Elaboration of a non intrusive diagnosis tool for the detection of water management and CO poisoning defaults in PEMFC stacks

EIFER / FC LAB Systèmes pile à combustible

Philippe MOÇOTÉGUY

Nadia STEINER

Sébastien WASTERLAIN
Daniel HISSEL
Denis CANDUSSO
Fabien HAREL
Xavier FRANCOIS

AREVA / HELION HYDROGEN POWER

Vincent RAIMBAULT

CEA

Alain GIRAUD
Fabrice AUZANNEAU
Sébastien ROSINI

INRIA

Pierre-Alexandre BLIMAN
Mohamad SAFA
Michel SORINE

Edition 2006

AGENCE NATIONALE DE LA RECHERCHE ANR

PAN-H

Outline

- Introduction
- Developped measurements
- Stacks characterization
- Developped model
- Conclusions and future work

Scope of the study

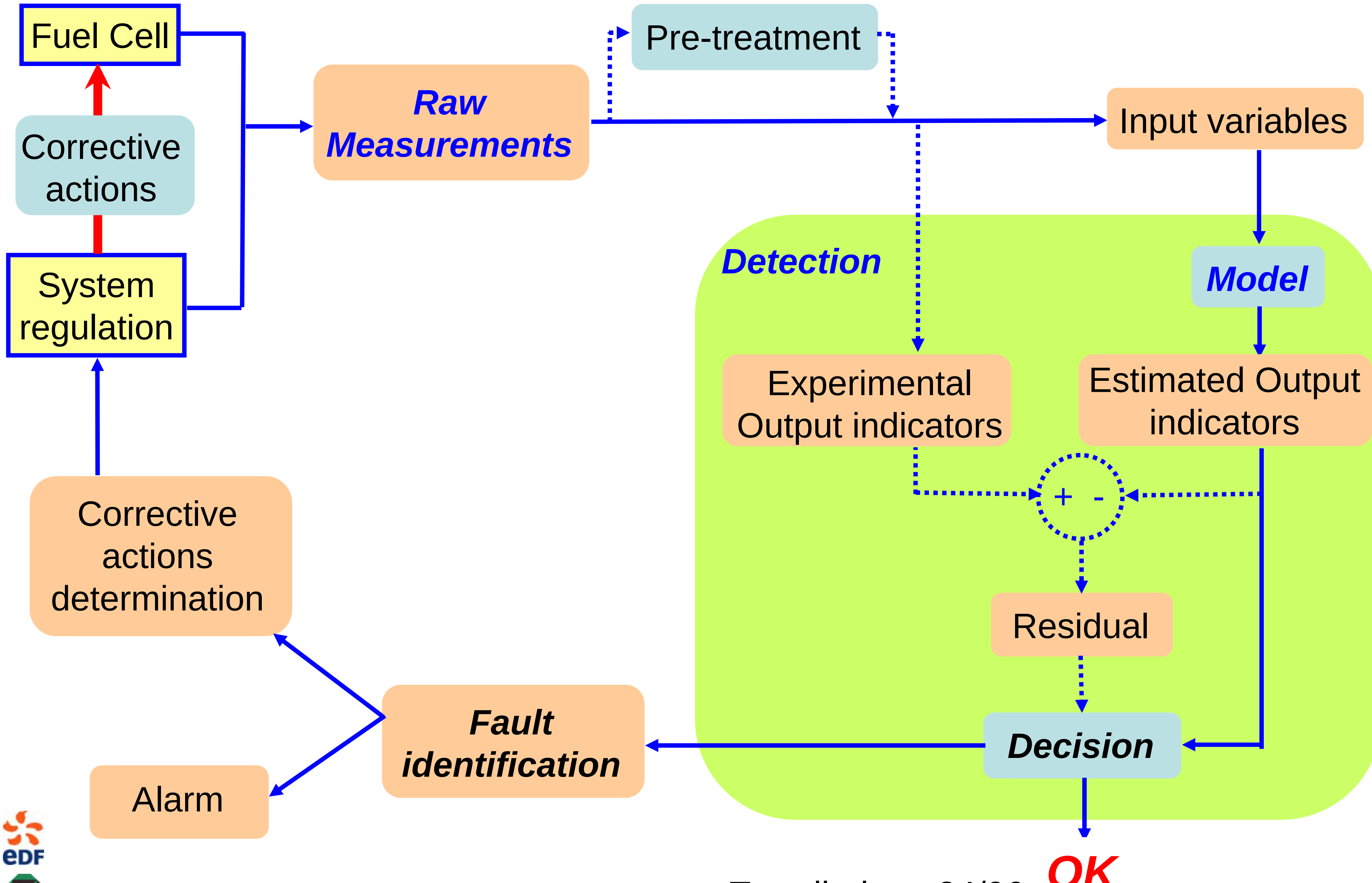
- **Fuel cell insufficiently mature, partly due to limited lifetime**

