insight

ImplementatioN in real SOFC Systems of monItoring and diaGnostic tools using signal analysis to increase tHeir lifeTime.

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START DATE JANUARY 1ST 2017
DURATION 36 MONTHS

Objectives

Stacks lifetime
+5%

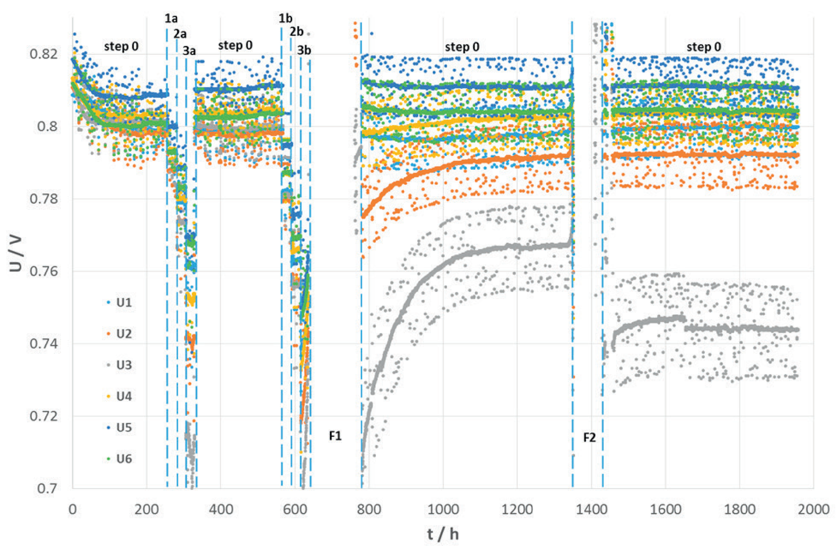
Availability
+1%

Total Cost Ownership
-10%/kWh

EXPERIMENTAL TESTING AND CALIBRATION

SOFC 6-cells short stack from SOLIDpower tested at CEA in collaboration with IJS.
Fuel starvation has been gradually tested with EIS and PRBS measurements implemented every 6 h during 2000 h of test.

step 0 - FU=77.4% nominal operating conditions 750°C, i=0.4 Acm-2
1a - FU=82.4% by decreasing H2 flow rate
2a - FU=87.4% by decreasing H2 flow rate
3a - FU=92.4% by decreasing H2 flow rate
1b - FU=82.4% by increasing current
2b - FU=87.4% by increasing current
3b - FU=92.4% by increasing current
F1 - OCV after H2 supply shutdown
F2 - OCV after H2 supply shutdown



HARDWARE DEVELOPMENT

The project hardware includes a dedicated ECU, called Bitron Box, currently under development.

First release is planned for September 2018.

The main architecture consists of:
- An embedded Linux board (Beagle bone Black v3) to run high level algorithms.
- A dedicated custom board (Bitron board) dedicated for data sampling and conversion, equipped with:
  - Analog input filters for noise attenuation.
  - Four acquisition channels: two used for acquiring DC signals and two for AC signals.

The ADC conversion, made with a 24bit resolutions Sigma Delta device by Texas Instruments, runs at a maximum sampling rate of 75kSps.

- STM32F4 microcontroller equipped with an ARM Cortex M4 core and a maximum clock frequency of 168 Mhz.
- Extended RAM module for increasing the number of data samples buffered before the post-processing part.

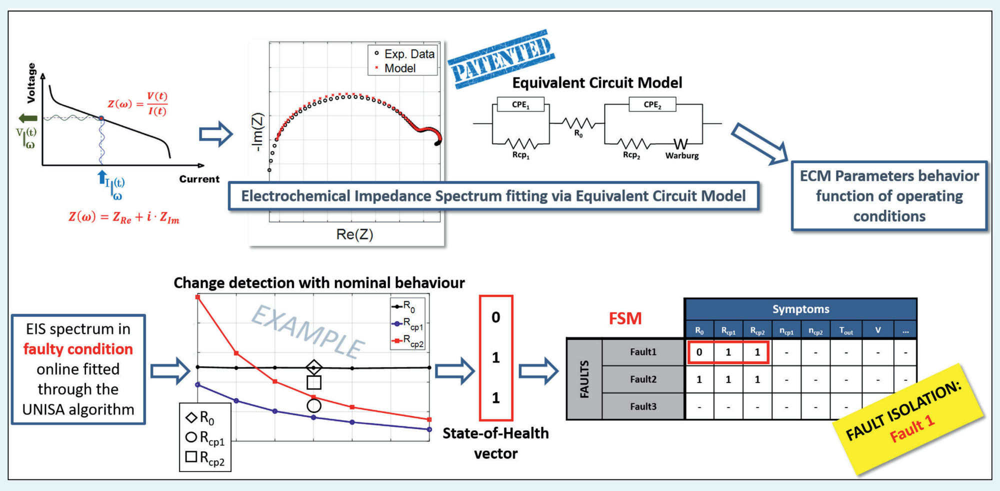
The overall system communicates over a TCP protocol to exchange commands and data between the components of the system.

