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Artificial Neural Network Based Model of Photovoltaic Thermal (PV/T) Collector

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Abstract
This paper presents a new application of Artificial Neural Network (ANN) for modeling a Photovoltaic Thermal collector (PV/T). Both thermal and electrical modeling performed. Ambient temperature of collector, cell temperature, fluid temperature at duct inlet, fluid velocity in duct, solar identity and time are used in the input layer and the thermal efficiency and electrical efficiency are outputs. Networks with different hidden layers used for modeling and performances evaluated with maximum correlation coefficient (R^2), minimum root mean square error (RMSE) and low coefficient of variance (COV). The results showed that the ANN with 1 hidden Layer and 10 neurons in this layer has the best performance. The experimental data measured at meteorological conditions of Zahedan were used as training data. The Levenberg-Marquard backpropagation algorithm has been used for training network. The results of this work indicated that for evaluating PV/T performance researchers can use this method by conducting limited experiments.

Keywords: Artificial Neural Network, Photovoltaic thermal collector (PV/T), Thermal and electrical modeling.

1. Introduction
Solar energy conversions has various advantages such as short time duration of installation and long life of operation, circuit simplicity, no need of moving part and realize a salient, safe, not pollutant and renewable source of electricity [1]. Photovoltaic is a marriage of two words: the Greek word 'photo', meaning light, and 'voltaic', meaning electricity. Photovoltaic technology used to describe the hardware that converts solar-energy into usable power, generates electricity from light. Photovoltaic is the direct conversion of light (photons) into electricity (voltage) using semiconductor materials [2]. A photovoltaic thermal hybrid solar

system (or PV/T system for simplicity) is a combination of photovoltaic (PV) and solar thermal components systems which produce both electricity and heat from one integrated component or system. In other words, PV is used as part of the thermal absorber. By cooling the solar cells with a fluid stream like air or water, the electricity yield can be improved. But conceptually the better design is to re-use the heat energy extracted by the coolant. Then the energy yield per unit area of panel (or facade in the case of building-integrated installation) can be improved. These are the incentives leading to the evolvement of PV/T hybrid solar technology [3]. **Figure** 1 shows the main features of a flat-plate PV/T collector. Therefor evaluating performance of a PV/T system is a problem should be attendant. But for mathematical modeling of a PV/T system nonlinear equations must be solved and requires the system characteristics provided by manufacturers and often are not available.

ANNs can be considered as simplified mathematical models of brain-like systems and they function as parallel-distributed computing networks. However, in contrast to conventional computers, which are programmed to perform specific task, most neural networks must be taught, or trained. They can learn new associations, new functional dependencies and new patterns. Neural networks obviate the need to use complex mathematically explicit formulas, computer models and impractical and costly physical models [4]. Several studies performed on ANN modeling of solar thermal systems and although photovoltaic systems. Marianna Blazani et al. used a feed-forward neural network containing of 6 and 12 neurons for modeling a

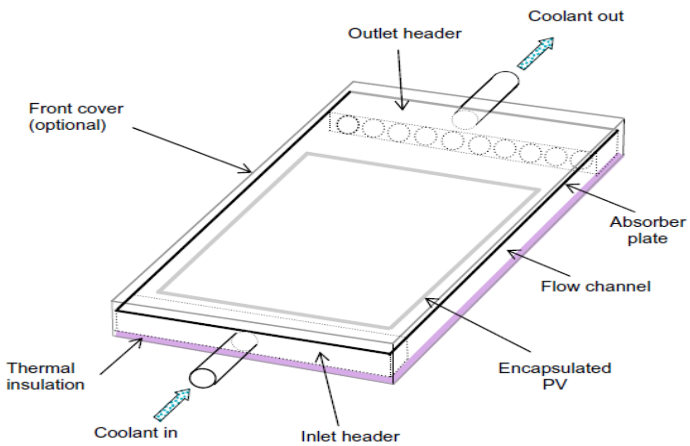

Figure 1. Main features of a flat-plate PVT collector [3].

photovoltaic module [1]. Takashi Hiyama et al. presented a neural network for the estimation of maximum power generation from the PV module. In their work irradiation, temperature and wind velocity utilized as the input and the output was the maximum power generation [5]. I Farkas et al. introduced and analyzed different approaches to the modeling of flat-plate solar collectors and modeling simulations with an artificial neural network ANN technique were carried out. A sensitivity study was performed on the parameters of the neural network [6].

