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A hybrid model of an artificial neural network with thermodynamic model for system diagnosis of electrical power plant gas turbine

M. Talaat [a,*], M.H. Gobran [b], M. Wasfi [b]

[a] Electrical Power & Machines Department, Faculty of Engineering, Zagazig University, P.O. 44519, Zagazig, Egypt
[b] Mechanical Power Department, Faculty of Engineering, Zagazig University, P.O. 44519, Zagazig, Egypt

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ABSTRACT

In this paper, the diagnosis system of power plant gas turbine has been developed to detect the deterioration of engine performance. This system can be analyzed the gas path measurement to predict the deterioration of engine main component by using artificial neural network. The deterioration performance data of gas turbine was generated by using the thermodynamic model. So, the artificial neural network model was built to predict the deteriorated characteristics of gas turbine. Thermodynamic model was used to simulate gas turbine performance as well as the deterioration of engine components (compressor, combustion chamber and turbine) which were represented by changing component characteristic parameters (efficiency and flow capacity). On one hand, the probability of these deteriorated components was simulated to generate deteriorated data (measurement parameters and deterioration degree of each component). On the other hand, the neural network was trained with deterioration data and the best structure of neural network (number of hidden layers, number of neurons in hidden layer and transfer function) was selected based on the minimum value of the mean square error. The different deterioration data (testing data) was generated in thermodynamic model to test the effectiveness of the neural network. The comparison between the mean square error value of single and multi-neural network output parameters at training and testing data were achieved. In final, the testing with the real engine data were achieved.

1. Introduction

The performance of the gas turbine is progressively deteriorated due to many factors such as poor fuel quality, air pollution, deterioration of auxiliary systems and aging of the main components (compressor, combustion chamber and turbine) (Awang Saifudin and Mazlan, 2014). The engine performance deteriorates under good operating condition, so the diagnosis and supervision system of gas turbines has great importance for operators to maintain proper performance for safe operation (Razak, 2007). The gas turbine deterioration is classified to the deterioration recovered by cleaning of components and the other deterioration replaced before causing a dangerous problem. There are several methods to study the deterioration in gas turbine engine; the computational fluid dynamic is accurate to study the deterioration of component parts such as compressor blades and turbine blades (Morini et al., 2010). It is difficult to be used in calculating the overall performance of engine deterioration. The thermodynamic modeling is the suitable method to calculate the performance of engine deterioration. The deterioration of engine components is simulated by using and changing the performance maps. By using this method, several deterioration is studied such as fouling for the compressor in power plant, erosion for the turbine in aircraft (Roumeliotis, 2010), diagnose gas-path faults in gas turbines by minimizing the differences between the observed and simulated data for the engine behavior (Ogaji et al., 2005) and suggested a good maintenance schedule for gas turbine engine (Ogbonnaya, 2011). Artificial neural networks ANNs are promising tools for gas turbine deterioration which is detected as they achieve significant success in system modeling and powerful ability to connect enormous groups of inputs and outputs by using non-linear relationships with high accuracy (SadoughVanini et al., 2014). ANNs have many advantages due to the special structure and algorithm for those networks. The ANNs methodology is a good alternative to statistical modeling techniques for obtaining data sets for nonlinear systems (Asgari et al., 2013; Nikpey et al., 2013). A new theoretical optimization for neural network structure and training algorithm had been presented by others (Liu and Cao, 2010; Liu et al.,

* Corresponding author.
E-mail addresses: m_mtalaat@eng.zu.edu.eg, m_mtalaat@yahoo.com (M. Talaat).

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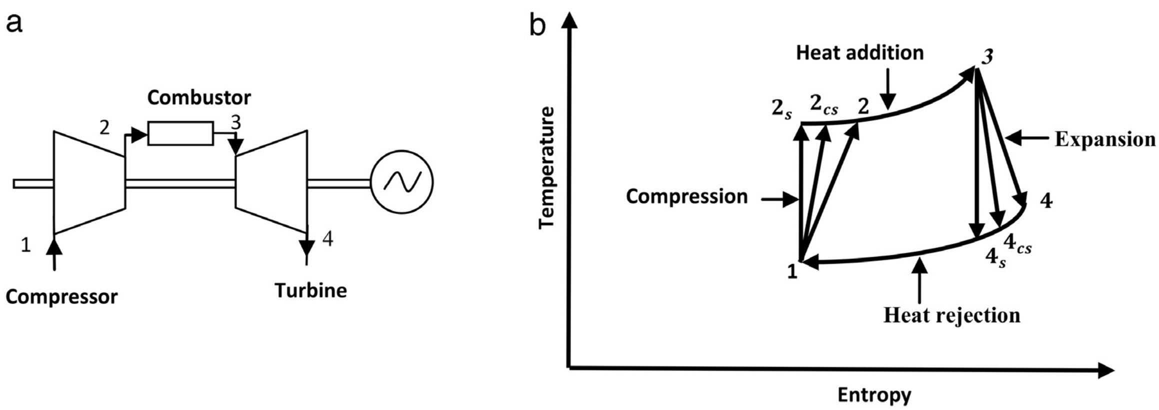

Fig. 1. Simple cycle gas turbine engine; (a) schematic diagram, (b) thermodynamic cycle.

