Project **RUBY**

Robust and reliable general management tool for performance and durability improvement of fuel cell stationary units

HARDWARE FOR ON-FIELD EIS:

STATE OF THE ART, SOLUTIONS AND ISSUES

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Summary

- Different hardware can be used for performing ON-LINE Electrochemical Impedance Spectroscopy (EIS)
- Different solutions show advantages/drawbacks and require significant or minor changes to existing hardware
- EIS-oriented stimuli injection is the major issue
- Measurements with satisfactory accuracy is a challenging issue as well
- Activities carried out in some projects demonstrate ON-LINE EIS is a feasible task
- More market/industries sensibility is expected in the field of ON-LINE diagnosis
- An increasing room for research and development in ON-LINE monitoring and diagnosis is envisaged

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H2020 Programme Grant Agreement Number 875047

EIS-diagnosis focused EU projects pathway

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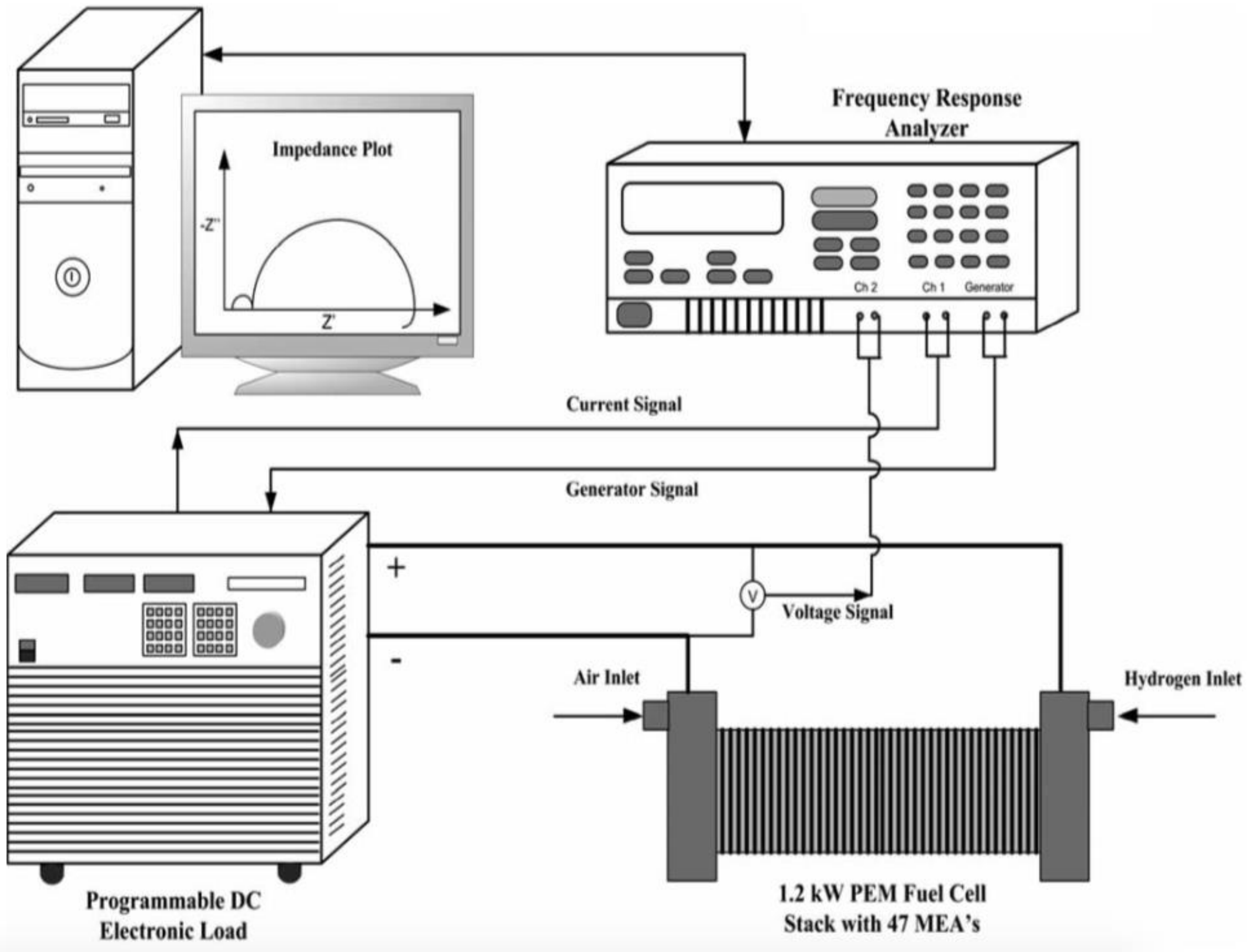
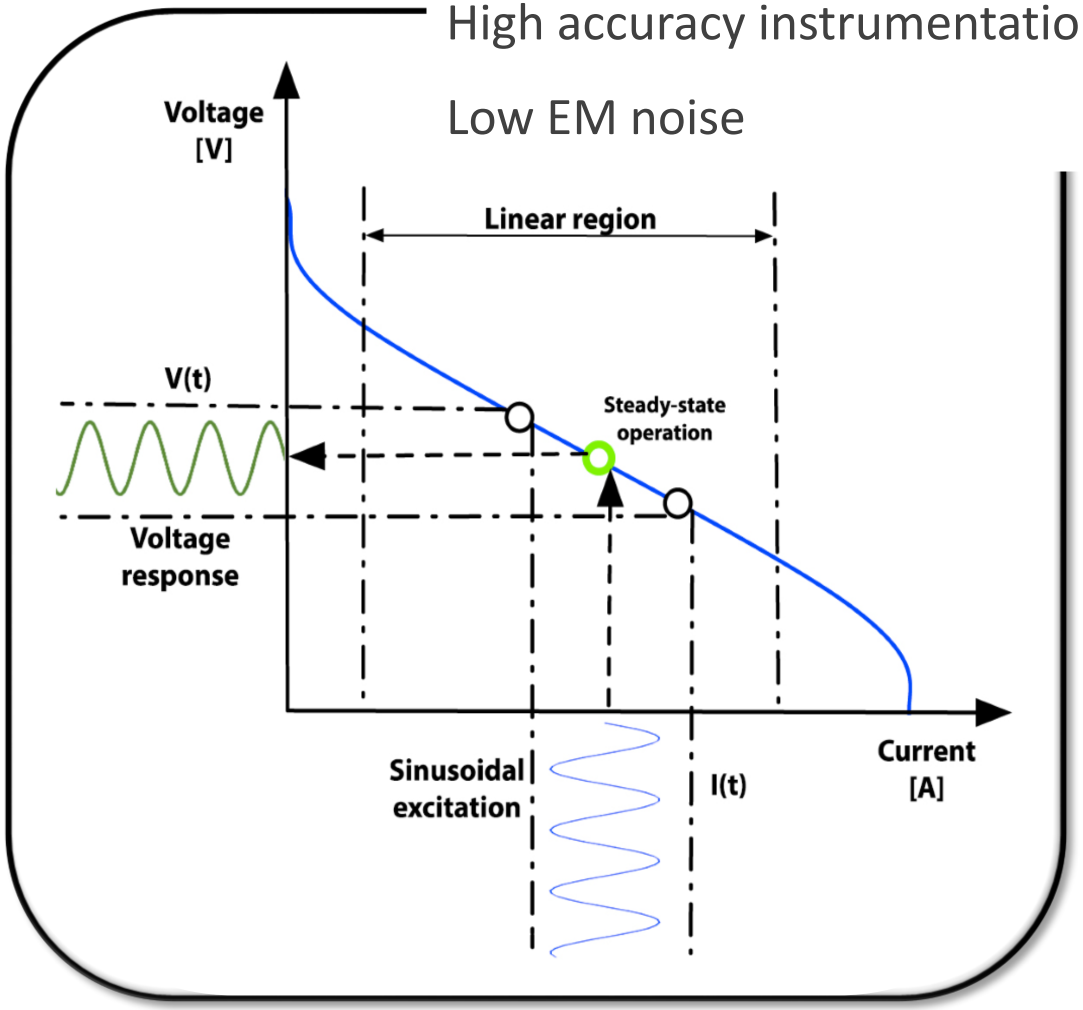
EIS principle and laboratory implementation



Simple idea

High accuracy instrumentation

Low EM noise



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What is challenging in on-field EIS?