Adel Mellit et al. investigated possibility of using an adaptive Artificial Neural Network, in order to find a suitable model for sizing Stand-Alone Photovoltaic (SAPV) systems, based on a minimum of input data [7]. Adnan Sozen et al. developed a new formula based on artificial neural network (ANN) technique to determine the efficiency of flat-plate solar collectors. Meteorological data of summer session (from July to September) for Ankara were used as training data in order to train the neural network. Surface temperature in collector, date, time, solar radiation, declination angle, azimuth angle and tilt angle are used in the input layer of the network. The efficiency of flat-plate solar collector is in the output layer [8]. Moh'd Sami S. Ashhab modeled A photovoltaic solar integrated system with artificial neural networks. Data relevant to the system performance was collected on April, 4th 1993 and every 15 min during the day. This input–output data is used to train the ANN [9]. Hui Xie developed a new approach based on artificial neural network to determine the performance of solar collectors. He used the meteorological data measured in Beijing for training network. Ambient temperature of collector, solar identity, declination angle, azimuth angle and tilt angle were used in the input layer and the efficiency and heating capacity in the output layer [10].

As mentioned in all of above articles and many other works paid attention to modeling PV systems or solar collector by using ANN, but there is no work conducted to evaluate the performance of a PV/T collector based on ANN. The objective of this study is to present an ANN based model to evaluate thermal and electrical performance of a PV/T system. For this reason we first examine different networks with different hidden layers and neurons then choose best of them for modeling PV/T system. Finally use the best network for performance evaluation of system.

2. Classical Model

PV/T system converts solar energy in to heat and electricity. So for system modeling we should must do for system both thermal and electrical model.

2.1. Thermal model

The proof governing equations of PV/T thermal analysis is exist in many references [11], [12], [13] so for brief in this section we only review some of them. Writing energy balance for each component of PV/T system gives fluid temperature at outlet of the duct, heat absorbed by fluid and thermal efficiency of system as follows:

$$T_{f,out} = (T_{amb} + \frac{h_{p1} h_{p2} (\alpha\tau)_{eff} G}{U_L})(1 - \exp(\frac{-WU_L L}{\dot{m} C_p}) + T_{f,in} \exp(\frac{-WU_L L}{\dot{m} C_p}) \qquad (1)$$

$$Q_u = \dot{m} C_p (T_{f,out} - T_{f,in}) \qquad (2)$$

$$\eta_{th} = \frac{Q_u}{WLG} \qquad (3)$$

Where $T_{f,out}$, $T_{f,in}$, T_{amb}, G, W, L, $\dot{m}$, C_p, Q_u and η_{th} are respectively fluid temperature in duct outlet, fluid temperature in duct inlet, ambient temperature, solar radiation identity, length of the fluid duct, the mas flow rate of fluid, the heat capacity of fluid, heat absorbed by fluid and thermal efficiency. Also h_{p1} and h_{p2} are convection heat transfer coefficients. And $(\alpha\tau)_{eff}$ is the absorb coefficient and defined as follows:

$$(\alpha\tau)_{eff} = \tau_g (\alpha_c \beta_c + \alpha_T (1 - \beta_c) - \beta_c \eta_{el}) \qquad (4)$$

Where τ_g, α_c, β_c, α_T and η_{el} are respectively transitivity of glass, absorptivity of solar cell, packing factor of solar cell, transitivity of tedlar and electrical efficiency. Just as seen in Eq. (1) and (4) for thermal modeling the electrical efficiency is required. So in the next section review the electrical model of system.

2.2. Electrical model

A PV module is nonlinear device and can be represented by its current–voltage (I–V) characteristic curve. There are several mathematical models, which can describe I–V characteristic curve [11]. Five-parameter photovoltaic model (is shown **Figure 2)** for I–V characteristic curve is defined as [11], [14]:

$$I = I_L - I_0[\exp\frac{V + IR_s}{a} - 1] - \frac{V + IR_s}{R_{sh}} \qquad (5)$$

Where I, I_L, I_0, V, R_s, R_{sh} and a are respectively load current, light current, diode reverse saturation current, voltage, series resistant, shunt resistant and ideality factor. In order to calculate five reference parameters (a_{ref}, $I_{L,ref}$, $I_{o,ref}$, $R_{s,ref}$ and $R_{sh,ref}$), five pieces of information are needed at reference conditions. These five pieces of information are defined as follows:

