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Application of support vector machine for prediction of electrical and thermal performance in PV/T system

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ABSTRACT

In photovoltaic–thermal (PV/T) system analysis, solar collectors with numerous design concepts have been used to purvey the thermal and electrical energy effectively. In this study, two types of solar thermal collectors in PV/T system are proposed and fabricated called design A and design B respectively. In order to investigate the effects of collector type on the system performance a thin flat metallic sheet (TFMS) and fins were introduced as an effective heat absorber and heat sink in the collectors. Extensive experiments were carried out for different conditions under indoor solar simulator. Then PV/T thermal and electrical efficiency were calculated by using data obtained from experiments. Here, support vector machine (SVM) model is designed to estimate the thermal and electrical output which predicts the values for some input variables. For this purpose, three SVM models namely SVM coupled with the discrete wavelet transform (SVM-Wavelet), the firefly algorithm (SVM-FFA) and with using the radial basis function (SVM-RBF) were analyzed. The estimation and prediction results of these models were compared with each other using statistical indicators i.e. root means square error, coefficient of determination and Pearson coefficient. The experimental results show that a significant improvement in predictive accuracy and capability of generalization can be achieved by the SVM-Wavelet approach. Moreover, the results indicate that proposed SVM-Wavelet model can adequately predict the electrical and thermal efficiencies of PV/T system. In the final analysis, a proper sensitivity analysis is performed to identify the influence of considered input elements on performance prediction of PV/T system.

1. Introduction

Solar energy is considered as the most reliable energy source in nature for harvesting in different areas, which can reduce our dependence on fossil fuels and also helps in reducing greenhouse gas emissions. The application of solar energy is mainly classified in two categories by solar thermal and photovoltaic system [1]. Then, it is also included the combined solar photovoltaic-thermal energy (PV/T) in order to utilize the wasted heat energy [2]. Solar air collector (SAC) is considered as the key component of harnessing thermal energy from any solar energy systems, described by Caner et al. [3]. PV/T is gaining popularity in building technology due to simultaneous electrical and thermal output from the same system. For example, the thermal energy output has been used in heating domestic hot water [4], building thermal heating [5], heat pump [6] etc. Meanwhile, the building-integrated photovoltaic with thermal energy recovery system (BIPV/T) is growing fast day by day to harness solar energy to meet the optimal integration of renewable energy [7]. PV/T has been shown as main part of the BIPV/T design [8], where the photovoltaic (PV) cell can convert solar radiation to electricity and the rest is converted to heat [9]. Researchers have introduced different PV/T design concept to achieve optimum electrical and thermal output. The outputs are mostly dependent on the photovoltaic internal-external factors and the types of thermal collectors respectively [10].

PV efficiency falls when PV cell temperatures increases which is pointed by Vera et al. [11]. In order to develop the solar PV efficiency, water and air have been used concurrently for cooling systems. A wide research met satisfactory result by using several fluids as a heat transport medium in collectors, but mostly focused on water [12–14], air [15–17] type PV/T collectors, also refrigerant (R410a) was used as the working fluid by Shan et al. [18]. Hybrid

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Nomenclature

ANN	artificial neural networks
BIPV/T	building integrated photovoltaic thermal
PV/T	photovoltaic thermal
PV	photovoltaic
RBF	radial basis function
RMSE	root means square error
SAC	solar air collector
SVM	support vector machine
TFMS	thin flat metallic sheet
$A_{c.t}$	collector area (m^2)
b	scalar
C_a	specific heat (J/kg/K)
G	irradiation (W/m^2)
$\dot{m}_a$	mass flow rate (kg/m^3)
Q_u	useful heat transfer rate (W)
R_2	coefficient of determination
r	Pearson coefficient
T_{in}	collector inlet temperature (°C)
T_{out}	collector outlet temperature (°C)
T_f	collector mean air temperature (°C)
v	air flow velocity (m/s)
x	input space vector

Greeks

φ(X)	high dimensional space
Υ, ε and C	RBF parameters
ξ_i	positive slack variables
η	efficiency
ρ	fluid density (kg/m^3)

Subscript

a	air
c	pv cell
f	fluid
in	inlet
th	thermal
o	overall
out	outlet
ref	reference

heat absorber fluid (water and air) was used in PV/T system which was strongly established by Zondag et al. [19]. In terms of easy operation and maintenance, air is considered as more suitable than water type cooling fluid and power consumption is less compared with water cooling, concluded by Tonui et al. [20]. In some rigorous reviews, recent development and applications of PV/T were discussed on the various configurations with several augmented methods of flat plate PV/T collector models [2,21–24]. In addition, some effective ways can be used to increase the convective heat transfer effect inside the collector channel, such as using corrugated polycarbonate material [25], graphite material [26], galvanized steel [17] and phase change materials (PCM) [27].

