HEALTH-CODE

Real operation pem fuel cell HEALTH-state monitoring and diagnosis based on DC/DC Converter embeddeD Eis (671486)

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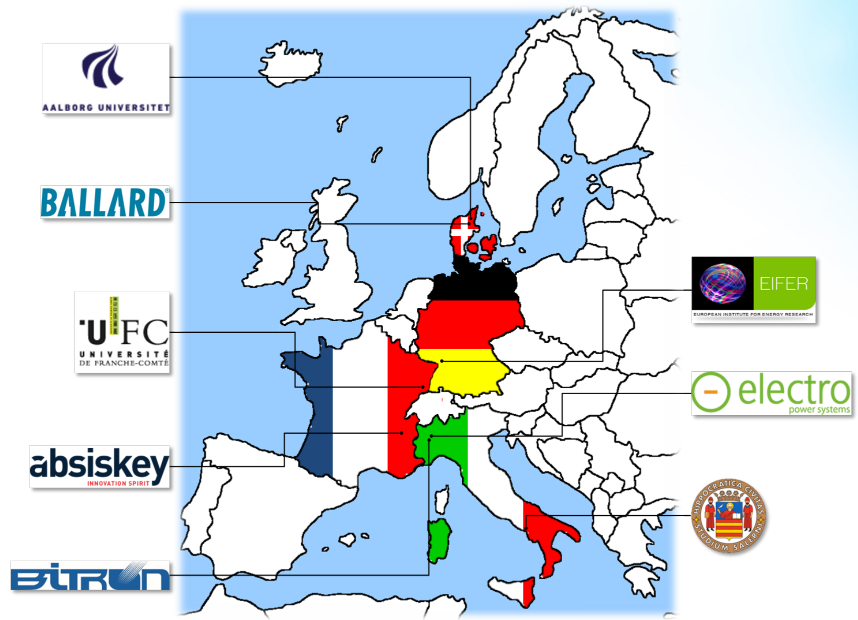
PROJECT OVERVIEW

PROJECT INFORMATION	
Call topic	FCH-02.3-2014
Topic title	Stationary fuel cell system diagnostics: development of online monitoring and diagnostics systems for reliable and durable fuel cell system operation
G.A. #	671486
Pillar	Energy
Start/End	01/09/15 – 31/12/18
Budget (€)	2,358,736 (100% FCH2JU)
Completion	35% @ M14

PARTNERS

1. Università degli Studi di Salerno (I);
2. Aalborg Universitet (DK);
3. Ballar Power Europe AS* (DK);
4. European Institute for Energy Res. (D);
5. Electro Power System S.p.A. (I);
6. Bitron Industrie S.p.A. (I);
7. Université de Franche-Comté (F);
8. Absiskey SAS (F).



*Former Dantherm Power A/S.

PROJECT SUMMARY

HEALTH-CODE aims at implementing an **advanced monitoring and diagnostic tool based on <u>Electrochemical Impedance Spectroscopy</u> for <u>air/reformate-fed μ-CHP</u> and <u>oxygen/hydrogen-fed backup PEMFCS</u>**.

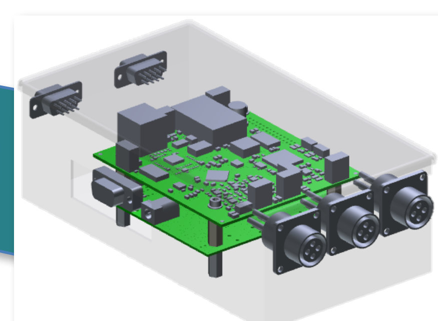
The tool is able to determine FC status (condition monitoring) to **support stack failures detection** and to **infer on the remaining lifetime**.

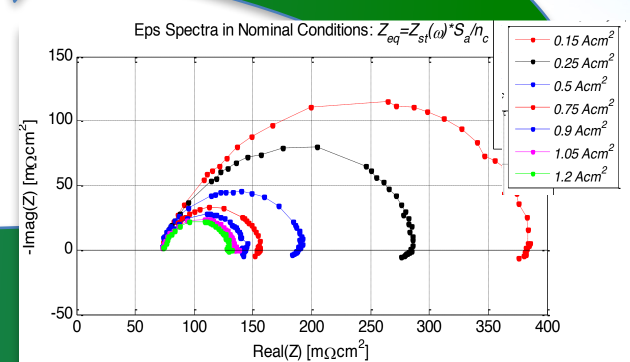
Embedded low cost on-line EIS

Fault Diagnosis

&

Lifetime inference

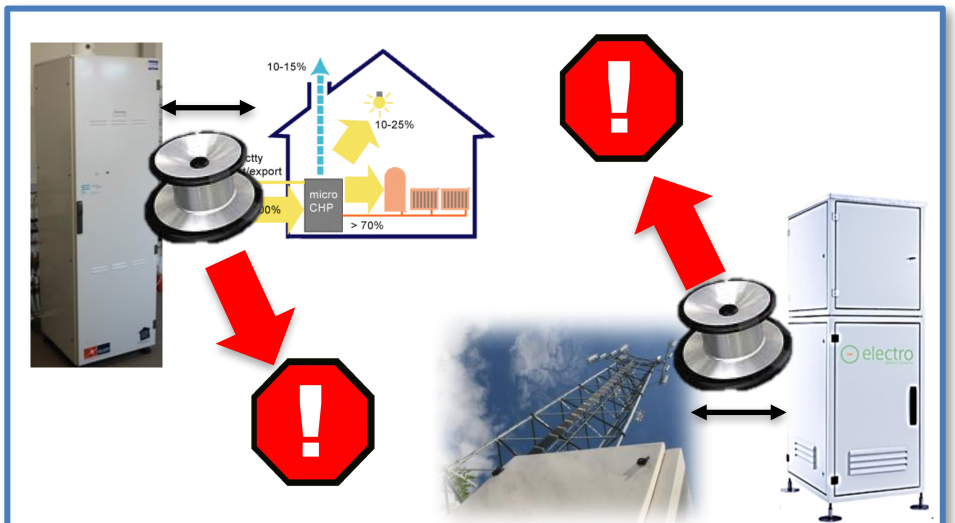




PROJECT OBJECTIVES

1. Enhancement of **EIS-based diagnosis for embedded on-line applications**;
2. Development of a monitoring and diagnostic tool for **state-of-health assessment, fault 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 experimental campaign for tool development.

