insight

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

START DATE JANUARY 1ST 2017
DURATION 36 MONTHS

Objectives

Stacks lifetime
+5%

Availability
+1%

Total Cost Ownership
-10%/kWh

EXPERIMENTAL TESTING AND CALIBRATION

- Faults most critical identified: fuel starvation, C deposition and gas leakage
- Testing protocol defined, testing matrix shared among partners
- Specific devices to measure PRBS and THD installed for measurements
- Results :
  - EIS+DRT, THD, PRBS + conventional signals recorded and analysedT
  - Conventional signals = usable for diagnostic use vthanks to statistical treatment
  - EIS = valuable tool, with DRT for more accurate analysis
  - THD and PRBS = quick analysis tool, with answer consistent with conventional EIS
- But some faults easier to detect than others, averaging effect on a whole stack can be problematic

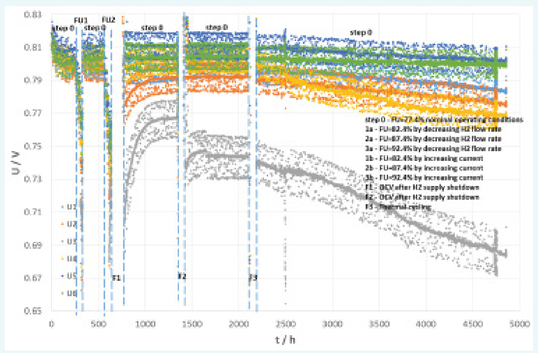


Fig 1 SOFC 6-cells short stack from SOLIDpower tested at CEA in collaboration with IJS. Fuel starvation protocol with EIS and PRBS measurements implemented every 6 h during almost 5000 h of test.

HARDWARE DEVELOPMENT

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

First release, planned for September 2018, was developed and tested (hardware and software).

Then the new board has been improved and integrated in the final design of the BitronBox v2.

The main architecture consists of :

- an embedded Linux board (Beagle bone Black v3) for configuration, user inputs, acquisition commanding and storage;
- an embedded Linux board (Raspberry 3B +) for running diagnostic algorithms and showing outputs;
- the release 2 of PCB was realized to obtain a better layout of dedicated custom board (AFE-Bitron board).
- AFE Board is dedicated for data sampling and conversion, equipped with :
  - analog input filters for noise attenuation (new cut-off frequency 10kHz)
  - 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.

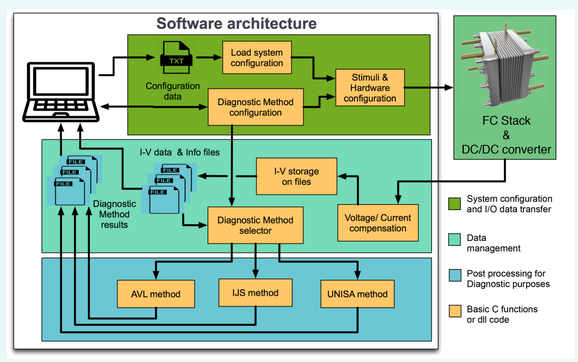
The overall system communicates over a TCP protocol to exchange commands and data between the components of the system.

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.

