Sliding Mode Control for Uncertain Thermal SOFC Models with Physical Actuator Constraints

Thomas Dötschel[1], Ekaterina Auer[2], Andreas Rauh[1], and Harald Aschemann[1]

[1]Chair of Mechatronics
University of Rostock
D-18059 Rostock, Germany
{Thomas.Doetschel,Andreas.Rauh,Harald.Aschemann}@uni-rostock.de

[2]Faculty of Engineering, INKO
University of Duisburg-Essen
D-47048 Duisburg, Germany
Auer@inf.uni-due.de

Abstract

Mathematical models for the dynamics of high-temperature Solid Oxide Fuel Cells (SOFCs) can be subdivided into thermal, fluidic, and electro-chemical system components. For the purpose of automatic control design of such systems, it is especially important to focus on the thermal subsystem. This results from the fact that high operating temperatures are advantageous for the efficiency of SOFCs. Moreover, high operating temperatures are necessary to enable the conductivity of oxygen ions through the electrolyte [1]. Typically, thermal models for SOFCs are characterized by their instationarity, where three different operating phases can be distinguished.

Firstly, the heating phase is characterized by a transient process which starts at the thermodynamic equilibrium and leads the SOFC stack module to its high-temperature operating point. Secondly, variable electrical loads influence the thermal behavior of the SOFC during its usual operating mode. Thirdly, again an instationary cooling process takes place during the shutdown phase of the system.

In this contribution, a model-based robust control law is derived with the focus on the rejection of disturbances in the standard operating point of SOFCs. For that purpose, a mathematical model is derived for the thermal behavior of the stack module on the basis of the first law of thermodynamics. To approximate the spatial temperature distribution in the interior of the stack module, a semi-discretization scheme is applied to determine a finite volume representation in terms of a set of nonlinear coupled ordinary differential equations (ODEs). In [3] and [4], interval-based global optimization routines accounting for an imperfect system knowledge were introduced for the identification of the parameters of these ODEs. These methods start with an initial guess for a parameter range, in which the a-priori unknown parameters are guaranteed to be included. Then, a bisection scheme is employed to determine feasible enclosures for the parameter ranges which are consistent with both the semi-discretized system model and the measured data.

These parameter intervals are treated as uncertainties for which a robust control law has to be determined. In this presentation, interval methods are used for the derivation of guaranteed stabilizing control procedures on the basis of suitable Lyapunov functions making use of the sliding mode control approach. In [2], a first attempt has been published for the design of such controllers under consideration of interval parameters representing a limited system knowledge as well as the effects of disturbances. In SOFC systems, the enthalpy flow of the cathode gas is provided as a control input for the thermal behavior. This enthalpy flow can be adapted by both manipulating the air mass flow and the temperature difference between the supplied air in the preheating unit and in the inlet elements of the fuel cell stack module. If the above-mentioned sliding mode control procedure is employed to determine the enthalpy flow, further physical restrictions have to be accounted for which result from the admissible operating ranges of both the valve for the air mass flow and the temperature of the preheating unit. Moreover, the variation rate of the temperature difference between the preheating unit and the stack module's inlet elements has to be restricted to prevent damages due to thermal stress. These feasibility constraints are taken into account in terms of an appropriate cost function which is evaluated along with the design criteria for the guaranteed stabilizing interval-based sliding mode control law.

Results for the interval-based verified parameter identification of the SOFC test rig available at the Chair of Mechatronics at the University of Rostock and simulation results for the above-mentioned control approach conclude the presentation, along with an outlook on our future research.

References

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