Fuel cells systems are usually designed to smooth out stack current or voltage perturbations

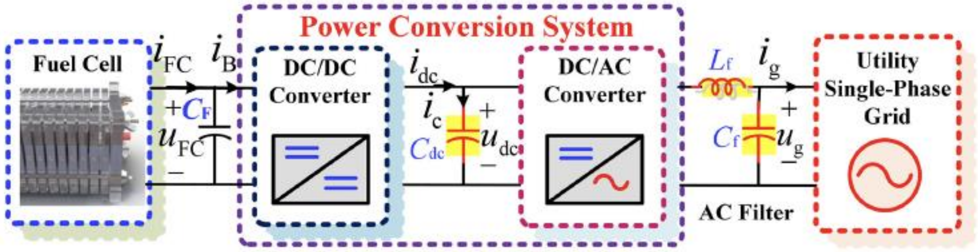

Fig. 1. Block diagram of two-stage grid-tied fuel cell distributed generation.

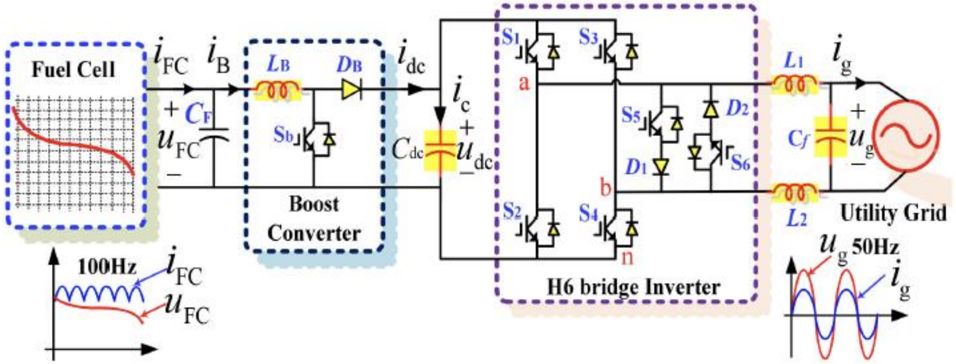

Fig. 2. Circuits of single-phase grid-tied PEMFC system and its key waveforms of dc input/ac output.

For instance, oscillations due to single-phase operation are avoided (in the same EIS frequency range…)

Suitable control strategies are used in order to **avoid** additional passive filtering and increase of the DC-bus capacitance.

Large electrolytic capacitors also affect power **electronic circuits lifetime and reliability**.

IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 69, NO. 6, JUNE 2022 5625

DC and AC Power Quality Control for Single-Phase Grid-Tied PEMFC Systems With Low DC-Link Capacitance by Solution-Space-Reduced MPC

Bin Liu, Guojin Li, Deqiang He, and Yanming Chen

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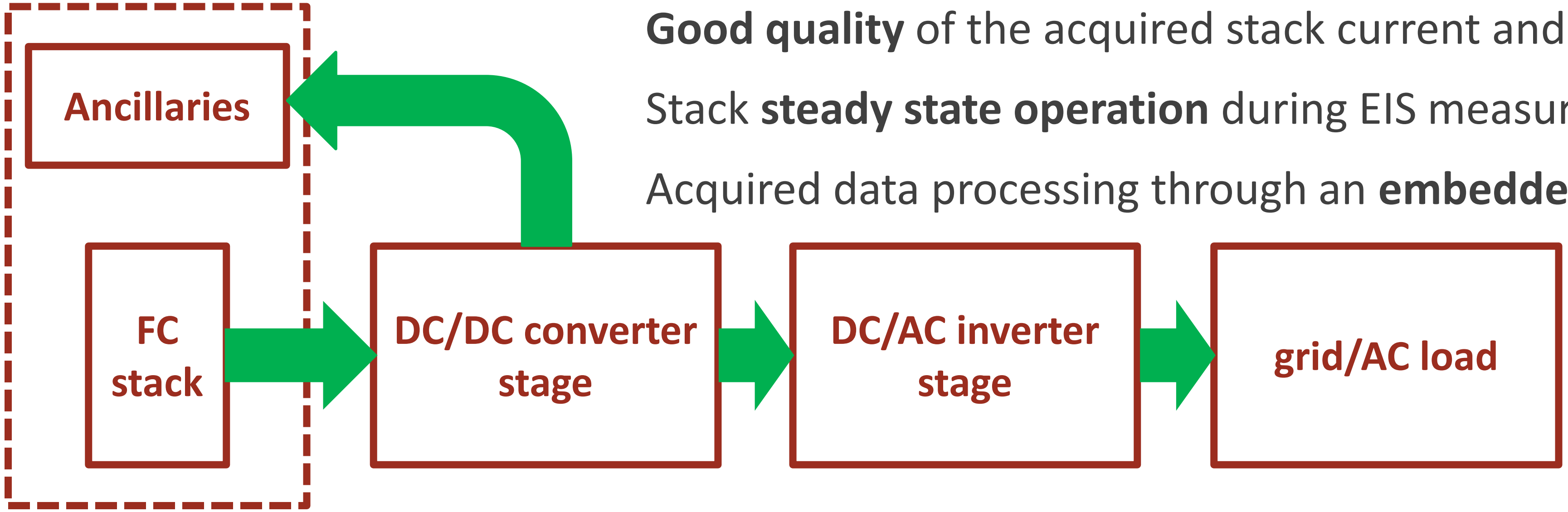
What is challenging in on-field EIS?

Constant amplitude of the injected disturbance in a wide range of frequency

Good quality of the acquired stack current and voltage waveforms

Stack **steady state operation** during EIS measurements

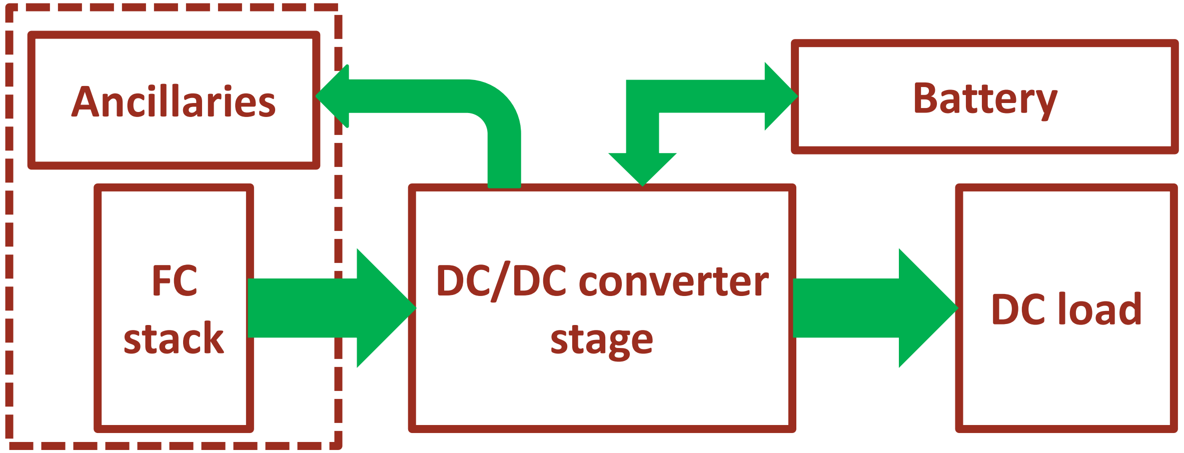
Acquired data processing through an **embedded processor**



Some configurations are available in stationary applications

AC applications have a high voltage bus in DC

DC configurations are used also in backup applications



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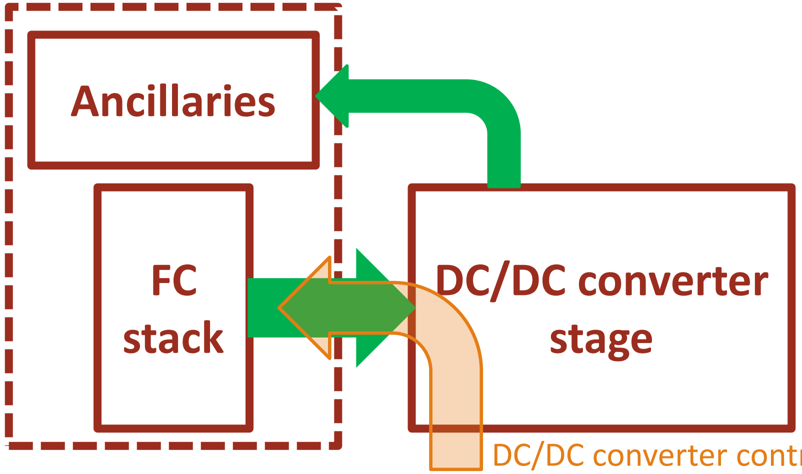
The on-field EIS perturbation injection strategies

