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

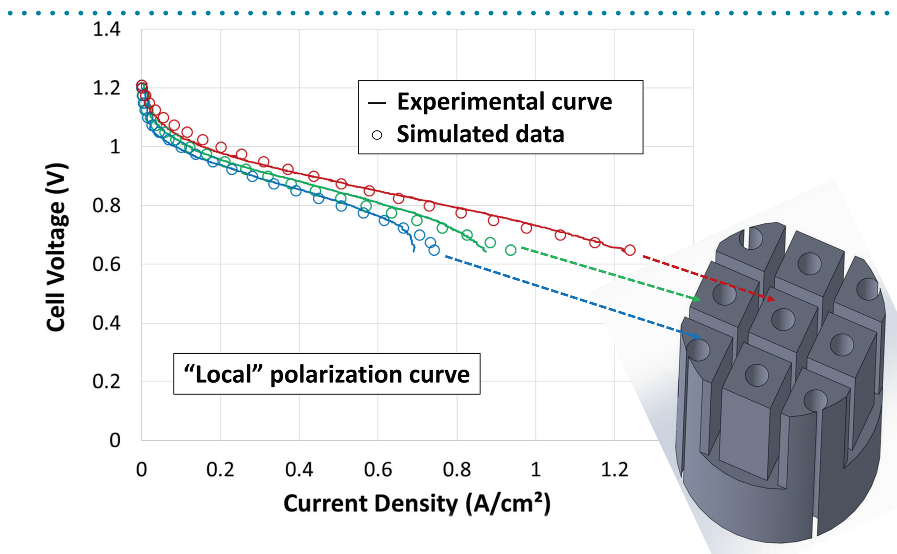
PARTNER

EXPECTED RESULTS

RESULTS YEAR 1

CEA

Local current monitoring and model correlation.
Study the local conditions in terms of current and fuel utilisation on SOFC cells to better understand their impact on cell degradation.
Be able to get this information on classical cells without the need of special geometries/manufacturing.



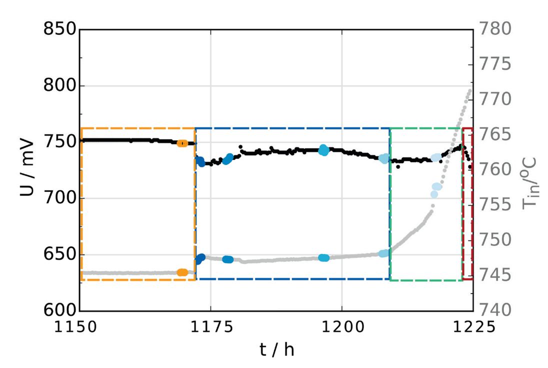
- Measurement done on a classical SOLIDpower cell using a current collector with 9 local voltage measurements
- Gas distribution: inlet at the center, outlet at the periphery
- Good correlation between experiment and model
- Large difference in terms of current density along the cell diameter: 2 times larger at the center than at the periphery in case a high fuel utilisation is used (> 80%)

PERSPECTIVES

Continue the mapping with various experimental conditions.
Identify limit conditions above which there is a risk of degradation, the associated signals, in order to be able, in stack, to make a diagnosis of risky conditions and take corrective measures in order to increase lifetime.