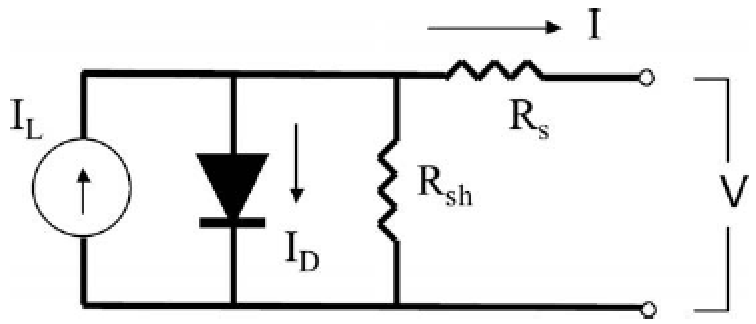

Figure 2. Equivalent electrical circuit in the five-parameter photovoltaic model [14]

At short-circuit current	$I = I_{sc,ref}$, $V = 0$
At open-circuit voltage	$I = 0$, $V = V_{oc,ref}$
At the maximum power point	$I = I_{mp,ref}$, $V = V_{mp,ref}$
At the maximum power point	$[d(IV)/dV]_{mp} = 0$
At short circuit	$[dI/dV]_{sc} = -1/R_{sh,ref}$

With substituting above five pieces of information to Eq. 5, five parameters of the model in reference condition find and for new climatic and operation conditions a set of translation equation required. After solving and translate above equations for new condition the (I-V) characteristic curve find and give the maximum power point voltage and it's correspond current (V_{mp} and I_{mp}). So the electrical efficiency is defined below:

$$\eta_{el} = \frac{V_{mp} I_{mp}}{S} \tag{6}$$

Where S is the solar energy absorbed by the photovoltaic module.

3. ANN configuration

Differetnt feed-forward neural network size have been implemented by varying the number of hiden layers and their neurons. Ambient temperature of collector, cell temperature, fluid temperature at duct inlet, fluid velocity in duct, solar identity and time are used in the input layer and the thermal efficiency and electrical efficiency are outputs. The ANN architecture is depicted in **Figure 3.** The experimental data was measured in Zahedan used for training all networks. In the hidden layers of the networks sigimoid transfer functions and in the output layer linear transfer functions were used. The Levenberg-Marquard backpropagation algorithm has been used for training networks.

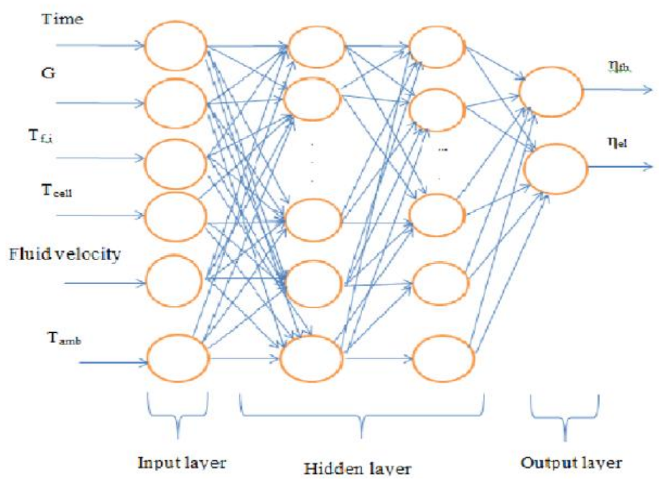

Figure 3. Architecture of the ANN

4. Results

Structure of used networks and their performances is listed in **Table 1**. For networks performance evaluation the correlation coefficient (R^2), root mean square error (RMSE), and coefficient of variance (COV) calculated from below Eqs. (7-9):

$$R^2 = 1 - \left(\frac{\sum_{i=1}^{N} (a_i - p_i)^2}{\sum_{i=1}^{N} a_i^{\,2}} \right) \tag{7}$$

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (a_i - p_i)^2} \tag{8}$$

$$COV = \frac{RMSE}{\sum_{i=1}^{N} a_i} \times 100 \tag{9}$$

Where N is the number of the data measured in experimental study, α and p is refer to the experimental and simulated data, respectively. When the RMSE and COV are smaller and the R^2 is approaches 1 the network has the better performance.