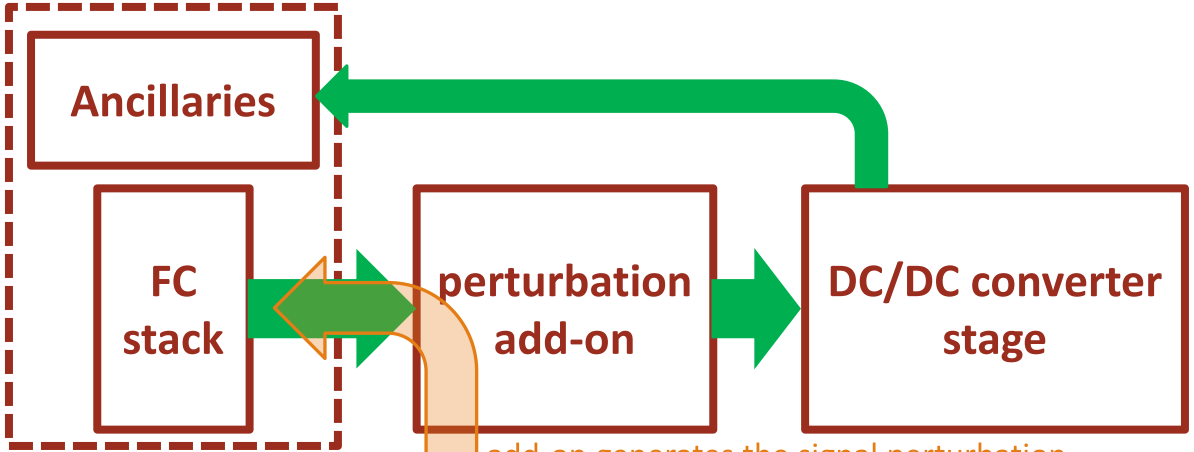
Switching converter-based actuation



The EIS perturbation has to be injected through the switching converter, which has to be suitably adapted for this new action

DC/DC converter control signal perturbation

EIS perturbation injection through add-on hardware



The switching converter remains unchanged, but a new hardware is interposed to perform the required function

add-on generates the signal perturbation

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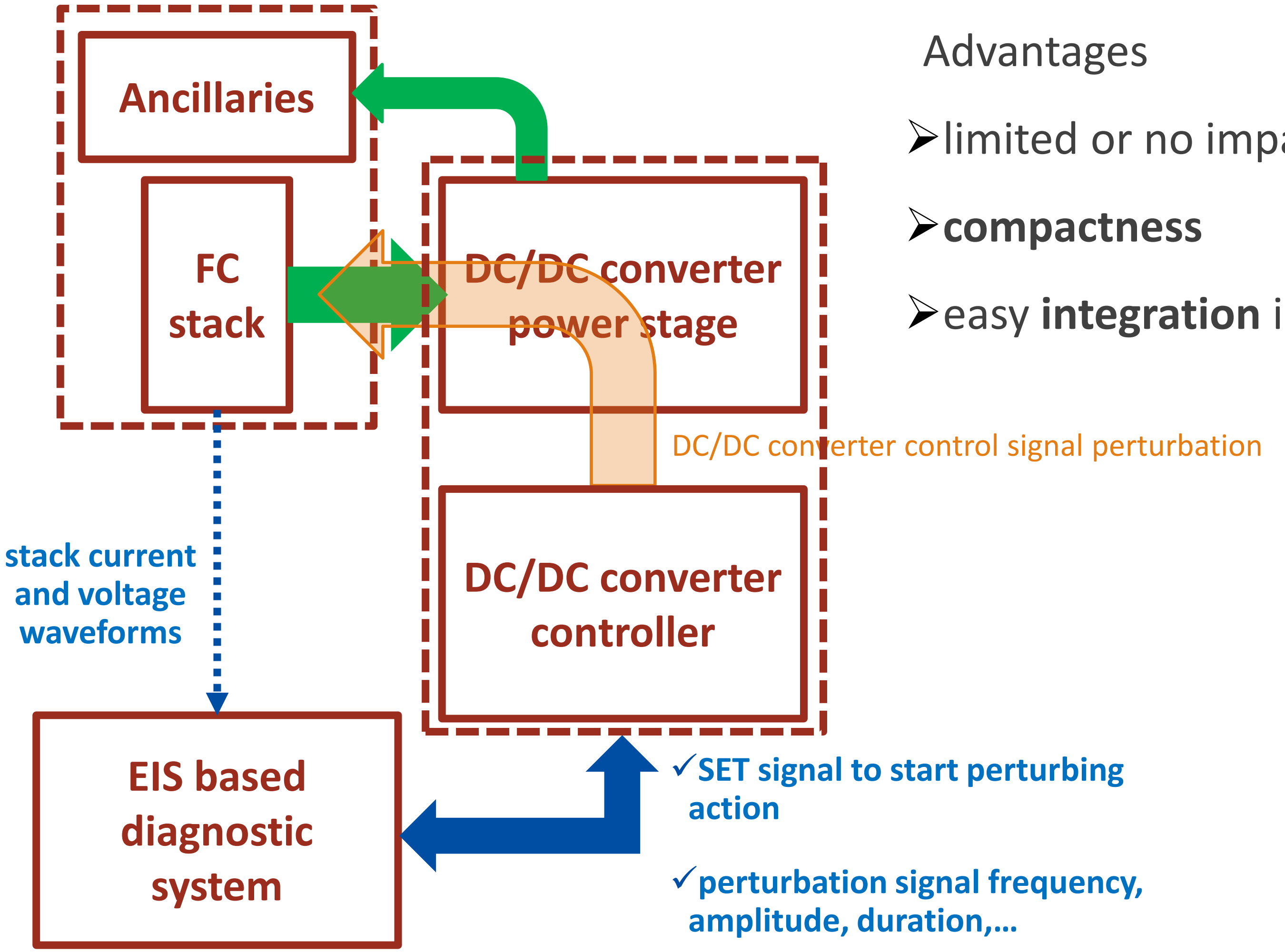
Switching converter-based actuation



Advantages

- limited or no impact on the **conversion efficiency**
- **compactness**
- easy **integration** in the system as a whole

- ✓ SET signal to start perturbing action
- ✓ perturbation signal frequency, amplitude, duration,…
- ✓ GET status of the DC/DC converter

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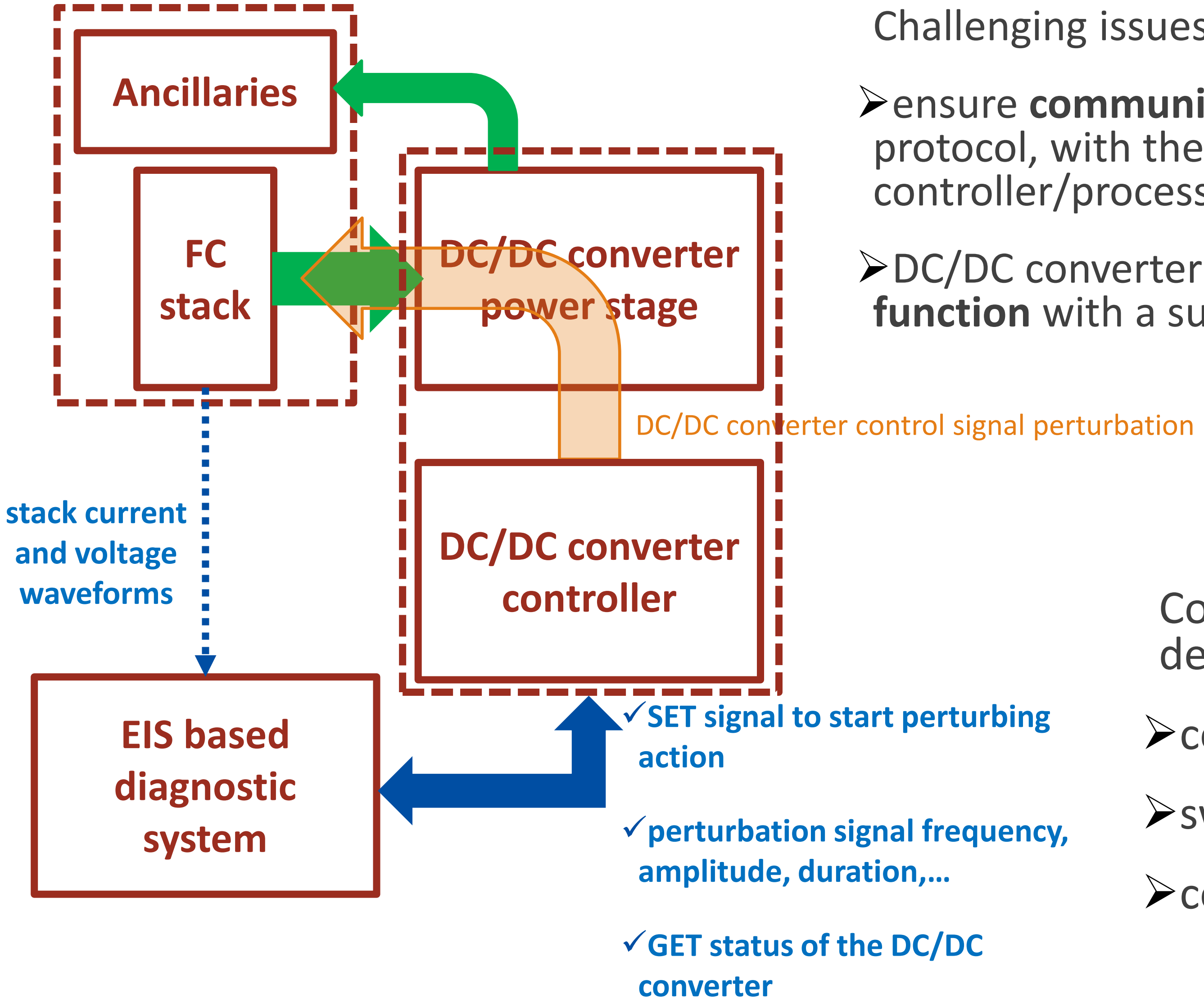
Switching converter-based actuation