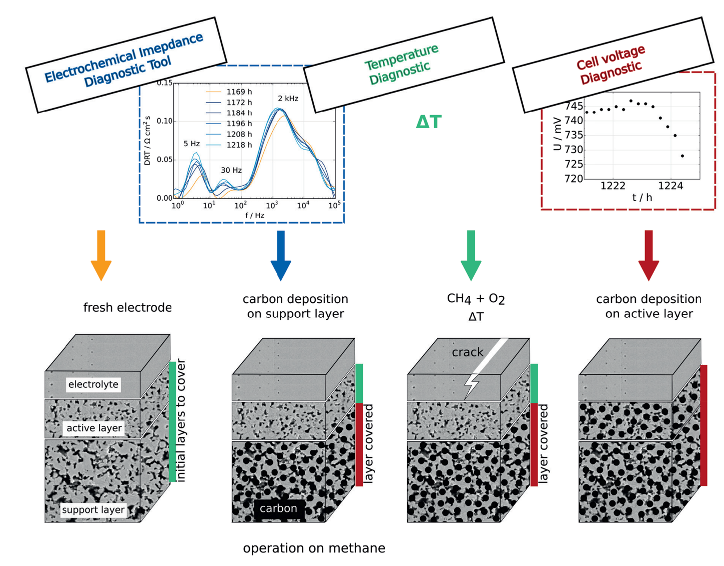
DTU Technical University of Denmark

Implemented set of diagnostic tools for stacks/systems into a practical device.



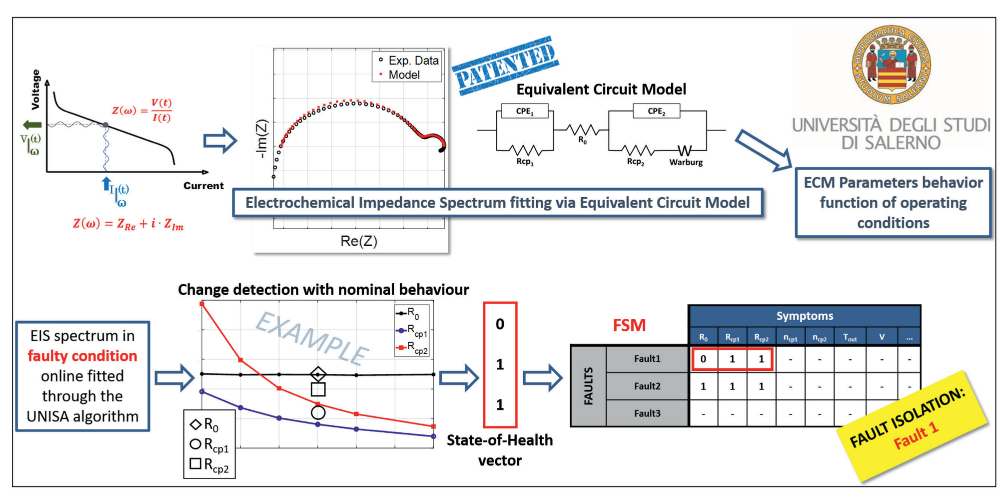
Developement and Evaluation of Diagnostic Tools for early failure detection

e.g. fuel starvation, carbon deposition, etc.



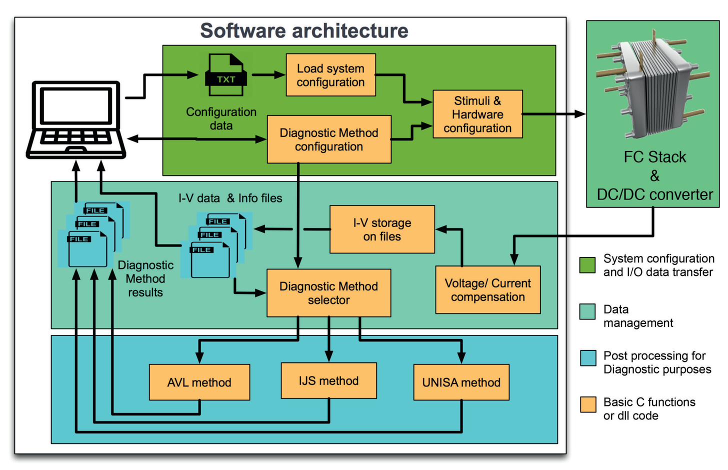
UNISA

Monitoring, Diagnostic, Lifetime, Mitigation 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 an Equivalent Circuit Modelling (ECM) approach through which significant parameters are identified. Parameters extraction is performed by means of a UNISA proprietary patented technique, which allows high generalizability and fast fitting performances. An offline characterization of such parameters allows to map them in both nominal and faulty states. 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.

HW & firmware engineering for on-board use.



