illustrated in Fig. 1 and its photographic view in Fig. 2. The specifications are listed in Table 1. The sectional view of PV-TE is shown in Fig. 3. The SPV-THP consists of basic components such as, R134a based hermetically sealed type constant frequency reciprocating