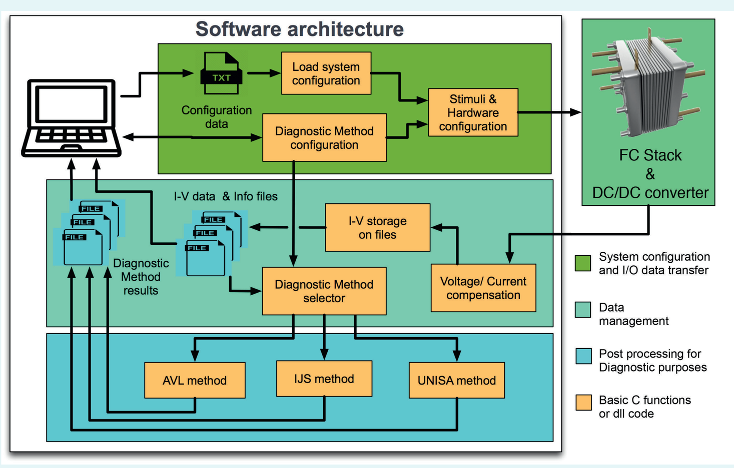
The final objective of the proposed system is to provide an "on site" device to increase the quality of the analysis minimizing production costs. Therefore, demonstrating its reliability and affordability for an industry use, which nowadays, is limited by costly laboratory instrumentations.

ALGORITHMS DEVELOPMENT

Monitoring and Diagnostic Tools

UNISA is developing a diagnostic algorithm for Detection and Isolation of faults at single cell and stack level based on Electrochemical Impedance Spectroscopy. The algorithm follows a generic and fast fitting technique to extract Equivalent Circuit Model (ECM) parameters to map offline both nominal and faulty states of the system. This helps in designing reference patterns through which fault detection is performed. Indeed, online EIS measurements are used for real time estimation of ECM parameters, then compared with their nominal mapped values. If a sensible divergence occurs, a symptom arises. Symptoms collection and comparison with faulty patterns allows afterwards State-of-Health estimation.



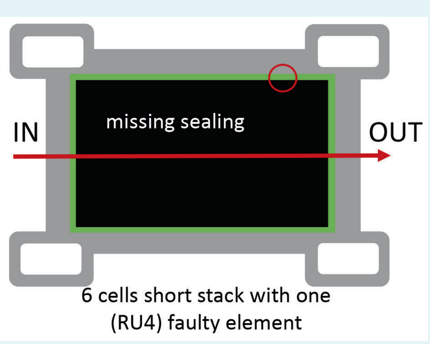


The Linux-based board sends acquisition commands to the Bitron board. Once the acquisition is completed the data samples are stored as binary files on the Linux-based board. Those data files are used in a second time for the elaboration process by the algorithms developed by all the partners. The aim here is to create a sort of interface which can be interpreted as a standard for all the working algorithms. The selected approach allows to minimize each Software modules complexity which are independent. Furthermore,they can be easily tested and validated creating "ad hoc" test suites with the objective to guarantee robustness and reliability.

The figure shows the schematics of the high level (HL) software; it has been conceived to include EXTERNAL CODE that takes as input the acquired data for performing on the Linux-based board the diagnostic methods.