Challenging issues & drawbacks

- ensure **communication**, through a suitable protocol, with the DC/DC converter controller/processor
- DC/DC converter **control-to-input transfer function** with a suitable bandwidth

Control-to-input transfer function depends on:

- converter input filter
- switching frequency
- converter control loops

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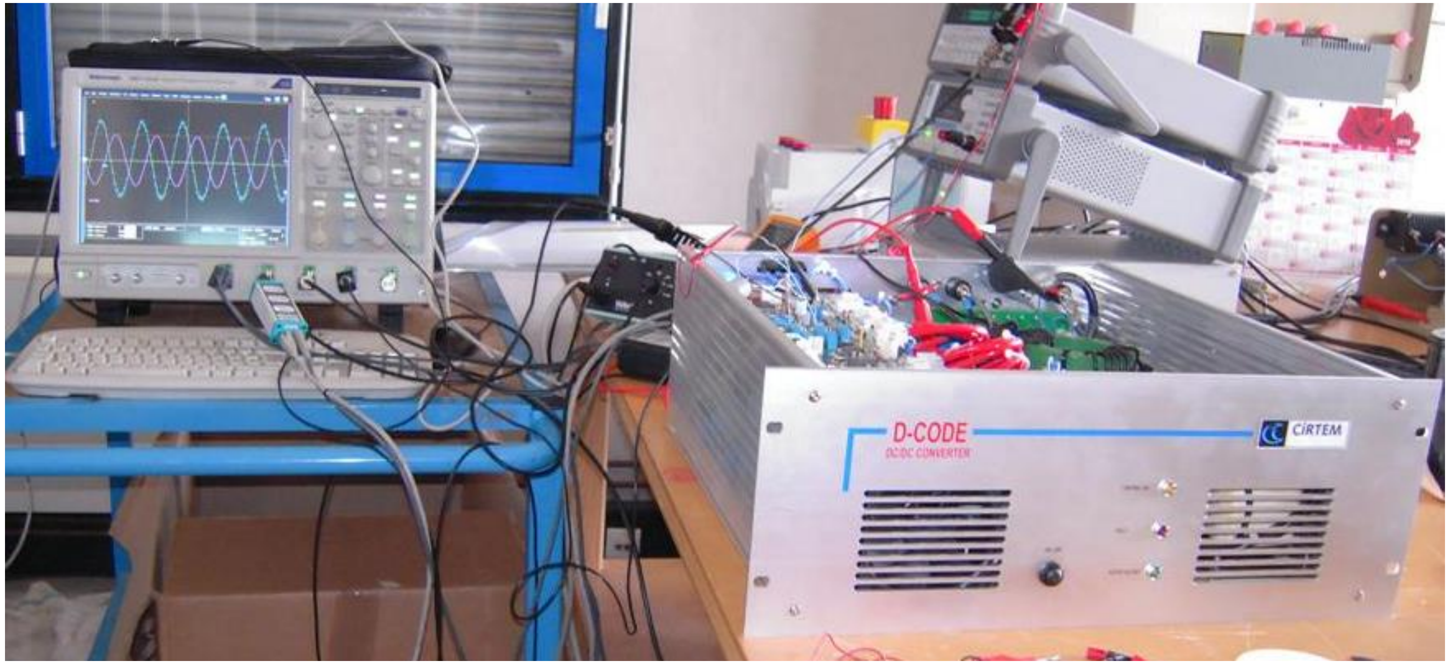
Switching converter-based actuation

Designed, engineered and developed converters



https://www.cirtem.com/
CIRTEM developed a HV converter by using a transformer-less topology and proprietary techniques for the reduction of switching and conduction losses. These choices have led to high conversion efficiency.

Boost topology (15-60V up to **380V**)
Three interleaved legs (lower input ripple)
Hard switching: 9-18 kHz (preferred 18 kHz)
Current reversible topology: EIS analysis when the DC current of the FC is zero
600 V IGBTs with SiC diodes (high efficiency)

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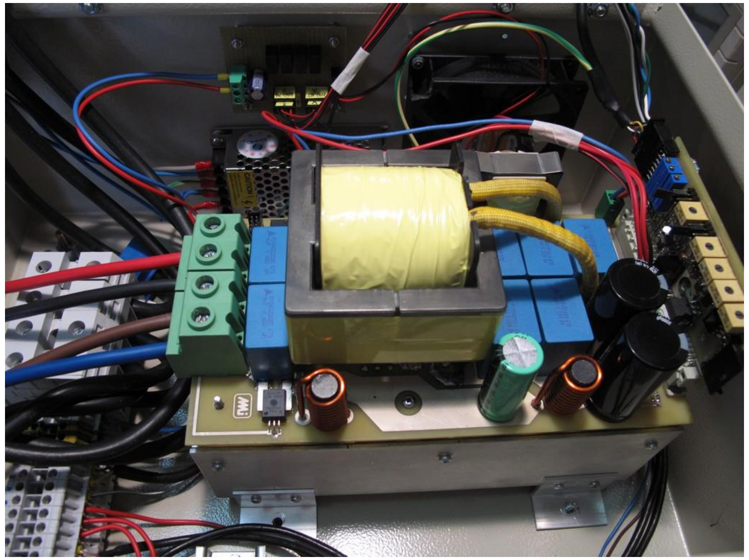
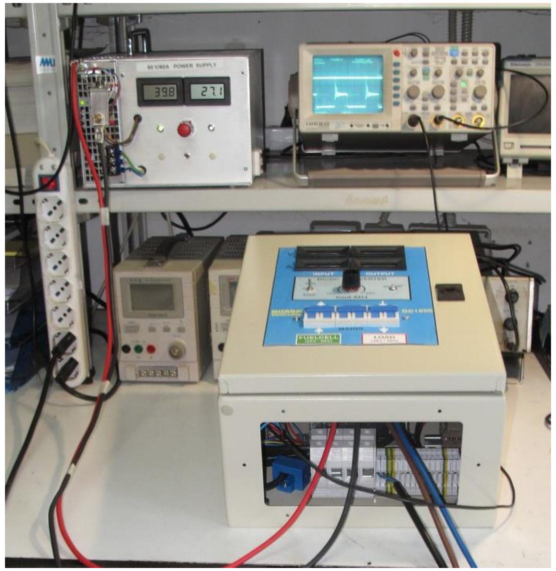
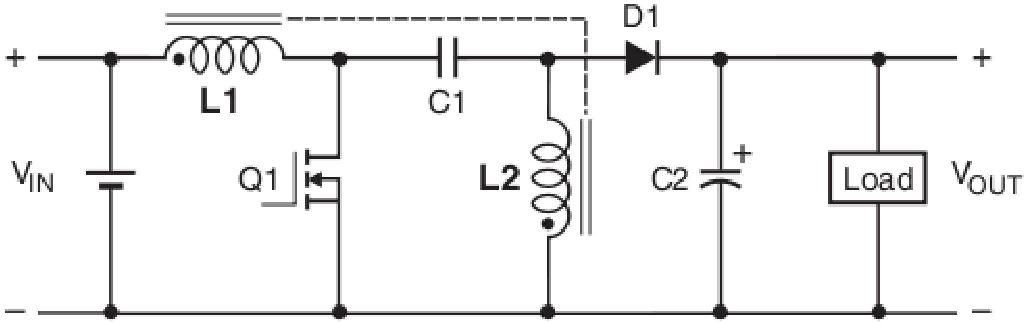
Switching converter-based actuation

Designed, engineered and developed converters







https://www.micropi.it/

Stack voltage range [15 V, 60 V]
Output DC voltage **48 V**
Rated power 1.8 kW
Non inverting step-up/step-down DC/DC converter: coupled inductors SEPIC (Single Ended Primary Inductor Converter) topology.

