INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 36 (2011) 885–892

Available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he

Thermal modeling of a solid oxide fuel cell and micro gas turbine hybrid power system based on modified LS-SVM

Xiao-Juan Wu [a,*], *Qi Huang* [a], *Xin-Jian Zhu* [b]

[a] *School of Automation, University of Electronic Science and Technology of China, Chengdu 610054, China*
[b] *Institute of Fuel Cell, Shanghai Jiao Tong University, Shanghai 200030, China*

ARTICLE INFO

Article history:
Received 22 April 2010
Received in revised form
22 July 2010
Accepted 5 August 2010
Available online 12 October 2010

Keywords:
Solid oxide fuel cell (SOFC)
Micro gas turbine (MGT)
Least squares support vector machine (LS-SVM)
Particle swarm optimization (PSO)

ABSTRACT

For a solid oxide fuel cell (SOFC) integrated into a micro gas turbine (MGT) hybrid power system, SOFC operating temperature and turbine inlet temperature are the key parameters, which affect the performance of the hybrid system. Thus, a least squares support vector machine (LS-SVM) identification model based on an improved particle swarm optimization (PSO) algorithm is proposed to describe the nonlinear temperature dynamic properties of the SOFC/MGT hybrid system in this paper. During the process of modeling, an improved PSO algorithm is employed to optimize the parameters of the LS-SVM. In order to obtain the training and prediction data to identify the modified LS-SVM model, a SOFC/MGT physical model is established via Simulink toolbox of MATLAB6.5. Compared to the conventional BP neural network and the standard LS-SVM, the simulation results show that the modified LS-SVM model can efficiently reflect the temperature response of the SOFC/MGT hybrid system.

1. Introduction

Solid oxide fuel cell (SOFC) is considered a suitable candidate for the electric power plant applications. The energy conversion efficiency of a SOFC stack can reach up to 55%. However combined with a micro gas turbine (MGT), the theoretical research has shown that the overall SOFC/MGT hybrid power system efficiency can even reach up to 70% [1].

Thermal management is a critical factor for the performance of the SOFC/MGT hybrid power system. In order to effectively control the temperature, it is necessary to develop a suitable temperature model for the SOFC/MGT hybrid system. During the last several decades, based on mass, energy and momentum conservation laws, various mathematical models of the SOFC/MGT hybrid power system have been established [2,3]. These models are very useful for analyzing the transient characteristics of the SOFC/MGT hybrid system. However, due to the complex nature of the physical process, the main problems with these models are the difficulties associated with their construction and the limited accuracy, which are very complicated for use as model based control methods.

To meet the demands of developing valid control strategies, a least squares support vector machine (LS-SVM) based on particle swarm optimization (PSO) algorithm is employed to describe the nonlinear temperature dynamic properties of the SOFC/MGT hybrid power system in this paper. LS-SVM is considered as an attractive method to establish the mathematical relationship of the dynamic system based on the input–output data. Compared with the

* *Corresponding author*. Tel.: +86 13679068274.
E-mail address: xj2_wu@hotmail.com (X.-J. Wu).
0360-3199/$ – see front matter © 2010 Professor T. Nejat Veziroglu. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijhydene.2010.08.022

above modeling method, LS-SVM can efficiently avoid using the complicated differential equations groups to describe the system. In comparison with neural network and standard SVM, LS-SVM has the following advantages: no number of hidden units has to be determined, no centers have to be specified for the Gaussian kernel when applying Mercer's condition, and fewer parameters have to be prescribed [4]. A number of applications of the LS-SVM in the fuel cell can be found in the literatures [5–7]. However, to our knowledge, practical application of LS-SVM to model and predict the SOFC/MGT hybrid system cannot be found in prior papers.