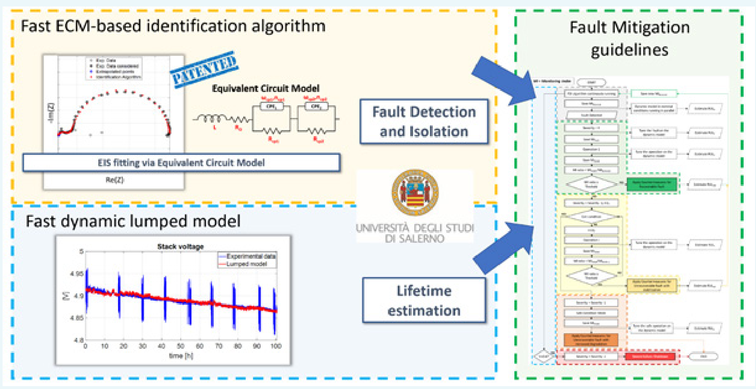
ALGORITHMS DEVELOPMENT

Monitoring and Diagnostic Tools

A diagnostic algorithm has been developed 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 derive significative features for a proper Fault detection and Isolation. It works on different technologies and configurations. The FDI algorithm, suitably coupled with a fast and dynamic lumped model allows estimating the Remaining Useful Life of the stack. Moreover, the diagnostic tool can be used in "reverse mode" to suggest the proper mitigation strategy to apply and to verify its effectiveness.



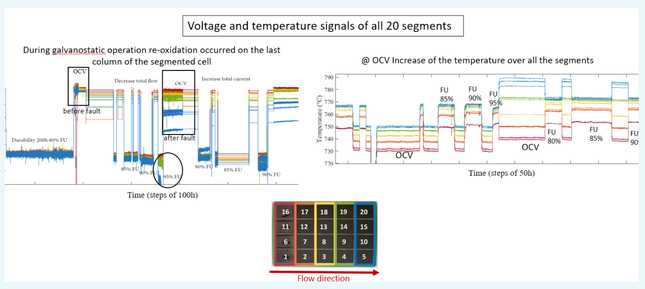
The Linux-based board sends acquisition commands to the Bitron board. Once the acquisition is completed the data samples are stored as binary files on the Linux-based board. Those data files are used in a second time for the elaboration process by the algorithms developed by all the partners. The aim 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.

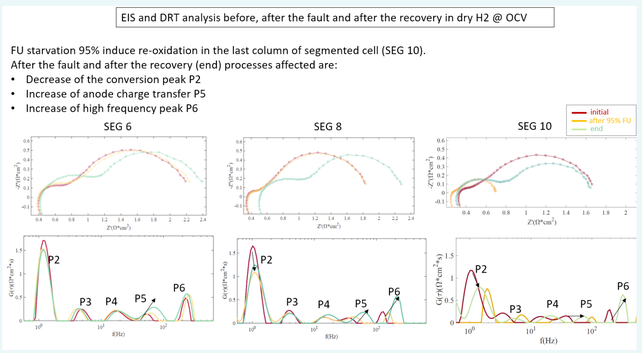


Furthermore,they can be easily tested and validated creating "ad hoc" test suites with the objective to guarantee robustness and reliability.

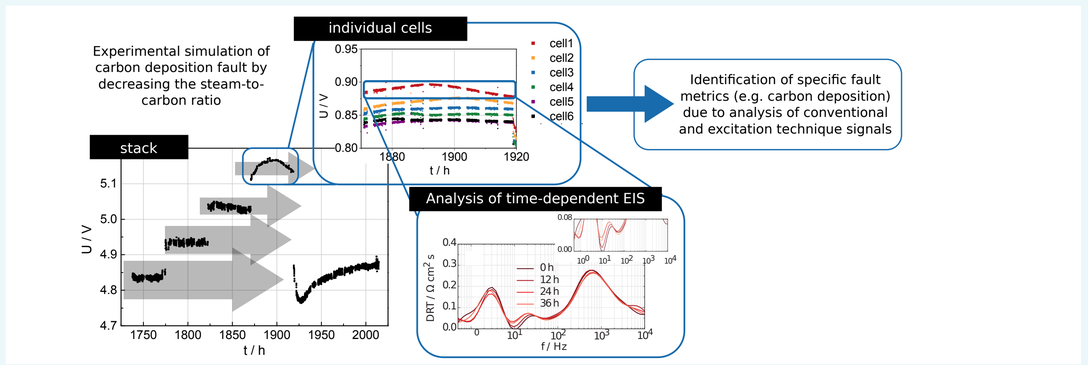
The figure shows the schematics of the high level (HL) software; it has been conceived to include EXTERNAL CODE that takes as input the acquired data for performing on the Linux-based board the diagnostic methods.

