Available online at www.sciencedirect.com

SCIENCE DIRECT®

Energy Conversion and Management 47 (2006) 1032–1050

ENERGY CONVERSION & MANAGEMENT

www.elsevier.com/locate/enconman

Modeling and control of PEMFC based on least squares support vector machines

Xi Li *, Guang-yi Cao, Xin-jian Zhu

Institute of Fuel Cell, Shanghai Jiao Tong University, 156 Post Box, 1954, Huashan Road, Shanghai 200030, PR China

Received 14 June 2004; received in revised form 25 October 2004; accepted 29 April 2005
Available online 6 January 2006

Abstract

The proton exchange membrane fuel cell (PEMFC) is one of the most important power supplies. The operating temperature of the stack is an important controlled variable, which impacts the performance of the PEMFC. In order to improve the generating performance of the PEMFC, prolong its life and guarantee safety, credibility and low cost of the PEMFC system, it must be controlled efficiently. A nonlinear predictive control algorithm based on a least squares support vector machine (LS-SVM) model is presented for a family of complex systems with severe nonlinearity, such as the PEMFC, in this paper. The nonlinear off line model of the PEMFC is built by a LS-SVM model with radial basis function (RBF) kernel so as to implement nonlinear predictive control of the plant. During PEMFC operation, the off line model is linearized at each sampling instant, and the generalized predictive control (GPC) algorithm is applied to the predictive control of the plant. Experimental results demonstrate the effectiveness and advantages of this approach.

Keywords: Proton exchange membrane fuel cell; Operating temperature; Least squares support vector machines; Linearization; Generalized predictive control

* Corresponding author. Present address: Department of Control Science and Engineering, Huazhong University of Science and Technology, PR China. Tel.: +86 0276 353 4977.
E-mail address: lixi@mail.hust.edu.cn (X. Li).

0196-8904/$ - see front matter
doi:10.1016/j.enconman.2005.04.002

1. Introduction

The PEMFC is a clean energy source with high efficiency and a high technology subject that has been rapidly developed in many countries. In order to improve the generating performance of the PEMFC, prolong its life and guarantee safety, credibility and low cost of the PEMFC system, it must be controlled efficiently. For example: dehydration and aging of the electrolyte membrane are two primary factors that impact its life. The voltage characteristic and current density are the most important indices that are used to judge the performance of the PEMFC. However, the two points above are closely related to the operating temperature of the fuel cell (FC), which ranges from 50 to 100 °C. On the one hand, a temperature rise can improve the speed of the electrochemical reaction and transport speed of the protons in the electrolyte membrane. However, on the other hand, a temperature rise increases the water vapor partial pressure, which makes the transport effects of the reaction matter worse, lowers the thickness of the catalyzed layer reaction of the anode and cathode, impacts the fuel cell's performance greatly, makes the dehydration worse and worse and, moreover, shortens the life of the electrolyte membrane. Consequently, it is crucial for improving the performance and life of the fuel cell that the operating temperature be controlled in an appropriate range. The transfer function, the model of the PEMFC stack, must be established in order that the object can be controlled efficiently [7].

As we all know, accurate mathematical models must be established in traditional and modern control theory. However, according to analysis of the PEMFC system, the dynamics of the PEMFC system is a nonlinear system with multi-input and multi-output as well as multiple recycling gas flow loops, multiple phase flows and complex chemical and electrochemical reactions. It is very difficult to model the PEMFC system using the traditional methods. Over the last decade, many researchers all over the world have made great progress on PEMFC modeling to improve its performance and cost competitiveness with energy conversion devices currently available. Various mathematical models have been established in the research on the internal mechanisms, ranging from a one dimensional non-isothermal model to a three dimensional non-isothermal and non-isobaric model. These models describe distinctly internal microscopic characteristics, including gaseous diffusion, thermal conduction, liquid water transportation etc. [9–11], but their expressions are too complicated to be used in a control system, especially in the design of online control. Many kinds of static and dynamic resolution models have been established for different aspects that played important roles in analyzing and improving the performance of PEMFCs, but too many given assumptions and hypotheses lead to many limitations of these models [12–14]. Reports about controlling the temperature of the PEMFC stack are much less than those about thermal models. In Refs. [18,19], the temperature control is only mentioned and the thermal model and control strategy are not discussed. Because a stack consists of multi-cells and a mono-cell consists of different components, e.g. bipolar plates, membrane electrode assembly, many physical parameters of a stack are difficult to determine. Moreover, the thermal models, as shown later in this paper, are nonlinear models with uncertainty and disturbances such that a conventional controller can not obtain satisfactory control. By our knowledge, only a few publications discussed the control problem of a PEMFC stack. In Refs. [15–17], the authors considered the control problems of a PEMFC using conventional proportional integral derivative (PID) and fuzzy logic control, which are difficult to solve in nonlinear and complicated control problems. Consequently, a nonlinear model predictive control (NMPC) algorithm based on a least squares support