The regularization factor and the width coefficient of the kernel functions have great influences on the performance of LS-SVM. Therefore, to gain better forecasting results, how to set the parameters of the LS-SVM is very crucial. Grid search is often used to select the regularization constant and the parameter of kernel function [8]. This procedure requires a grid search over the space of parameter values and needs to locate the interval of feasible solution and a suitable sampling step. This is a tricky task since a suitable sampling step varies from kernel to kernel and the grid interval may not be easy to locate without prior knowledge of the problem. Thus, an improved PSO algorithm is here applied to tune the regularization and kernels parameters of the LS-SVM. PSO is an evolutionary computation technique based on swarm intelligence. Compared to other heuristic techniques, PSO has many advantages, e.g., it can be used effectively to exploit the distributed and parallel computing capabilities, to escape local optimal, and to implement in a few lines of computer codes [9]. The optimal parameters searched by the improved PSO algorithm will insure the LS-SVM model in best performance. A physical model of a 220 kW SOFC/MGT hybrid power system is used to generate the data required for the training and prediction of the modified LS-SVM model.

2. Description of SOFC/MGT hybrid power system

A topping cycle pressurized SOFC/MGT hybrid power system is shown in Fig. 1 [10], which is designed on the basis of the tubular technology pioneered by Siemens Westinghouse in the 1970s. In order to avoid excessive thermal stresses in the stack, the SOFC operating temperatures require preheating the fuel and air streams. Thus, it is mandatory to use heat exchangers that can transfer the high thermal energy rates of SOFC outlet streams increasing air and fuel inlet temperature. The steam needed to support the internal reforming reaction is obtained by re-circulating part of the anode outlet stream.

The operation of the SOFC/MGT hybrid power system can be summarized as follows:

- Air (stream 1) is pressurized by an air compressor up to the fuel cell operating pressure (stream 2). The pressurized air is then passed through heat exchanger 2 and heat exchanger 1 to be preheated. The pressurized and preheated air (stream 4) enters to the fuel cell.

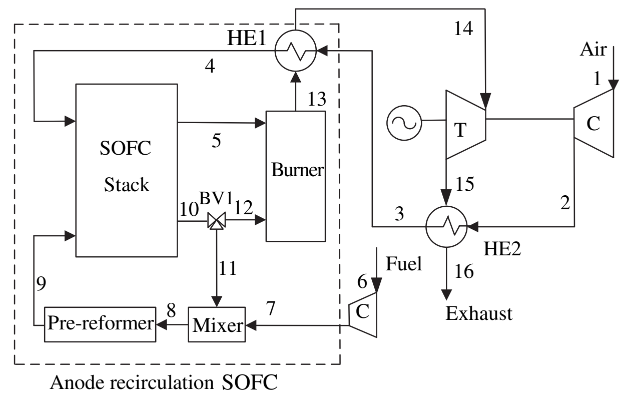

Fig. 1 – Structure diagram of SOFC/MGT hybrid power system.

- Fuel (stream 6) is pressurized by a fuel compressor up to the fuel cell operating pressure (stream 7), and then brought to the mixer to blend with the anode recirculation stream (stream 11) in order to support the steam reforming reaction in the pre-reformer and in the anode compartment of the fuel cell. The energy required to support the pre-reforming reaction is derived from the hot stream. The non-reacted fuel (stream 9) is involved in the internal reforming reaction within the anode compartment of the SOFC stack. Here, it is converted into the hydrogen that participates in the electrochemical reaction. The electrochemical reactions between the fuel and air in the fuel cell produce dc electricity and release thermal energy.
- The exhausted high temperature fuel from the SOFC anode (stream 12) is mixed with the depleted air coming from the SOFC cathode (stream 5) and combusted in the catalytic burner. The outlet flow temperature (stream 13) is then passed through heat exchanger1. The preheated gas (stream 14) is high enough to be used in the turbine.
- The mechanical power is produced by expansion of the high temperature gas in the turbine. This mechanical power rotates the GT shaft which is coupled to a synchronous generator to generate electricity.

3. Thermal physical model of SOFC/MGT hybrid power system

Certain assumptions are made in developing the dynamic model for the SOFC/MGT hybrid power system: (1) the fuel is only methane gas; (2) both air and fuel are assumed as the ideal gas, which makes them satisfy the ideal gas state equation. Other assumptions can be obtained from Refs. [11–13].

3.1. *Bypass valve, mixer and pre-reformer models*

In order to supply steam for the reforming process, a certain part of the anode exhaust gas must be recycled. The suction of the recycle stream and the mixing with the fresh fuel is performed by an ejector. High recycle flow rates at low pressure differences are typically achieved by subsonic mixing ejectors.