Performance, Durability, Availability



Reduce OPEX

D-CODE LEGACY TO HIGHER TRL

EIS board TRL: 4 → 5/6

The EIS board from D-CODE is re-engineered for high quality measurements and embedded applications, thus moving from lab-scale to system on-line.

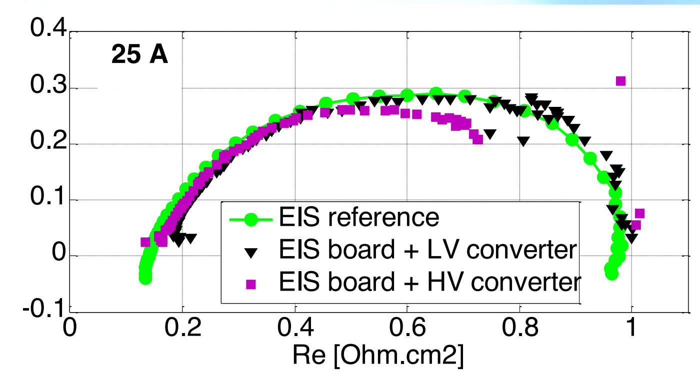
DC/DC converters TRL: 4 → 6

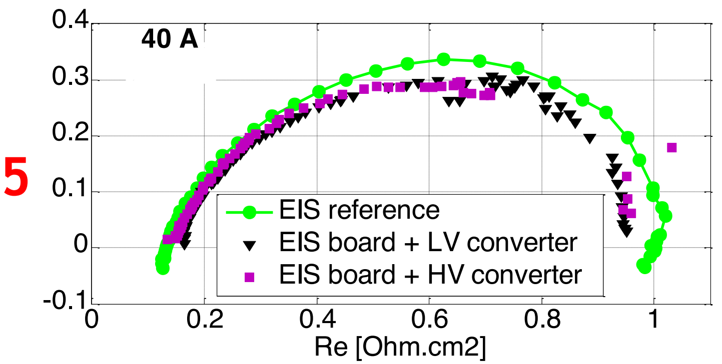
Conventional HW is modified/re-engineered to allow flexibility and multiple market choice for manufacturer strategies.

Monitoring & diagnostic algorithm TRL: 3 → 4/5

Enhancement for proper isolation of 5 faults and reliability (attention to air-fed and oxygen-fed differences).

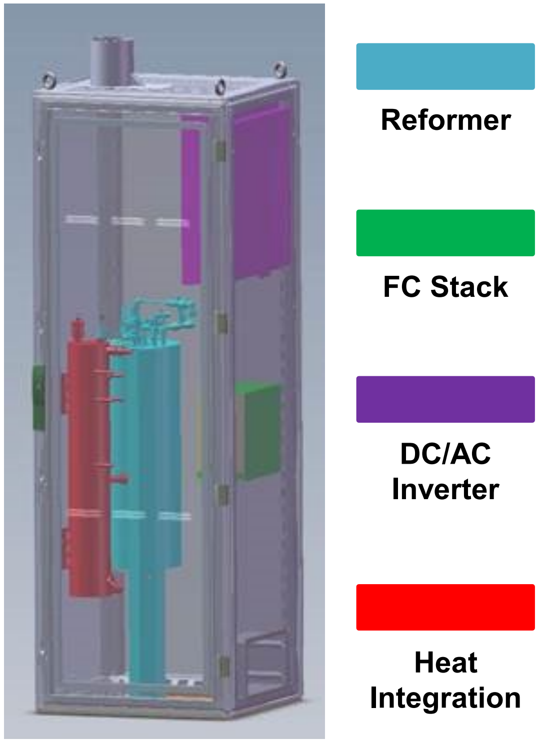
EIS - lab equipment vs. board





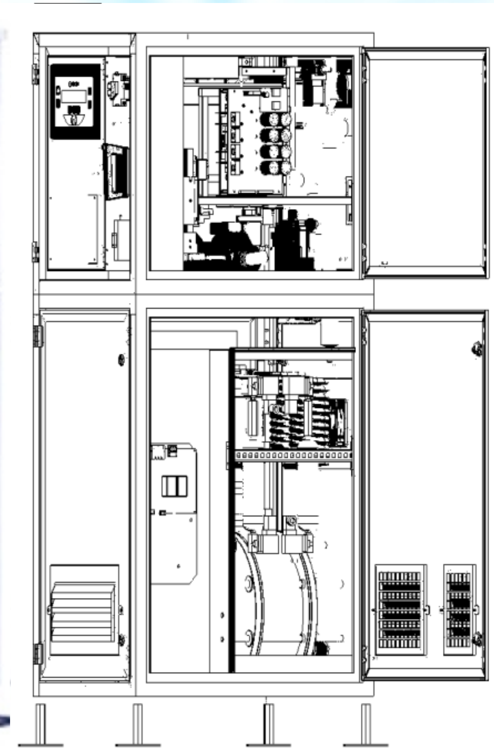
FUEL CELL SYSTEMS

Ballard Europe μ-CHP system



Rated power: 1.3 kW;
Cooling system: Water cooled;
Reactants: **Air** & **Reformate**;
Applications: Residential heat and electric power production.

