Mise en place de diagnostics/pronostics pour la gestion de l'état de santé, la maintenance et l'optimisation des performances des stacks à oxyde solide utilisés par les modules d'électrolyseurs à haute température pour la production d'hydrogène vert

Enablement of Diagnostics/Prognostics for Health Management, Condition Based Maintenance and Performance Optimization of Solid Oxide Stacks used by High Temperature Electrolyzer Modules for Green Hydrogen Production

Background Information – Key Drivers

To efficiently produce high volumes of green H2, at economically compelling costs, the use of advanced technology components such as Solid Oxide Cells (SOC) and subsequent stacks, as core technology for large scale industrial systems, is an ambitious but credible path – supported by France and Europe given obvious decarbonation and industrialization benefits.

Outstanding technical progress has been made over the last 15+ years to understand and improve the performance and durability of SOC based technology and components. Understanding the physics of failures and degradation mechanisms, combining modeling and experimental work have translated into significant design, materials and process improvements over time but remain key R&D focus areas still. Indeed, multi-stack based SOC solutions must operate at very high temperatures (between 700 to 800 deg. C) for many years with minimum and controlled degradation of their overall performance.

Intrinsic performance degradation over time and potential failures impacting industrial processes go hand in hand with needs to enable and develop sensible Prognostics and Health Monitoring (PHM), derived Condition-Based Maintenance (CBM), as a way to reduce the Total Cost of Ownership (TCO) and safely produce cost-efficient hydrogen for various industrial applications.

Performing PHM in Ultra High Temperature Electrolyzer Modules is still an open field of applied research, with no solutions to allow UHT Electrolyzer to be used widely in society. The very high temperature of operation forbids many types of direct measurements on the stacks; highly expensive sensors per cell or per stack would render the technology commercially inviable; models to predict degradation are still unreliable as the technology is relatively new.

Work Description

The first part of the PhD work will consist of understanding the operation of SOC technology and its use for industrial applications, gathering information about existing SO cells & stacks models and potential monitoring solutions. The PhD candidate will benefit from access to prior art, legacy and ongoing R&D work done by CEA teams/resources. She/he will also interact with the Genvia/CEA

systems engineering/R&D teams in charge of developing High Temperature Electrolysis (HTE) modules for industrial demonstrators.

Indeed, the development of effective PHM and derived CBM solutions requires the development and use of hybrid models combining relevant physics and measurements/data. There are two aspects that go hand-in-hand for this research:

1. Data definition and acquisition: Definition of the raw data that will be used for the system health monitoring and prognostic. Work will consist to define, to acquire and to store the data.
2. The design and choice of elements to serve as direct measurement, indirect measurement, and canary; these can be designed/chosen based on models and/or the understanding of the stack and module and/or experiments with prototypes
3. The creation of models: to be used as part of the diagnostics and prognostics interpretation, "fed" by the measurement data (provided by the point below)
4. Data analysis: Raw data have to be processed through defined algorithm. AI, bigdata, filtering technics should be evaluated/considered (Signal processing, data mining, deep learning…).
5. System health characterization: Identification of the parameters to be used to monitor the status of the system These parameters will also be used to do prognostic and to define predictive maintenance or to send system alert.
6. System correction: Use of health system parameters to determine and to optimize working operation to increase lifetime of the sub-system without failure.

One particular challenge is to explore and define, through collaboration work, design provisions for "passive elements" that could be added to the cells or stacks to assist with their location identification and performance monitoring, enable indirect measurements of key parameters such as temperature, voltage, currents or even pressure profiles with a resolution at the stack, ideally cell level. Such indirect measurements, assisted by design provisions, can be done permanently from outside the hot zone and/or through periodic inspection of the hot zone by metrology means under development. The provision for including passive elements into the design should also consider the possibility of adding elements with known degradation over time, i.e. so-called canaries, matching typical degradation of core elements which are present in high number and difficult to monitor individually.

In addition to theoretical/analytical work, we foresee opportunities for the PhD candidate to build prototypes and perform lab experiments as needed.

Candidate skills and knowledge required

Strong physics and (applied) mathematics background.

One (or both) of the following backgrounds:

- Physics and applied mathematics (analytical and numerical modelling skills)
- Mechanical/materials engineering or electrical engineering with modelling competencies

Experience/interest in experimental work, or experience/interest in close collaboration with colleagues in experimental work

Diplôme Grande école or University with relevant degrees.

Workplace

CEA/DRT/LITEN, Grenoble - France.

Short duration trips in France to interact with various team members from various locations, e.g. Clamart, Saclay, Bruyères-le-Châtel, are to be expected.

Duration

3 years starting October/November 2021.

PhD Support Team

TBD

Application

To apply, please send your resume and cover letter to info@genvia.com with the subject heading [Thesis Application – NAME].

