SJSU SAN JOSÉ STATE UNIVERSITY

CALIFORNIA STATE UNIVERSITY LONG BEACH

Fuel Cell System Development for Heavy Duty Vehicles

Project 2441
April 2025

Yu Yang, PhD   Hen-Geul Yeh, PhD   Bryan Aguirre

Introduction

In California's efforts to combat climate change through electrification, hydrogen fuel cells have emerged as a promising solution for reducing carbon emissions and dependence on fossil fuels, especially in the high-polluting heavy-duty transportation sector. One type, Proton Exchange Membrane Fuel Cells (PEMFCs), stand out due to their low operating temperatures, compact design, and high-power density. However, optimizing their performance requires accurate modeling and control strategies due to critical safety concerns. This research focuses on developing efficient models for PEMFC subsystems-humidification, cooling, and oxygen supply using closed loop system identification techniques to support the integration of fuel cell systems into vehicles and power supply. The goal is to design an approach to effectively capture system dynamics while ensuring safe and stable operations. This study used MATLAB/Simulink simulations to test various transfer function models to identify the best fit for each subsystem. The proposed approach can construct system models while requiring minimal prior knowledge, enabling real-time implementation, and ensuring non-disturbed operations.

Study Methods

The study builds data-driven models for key components such as humidifier, cooling, and oxygen supplier using a closed-loop system identification technique based on the operational data from a well-established PEMFC system in Simulink. To effectively and safely understand how these components work together, the study uses closed-loop identification that employs a proportional (P) controller and a pseudo-random binary sequence (PRBS) as the setpoint excitation. This helps us capture how input and output relate to each other. The system behavior can be represented by different structures, such as first-order, second-order, first-order plus time delay, and second-order plus time delay transfer functions. We derive their closed-loop form mathematically and utilize a system identification toolbox to estimate gain, time constant, damping coefficient, and time delay, respectively. The best model with the highest fit to the historical data is then identified.

Findings

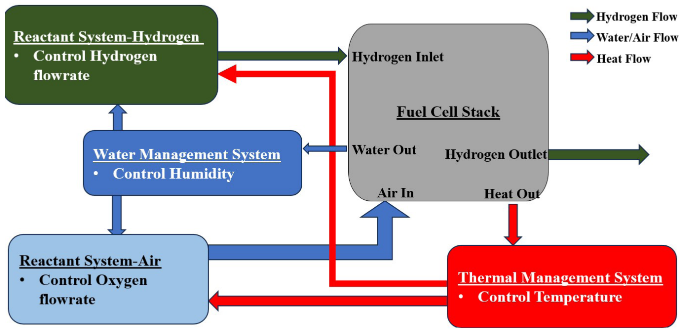
Through a simulation study, we build a closed-loop identification approach for fuel cell input output modeling. Our results show that:

- Closed-loop identification proves particularly effective for the hydrogen-powered fuel cell system modeling with critical safety concerns.
- First-order, first-order plus time delay, second-order, and second-order plus time delay transfer functions are sufficiently accurate to model the subcomponents (humidifier, cooling, and oxygen supplier) of a fuel cell system. Users may choose a proper model based on the best fits to the testing data.
- Data collected during vehicle start-up processes are highly valuable for modeling subcomponents.

Closed-loop identification constructs transfer function models to assist the fuel cell operations safely and effectively, which supports sustainability goals by potentially advancing the electrification of polluting heavy-duty vehicles.

Policy Recommendations

The research team recommends integrating closed-loop identification techniques into the fuel cell management system for real-time modeling of each subcomponent for fuel cells during the operations. The resulting model can be used for model-based regulator tuning, fault detection, and energy optimization. The integration of closed-loop identification techniques will enable continuous monitoring and adjustment to ensure that the system responds optimally to changing conditions. This approach can enhance system reliability by identifying potential faults early, reducing downtime and maintenance costs, and contributing to the overall efficiency of fuel cell operations. Ultimately, improving the performance and reliability of fuel cell systems is crucial for accelerating the transition to sustainable, zero-emission transportation, supporting broader efforts in the electrification and decarbonization of the transportation sector. Optimizing fuel cell technologies can help the state meet ambitious environmental goals and move closer to a fully sustainable energy future.



About the Authors

Dr. Yu Yang is an Assistant Professor at California State University, Long Beach (CSULB). His research interests include the data-driven modeling, advanced process control, machine learning, and global optimization under uncertainty.

Dr. Hen-Geul Yeh is a professor at CSULB. His research interests include communication systems, smart grids, optimization, controls, and electrical event detection, with focus on real-time Digital Signal Processing.

Bryan Aguirre holds a B.S. in Biochemistry from California State University, Los Angeles (CSULA) and earned an M.S. in Chemical Engineering from CSULB.

To Learn More

For more details about the study, download the full report at transweb.sjsu.edu/research/2441

MTI MINETA TRANSPORTATION INSTITUTE

MTI is a University Transportation Center sponsored by the U.S. Department of Transportation's Office of the Assistant Secretary for Research and Technology and by Caltrans. The Institute is located within San José State University's Lucas Graduate School of Business.