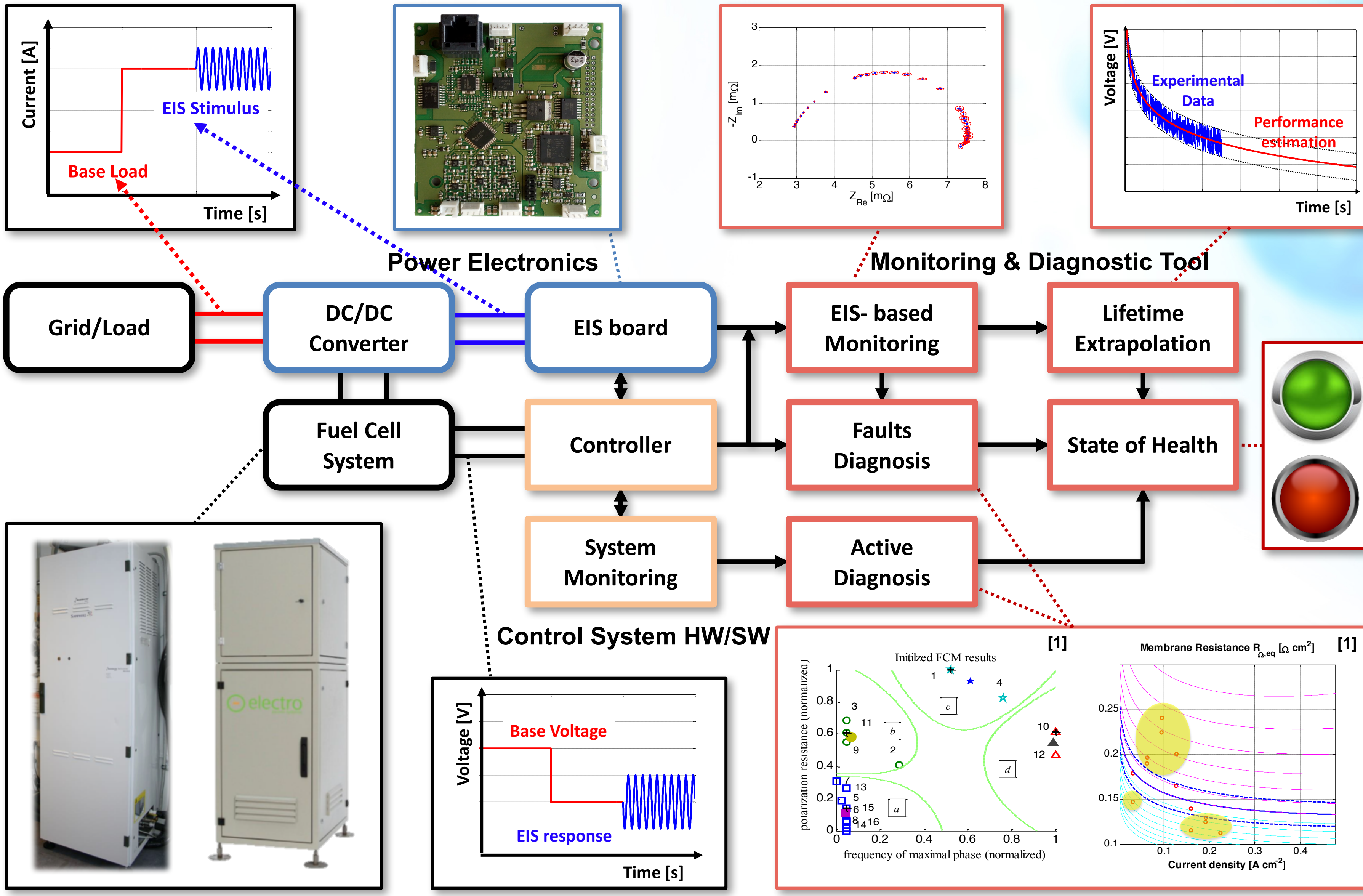
EPS backup system



Rated power: 3 kW;
Cooling system: Water cooled;
Reactants: **Pure Oxygen** & **Hydrogen**;
Applications: Backup/grid-connected electric power production with H_2 as energy buffer.

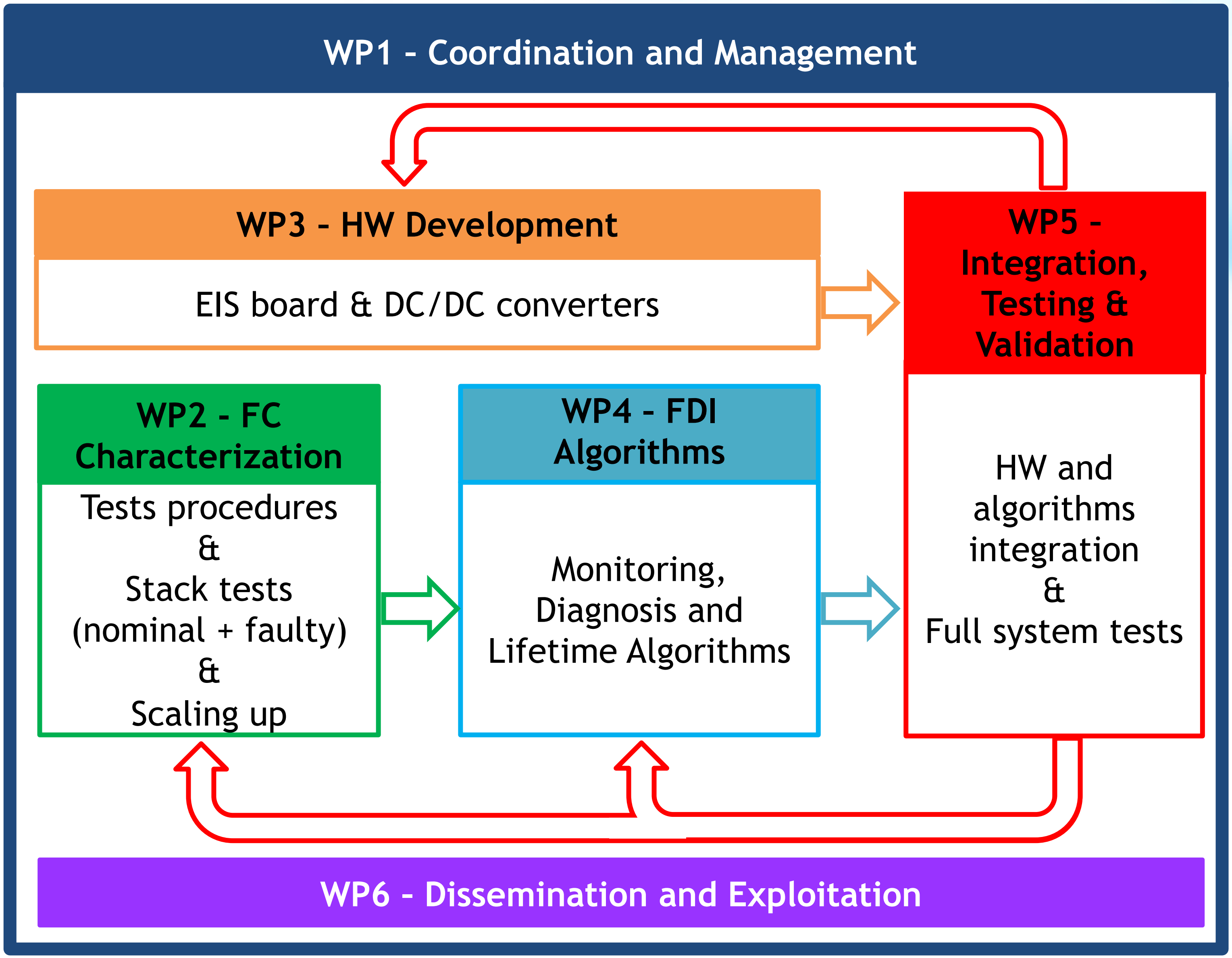
ON-LINE EIS

MONITORING, DIAGNOSTICS, LIFETIME



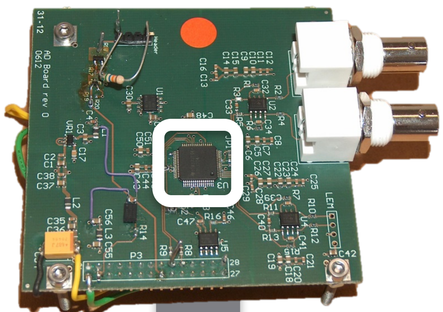
[1] D-CODE Project final report: www.d-code-jti.eu