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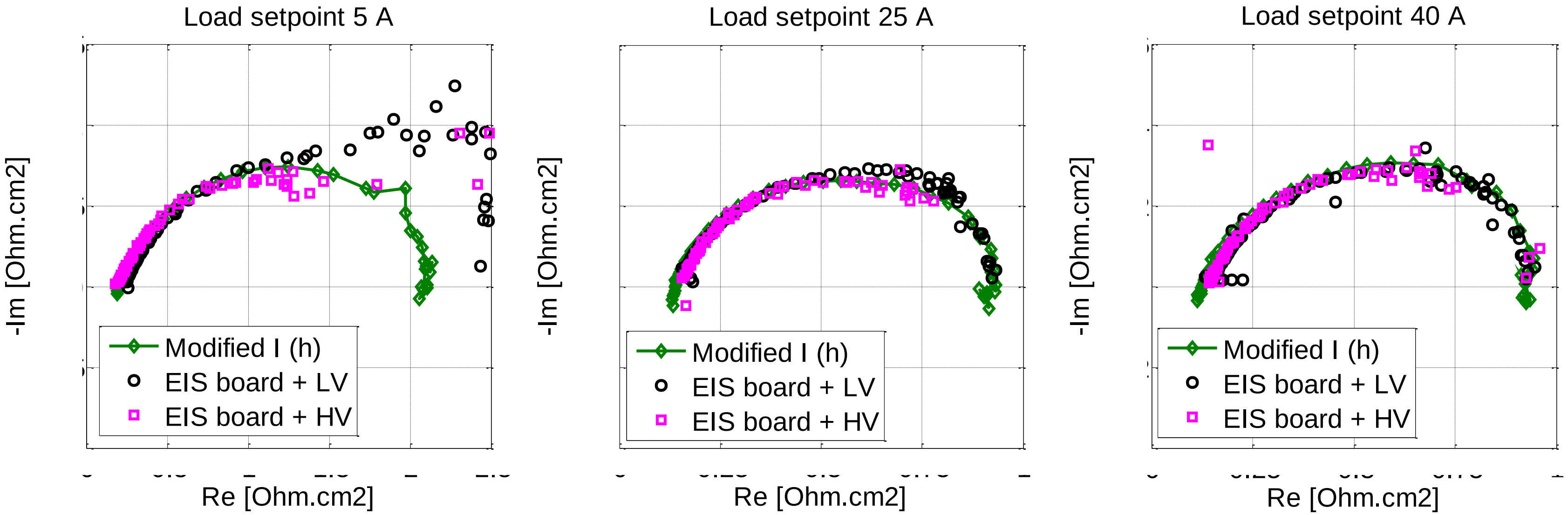
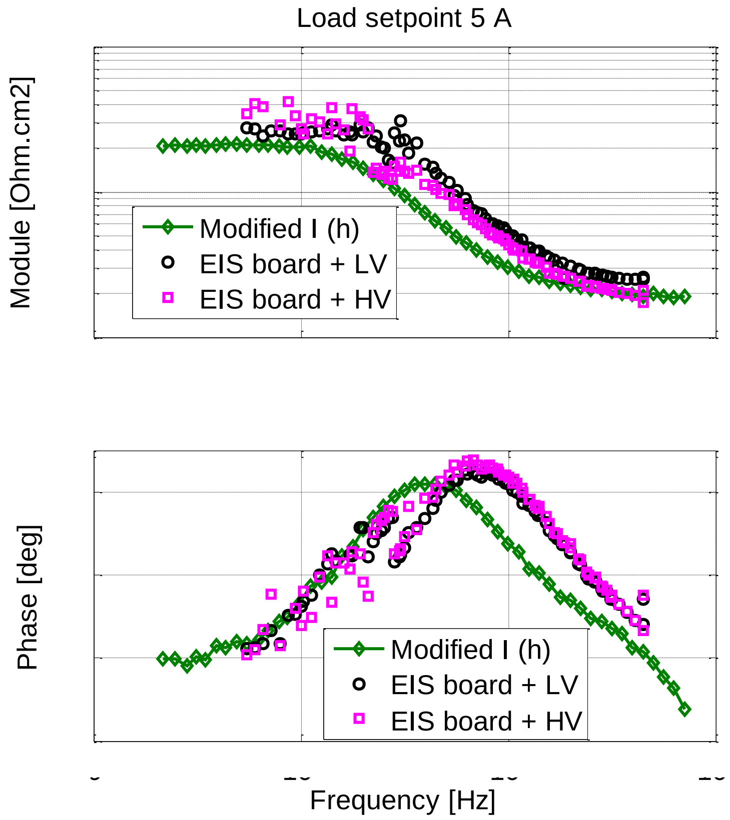
Some experimental data

Clean Hydrogen Partnership

Designed, engineered and developed converters





Comparison among data acquired through **laboratory equipments**, **high voltage** DC/DC converter and **low voltage** DC/DC converter.

DECODE

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Switching converter-based actuation

Designed, engineered and developed converters

230 V **inverter**

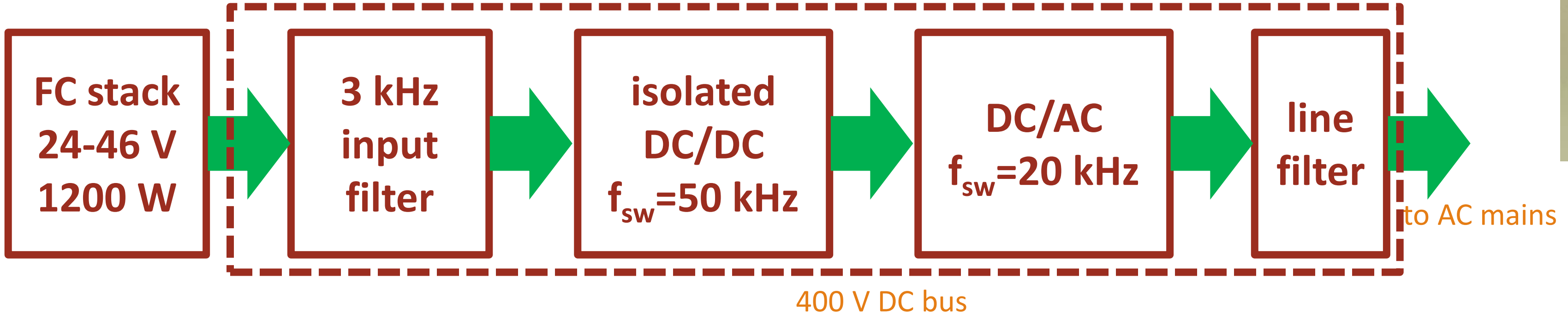
DC Input current range: 0-45A (step 1 A)

Rated power 1.2 kW

Stimulus frequency range 0.05Hz to 2000Hz

Stimulus amplitude range 0-10% of the DC current

https://www.micropi.it/



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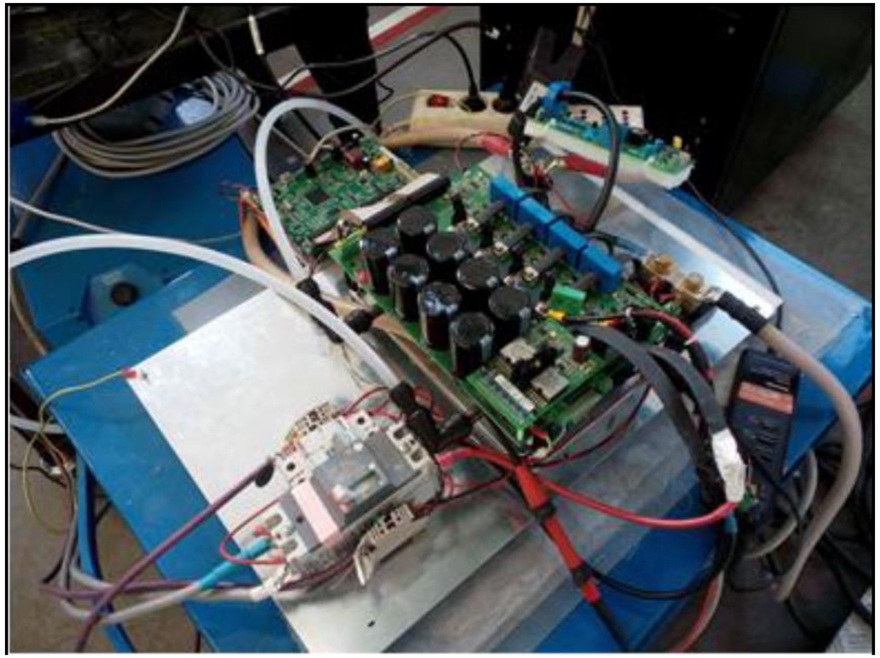
Switching converter-based actuation

