Model-based Control of Fuel Cells: Optimal Efficiency

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Extended Abstract

Fuel cells have generated enormous interest as alternatives to standard internal combustion engines for stationary as well as for mobile applications, because of their potential for high efficiency as well as the promise of alternative energy sources. Numerous research groups from many scientific and engineering disciplines are investigating various aspects including the materials and configuration of the electrodes and membrane, fuel sources, modelling, and the costs involved in the manufacture of fuel cells and the “hydrogen economy”.

To date, stack dynamics and control have not received full attention, with most attempts to control fuel cell stacks being rudimentary at best, relying on simple models and control schemes. Fuel cell models of different complexity have been proposed, describing the performance of fuel cells under an array of conditions (e.g., Costamagna, 2001, Yi and Nguyen, 1998). These models are then used to evaluate optimal schemes of external heating, humidification and fuel composition, generally from steady-state considerations alone (Fuller and Newman, 1993). However, the dynamic response of fuel cells is important for vehicular applications, since the power demands fluctuate, and thus the optimal steady-state operation conditions do not exist. Amphlett et al (1996) presents an empirical time-dependent model for a fuel cell stack. This model assumes uniform conditions spatially and links the dynamics of the system to the dynamics of the solid temperature. However, an empirical model is only useful for a given system under specific conditions. Moreover, it is of limited use as a research tool since it offers no insight and understanding of the process. Pukrushpan et al (2002) introduce a single-input-single-output method using a simple model and Kang et al (2001) use traditional linear control methods using first degree transfer functions as models. However, linear controllers will only provide adequate regulation for a relatively small range of operating conditions.

The relevant control issue is how to control the fuel cell to ensure acceptable response time for fluctuating power demands, while at the same time maximizing its fuel efficiency. To address this, we have described a model-based controller for the regulation of a proton exchange membrane (PEM) fuel cell stack, focusing on the crucial issue of how to control the stack to ensure stability and acceptable response time for the power demand over the entire operating range. A model accounting for spatial dependencies of voltage, current, material flows, and temperatures in the fuel channel has been developed, and was presented in last year’s AIChE Annual Meeting (Golbert and Lewin, 2004). Results show improved performance and robustness when using model-based control in comparison with that obtained using an adaptive controller. This controller has also been used to improve overall efficiency of a fuel cell operating under dynamic conditions. As will be demonstrated in our presentation, since the controller manipulates a number of manipulated variables, it takes advantage of all of the degrees of freedom to simultaneously satisfy power demands while optimizing the fuel efficiency of the entire system.

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