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Design and Performance Evaluation of an Explicit Parametric Controller for a Solid Oxide Fuel Cell (SOFC) System: A Comparative Study

Dimitrios I. Gerogiorgis,[a] Konstantinos I. Kouramas,[a] Nikos Bozinis,[b] Efstratios N. Pistikopoulos[a,b]

[a]*Centre for Process Systems Engineering (CPSE), Imperial College London, South Kensington, London SW7 2AZ, UK*
[b]*Parametric Optimization Solutions (ParOS), 1 Hammersmith Grove, London, W6 0NB, UK*

1. Summary

This paper addresses the design and performance evaluation of an *explicit parametric controller* or ParOS controller for a Solid Oxide Fuel Cell (SOFC) system, which ensures that output voltage is provided at the desired values in the presence of current load fluctuations. Dynamic simulation based model identification and reduction is used to build an approximate but accurate and computationally manageable mathematical description (input-output ARX model). A model predictive control (MPC) problem is formulated that minimizes the voltage tracking error and control effort and satisfies the underlying operational constraints, and the problem is solved off-line by parametric optimization techniques to obtain the explicit parametric controller for the SOFC system. The performance of the controller is evaluated via dynamic simulation of the closed-loop system and for a variety of current load changes.

Keywords: solid oxide fuel cells, model predictive control, explicit parametric controllers

2. Extended Abstract

Fuel cell power systems have exceptional potential and applications for both stationary and mobile applications, due to their outstanding energy efficiency and environmental characteristics. Their heterogeneous nature gives rise to challenging modelling, simulation and design problems, which are further complicated by the many technology variations (SOFC, PEMFC, alkali, etc.) as well as by the multiscale nature of simultaneous physicochemical and electrical phenomena. Because fuel cells need be studied as mechanical, chemical, thermal as well as electrical systems, the system-level modelling and control goals pose great challenges to the scientific community. These challenges are further perplexed by numerical as well as model configuration management issues; moreover, rigorous PDE models are unreasonably enormous for online control purposes.

Model Predictive Control (MPC, Morari and Lee, 1999) has been widely adopted by industry to address multivariable problems with input and output constraints, based on a receding horizon philosophy and using online computation of a series of future control steps, with implementation of only the first one and re-calculation of the optimal control action profile at every time step. The fundamental principle for online MPC is that computation of the control action at each time step is reasonably faster than the intrinsic timescale of the process, or else control is problematic. Consequently, online MPC is infeasible when unmanageable models are needed for accuracy, as there is not enough time available between sampling instances to solve the optimization problem.

Control of fuel cell power systems is a challenging objective, due to the highly nonlinear and complex dynamics (heat transfer and fluid flow) and the varying operating conditions of these processes (Papadias and Chmielewski, 2005). The control objective in fuel cells is often to ensure the tight tracking of a desired FC temperature profile, despite the possible perturbations of the nominal operating conditions. The problem has already been treated with the use of a variety of classical control methods; however, the research on process systems is steadily focusing on the exploitation of advanced control methods such as Model Predictive Control (MPC) that can guarantee optimal performance, constraint satisfaction and robustness. To the best of our knowledge, there are no works of MPC implementation for fuel cell power systems. Nonetheless, Stefanopoulou and co-workers have developed observer-based static (sFF) and dynamic (dFF) feedforward controllers for fuel cell systems (Varigonda et al., 2003; Pukrushpan et al., 2004). Furthermore, feedback controllers have been developed for fuel cell power systems, relying on First-Order Plus Dead-Time (FOPDT) transfer functions.

The MPC problem for fuel cell control is still a critical issue that can offer important benefits, especially inasmuch as physical embedding of the controller in the power system is concerned. Explicit parametric or ParOS controllers is a novel, well-established control method which has the ability to perform all the MPC computations off-line, thus reducing control action computations to simple function evaluations (Bemporad et al., 2002; Pistikopoulos et al., 2002).

This paper addresses the development of a parametric controller for a Solid Oxide Fuel Cell (SOFC) system, and the investigation of its performance. Parametric control of the SOFC system temperature is achieved via formulating an online optimization problem, which relies on offline computation, determination and storage of (a) the subregions of the parameter space over which different control action laws apply, (b) the explicit control action function for each of the aforementioned subregions. Previously validated, mathematically rigorous SOFC models which have been extensively used for dynamic simulation and form the basis for the controller design problem; model identification and reduction methodologies (ARX) are employed in order to obtain a numerically accurate but also computationally manageable description of the highly complex and nonlinear SOFC system. The problem addressed focuses on temperature control via suitable manipulation of the fuel and oxidant flowrates, and use of the produced voltage signal. The open- and closed-loop simulation results are evaluated and compared for a range of operation conditions.

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