EFC23 European Fuel Cells and Hydrogen
PIERO LUNGHI CONFERENCE
September 13th-15th 2023
Capri / Italy

State-of-Health Observer for Polymer Electrolyte Membrane Fuel Cells

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Keywords: degradation, Kalman filter, polymer electrolyte membrane fuel cell, state-of-health

Abstract: The polymer electrolyte membrane fuel cell (PEMFC) is a promising candidate for sustainable mobile applications but is prone to degradation. State-of-health observers assist in extending the lifetime by enabling online diagnosis. This work introduces a novel state-of-health observer simultaneously estimating the PEMFC gas composition (for degradation diagnosis) and a degradation-related time-varying parameter (to assess the state of health). It is based on an extended Kalman filter, and the modeling basis is a control-oriented PEMFC model. The validation is conducted via simulation where artificial degradation is considered, and the excellent estimation results of oxygen mass and ohmic membrane resistance are shown.

Introduction: The PEMFC has good prospects for replacing internal combustion engines in mobile applications. However, the challenge of its limited lifetime (e.g., carbon corrosion due to fuel starvation) has to be resolved for increased market penetration. Here, observers assist in resolving the challenge by enabling online diagnosis (e.g., gas composition estimation). Observers simultaneously estimating the current state of health and the internal gas composition for degradation diagnosis of PEMFCs have not been reported in the literature. This paper presents a state-of-health observer based on a control-oriented PEMFC stack model [1] to bridge this knowledge gap. The observer is based on an extended Kalman filter algorithm [2], and it simultaneously estimates the PEMFC gas composition and a degradation-related time-varying parameter (bulk membrane ohmic contact resistance). The validation is conducted in a simulation study, and the estimation results for the oxygen mass ($MSE = 4 \cdot 10^{-12}$) and the membrane resistance ($MSE = 4 \cdot 10^{-6}$) are shown. The estimation performance is excellent, which serves as the basis for experimental validation.

Fuel Cell Model: The modeling basis [1] is a zero-dimensional control-oriented PEMFC stack model derived from a 30 kW system test stand. This model is beneficial because it is modeled in a physically motivated way to obtain meaningful internal states, and the concentration modeling is experimentally validated. The model has nine states (four masses each in the cathode and the anode, membrane water activity), ten inputs (current, temperature, two pressures, two relative humidities, two valve positions, mass flow, power), and five outputs (stack voltage, three pressures, mass flow).

State-of-Health Observer: The designed observer is based on [2], an extended Kalman filter algorithm for nonlinear systems. Compared to the standard setting of state estimation, the model state vector is extended with the observed time-varying parameters to estimate them simultaneously. So, changes in degradation-related parameters, which affect the outputs, allow conclusions about the system's state of health. These parameters are modeled as integrated white noise.

Results: The designed observer is validated in simulation, and the used excitation signal is a chirp current signal, as given in [1]. The signal is repeated many times to reach an overall experiment length of 100 h, and an increasing trend is artificially implemented to the bulk membrane ohmic contact resistance to demonstrate degradation. Gaussian noise is added to the simulated outputs, serving as the observer's "measured" input, which provides degradation and gas composition information from the "reality." Only the estimation of the cathode oxygen mass and the resistance are shown in Fig. 1 to keep this work concise. The assumed real signals are thick, and the estimated counterparts are thin. In Fig. 1a, the observer corrects the wrong initializations within seconds, and in Fig. 1b, the estimation follows the increasing trend of the resistance over many hours, indicating degradation.

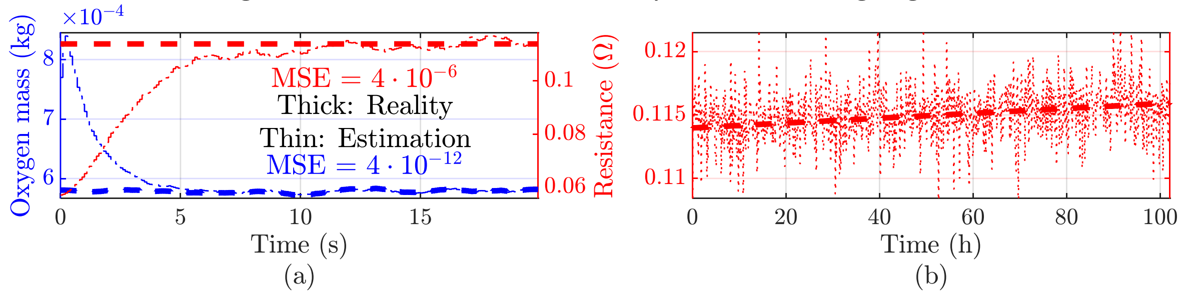

Fig. 1: Estimation results of cathode oxygen and bulk membrane contact resistance. MSE is based on the 100 h experiment.

Conclusions: A state-of-health observer was developed based on a control-oriented PEMFC model, which simultaneously estimates gas composition and degradation. It is validated via simulation, and the result is promising to pursue the research in this direction. The following steps are a more in-depth results analysis and a validation with real experimental data.

Acknowledgment: This project is supported with funds from the Climate and Energy Fund and implemented in line with the "Zero Emission Mobility" programme (grant number 878123). The research was partially funded by the CD Laboratory for Innovative Control and Monitoring of Automotive Powertrain Systems.

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