Validation of algorithms on lab scale system

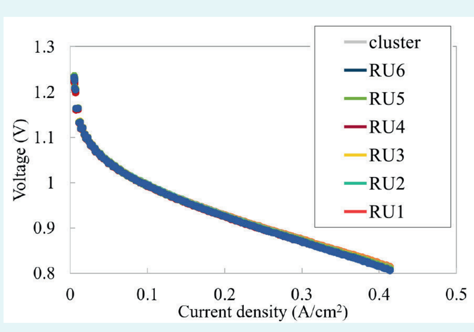
EIS signature identification for fault detection – RU4 3mm missing sealing (EPFL)



6 cells short stack with one (RU4) faulty element

Leakage due to missing sealing close to the flow outlet is difficult to detect.

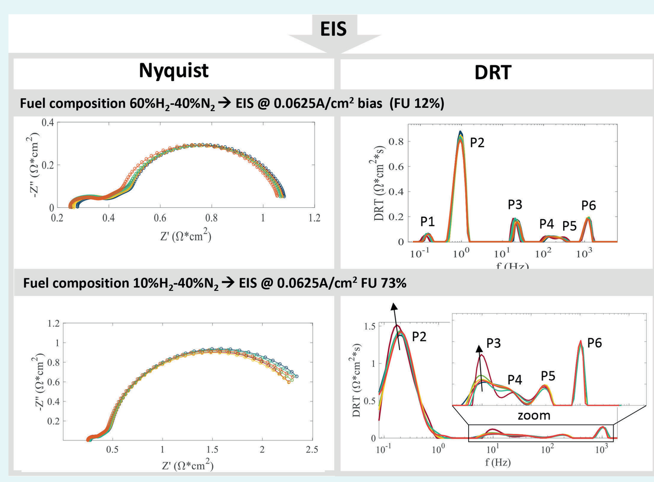
From i-V curves no difference in:
- OCV
- performances among the different RUs

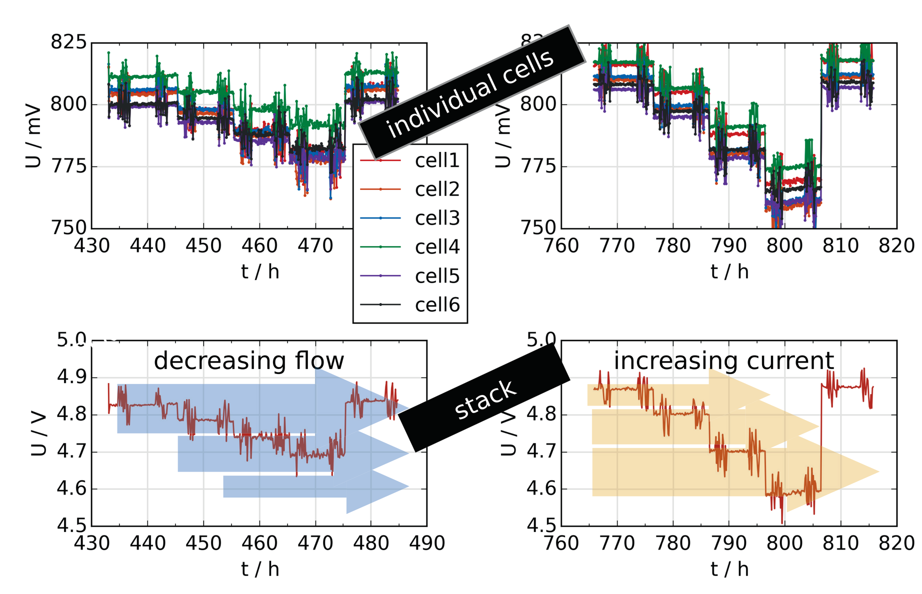


No difference are detected even by EIS with nominal fuel flow operation at low current density.

Changing operating conditions can improve fault detectability.

By increasing the conversion rate the DRT analysis shows a shift of the gas conversion peak (P2) and an increase of the resistances of the anode diffusion process (P3) of the faulty element if compared with the healthy elements.