Table1. ANN structure and performance evaluation

ANN model	Network structure		R^2	RMSE	COV
ANN1	6-10-2	η_{th}	0.9976	0.3974	0.0526
		η_{el}	0.9822	0.1342	0.0132
ANN2	6-20-2	η_{th}	0.9775	1.169	0.1557
		η_{el}	0.9761	0.1541	0.0152
ANN3	6-10-10-2	η_{th}	0.9955	0.5575	0.0742
		η_{el}	0.9822	0.136	0.0134
ANN4	6-20-20-2	η_{th}	0.9881	0.8905	0.1186
		η_{el}	0.9318	0.2721	0.0268

According to the statistical values is given in **Table 1**, the ANN1, which consist of one hidden layer with 10 neurons, has the best performance for simulating the PV/T collector. The model ANN3 is also good performance but ANN1's performance is better than it and has the lower error. There for we use the ANN1 for simulation of PV/T performance.

Thermal and electrical efficiency simulated by ANN and measured by experiments were compared in **Figure 4** and **Figure 5**. The simulation results for the thermal efficiency yield a correlation coefficient of 0.9976, with RMSE and COV values of 0.3974 and 0.0526, respectively. As shown in **Figure 4** the simulated values are close to the experimental values. Thermal efficiency is a major parameter for PV/T and if the system is designed for optimum thermal efficiency can help increasing electrical efficiency and also to use losing heat in PV module for heating fluid.

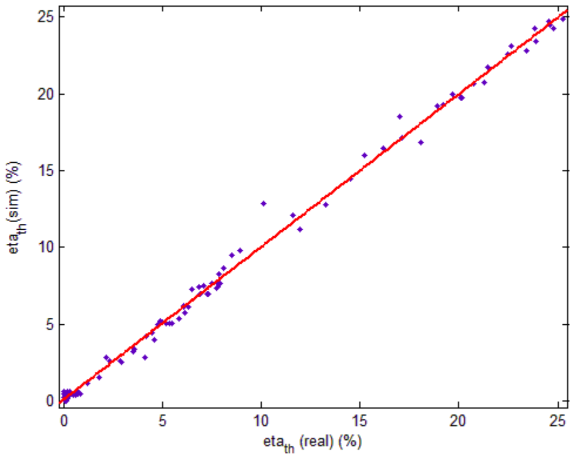

Figure 4. ANN simulated thermal efficiency vs. experimental value

The simulation for the electrical efficiency gives the correlation coefficient of 0.9822, with RMSE and COV values are 0.1342 and 0.0132, respectively. The results confirm that the efficiency simulated by ANN is very close to experimental efficiency and **Figure 5** shows the compression between experimental and ANN simulated electrical efficiency, which is the most important parameter in PV/T collector.

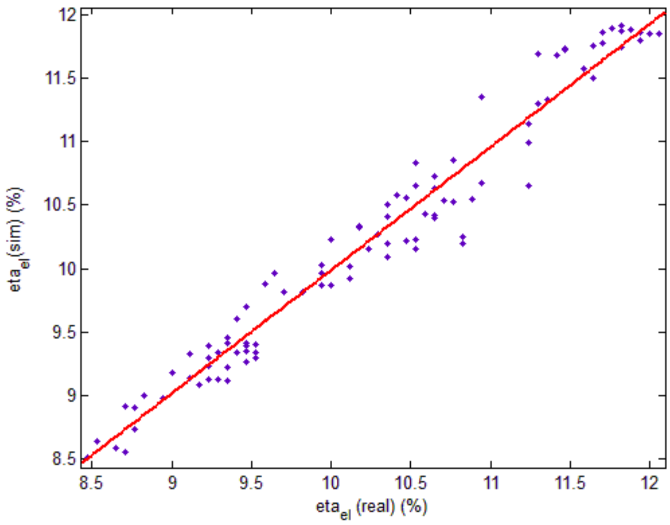

Figure 5. ANN simulated electrical efficiency vs. experimental value

5. Conclusion

A neural network based model of a PV/T collector has been presented. The advantage of Artificial Neural Network model ANN simulation over mathematical models is that it does not require the knowledge of internal system, such as reference condition in this study, may not be available. Also ANN model involve less computational effort and offers a compact solution for nonlinear and multiple-variable problems. In this study backpropagation feed-forward network were used and the model with one hidden layer and 10 neurons in hidden layer has the best performance and used for simulation. Finally, this work confirmed that the ANN can use for PV/T systems modeling and in future can help to researchers to model their own PV/T system by conducting limited experiment and forming network can be with good correlation for modeling their system in other working condition whit out spending time and cost. Also they can use ANN for control PV/T system for working on optimum condition.

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