PROJECT FRAMEWORK

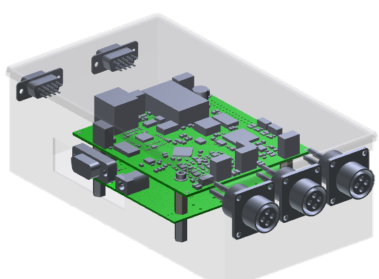


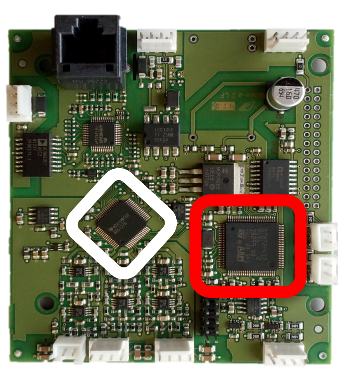
EIS BOARD

FROM D-CODE (slave)



TO HEALTH-CODE

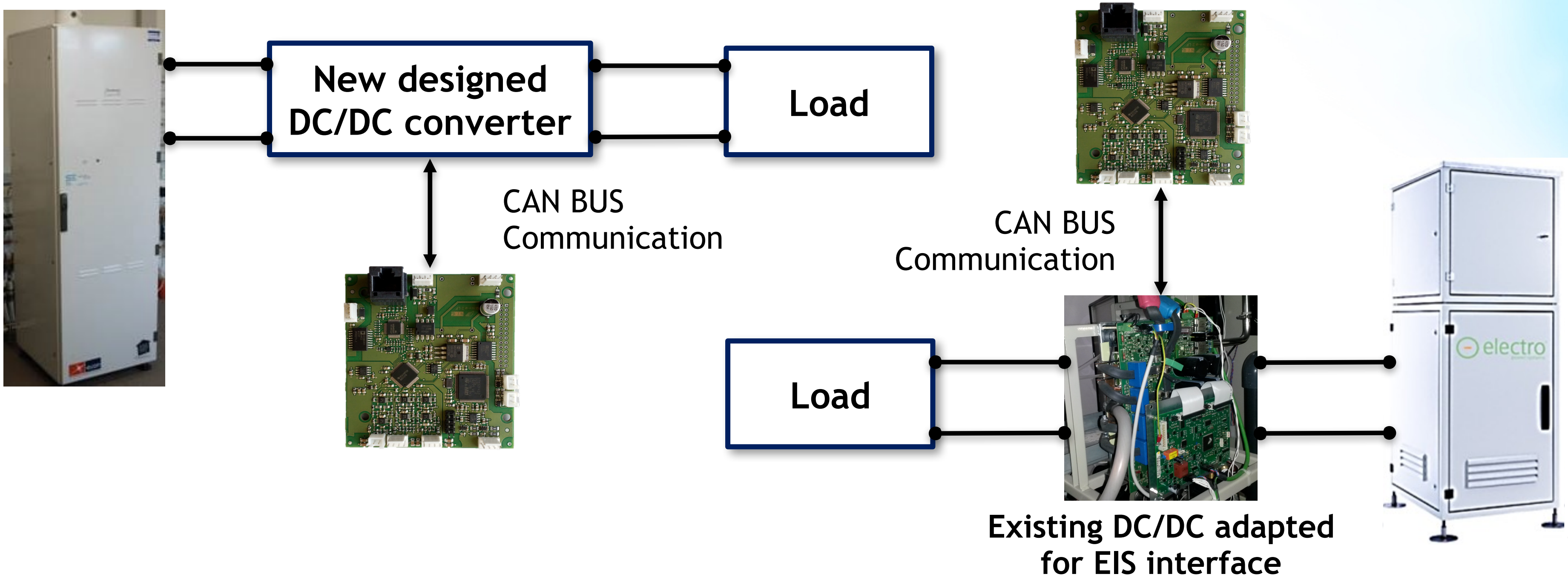




BOARD FUNCTIONS	D-CODE	HEALTH-CODE
Voltage input	✓	✓
Current sensor input	✓	✓
Current shunt input	✗	✓
Analog filtering	✗	✓
ADC 24 bit	✓	✓
PWM from Beagle Board	✓	✓
Real Time microprocessor	✗	✓
Aux SRAM	✗	✓
PWM from RT micro	✗	✓
ISO CAN interface	✗	✓
ISO COM interface	✗	✓
100Tbase ETH interface	✗	✓
ADC clock tunable	✗	✓
ADC SW configurable	✗	✓

