

FERS EALTH

Real operation pem fuel cell HEALTH-state monitoring and diagnosis based on DC/DC COnverter embeddeD Eis

Programme Review Days 2018 Brussels, 14-15 November 2018



FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

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PROJECT OVERVIEW

• Call year: 2014

Call topic: FCH-02-3-2014

Stationary fuel cell system diagnostics: development of online monitoring and diagnostics systems for reliable and durable fuel cell system operation

- Project dates: 01/09/15 31/12/18
- Stage of implementation 01/11/2018: 95%
- Total project budget: 2,358,736€
- FCH JU max. contribution: 100%







*Former Dantherm Power A/S.





PROJECT OBJECTIVES

- Enhancement of EIS-based diagnosis for embedded on-line applications; 1.
- Development of a monitoring and diagnostic tool for state-of-health assessment, fault 2. detection and isolation as well as degradation level analysis for lifetime inference;
- 3. EIS-oriented experimental analysis for **5 failure modes**: i) fuel composition, ii) air starvation, iii) fuel starvation, iv) sulphur poisoning, v) flooding & dehydration;
- 4. EIS scaling-up algorithm to reduce time and costs of new stack characterization.

Performance, Durability, Availability





Reduce OPEX







PROJECT ACHIEVEMENTS

Embed the tool for Electrochemical Impedance Spectroscopy (EIS) for advanced **Fuel Cells Monitoring & Diagnosis.**

HW enhancement and interfacing (Converters), Monitoring & Diagnostics (Algorithms).

EIS board (TRL 6)

EIS board has been prototyped (proto 2) ready to be engineered for system embedding.

Converter (TRL 6)





The tool performs EIS-based condition monitoring of FC stacks and isolates 5 stack faults. Advanced knowledge (Air+Ref./O₂+H₂-fed stacks) 2200+ EIS spectra; New device (EIS Board);

> **Conventional HW is** modified/re-engineered to allow flexibility and multiple market choice for manufacturer strategies.

Algorithms (TRL 5)

Detection and Isolation of 5 faults in stacks fed with Air+Reformate / O_2 + H_2 .

EIS board cost < 500€ (3% of Total Cost of Ownership)









PROJECT CONCEPT

















PROJECT PROGRESS & ACTIVITIES



under completion. connected).

and tested.

system to be finally assessed.



- **Experiments**: Air-fed (µ-CHP) and O2-fed (backup) stacks fully tested in both nominal and faulty conditions (fuel starvation, air/O2 starvation, flooding, drying, CO contamination and Sulphur poisoning); final system testing
- **EIS board**: final version of EIS board completed and verified in relevant environment (EIS measurements performed with DC/DC converter
- **DC/DC converters**: modified EPS converter and BPSE new converter completed
- **Diagnostic algorithms**: all algorithms trained and tested on all the performed EIS measurements (algorithms benchmarking); characterization on FC
- System integration: FC systems (BPSE µ-CHP and EPS backup) integrated with DC/DC converters and BITRON final EIS board; algorithm on-board implementation done for final algorithm verification (ongoing).













EIS SPECTRA MEASURED ON SHORT AND FULL STACKS

- Nominal spectra set the monitoring reference
- Faulty ones drive the setting of faults isolation algorithm







- air/O2 starvation,
- flooding/drying,
- **CO** contamination
- sulphur poisoning





O₂ fed



2200+ EIS spectra for stacks (10%) and cells, **25% in nominal** and **75% in faulty operations**

Air fed







Air fed



- data;
- systems lifetime. Physical





- Power Sources 353, 277-286.