References

1- State of health estimation and remaining useful life prediction of solid oxide fuel cell stack - September 2017 · Energy Conversion and Management 148:993-1002 - Boštjan Dolenc, Jožef Stefan Institute, P. Boškoski, Martin Stepančič, Jožef Stefan Institute

2- Failure Prognosis Based on Relevant Measurements Identification and Data-Driven Trend-Modeling: Application to a Fuel Cell System - February 2021 - Processes 9(2) - DOI:10.3390/pr9020328 - Mohand Arab Djeziri, laboratoire d'Informatique et Systèmes (LIS), Oussama Djedidi, Mines Saint-Etienne - Jean-Luc Seguin, Aix-Marseille Université

3- Thesis: Daniel Hissel, Marie Péra. Diagnostic & health management of fuel cell systems: Issues and solutions. Annual Review in Control, 2016, 42, pp.201 - 211. ffhal-02380293ff

4- State of health estimation and remaining useful life prediction of solid oxide fuel cell stack - Energy Conversion and Management - Volume 148, 15 September 2017, Pages 993-1002 - Jožef Stefan Institute, Department of Systems and Control, Jamova cesta 39, SI-1000 Ljubljana, SloveniabVTT Technical Research Centre of Finland Ltd., FinlandcJožef Stefan International Postgraduate School, Jamova cesta 39, SI-1000 Ljubljana, Slovenia

5- Thesis: Contrôle tolérant au vieillissement dans des systèmes pile à combustible PEMFC Par Madame Rania MEZZI – June 2017

6- Thesis: Survey of prognostics methods for condition-based maintenance in engineering systems Ehsan Taheri, Ilya Kolmanovsky, Department of Aerospace Engineering, University of Michigan, Ann Arbor, MI 48105, USA Oleg Gusikhin, Ford Research & Advanced Engineering

7- SOH ESTIMATION AND RUL PREDICTION FOR SOFC BASED ON THE FRAMEWORK OF DATA-DRIVEN AND DEGRADATION MODEL - nternational Conference on Applied Energy 2019 - Aug 12-15, 2019, Västerås, Sweden - Paper ID: 0655

8- Thesis: Elodie Lechartier. Contribution au pronostic de pile `a combustible PEMFC basé sur modèle semi-analytique. Energie ´électrique. Université de Franche-Comté, 2016. Français. <tel-01345232>

9- Machine learning toward advanced energy storage devices and systems Tianhan Gao1 and Wei Lu - Science 24, 101936, January 22, 2021 ª 2020

10- A review of diagnostic and prognostic capabilities and best practices for manufacturing Gregory W. Vogl1 · Brian A. Weiss1 · Moneer Helu1 – Springer - DOI 10.1007/s10845-016-1228-8

11- Thesis: Solid oxide fuel cell modeling and lifetime prediction for real-time simulations par Rui Ma en partenariat avec FEMTO-ST : Franche-Comté Electronique Mécanique Thermique et Optique - Sciences et Technologies (Besançon)(laboratoire)et de Université de technologie de Belfort-Montbéliard(Etablissement de préparation) .

12- Electrochemical model for SOFC and SOEC mode predicting performance and efficiency December 2014 - International Journal of Hydrogen Energy 39(35):20844-20849 - DOI:10.1016/j.ijhydene.2014.08.139 - Dino Klotz - I2CNER - International Institute for Carbon Neutral Energy Research, Fukuoka, Kyushu, Japan - André Weber - Karlsruhe Institute of Technology

13- Assessment of a Solid Oxide Electrolysis Cell Performance Applying a Prediction Tool with Correlation Equations Mina Nishi1, Hiroshi Morita1, Kenji Yasumoto1, Takashi Okawa2 and Yoshihiro Mugikura1 © 2019 ECS - The Electrochemical Society ECS Transactions, Volume 91, Number 1

14- Thesis: Dynamic modelling and nonlinear model predictive control of a reversible solid oxide fuel cell for grid-tied power tracking - R.A. Schotman 2019 - Delft University of Technology

15- Life Time Performance Characterization of Solid Oxide Electrolysis Cells for Hydrogen Production July 2015 - ECS Transactions 68(1):3359-3368 - DOI:10.1149/06801.3359ecst
16- Online-monitoring as a tool for state-ofthe-health prognostic and prediction of remaining useful lifetime of electrochemical fuel cell systems - 8th Edition of International Conference on Chemical Sciences June 14-15, 2018 London, UK - Vanja Subotic - Graz University of Technology, Austria
17- State of health estimation and remaining useful life prediction of solid oxide fuel cell stack B. Dolenc, P. Boskoski, M. Stepancic, A. Pohjoranta, D. Juricic - Journal Energy Conversion and Management - Volume 148 - 1 Jan 2017
18- Quantitative review of degradation and lifetime of solid oxide cells and stacks Skafte, Theis Løye; Hjelm, Johan; Blennow, Peter; Graves, Christopher R. Published in: Proceedings of 12th European SOFC & SOE Forum 2016
19- Fault analysis and diagnosis of solid oxide fuel cell system - Wu Xiao-long;Jing Su-wen;Xu Yuan-wu;Li Xi - IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society