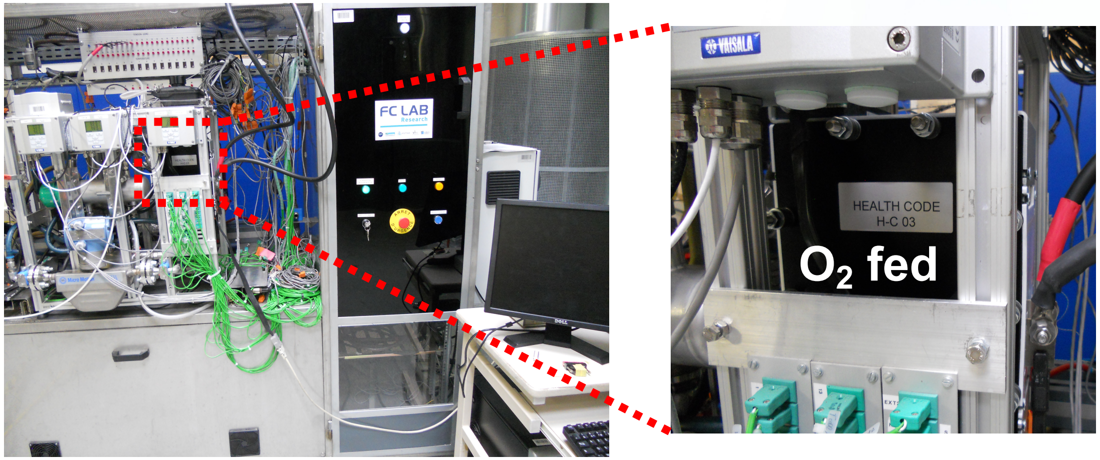
POWER ELECTRONICS

- **One DC/DC power for each tested FC system** is considered (i.e. Ballard Power EU µ-CHP system and EPS backup system);
- This work will lead to **useful guidelines** for any company who would like **to implement the EIS board** on its own FC system:
  1. design a new new DC/DC converter for EIS board interfacing;
  2. modify an available one to allow the communication with the EIS board.



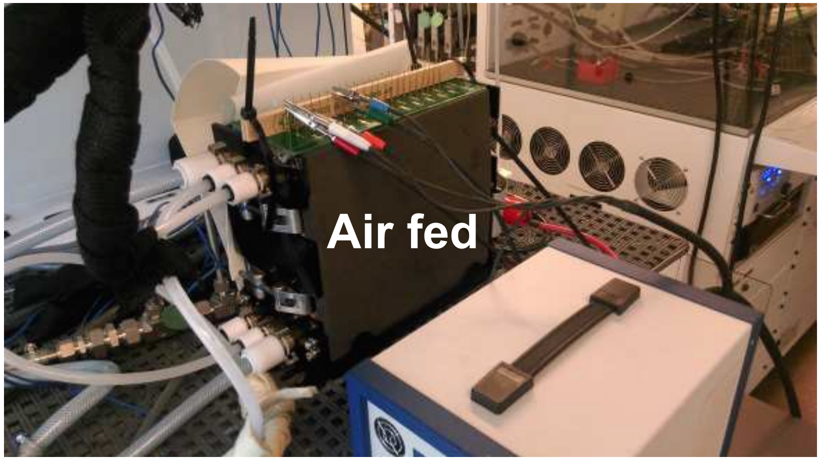
EXPERIMENTS

EPS short stack @ UFC

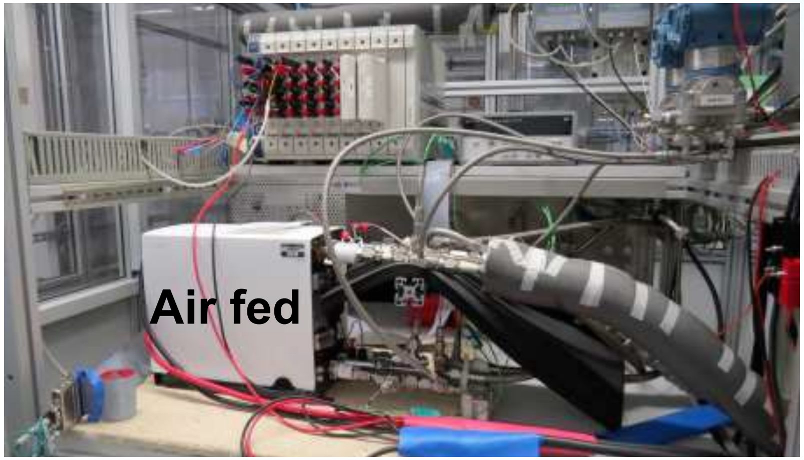


Overall expected number of EIS spectra between **1000** and **1500**
Under nominal and faulty operations

