APPLICATION OF ARTIFICIAL NEURAL NETWORK (ANN) METHOD TO EXERGETIC ANALYSES OF GAS TURBINES

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ABSTRACT

In this study, ANN method is applied to exergetic analyses of gas turbines (GT) by using actual operating data of 3 GTs. These 3 GTs are operating to supply heat and power in a cogeneration system of a ceramic factory, located in Izmir, Turkey. Fast ANN (FANN) package (library) has been chosen as an ANN application to implement into the C++ code named CogeNNExT, which has been written and developed by the authors.

After assuming which inputs of GTs are needed, comparisons between the exergy values obtained from exergy analysis and the exergy values obtained from ANN method are made. In these compressions, cross tests are also applied. In an example ANN trained by data of first GT and using this trained data, ANN exergy results are calculated and compared by actual second GT results. All of the results of exergetic analysis of GTs are compared and shown by graphics.

As a result of analysis, ANN is successfully applied to obtain exergetic results of GTs. These are shown by graphics including input, output, fuel, product exergies and exergy destruction results of GTs. RMSE (Root Mean Square Error) values are found under 0.01 which means that data set including inputs and outputs of many GTs would be perfect to obtain much closer exergetic results by an ANN.

Key words: gas turbine; exergy; artificial neural network; ANN; FANN

INTRODUCTION

Gas turbines engines -mostly called as “gas turbines” however turbine is a part of these engines- are axial rotary machines where both compression and expansion processes take place. Gas turbines are work by the Brayton cycle theory which was first proposed by George Brayton (Cengel and Boles, 2006). Combined heat and power (CHP) systems also called cogeneration systems involve the production of both thermal energy, generally in the form of steam or hot water, and electricity (Balli et al., 2008). By using these systems, the efficiency of energy production can be increased from current levels that vary from 35 to 55% in the conventional power plants to over 80% in the CHP systems (Rosen and Dincer, 2005). Exergy is maximum amount of work, which can be produced by a system or a flow of matter or energy as it comes to equilibrium with a reference environment by reversible (Rosen, 2006).

Artificial Neural Network (FANN) is a free library developed by Nissen and written in ANSI C (Nissen, 2008). Library implements multilayer feed forward networks and supports both fully connected and sparse connected networks. It offers support for execution in fixed point arithmetic to allow for fast execution on systems with no floating point processor. FANN library is designed to be fast, versatile and easy to use and it is significantly faster than other libraries on systems without a floating point processor, while the performance was comparable to other highly optimized libraries on systems with a floating point processor (Nissen, 2003; Nissen, 2008).

In the open literature, as the best of the author's knowledge, there is no study on the ANN based exergy analysis of GTs. In addition to the motivation behind the present study is also the previous success of ANN for the energetic and exergetic analysis on a cogeneration system (Yoru, 2008). By using one month data of investigated GTs within 1 hour intervals, constants and assumptions, generated code is able to generate many different results for the ANN analyses. Full details, descriptions and schematics of this investigated gas turbines and whole cogeneration system have been given in the dissertation of this study (Yoru, 2008).

THEORY OF ARTIFICIAL NEURAL NETWORK

ANN is a network consisting of connected artificial neurons, including inputs, outputs and layers. The input and output layers contain number of neurons equal to number of input and output parameters, respectively. For the beginning a ANN study there are good sources to apply ANN especially to the mechanical engineering problems. Hassoun (1995) introduced most concepts of ANN, while Hertz (1991) described the mathematics of ANN very thoroughly. Anderson (1995) used a more psychological and physiological approach to NN and ANN.

A general mathematical equation for a modeled single artificial neuron is

$$y(x) = g\left(\sum_{i=0}^{n} w_i x_i\right) \tag{1}$$

where *y(x)* is one output axon, *x* is a neuron with *n* input dentrites $(x_0...x_n)$, w is weight and *g* is a sigmoid function. Activation function *g* should be a simple threshold function returning 1 or 0 (Nissen, 2003). This single artficial neuron, simple network models and example sigmoid functions are shown in the ANN literature (Nissen, 2003).

SYSTEM DESCRIPTION

Investigated GTs are able to supply both electricity and heat for the ceramic factory located in Izmir, Turkey, with a total installed capacity of 13 MW. Whole cogeneration system of factory includes 3 GTs, 6 spray dryers and 2 exchangers and planted in the factory. Investigated GTs are single shaft engines and fueled by natural gas (NG). Taurus 60 model GT has 4.6 MW power generation capacity. This engine is the first installed and the oldest GT. The other two Centaur 50 model GTs have 4.2 MW power generation capacities. All GTs work with 15000 rpm and within reducer generators work with 1500 rpm at 50 Hz electricity. GTs are able to supply all electricity demand of factory when all of them work together.

