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ScienceDirect
Journal of Power Sources 160 (2006) 232–245
JOURNAL OF POWER SOURCES
www.elsevier.com/locate/jpowsour

Effects of parameter uncertainty on the performance variability of proton exchange membrane (PEM) fuel cells

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Received 4 December 2005; received in revised form 3 January 2006; accepted 5 January 2006
Available online 17 February 2006

Abstract

Operation of fuel cells is subject to inherent uncertainty in various material and operating parameters, which causes performance variability and impacts the reliability of the cells. Analysis of the interactive effects of parameter uncertainty on the fuel cell performance is imperative in a robust design endeavor. To this end, a methodology for simulation of fuel cell operation under uncertainty is presented by considering a one-dimensional nonisothermal description of the governing physical phenomena. A sampling-based stochastic model is developed, and parametric analysis is presented to elucidate the effects of uncertainty in several operating parameters on the variability of power density of the fuel cell. Robust design maps are derived from the analysis which provide for selection of cell temperature and anode and cathode pressures as functions of the input parameter uncertainty and target maximum acceptable variability in the power density.

Keywords: Proton exchange membrane (PEM) fuel cell; Stochastic analysis; Design under uncertainty

1. Introduction

Power sources consisting of proton exchange membrane (PEM) fuel cells offer the advantages of low operating temperature and pressure, quick start-up, and pollution-free operation [1]. The overall cell performance is governed by the critical issues of water and thermal management [2–7]. Extensive studies on modeling and computer simulation of PEM fuel cells have been developed towards improved water and thermal management through better understanding the transport and electrochemical processes. Bernardi and Verbrugge [8,9], Springer et al. [10,11], Baschuk and Li [12], and Rowe and Li [13] developed one-dimensional models for steady state operation of fuel cells, assuming perfect membrane hydration. Amphlett et al. [14,15] studied the transient response of a fuel cell stack by performing a global heat and mass balance analysis, and the details of electrochemical phenomena inside the cell were ignored. Two-dimensional modeling of transport phenomena in PEM fuel cells was presented by Gurau et al. [16], Um et al. [17], Wang et al. [18], You and Liu [19] and You [20], where two-phase flows in the fuel cell systems were also discussed. Mishra et al. [21] reported theoretical and experimental study on the effects of different gas diffusion layer materials and contact pressure on the electrical contact resistance. A methodology for model-based design based on a one-dimensional nonisothermal model was presented by Mishra et al. [22], in which the optimum operating and design parameters were identified using a comprehensive parametric analysis on the various physical and electrochemical phenomena. Mawardi et al. [23] extended this analysis to provide an optimization framework to derive more general optimum solutions.

The application of cell level models to predicting the fuel cell performance is based on the assumption that the parameters representing the physical and electrochemical phenomena, and the material properties of the fuel cell are deterministic. It must be realized that significant uncertainty is inherent in such parameters [24,25], arising from sources such as operating parameter fluctuations, inaccuracies in process control, empirical determination of the electrochemical model parameters, and environmental uncertainties. Operating parameters such as cell temperature, anode and cathode pressures, relative humidity, reactants stoichiometry, and dry gas mole fractions

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doi:10.1016/j.jpowsour.2006.01.017