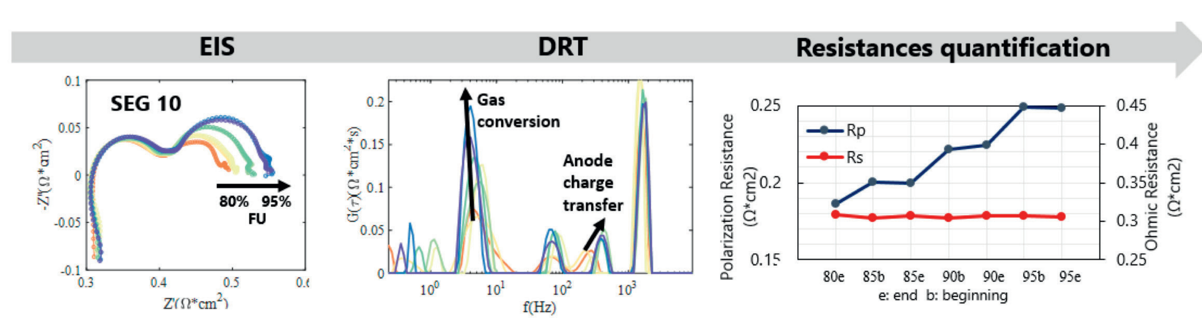
The Linux board sends acquisition commands to the Bitron board. Once the acquisition is completed the data samples are sent back and stored inside the Linux file system as binary files. Those data files are used in a second time for the elaboration process by the algorithms developed by all the partners. 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 take as input the acquired data for performing on board the diagnostic methods.

To assure the correct data exchange and a proper hardware configuration, the HL software executes each diagnostic method as a call to the corresponding C function.

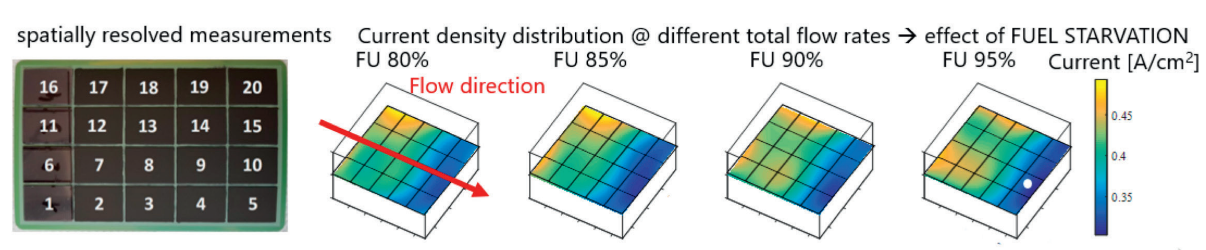
EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Addition of new diagnostic tools on existing instrumented advanced stack test benches for validation.



- Measurement on 2-cells short stack with a segmented SOLID Power cell
- Gas distribution: co-flow Air-Fuel according to the arrow direction
- Possibility to create spatial maps (current density)
- EIS combine with DRT and CNLS to quantify elementary process' contributions

Improved lifetime prediction tool calibrated with spatially resolved measurement data, e.g. signal response from a SRU with a known local defect introduced on purpose.



PERSPECTIVES

- Continue the mapping according to the test protocol
- Test a cell with purposefully introduced faults on different segments
- Experimental data to fed lifetime modeling

IJS

PRBS-based diagnosis and prognosis.
The aim is to use unconventional non-sinusoidal system probing in order to reduce the time for experiment, increase the robustness to noise, investigate new techniques for degradation diagnosis and prognosis of the remaining life span.

IJS is working out a novel health assessment procedure for stacks/cells by using non-sinusoidal perturbation in terms of step-like pseudo-random binary signal (PRBS). When using the PRBS current signal, the fuel cell system is excited by all the frequencies from a broad spectrum at the same time. Thanks to that, the duration of system excitation is considerably reduced **up to an order of magnitude**.
Furthermore, to characterize the FC system dynamics, a class of fractional-order models (FOS) and their identification from the acquired current and voltage samples has been investigated. The estimated FOS model parameters are employed to determine the degradation mode via statistical decision making. In the perspective, the time evolution of the related model parameters is modelled as a stochastic process, which is used to predict the future trend.