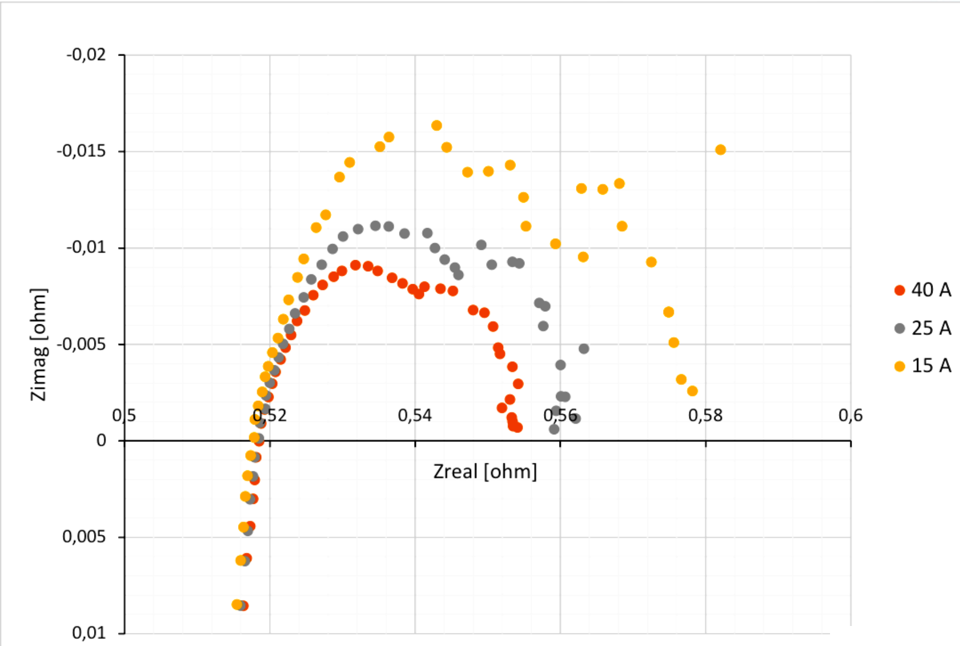
Ballard stack @ AAU



Ballard stack @ EIFER



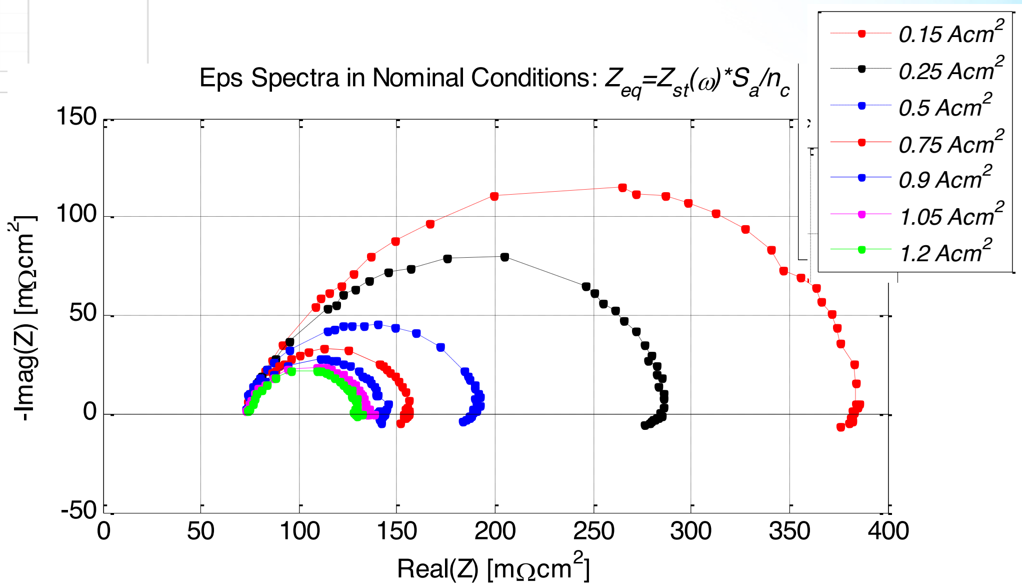
EIS CHARACTERIZATION



Preliminary EIS results @ AAU
Tests done on air/reformed-fed stack in nominal conditions @ 15 A, 25 A and 40 A.

About 160 spectra measured to date, 110 of which in faulty conditions.

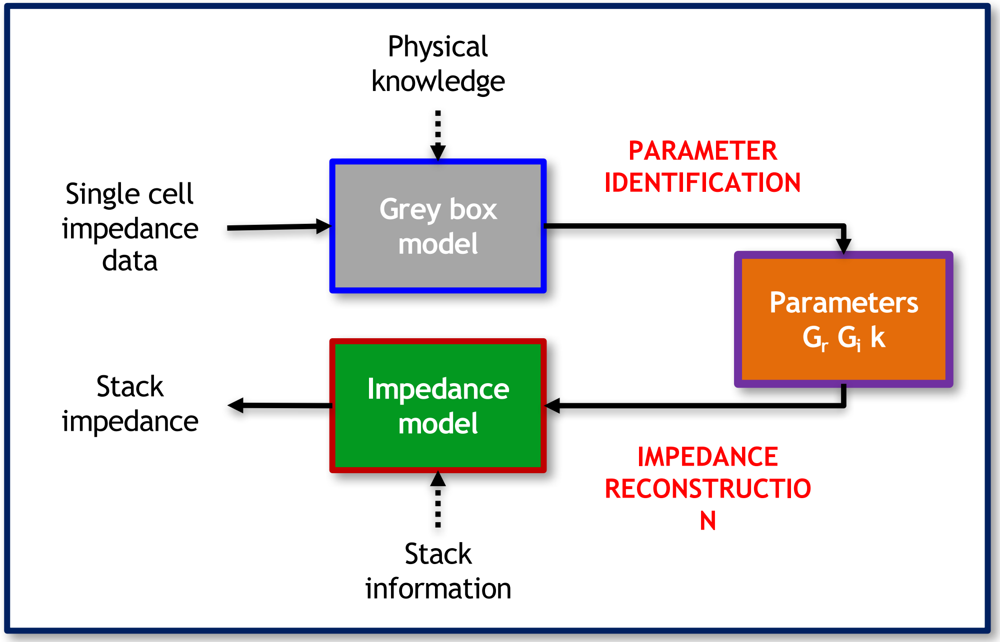
Preliminary EIS results @ UFC
Tests done on oxygen/hydrogen-fed short stack in nominal conditions.

