PhD Topic: "Hybrid LPV-Learning Framework for Fault Diagnosis and Fault-Tolerant Control of PEM Fuel Cell Systems"

We offer a fully-funded joint PhD position between the Université Polytechnique Hauts-de-France (France) and the Federal University of Amazonas (Brazil). The PhD degree of the successful candidate will be awarded by both partner universities.

Supervision team

- Prof. Sébastien Delprat and Dr. Anh-Tu Nguyen, Laboratory LAMIH-CNRS UMR 8201, INSA Hauts-de-France and University Polytechnique Hauts-de-France (UPHF), Valenciennes, France
- Dr. Iury Bessa, Federal University of Amazonas (UFAM), Manaus, Brazil

Locations
1.5 years at UFAM (Manaus, Brazil) and 1.5 years at LAMIH-UPHF (Valenciennes, France).

Application deadline: 10th January, 2026.

Expected starting date: April, 2026.

I. Context and motivation

Proton Exchange Membrane Fuel Cell (PEMFC) systems are among the most promising technologies for clean power generation in transportation, stationary backup power, and portable applications. However, their complex, strongly coupled multi-physics nature, involving electrochemical reactions, two-phase flow, heat transfer, water management, and gas transport phenomena, makes safe, efficient, and durable operation extremely challenging under highly variable load profiles. Traditional control and monitoring strategies, typically designed around decoupled or locally linearized subsystems, fail to guarantee robust performance and durability in real-world conditions. Strong nonlinear interactions exist between the air-supply (cathode pressure and oxygen excess ratio controlled via compressor and back-pressure valve), thermal management (stack temperature), and hydration management (membrane water content). For example, aggressive compressor action can dry out the membrane, while excessive humidification can lead to cathode flooding and oxygen starvation, both potentially catastrophic faults. There is therefore a critical need for advanced nonlinear observation and control frameworks capable of (i) accurately estimating unmeasurable states and detecting incipient faults (flooding, drying, sensor/actuator failures), and (ii) reconfiguring control actions in real time to maintain safe oxygen stoichiometry, adequate hydration, and thermal balance despite partial model knowledge and faulty conditions.

II. Objectives of the PhD project

The PhD project aims to develop a resilient, data-efficient framework for modeling, fault detection & isolation (FDI), and fault-tolerant control (FTC) of PEMFC systems. The approach explicitly combines model-based Linear Parameter-Varying (LPV) techniques with lightweight learning-based corrections to achieve high performance and robustness without requiring large offline training datasets or long training phases. This resilient control and diagnosis problem is particularly challenging because of (i) the highly nonlinear, multi-time-scale, and parameter-varying dynamics of PEMFC systems, (ii) significant modelling uncertainties (aging, manufacturing dispersion, two-phase phenomena), and (iii) the stringent real-time constraints of embedded fuel-cell control units. The project addresses the following interconnected scientific challenges.

- **Challenge 1 – Hybrid data-efficient modelling**: Develop a hybrid LPV modeling framework that augments a physically structured, nominal LPV model of the PEMFC air-supply, thermal, and hydration subsystems with lightweight learning-based uncertainty terms, preserving computational tractability while drastically improving predictive accuracy.
- **Challenge 2 – Joint state-and-fault estimation & FDI**: Design estimation algorithms capable of simultaneously estimating unmeasurable states (e.g., membrane water content, liquid water saturation, partial pressures), actuator/sensor faults (compressor failure, pressure-sensor drift, flooding/drying), and unknown disturbances (load transients, humidity variations) with formal convergence guarantees.
- **Challenge 3 – Fault-tolerant control**: Develop an integrated LPV fault-tolerant control architecture that exploits the estimates from Challenge 2 to maintain safe operation (adequate oxygen excess ratio and hydration, thermal limits) under faulty and uncertain conditions, using reconfiguration or accommodation strategies with minimal performance degradation.
- **Challenge 4 – Experimental validation**: Validate the complete framework on real time hardware in loop simulations with OPAL-RT at UFAM and on a high-fidelity PEMFC test bench available at LAMIH-CNRS laboratory.