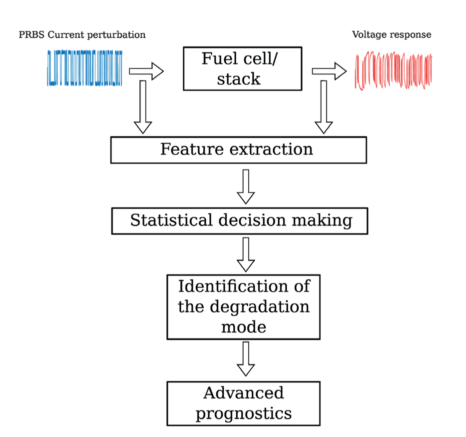


Fig.1: The diagnostic and prognostic procedure

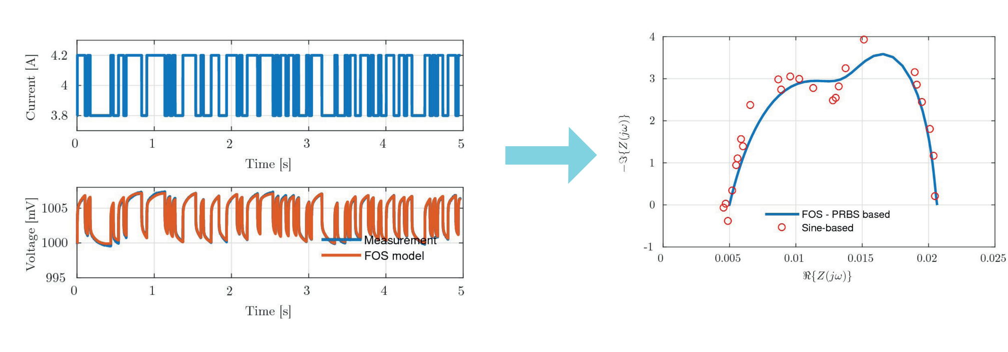


Fig.2: Response of the cell voltage to PRBS current excitation (left). The comparison of FOS model in the frequency space and conventional sine-based EIS curve is shown on the right. Note that in the particular case a 5 seconds recording suits to get high quality model of the FC system.

Bitron

Development of Advanced Monitoring, Diagnostic and Lifetime Tool (MDLT)

The first release of the Bitron Box, is under construction. First samples will be released in September 2018. The main architecture is so defined:

- A Linux board (Beagle bone Black v3), is devoted for the high-level implementation part, where the several partner's algorithms run and compute a post processing elaboration of the data samples previously acquired.
- A Bitron board, which is a full custom device responsible for the data samples acquisition part. It takes command from the Linux board. Then thanks to a dedicated TCP communication protocol, developed together with UNISA partner, shares the data samples. The main features of the boards are given:

- Four acquisition channels: two used for acquiring the DC components, and the others two for acquiring the AC components.
- Pre-Conditioning input filters used for the noise attenuation of the several input signals. Those have been already designed and tested from a simulation point of view.
- For the acquisition, a specific Sigma Delta device has been chosen. It communicates with the microprocessor with SPI standard and provides accurate data with a maximum sampling frequency of 75 ksps and a resolution of 24 bits for all the selected channels.
- STM32F4 microprocessor with ARM Cortex M architecture, with maximum clock frequency 168 MHz.

- Extended RAM module for increasing the number of data samples to be sent in a second time to the Linux Board.
- A Real Time Operative System firmware has mostly been designed and tested for managing the acquisition part and the Ethernet data communication protocol with the Linux Board.

The final objective of the overall system is to provide an "on site" device which provides significant and useful results minimizing production costs. Therefore, demonstrating its reliability and affordability for an industry use, which nowadays, is limited by costly laboratory instrumentations.

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