The DC/DC converter of the FC stack has been suitably modified to inject the EIS stimuli with the required amplitude and in the suitable frequency range

This has been the **first time** an existing DC/DC converter, the FC system was already equipped with, has been modificed to host the EIS stimuli injection capability



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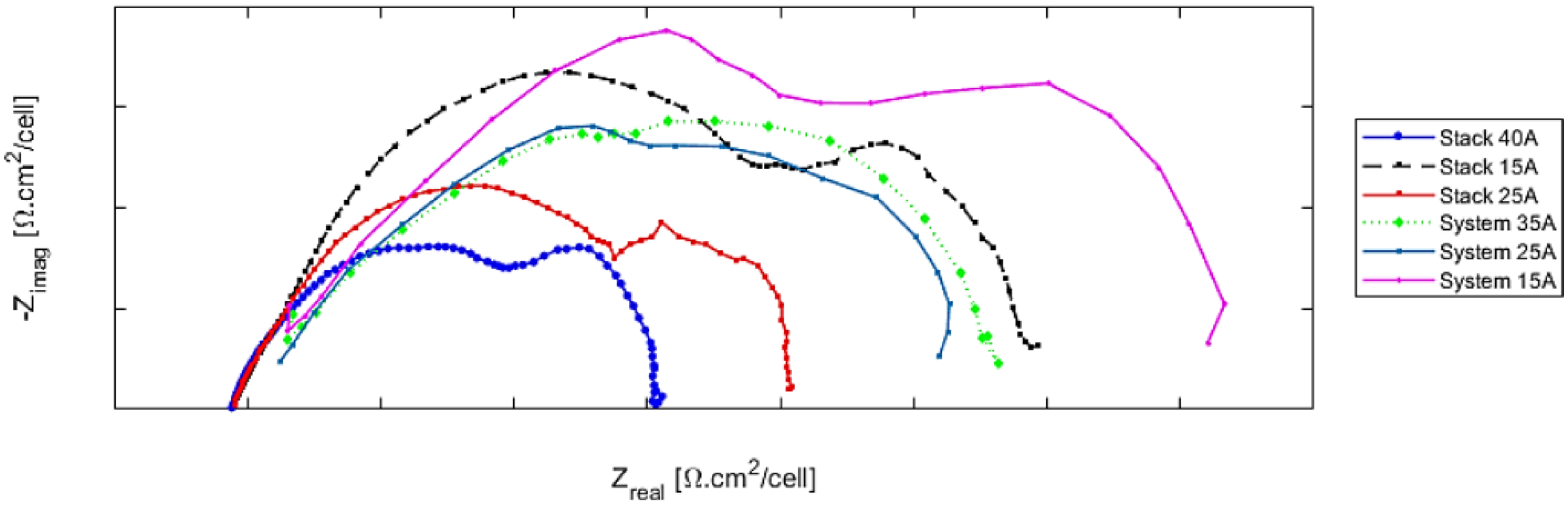
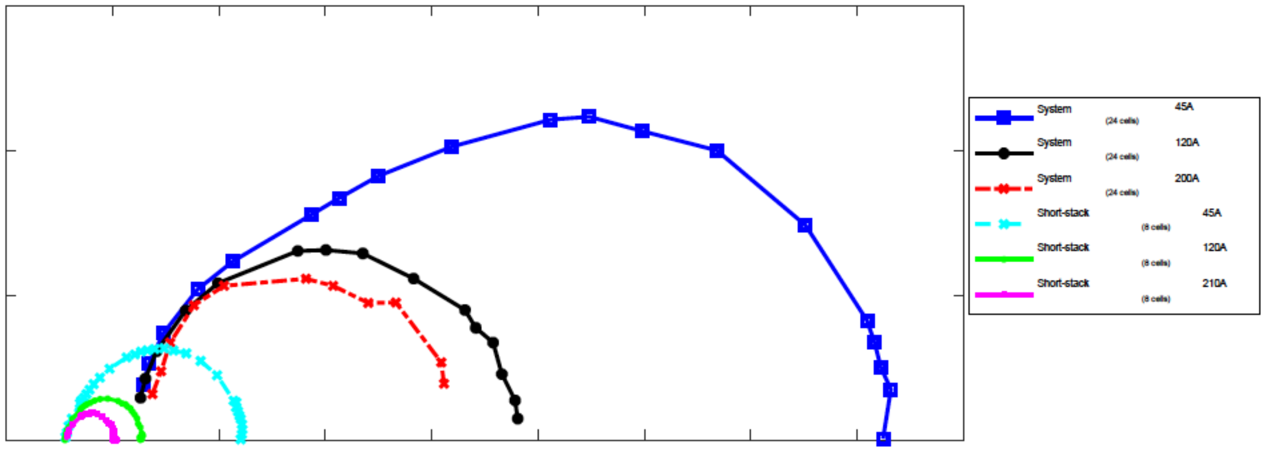
Experimental results





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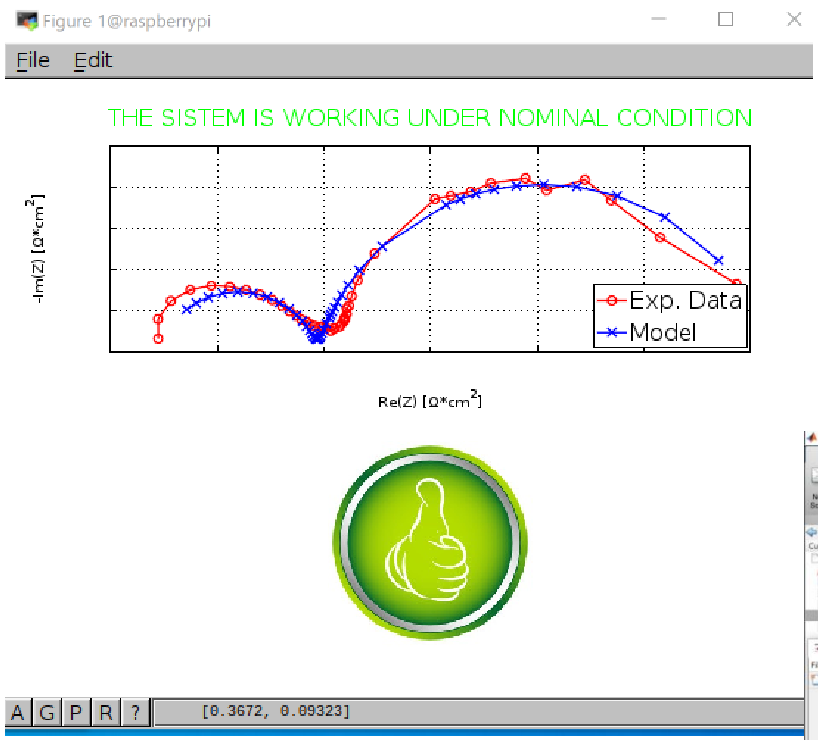
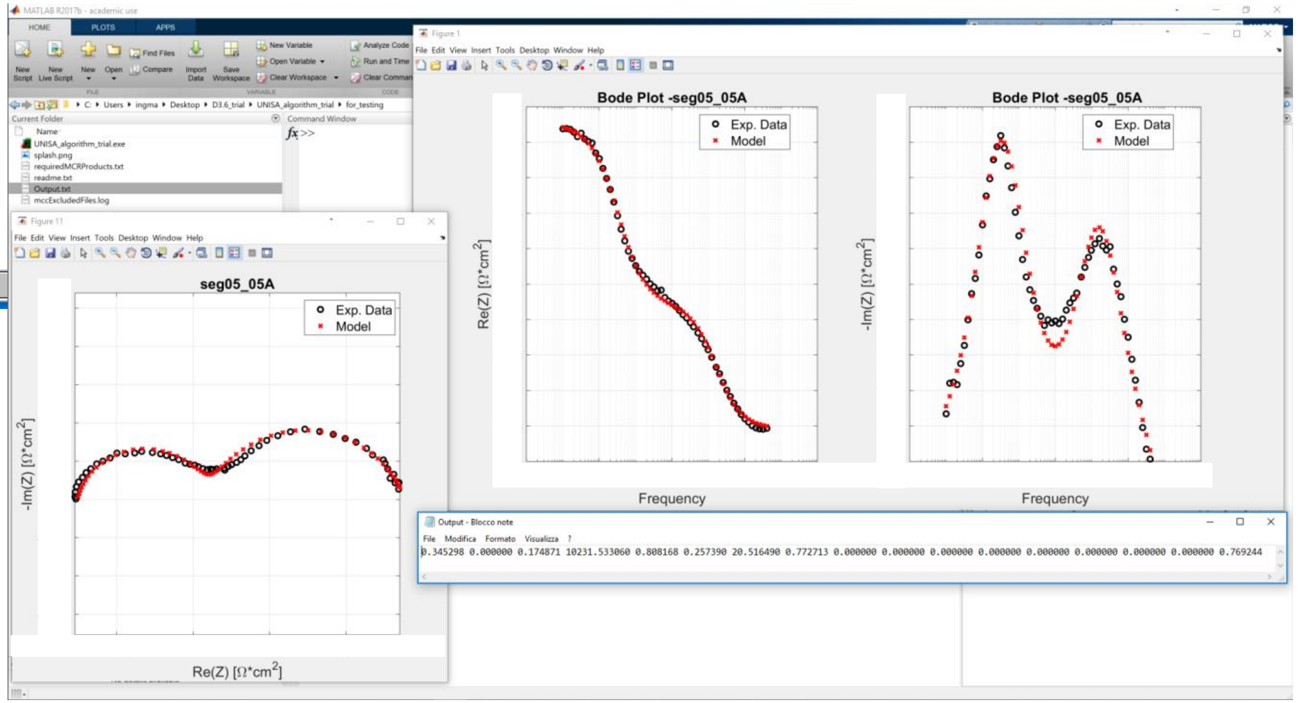
Switching converter-based actuation