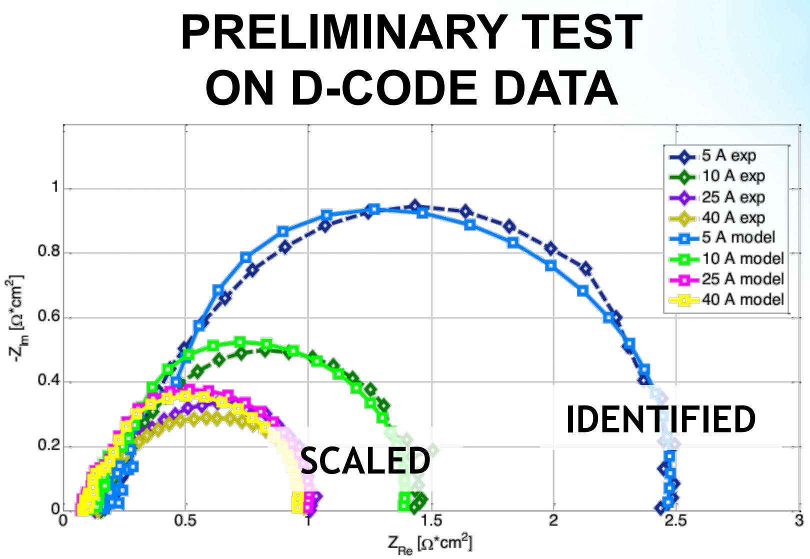


SCALING-UP

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

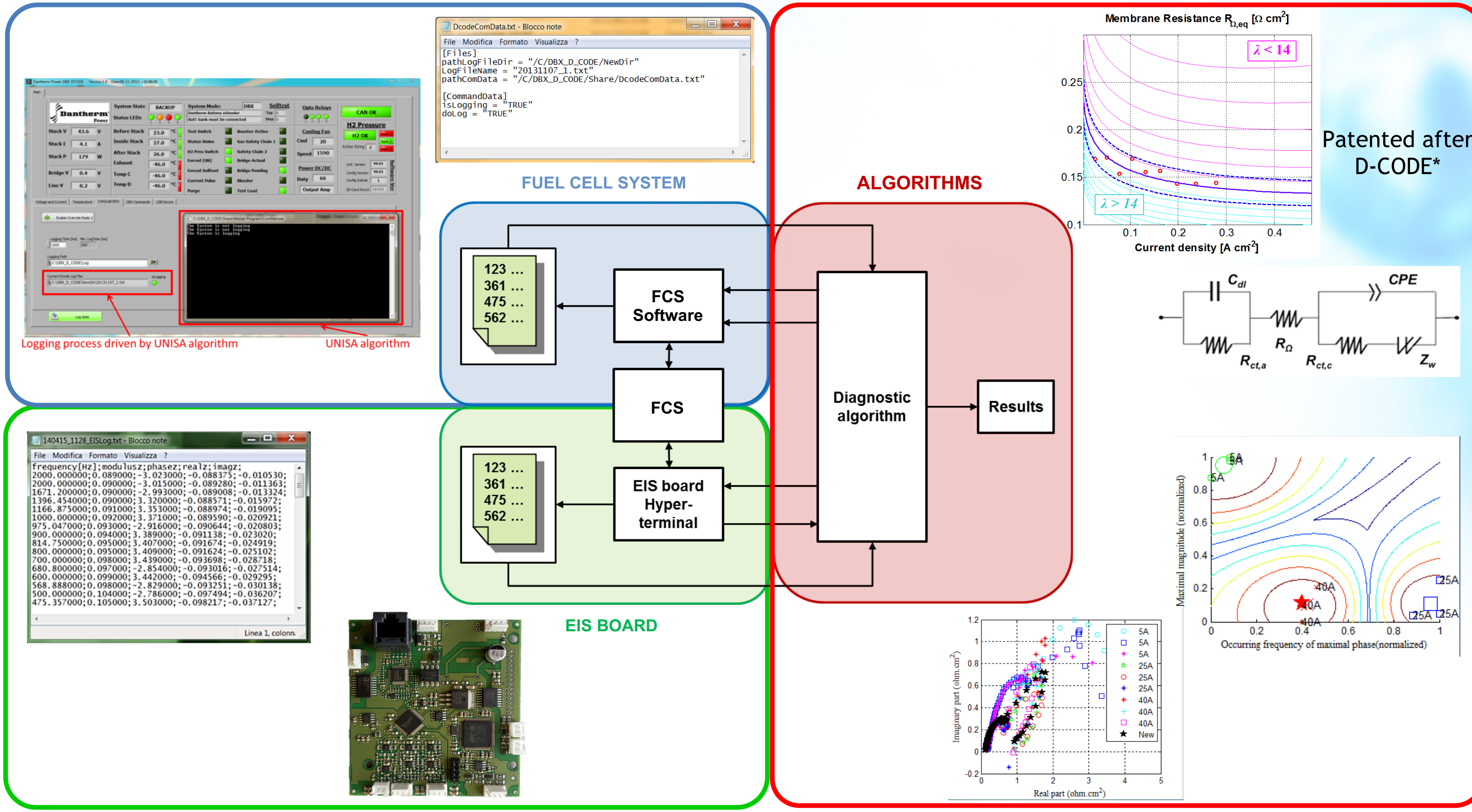
- Derive **stack faulty behavior** from single cell tests performed under faulty conditions to **improve FC systems lifetime.**





DIAGNOSTIC ALGORITHMS

FRAMEWORK FROM D-CODE



*Patent, No. PCT/IB2015/058258; Authors: Petrone R., Polverino P., Pianese C., Sorrentino M.; Title: Method For Monitoring And Diagnosing Electrochemical Devices Based On Automatic Electrochemical Impedance Identification.