• Reduce fuel cells (FCs) testing costs providing a scaling-up algorithm able to extrapolate full stack performance and impedance behaviour from single cell and/or short stack (i.e. single repeated unit – SRU)

• Derive stack faulty behaviour from single cell tests performed under faulty conditions to improve FC

Russo et al. (2016) - Application of Buckingham theorem for scaling-up oriented fast modelling of Proton Exchange Membrane Fuel Cell impedance, Journal of

Polverino et al. (2018) - Generalized scaling-up approach based on Buckingham theorem for Polymer Electrolyte Membrane Fuel Cells impedance simulation 10th International Conference on Applied Energy (ICAE2018), Aug 22-25, Hong Kong, China. (to be published on Energy Procedia – Selected for Applied Energy Special Issue





EIS-BOARD & CONVERTER

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USEFUL GUIDELINES for companies

- **NEW DC/DC converter** (designed to interact with the EIS board)
- **ADAPT AVAILABLE converter** to allow the communication with the EIS board.



sinusoid @6kHz of injected disturbance.





TESTED SYSTEMS

Ballard Europe µ-CHP system



Power: <u>Cooling</u>: **Reactants**: **Applications**:

1.3 kW; Water cooled; Air & Reformate; Residential µ-CHP









ACQUIRED SPECTRA

EPS backup/energy system





DC/DC converter



3 kW; Water cooled; **Oxygen & Hydrogen;** Backup electric power 10 H_2 as energy buffer.





















PRELIMINARY ANALYSIS ON DIAGNOSIS RESULTS









Diagnostic tools ver1	Ballard	EPS
Precision	87%	90%
Error	20%	20%

15%

Version 1 of Diagnostic Tools Version 2 is under assessment (better detection and threshold evaluation)





LIFETIME INFERENCE







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IMPACT

The implementation of HEALTH-CODE **outcomes** will:

- help in increasing electrical efficiency and durability of the different fuel cells used for power production
- contribute to **reduce degradation** by implementing the monitoring and diagnostic tool
- lead to a reduction of total cost ownership (TCO) by increasing the FC system efficiency
- contribute to improve grid stability (with advanced **monitoring**) in the future by applying stationary fuel cells together with energy storage; the EPS backup system has grid interface for H₂ & O₂ production and can support grid balancing





envisaged by industrial Improvements partners **BPSE** and **EPS** are:

- Lifetime from B10-5 to B10-10 (BX-Y: X%) of running systems will experience a fault in Y years)
- **Efficiency** from 32 to 36%
- **Availability** from 99.6% to 99.9%
- Durability increase 30%
- Warranty condition from 15000 h/1000 cycles to 20000 h/1500 cycles





DISSEMINATION ACTIVITIES

Papers (3 Published - 2 Under Submission)



Fuel Cells

Characterization of an H_2/O_2 PEMFC Short-Stack Performance Aimed to Health-State Monitoring and Diagnosis

R. Petrone^{1,2*}, C. Vitagliano³, M.-C. Péra^{1,2}, D. Chamagne^{1,2}, M. Sorrentino³ ¹ FEMTO-ST, CNRS, Univ. Bourgogne Franche-Comte, rue Thierry Mieg, F-90010 Belfort Cedex, France ² FCLAB, CNRS, Univ. Bourgogne Franche Comte, rue Thierry Mieg, F-90010 Belfort Cedex, France

³ UNISA, DIIN, University of Salerno, Salerno, Italy

Received June 22, 2017; accepted September 07, 2017; published online November 06, 2017

Proton exchange membrane fuel cell (PEMFC) is one of the this purpose, the experimental activity performed to characmost promising technologies in energy conversion. Neverthe- terize the stack health-state both in normal and abnorma less, improper operating conditions can severely affect the conditions is presented. Particular attention is dedicated to fuel cell (FC) lifespan. It is a matter of fact, that several degra- the effects caused by improper co s could take place inside the cell in case of chemical imp can show critical effects on PEMFC performance. Further- diagnosis purpo more, if the exposure time to these faulty conditions resulted quite long, irreversible degradations and system ageing Keywords: Diagnosis, EIS Spectra, Hydrogen/Oxygen PEM vould occur. This work aims to investigate the impact of Fuel Cells, State-of-Health

conditions on H₂/O₂ PEMEC short-stacks performance. To conditions. Among these, improper tions. Depending on the faulty conditions, the experime fuel quality and starvation conditions results are then analyzed for health-state me



ournal of Power Sources 353 (2017) 277-286

Contents lists available at ScienceDirect

Journal of Power Sources

Application of Buckingham π theorem for scaling-up oriented fast modelling of Proton Exchange Membrane Fuel Cell impedance