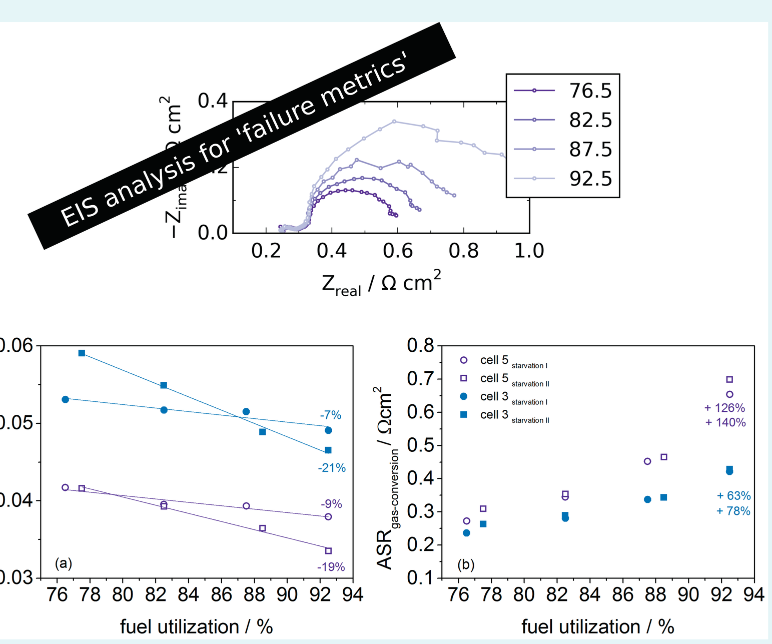


Experimental simulation of close-to-real stack failures - ***fuel starvation*** (ensured by DTU)

- Investigation of conventional measurements for failure detection on stack and cell level

- Electrochemical impedance characterization for a more detailed 'failure metric' examination i.e. *increase of $ASR_{gas\text{-}conversion}$* and *decrease of $ASR_{fuelelectrode}$*

PERSPECTIVE
Experimental simulation of a ***carbon deposition*** fault



Lifetime Tools

Instead of conventional sine-based EIS evaluation, IJS is coming up with a much more efficient alternative relying on non-sinusoidal perturbation in terms of step-like pseudo-random binary signal (PRBS).

Features:
- high resolution of the evaluated EIS curve
- required time to run the experiment is by 10 times shorter than in conventional EIS
- even suitably exciting current during normal operation may suit to identify the model and hence characterise the system, the optimal model structure can be inferred from data
- the scheme is presently applicable to a serial connection of QR elements.

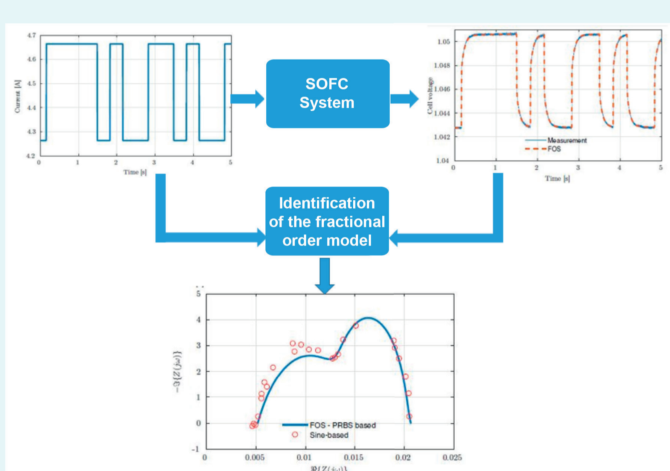


Fig.1: From non-sinusoidal excitation to SOFC model. Below is the comparison between conventional sine-based EIS (circles) and PRBS-based EIS (solid line).

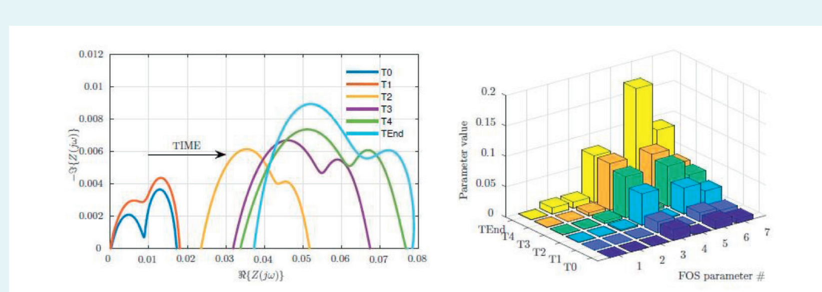


Fig.2: Evolution of EIS curves during the degradation process (left) and the parameters of the process model (right). The latter is obviously affected by the degradation.

SYSTEM INTEGRATION AND TESTING

Integration / testing in a commercial system

This project has received funding from the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) under grant agreement No 735918. This publication reflects the views only of the author, and the FCH JU cannot be held responsible for any use which may be made of the information contained therein.

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