ANALYSIS

Energy and exergy terms are used for measure of quantity and measure of quantity and quality due to entropy, respectively. The exergy analysis suggests the need for definition parameters that facilitate the assessment of the maximum amount of work achievable in a given system with different energy sources. Within assumptions as shown Table 1 the general energy and exergy balance equations which are used in the energy and exergy analyses of this study are given as follows. General energy balance equation for a steady-state, steady-flow process is given in Eq.2.

$$\dot{E}_{in} - \dot{E}_{out} = 0 \tag{2}$$

General exergy balance equation is can be written as shown in Eq.3.

$$\dot{E}x_{in} - \dot{E}x_{out} = \dot{E}x_{D} \tag{3}$$

where difference between exergy input and output is equal to exergy destruction.   Specific exergy (flow exergy) in calculated by from;

$$\psi = (h - h_0) - T_0\left(s - s_0\right) + \frac{V^2}{2} + gz \tag{4}$$

RESULTS AND DISCUSSION

As a result of analysis mean exergetic efficiencies of turbines of cogeneration system planted on Izmir ceramic factory are found 30.21% (I), 32.38% (II) and 31.22% (III). Energy rate supplied by total mean NG consumption of GTs is found 38191.2 kW (%88.97) and total mean electricity power generation from the generators of GTs is found 12279.82 kW (%28.60). Exergy rate supplied by total NG consumption of gas turbines is found 39367.49kW (%88.98), total electricity generation rate is found 12279.82 kW (%27.75). All of these results and detailed graphics of each component are described in the dissertation of Yoru [22].

Comparison of product and fuel exergy results of GT-2 and GT-3 is shown in Figure 1. GT-2 is trained gas turbine and GT-3 is tested gas turbine using ANN network of GT-2. From this analysis RMSE values of product and fuel exergies are found 0.002 and 0.00082 respectively.

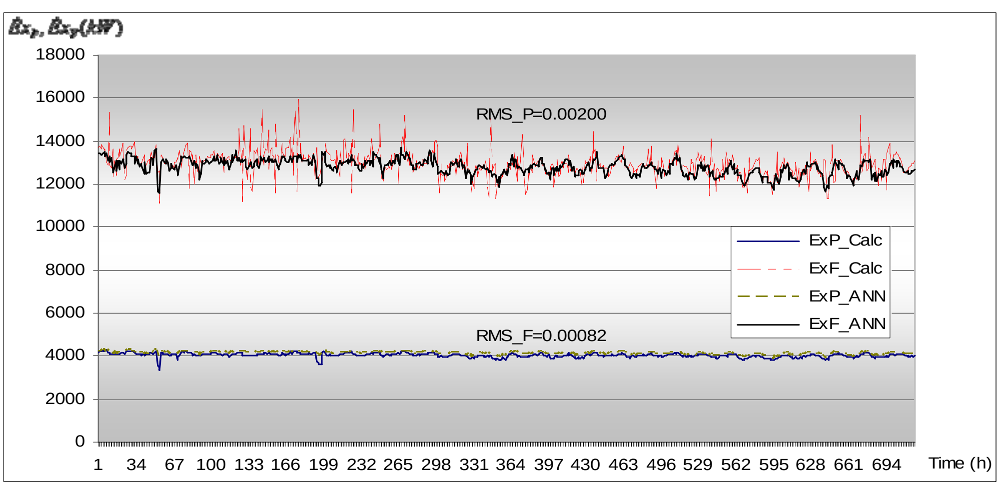

Figure 1: Comparison of product and fuel exergy results (Trained:GT-2 and tested on:GT-3)

CONCLUSIONS

The main conclusions, which can be drawn from the results of the pre study, may be listed as follows;

a) If a well trained ANN is generated by data of many GT's, ANN is able to find approximate exergy results by using inputs only. This means that a trained ANN is not require any thermodynamic equations or tables for the exergy analyses of GTs.

b) In future by using AI methods like ANN method, gas turbines would be much cleverer (in addition to cogeneration systems and jet planes) to define thermodynamic results like energy and exergy values. This will result robust cogeneration system with high exergy efficiency.

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