Luigi Russo, Marco Sorrentino^{*}, Pierpaolo Polverino, Cesare Pianese ering, University of Salerno, Via Giovanni Paolo II, 132, 84084 Fis

ABSTRACT

HIGHLIGHTS

A methodology to reproduce PEMFC impedance is propose • Non-dimensional parameters are defined by exploiting the Buckingham's π theorem Good accuracy in PEMFC impedance prediction is proved.

• The possibility to use this methodology with scaling-up purposes is demonstrated

ARTICLE INFO

Article history: Received 17 November 2016 Received 17 November 2010 Received in revised form 23 March 2017 Accepted 24 March 2017 Available online 10 April 2017

ochemical impedance spe oton exchange membrane fuel cell This work focuses on the development of a fast PEMFC impedance model, bupysical and geometrical variables. Buckingham's π theorem is proposed to development parameters that allow suitably describing the relationships linking the physica ons of the proposed similarity the sented and discussed. The major advantage resides in its str ility of the model to reproduce PEMFC impedance at different reduction of the experimental effort for the FCS lab characterization. More bility to use the model with scaling-up purposes to reproduce the full stacl ine, thus supporting FC design and development from lab-to commercial © 2017 The Authors. Published by Elsevier B.V. This is an open access article u

 Generalized scaling-up approach based on Buckingham theorem for Polymer Electrolyte Membrane Fuel Cells **impedance simulation**. Polverino, P.; Bove, G.; Sorrentino, M.; Pianese, C - ICAE2018, published on Energy Procedia – Selected for Applied Energy Special Issue submission.



<u>Under submission</u>: 2 journal papers on the state of the art of diagnostics techniques and PEMFC faults.



POWER SOURCES	
CrossMark	
starting from both ne non-dimensional ariables involved in il solution for those or computationally g approach are pre- plicability, thanks to s the model suitable ing and prognostics. to demonstrate the eratures. This results it is highlighted the bedance from single- m-scale. er the CC BY license org/licenses/by/4.0/).	

Conferences and events

- 6th Int. European PEFC & Electrolyser Forum 2017
- Electrochemical Science and Technology Conference and Annual Meeting of The Danish Electrochemical Society 2017
- IEEE, Vehicle Power and Propulsion Conference, 2017
- Fundamentals & Development of Fuel Cells, 2017
- 7th EFC "Piero Lunghi" Conference, 2017
- FCH2JU Review Days 2016 2017 2018

Students involvement

- 2 PhD students
- 1 master + 6 bachelor students







COMMUNICATIONS ACTIVITIES

Joint workshop HEALTH-CODE-DIAMOND Luzern (July 2017) - 6th EFCF

- 45+ Participants
- 16 presentations
 1 speech from industry
 1 special contribution
- 100+ Flyers distributed



Communication materials

- 2 flyers & 3 FCH JU posters
- 3 posters
- 1 video (on-board EIS diagnosis) on the website



www.pemfc.health-code.eu

Joint workshop HEALTH-CODE-INSIGHT Brussels (November 2018) – PRD2018

- 70+ Participants
- 12 presentations (4 speeches from industry)
- Future exploitation focus

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EXPLOITATION PLAN supported by 2+ potential industrial follow-up

Inputs for Business Plan

M18 Impact assessment Belfort (FR)

> I-CATAPULT 2018 EIFER innovation challenge

M37 SSERR exploitation Turin (IT)

Support Services for Exploitation of Research Results

PRODUCT

MARKET

FERS EALTH

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Thank You!