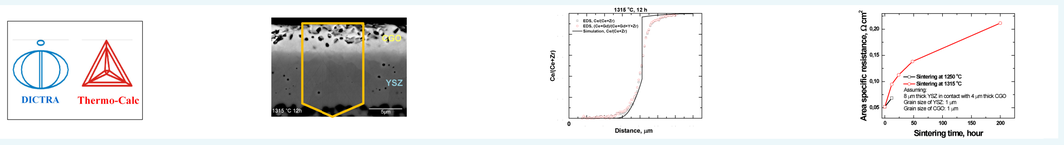
Validation of algorithms on lab scale system





The inter-diffusion induced microstructural degradation on the oxygen electrode side, namely the inter-diffusion between the CGO barrier layer and the YSZ electrolyte, causing serial resistance increase. A thermodynamic and kinetic database of the ZrO2-CeO2 system was established and validated with experimental data. The database was then applied to predict diffusion (composition) profiles and serial resistance increase during cell fabrication and long-term operation. A reasonable agreement with experimental data is achieved.





Lifetime Tools

Features :

- Extensive work to define the most useful metrics for assessing SoH, performance history and trajectory and lifetime
- Done from data of first testing campaign and other data available, on fuel starvation and C deposition
- Mitigation matrix designed
- Modelling of the degradation :
  - LSCF and composite electrode: physically based model of EIS
  - Cermet and Ni volatilization
  - Microstructural degradation of oxygen electrode : thermodynamic and kinetic database established and validated; used to predict composition profile and serial resistance increase upon interdiffusion issue
  - EIS model: steady state model with transitory terms included
  - Fast-lumped model to reproduce real system behavior with acceptable error
  - Thermoechanical degradation
- Preliminary fault signature matrix designed

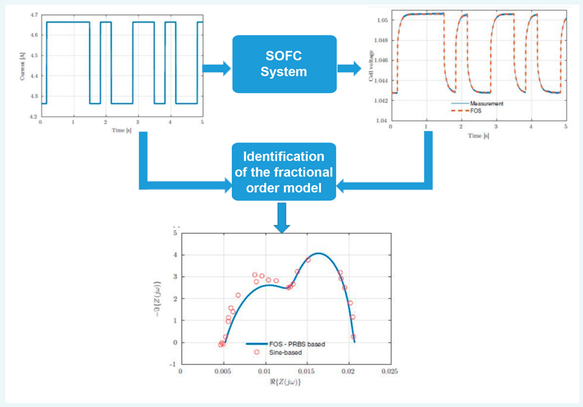


Fig.1: From non-sinusoidal excitation to SOFC model. Below is the comparison between conventional sine-based EIS (circles) and PRBS-based EIS (solid line).

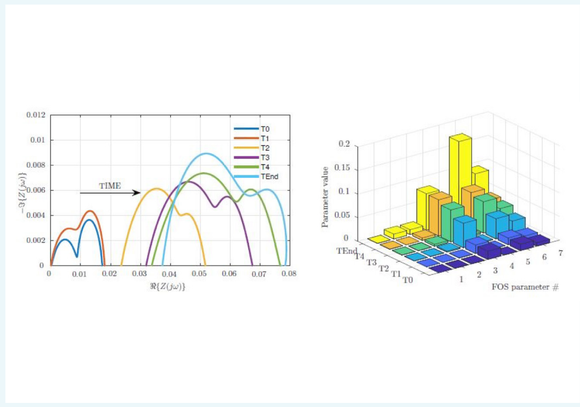


Fig.2: Evolution of EIS curves during the degradation process (left) and the parameters of the process model (right). The latter is obviously affected by the degradation.

SYSTEM INTEGRATION AND TESTING

In order to make sinusoidal/ PRBS stimulus and to perform THD and EIS measurements, works have been carried out to modify the DC/DC converter integrated in the commercial SOFC system to be operated on-site

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