The DC/DC converter of the FC stack has been **suitably modified** to inject the EIS stimuli with the required amplitude and in the suitable frequency range

First project of SOFC, thus the frequency range was suitably modified

(0.1 Hz up to 12 kHz, higher frequency limit)



Post-elaboration of data has been significantly improved

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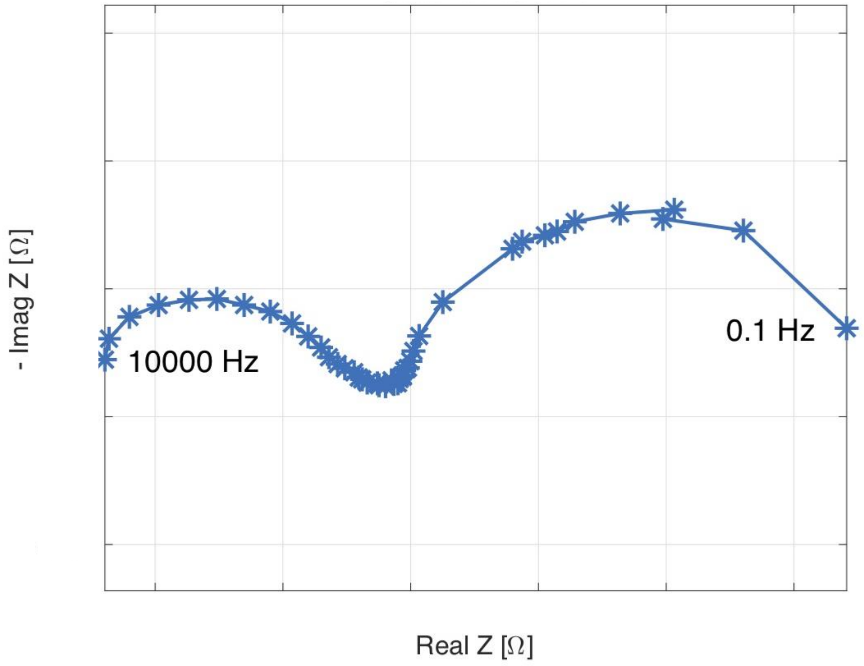
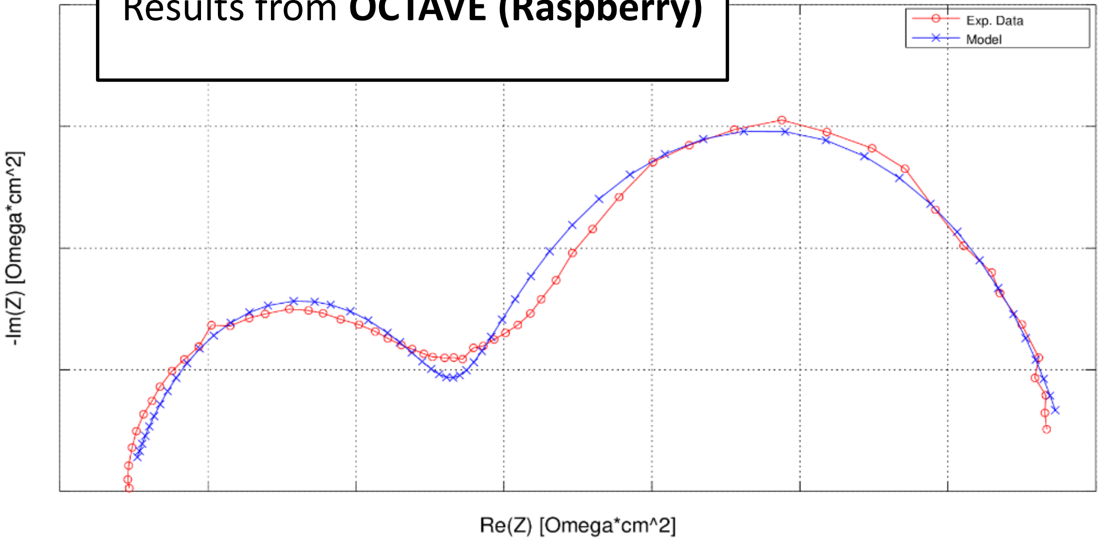
Switching converter-based actuation

In this project the EIS-oriented hardware was integrated into the FCS and a **web-server** allowed remote measurements (on Ethernet TCP/IP communication standard)



Results from **OCTAVE (Raspberry)**



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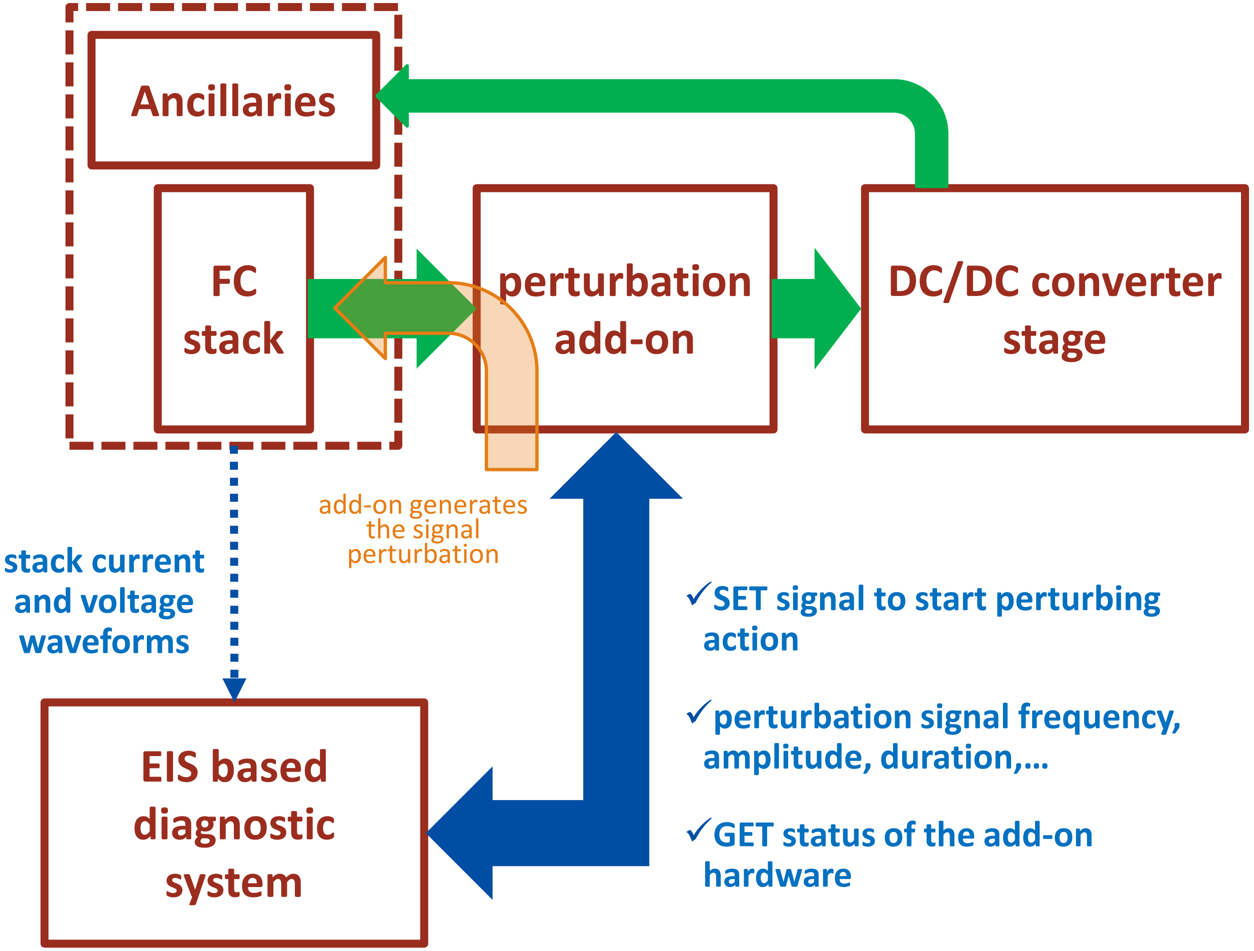
The on-field EIS perturbation injection strategies