2010b). The results obtained shown the desirable performance of a new neural networks. So, the neural networks have become easier to deal with more complex problems (Liu and Cao, 2010; Liu et al., 2010b). As such the researcher proposed a novel recurrent neural network based on the gradient method for solving linear programming problems, Finite time convergence of the proposed neural network is proved by using the Lyapunov method. Compared with the existing neural networks for linear programming, and the numerical simulation results have shown excellent performance of a new neural network (Liu et al., 2010a). The structure selection of network requires for any task which depends on the complication of the problem. The treatments of input and output layers are completed by using the amount of input and output groups which is called the training phase. Identifying the suitable number of neurons in hidden layers is the most important to complete the training process. This stage is completed by training the network several times using different numbers of neurons and selecting the appropriate number (Li et al., 2011; Palmé et al., 2011). The ANNs are used for calculating gas turbine performance and it is various advantages such as the required computational time is shorter when it is compared to the thermodynamic because the thermodynamic models perform various degrees of iterations of non-linear equations. The ability to generate the non-linear relationships between gas turbine parameters, and the treatment ability with large numbers of variables or parameters. In this paper, a thermodynamic model has been built to simulate the different probabilities of deterioration of engine components by using MATLAB environment. The deterioration data was applied to train a neural network and select the best network structure. Finally, the ANNs model has been tested to check the accuracy of predicting the deterioration of engine components for giving a set of performance parameters.

2. Thermodynamic degradation proposed model for industrial gas turbine

The studied engine is a single spool GE-9EA gas turbine which produces a rated electric power of 125 MW at sea level condition standard (15 °C, 101.35 kPa and 60% relative humidity). The axial flow compressor consists of compressor 17 rotor stages and an enclosing case. The combustion system is the annular reverse flow type which includes 14 combustion chambers. The three-stage turbine section is the area in which energy in a form of high state. In this model, the suitable operating point from compressor and turbine map has been calculated by using thermodynamic principle to get properties of all engine components. The thermodynamic cycle that represents the gas turbine is called Brayton cycle.

Fig. 1 illustrates a thermodynamic process of simple cycle gas turbine; the process $1 \overset{to}{\rightarrow} 2$ represents the compression of air in the compressor section, while the process $2 \overset{to}{\rightarrow} 3$ represents burning of a mixture of air and fuel in the combustion chamber section and the process $3 \overset{to}{\rightarrow} 4$ is an expansion of mixture hot gases in the turbine section to produce the output power.

The main function of this model is to find the air or hot gases properties (pressure, temperature, and mass flow rate) in all engine points. The performance maps of compressor and turbine represent properties (efficiency, pressure, and mass flow rate) of all available operating points of those components. So, by using the thermodynamic concept and iteration method, the suitable operating point of the compressor and turbine is found.

The thermodynamic concept that used in this model, whether that was the process $1 \overset{to}{\rightarrow} 2$ or $3 \overset{to}{\rightarrow} 4$; the following relations represent it (Cohen et al., 1987).

$$T_{(i+1)s} = T_i \times \left(\pi_{i:(i+1)}\right)^{\pm\left(\frac{\gamma-1}{\gamma}\right)} \quad (1)$$

where, T_i is the compressor or turbine inlet temperature, $T_{(i+1)s}$ is the compressor or turbine isentropic discharge temperature, $\pi_{i:(i+1)}$ is the compressor or turbine pressure ratio and γ is the isentropic index, ($i = 1$ and the signal is +ve) for compression process $1 \overset{to}{\rightarrow} 2$ and ($i = 3$ and the signal is −ve) for expansion process $3 \overset{to}{\rightarrow} 4$.

$$T_{(i+1)cs} = T_{(i+1)s} \times e^{\pm\left(\frac{s_i - s_{(i+1)}}{R_g}\right)} \quad (2)$$

where, $T_{(i+1)cs}$ is the compressor or turbine corrected isentropic discharge temperature, s is the entropy and R_g is the gas constant.

$$h_{(i+1)} = h_i + \frac{\left(h_{(i+1)cs} - h_i\right)}{\eta_c \overset{or}{\rightarrow} \eta_t^{-1}} \quad (3)$$

where, h is the enthalpy, η_c is the compressor efficiency and η_t is the turbine efficiency.

The enthalpy and entropy are given as functions of temperature (McBride et al., 2002)

$$\frac{H(t)}{R_g} = -a_1 T^{-1} + a_2 \ln(T) + a_3 T + \frac{a_4}{2} T^2 + \frac{a_5}{3} T^3 + \frac{a_6}{4} T^4 + \frac{a_7}{5} T^5 + b1 \quad (4)$$

$$\frac{S(t)}{R_g} = -\frac{a_1}{2} T^{-2} - a_1 T^{-1} + a_3 \ln(T) + a_4 T + \frac{a_5}{2} T^2 + \frac{a_6}{3} T^3 + \frac{a_7}{4} T^4 + b2. \quad (5)$$

Eq. (6) represents the energy balance

$$m_a^{\bullet} \times h_2 + \eta_b \times m_f^{\bullet} \times HV = \left(m_a^{\bullet} + m_f^{\bullet}\right) \times h_3 \quad (6)$$

where, $m_a^{\bullet}$ is the air mass flow rate, $m_f^{\bullet}$ is the fuel mass flow rate, HV is the heating value and η_b is the combustion efficiency.

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