III. Scientific methodology

The core methodological contribution is a real-time-capable design framework for observer-based FDI and FTC of PEMFC systems with partially unknown dynamics. A control-oriented quasi-LPV model of the PEMFC system will serve as the nominal scheduled model. To handle strong nonlinearities and unmodelled phenomena (two-phase flow, spatial effects, degradation), the nominal LPV model will be augmented with a learned uncertainty term. Two complementary lightweight learning strategies will be investigated to identify this uncertainty term with minimal data requirements.

1. **Physics-informed supervised learning** on short experimental or high-fidelity simulation datasets (Nguyen et al., 2023; Tian et al., 2025).
2. **Online adaptive neural networks with very few trainable parameters** whose weights are updated in real time using onboard measurements, inspired by adaptive disturbance rejection ideas (Zhao et al., 2021; Chen et al., 2023).

The resulting augmented LPV representation enables the use of powerful LPV synthesis tools. Unknown-input LPV observers and adaptive threshold schemes will then be designed for simultaneous state and fault estimation, yielding rapid and reliable FDI for typical PEMFC faults (flooding, membrane drying, compressor surge/stall, sensor bias). Finally, the estimation/FDI module will feed an LPV gain-scheduled fault-tolerant controller (e.g., virtual-actuator/sensor or predictive reconfiguration) that guarantees stability and performance using Lyapunov-based quadratic or parameter-dependent Lyapunov functions. Theoretical stability and performance proofs will be derived using convex LMI conditions. The complete framework will be implemented in MATLAB/Simulink and deployed on a dSPACE MicroAutoBox for real-time validation on a PEMFC test bench under aggressive load transients and artificially induced faults.

Figure: Hybrid fuel cell test bench at LAMIH-CNRS (Left : fuel cell system. Center: battery pack. Right: schematic).

Main requirements

- Master degree or equivalent in control theory, applied mathematics or related fields
- Excellent background in automatic control and excellent programming skills
- Fluency in English is required (French and/or Portuguese is not necessary). Some knowledge on machine learning or related fields, and real-time experimentations would be a plus.

If you are interested in this opportunity, please send us (iurybessa@ufam.edu.br, sdelprat@uphf.fr and tnguyen@uphf.fr) an email with

- Your detailed CV, including contact details of two academic referees
- Your academic transcripts and any relevant supporting documents (e.g., publications, awards)
- A brief cover letter explaining your interest in the research topic and how your skills and experience contribute to the PhD project

Some suggested references

Bessa, I., Puig, V., & Palhares, R. M. (2023). Reconfiguration blocks and fault hiding: Design, applications, and challenges. Annual Reviews in Control, 56, 100896. https://doi.org/10.1016/j.arcontrol.2023.05.001

Nguyen, C., **Nguyen, A.-T.**, & **Delprat, S.** (2023). Neural-network-based fuzzy observer with data-driven uncertainty identification for vehicle dynamics estimation under extreme driving conditions: Theory and experimental results. *IEEE Transactions on Vehicular Technology*, *72*(7), 8686-8696.

Pukrushpan, J., Stefanopoulou, A., & Peng, H. (2004). *Control of Fuel Cell Power Systems: Principles, Modeling, Analysis and Feedback Design*. Springer Science & Business Media.

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Xu, K., Chen, D., Mao, Z., Ding, Y., Hu, S., Xu, X., & Pei, P. (2025). Comprehensive review of proton exchange membrane fuel cell air supply system: Configuration, modeling, and control. *Journal of Power Sources*, *659*, 238396.

Zhang, X., Zhang, C., Zhang, Z., Gao, S., & Li, H. (2024). Coordinated management of oxygen excess ratio and cathode pressure for PEMFC based on synthesis variable-gain robust predictive control. *Applied Energy*, *367*, 123415.