Again, the support vector machine (SVM), one of the novel soft computing learning algorithms, has found wide applications in different fields [28–31]. Furthermore, it has been majorly applied in pattern recognition, forecasting, classification and regression analysis [32–34]. The most commonly used kernels include linear, polynomial inner product functions and the radial basis function (RBF). The selection of a kernel function largely depends on the nature of the observed data [35]. Biological inspired metaheuristic optimization algorithms such as ant colony optimization (ACO), genetic algorithm (GA), particle swarm optimization (PSO) and cuckoo search (CS) have found wide applications in different field of science [36–40]. These algorithms are based on the mechanism of selection of the fittest in biological systems. A more recent approach in biological inspired metaheuristic optimization algorithms is firefly algorithm (FFA) developed by Yang [41]. The FFA has been adjudging to be more efficient and robust in finding both local and global optima compare to other biological inspired optimization algorithms [42–45]. The prediction accuracy of the SVM model highly relies on proper determination of model parameters. Although organized strategies for selecting parameters are important, model parameter alignment also need to be made. In this study, the FFA is used for determination of SVM parameters.

The numbers of experimental investigations on flat plate PV/T collectors have been carried out since the late 1970s and more importantly, ANN technique was used in prediction of the flat plate solar collector performance [46]. The use of artificial intelligence methods in many application of thermal system performance analysis increases gradually such as in calculating the thermal performance of SAC. Artificial neural network (ANN) method gives some satisfactory predicted results proposed by Caner et al. [3], the method was working based on the data classification by training, validation and testing under eight inputs and single output variable. Again, a series of prediction model was developed by Varol et al. [27]. But SVM showed more popularity which is widely used machine-learning tools comparing with neural networks claimed by Esen et al. [47]. They recommended using SVM as a good, intelligent method in the case study of ground coupled heat pump (GCHP) for space heating purposes. In addition to the parametric analysis, SVM was modeled using five inputs and one output. The result shows that the SVM could predict co-efficient of performance (COP) effectively. The authors also intended to adopt the analysis in finding the system efficiency for modeling using least-square support vector machine (LS-SVM) [48], artificial neural network (ANN) and wavelet neural network (WNN) models [49] for three types of solar air heater (SAH).

In this study, the SVM was coupled with discrete wavelet transform. Wavelet transform (WT) has many useful basis functions to select from depending on the signal that is being analysed. Wavelet analysis was used to decompose the time series of data into its various components, after which the decomposed components can be used as inputs for the SVM model. Over the past few years, this technique has become of enormous interest in engineering applications [50,51].

The conventional algorithms employed for calculating thermal efficiency are usually complicated in solving the mathematical form because it involves the complex in solution for differential equations developed from thermal balance relation and individual part analysis in PV/T system [13,15,16,19,52–54]. All the energy calculation is based on the thermal interaction of heat flow between a flowing fluid and the collector body under steady state flow condition because the thermal performance depends on collector material, space, dimension and layout [3]. As a result, it appears some statistical error in proper curve fitting between theoretical and experimental values for various measurement, heat loss and uncertainty in the collector as well. In this case, SVM is used to overcome the complex mathematical form and mathematical routines found in classical methods of PV/T. It helps to learn the original information patterns within a multi-dimensional information domain and helps to eliminate long series of collector performance test.

Soft computing technology has been applied effectively in many different fields of engineering application due to their attractive capabilities in forecasting, modeling of complex nonlinear systems and achieving the optimum efficiencies. As mentioned, the PV/T technology has some remarkable benefits and several PV/T collector designs have been proposed and developed within the