LIFETIME INFERENCE

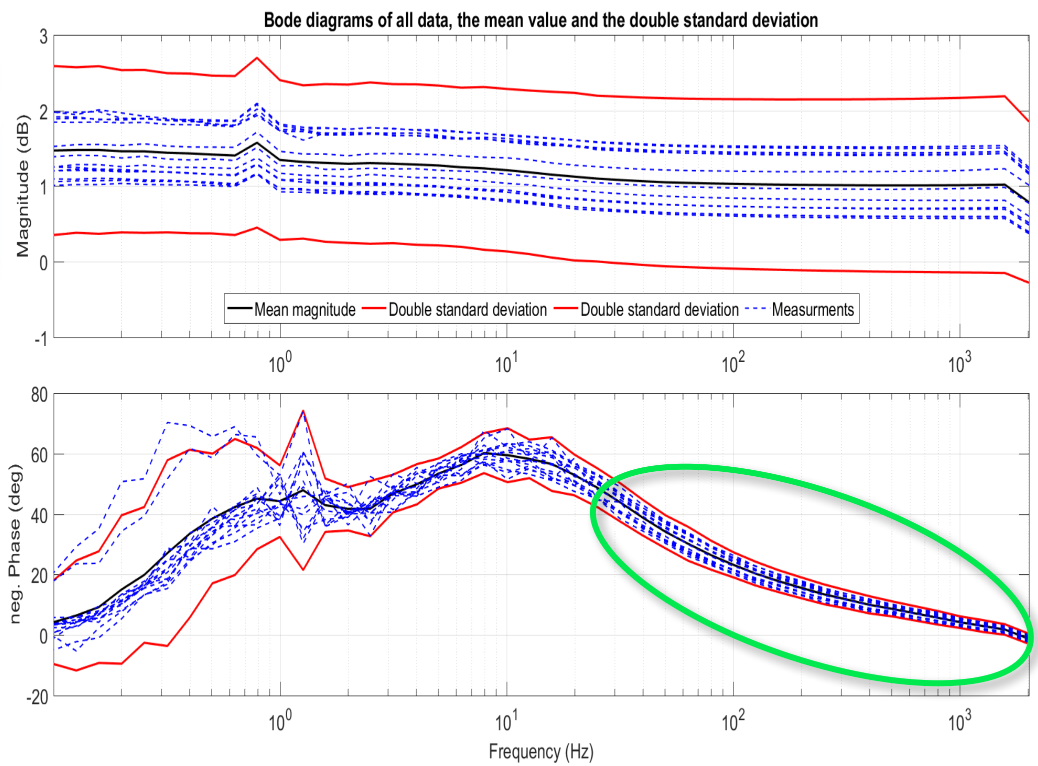
MAIN OBJECTIVE

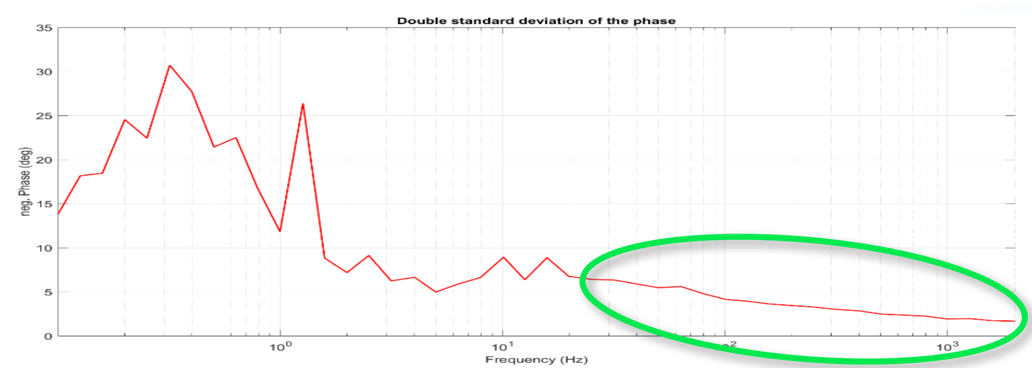
Upon analysis of experimental data, **EIS parameters** not changing with faulty conditions at different currents **are identified**: their variation can thus be only related to **ageing phenomena**.

EXAMPLE

Phase shift of the Bode Plot **at high frequencies**:

- small double standard deviation for all experiments, minor influence of faulty conditions;
- phase shift over time may be related to ageing.



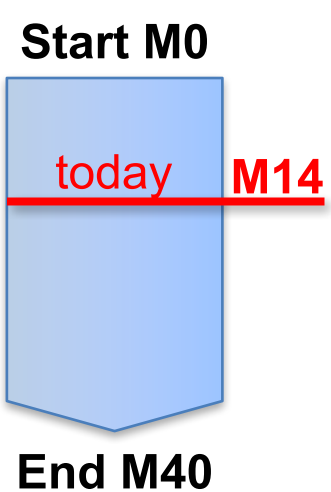


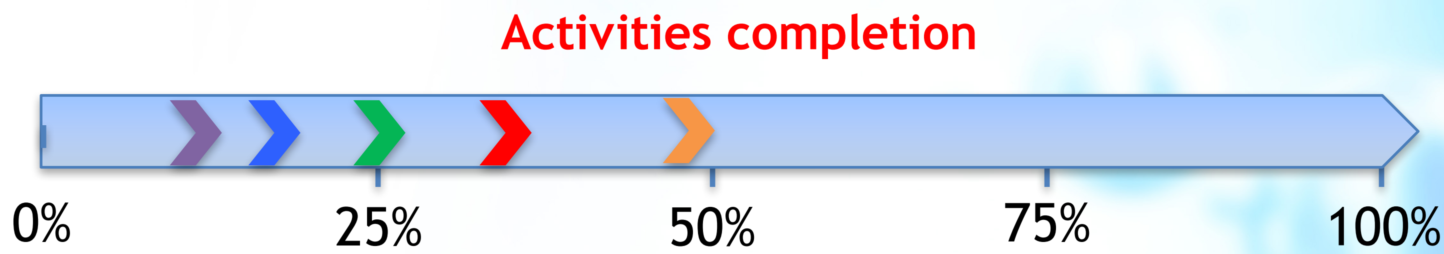
SYNERGIES WITH OTHER PROJECTS

Interactions with projects funded under EU programmes (FP7)	
D-CODE	Leverage of EIS board and power electronics hardware, as well as monitoring and diagnostic algorithms.
GENIUS	Application of Design of Experiment (DoE) approach, monitoring and diagnostic algorithms and Fault Tree Analysis.
FITUP	On-field tests of UPS systems to improve backup system reliability.
STACK-TEST	Harmonized test procedures for PEMFC stack under normal and faulty conditions.
DIAMOND	Modelling for control and diagnosis, fault tree analysis, advanced control, experiments.
SAPPHIRE	Control, diagnosis and prognosis of CHP PEM fuel cell systems.
Interactions with national and international-level projects and initiatives	
PROCIPE (F)	Prognosis of automotive and stationary PEM FC.
DIAPASON 1&2 (F)	Diagnostic methodologies, experiment in abnormal conditions, degradation mechanisms.
EXC-CELL (DK)	New generation of control algorithm with built-in diagnostics capabilities to improve operation.

PROJECT PROGRESS

- Experiments
- EIS Board
- DC/DC converters
- Diagnostic algorithms
- Scaling-up algorithm





Future steps towards Mid-Term (M20):

Experiments: 1st experimental campaign in unfaulty and faulty conditions is ongoing (data available @ M16); 2nd experimental campaign is scheduled (to be closed @ M24).

EIS board: first EIS board new generation prototype (available @ M14); preliminary tests are scheduled before M18.

DC/DC converters: EPS converter modifications ongoing (available @ M17); Ballard new converter designed, to be commissioned (prototype available @ M21).

Diagnostic algorithms: will be tested on the EIS measurements once first campaign is completed (after M16).

Scaling-up algorithm: characterized on literature data (M12) to be finalized and validated on project data (after M16).

EXPLOITATION PLAN & IMPACT

Exploitation

- Enhance **educational** activities in FCH (introduce control and diagnostic topics at BS & MS levels; strengthen PhD programs).
- Secure potentially **patentable** findings.
- Apply EIS-based monitoring for **control** of FCs
- Extend the methods to related fields (**other FCs** or technologies).
- Possible **spin-off** activities supported by national and EU programs.

Impact

- **Lifetime** from B10-5 to B10-10*.
- **Efficiency** from 32 to 36%;
- **Availability** from 99.6% to 99.9% and warranty condition from 15000 h/1000 cycles to 20000 h/1500 cycles.
- Establish structured research activities focusing on applied research topics.
- Build new collaboration with other industrial suppliers/partners.
- Increase know-how and potentially patent portfolio.

*** BX-Y: X% of running systems will experience a fault in Y years**

DISSEMINATION ACTIVITIES

Public deliverables

- D5.1 System Testing Procedure
- D5.3 Diagnostic Tool Final Validation
- D6.1 Project Website
- D6.6 Workshop N.1
- D6.7 Final Demonstration Workshop N.2

Conferences/Workshops

- Upcoming workshop to be organised jointly with DIAMOND project @ M23 (Summer 2017)

Social media

pemfc.health-code.eu

Next publications:

- 2 papers on fault analysis and diagnostic algorithms based on electrochemical impedance spectroscopy (EIS) are currently under preparation.
- 1 paper on scaling-up approach under preparation.

Patents:

- Algorithms and hardware development may lead to IP protection actions.

Thank You!

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