POLITECNICO MILANO 1863 | DIPARTIMENTO DI ENERGIA

UGA Université Grenoble Alpes

RESEARCH THESIS ON:

DESIGN OF AN ENERGY MANAGEMENT STRATEGY FOR THE RELIABLE AND EFFICIENT OPERATION OF FUEL CELL SYSTEMS USED IN HEAVY-DUTY VEHICLES

CONTEXT OF THE RESEARCH

The adoption of battery-electric systems for heavy-duty applications, such as trucks, buses, trains, maritime vessels and aircrafts, can significantly contribute to reducing greenhouse gas emissions in the transportation sector. However, this transition is severely constrained by excessive battery weight and challenging charging requirements. To address these issues, research efforts are focusing on hydrogen fuel cell technologies, specifically Proton Exchange Membrane Fuel Cell stacks (PEMFCs), which seem to offer a viable alternative. Nevertheless, widespread commercial deployment remains hindered by high system costs and limited durability. Achieving a guaranteed operational PEMFC lifetime of 25,000 hours across varying operating conditions has become a primary benchmark for economic viability. Accordingly, current research is considering the possibility of reducing PEMFC degradation by optimizing the power demand profile using a multi-stack fuel cell (MFC) architecture. Specifically, in an MFC, an Energy Management Strategy (EMS) distributes the load across several independent, lower-power fuel cell units. While traditional EMS algorithms focus on maximizing overall system efficiency and minimizing fuel consumption, PEMFC health-aware EMS approaches are now emerging. These strategies aim to extend the fuel cell lifetime by incorporating degradation modeling, State of Health (SoH) monitoring and Remaining Useful Life (RUL) predictions.

OBJECTIVES OF THE RESEARCH

In this context, the final objective of the thesis is to develop an EMS for PEMFC capable of simultaneously maximizing system efficiency, and minimizing fuel consumption and degradation. This requires bridging the gap between: degradation assessment and failure prognostics, on one side, and EMS design on the other side. The thesis work will build on previous research [1] in which a load-dependent model of fuel cell degradation was used to estimate the RUL in an EMS, and on a Matlab/Simulink simulator of a fuel cell vehicle [2]. The thesis will be structured into the following phases:

- *Literature Review*: Analysis of fuel cell degradation and health-aware energy management for hydrogen vehicles;
- *Problem Formulation:* Definition of the EMS optimization problem for a multi-stack fuel cell system including both reliability and operational objectives;
- *Degradation model:* Identification of a Health Index (HI) and a degradation model that effectively capture the impact of dynamic loads on the degradation of a fuel cell,
- *Prognostic modeling:* Development of a prognostic model to predict the RUL of a fuel cell and quantify the associated prediction uncertainty.
- *EMS strategy:* Design of the method to optimize load distribution across the fuel cell stacks for health-aware EMS strategy.
- *Validation:* Evaluation of the performance of the proposed approach across various operative scenarios (e.g. varying number of cells, different load cycles [3]), and benchmarking against reference EMS strategies.

Required Skills

Coding skills in MATLAB/python and good practices.
Technical communication skills in English.
Familiarity with reliability prognostic, reliability and optimization approaches will be appreciated. Knowledge on fuel cell technology is a plus.

Research Team

For further information and details about this thesis, please contact:

- **Prof. Catherine Cadet,** catherine.cadet@univ-grenoble-alpes.fr
- **Prof. Piero Baraldi,** piero.baraldi@polimi.it
- **Dr. Juan-Pablo Futalef,** juanpablo.futalef@polimi.it
- **Prof. Enrico Zio,** enrico.zio@polimi.it

References

[1] M. Houjayrie, C. Cadet, C. Bérenguer. Prognostic and Energy Management for Multi-Stack Fuel Cell Systems with Stochastic Non-Homogeneous Degradation. *ESREL SRA-E 2025 - 35th European Safety and Reliability & 33rd Society for Risk Analysis Europe Conference*, June 2025, Stavanger, Norway. pp.1530-1537, ⟨10.3850/978-981-94-3281-3_ESREL-SRA-E2025-P7472-cd⟩. ⟨hal-05279594⟩.

[2] Build Fuel Cell Electric Vehicle - MATLAB & Simulink

[3] Generate Drive Cycles for Real Driving Emissions - MATLAB & Simulink