OPTIMAL STATE-FEEDBACK REGULATION OF THE HYDROGEN EVOLUTION REACTIONS

V. COSTANZA†

†INTEC (UNL-CONICET), Nonlinear Systems Group
Güemes 3450, S3000GLN Santa Fe, Argentina
FAX: +54(342)455.0944 - E-mail: tsinoli@ceride.gov.ar

Abstract—A control strategy is developed in order to keep processes based on the hydrogen evolution reactions (HER) near operational steady states. The problem is treated in the context of Optimal Control for nonlinear systems subject to quadratic cost objectives. The original dynamics is shown to be accurately approximated by a bilinear model without increasing the dimension, so the state variables retain their physical meaning. Finite and infinite horizon optimal control strategies are developed, based on the Hamiltonian formalism, and introducing a novel approach for working on-line with generalized Riccati differential equations and the associated costate dynamics. When there exists a final penalty on the state deviation, then a first order quasi-linear partial differential equation is discovered and solved for the Riccati matrix. The observability problem is also treated, since the natural state (electrode surface coverage) can not be measured continuously. The output variable (current density) is fed into a high-gain nonlinear observer based on Lyapunov’s stability considerations. The whole approach allows for (in general time-dependent) state-feedback control.

Keywords—Optimal Control, Nonlinear Processes, Electrochemistry, Hydrogen Evolution Reaction, Hydrogen Technology.

I. INTRODUCTION

Hydrogen Evolution Reactions (HER) refer to the kinetics of most electrochemical processes where hydrogen is produced or consumed. Hydrogen production is becoming increasingly relevant in the industrial world due to the recurrent crisis in oil prices, the international pressure to mitigate global warming, and the high rate of depletion of other natural fuels. A sufficiently general formulation of HER include the Volmer-Heyrovsky-Tafel (VHT) model studied below and described in Section 2. Since these reactions usually evolve on the surface of metallic electrodes, abundant empirical work has been carried out to determine kinetic parameters for different cathodes (Ni, Pt, Pd, Co3O4) and environments (acidic or alkaline solutions) (see Harrington and Conway, 1987). But also, as new applications of clean technologies are announced, interest is growing in the design, operation, and optimization of industrial devices based on HER systems, such as fuel cells, batteries (Vincent and Scrosati, 1997), H2-decontamination and corrosion prevention processes for heavy metals (Al-Faqeer and Pickering, 2001), and cold nuclear fusion (Green and Britz, 1996; Yang and Pyun, 1998). The control of fuel cells operation has received special attention for non-isothermal proton exchange membrane prototypes (Golbert and Lewin, 2004; and the references therein), where the modeling aspects include pressure, heat, and mass transfer balances, so the problem takes a qualitatively different form. However, for conventional types of fuel cells with metallic electrodes where isothermal conditions are approximately maintained, the kinetics of set-point changes and steady-state operation instill HER-VHT equations as the main object governing the process.

The dynamics of HER systems are irreducibly nonlinear. This is confirmed by the detection of solution trajectories whose characteristics are only possible for nonlinear systems (in fact, oscillatory behavior in reaction systems have appeared early and frequently in the electrochemical context; see the extensive review by Hudson and Tsotsis, 1994). Simulations and experiments have also shown hysteresis-like cyclic behaviors (Costanza et al., 2003), bistability (see Costanza, 2005), strange attractors and chaos (Green et al., 2000). These somehow unexpected results shed light on the theory of adsorption mechanisms, spatial-temporal patterns of catalytic electrodes, and related physical problems. Closer to the traditional control point of view, some parameter variation strategies have been developed to avoid or to cope with nonlinear complexities in electrochemical systems (see for instance Kiss et al., 1997; Parmananda et al., 1999), with the main objective to make safe the operation of emerging industrial applications. The optimal control of set-point changes for HER equations with fixed parameter values and power-spending restrictions has