Additional circuitry injecting the stimulus



Advantages

- no modifications of the DC/DC converter needed
- adaptation to any fuel cell system

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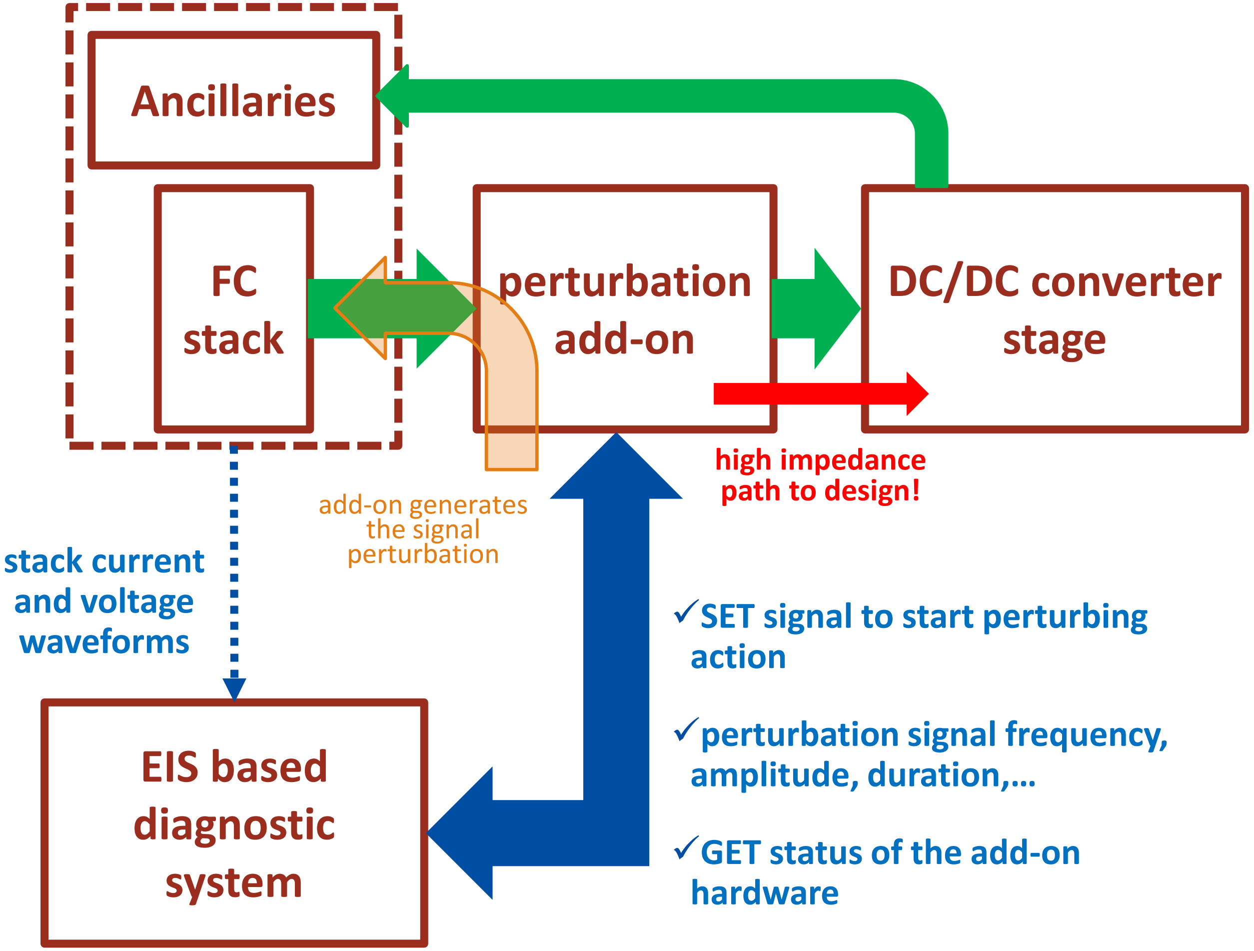
The on-field EIS perturbation injection strategies

Additional circuitry injecting the stimulus



Challenges and drawbacks

- overall conversion efficiency reduced
- generality of application that is only apparent
- bulky and heavy / difficult integration
- even more complicated design in case of reversible FC

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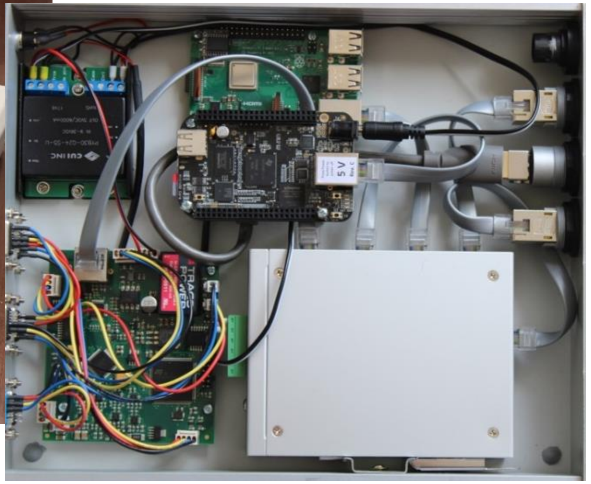
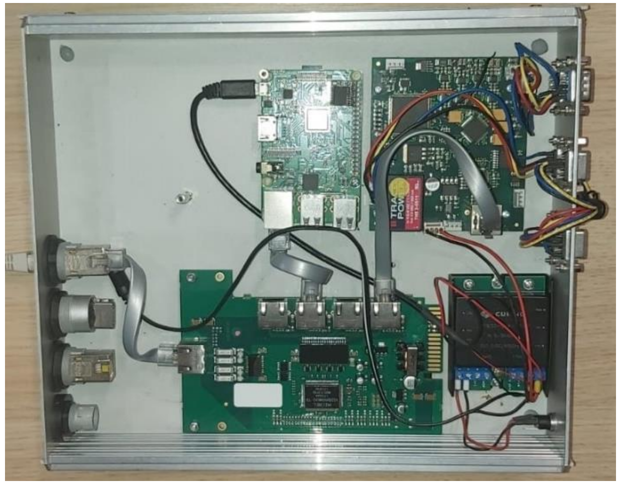
Diagnostic hardware and firmware functions

- supervise stimuli injection
- start/stop stimuli injection, injection duration, stimulus amplitude and frequency
- direct interaction with the power electronics controller through Ethernet TCP/IP channel (formerly PWM and CAN)
- Analog Front End (AFE) for stack current and voltage signal acquisition
- Acquisition of BOP variables for continuous monitoring functions implementation





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Conclusions

- Hardware for on-line EIS-based diagnosis has been the subject of investigations
- Modifications of the existing DC/DC converter have been demonstrated to be effective
- Implementation through a hardware add-on to be connected between stack and DC/DC converter on course
- Sinusoidal and PRBS-based EIS have been implemented
- PEM and SOFC fuel cell systems have been tested
- application to electrolyzer/reversible systems under test

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