  ⇒ Need for diagnosis tools to detect and classify failures or faulty operation modes so as to prevent or limit degradation.

- **Important causes of degradations / failures:**
  - Bad water management (flooding, drying): usually reversible and quite easy to control.
  - Poisoning: reversibility = f(pollutant nature, concentration), hardly controllable for air pollution, more easily for fuel pollutant like CO.
  - Carbon corrosion, catalyst oxidation; usually irreversible and impossible to control, particularly at stack level.

⇒ focus on water management and CO poisoning issues.

Basics on diagnostic



Outline

- Introduction
- Developpement of new measurement tools
  - New high power impedancemeter.
  - Integrated acquisition cardboard.
- Stacks characterization
- Developped algorithm
- Conclusions and future work

EIS measurement for high power stack

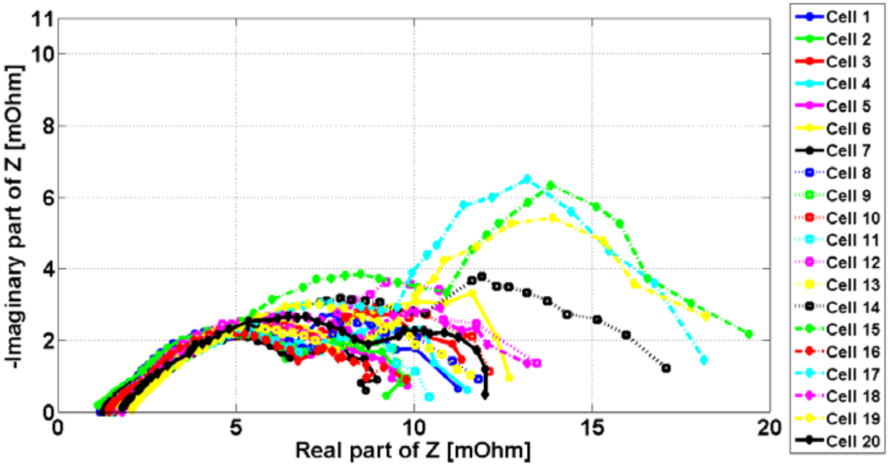
FC LAB Systèmes pile à combustible

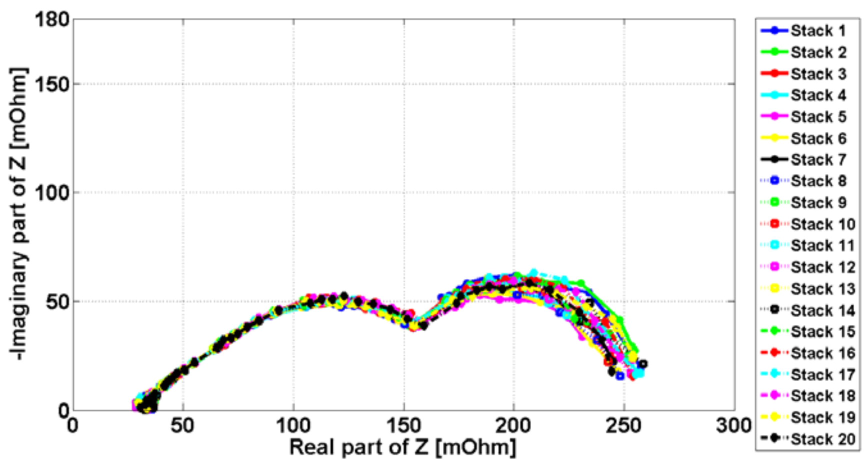
- Previous systems' limitations:

  Many impedancemeters of the pubic market are limited to a few Volts with regard to the measurement voltage.

⇒ Development of a new EIS system:

- High resolution digital analogic converter (26 bits).
- 32 acquisition channels (1 for I + 31 for U up to 300V).
- Allows 2 simultaneous measurements (stack + individual cells or groups of cells).





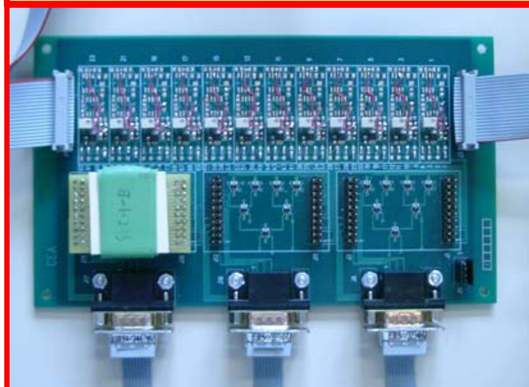
➔**Large dispersion in cell impedance spectra due to**
- cell position in the stack,
- cell state of health.

➔ **Stack impedance spectra are close and do not depend on time**

Developped acquisition tool principle

Imput signal generation:
- Current steps.
- EIS.

Acquisition cardboard

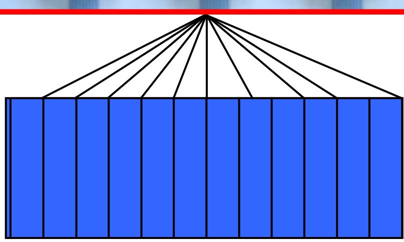


Cell nr

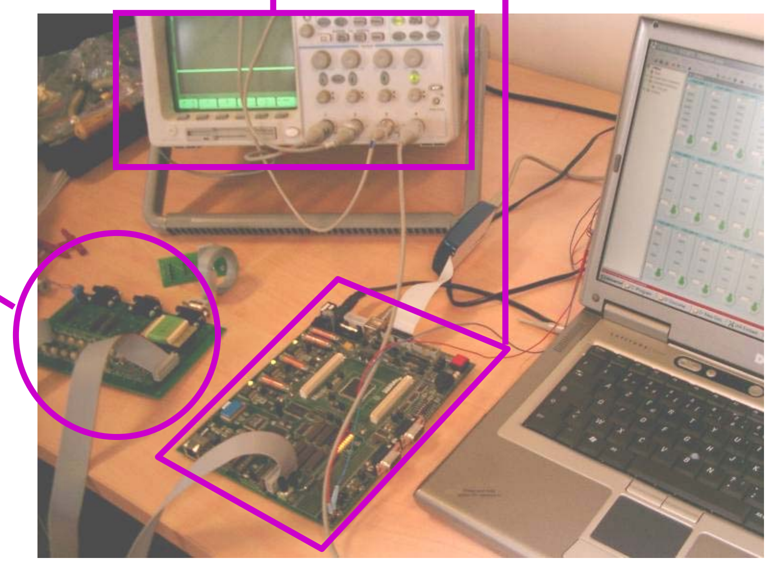
Data treatment cardboard (AMR 7)
- Data acquisition and treatment.software. *(Labview)*
- Control and reading of data coming from test bench.

U_{cell}

U_{stack}



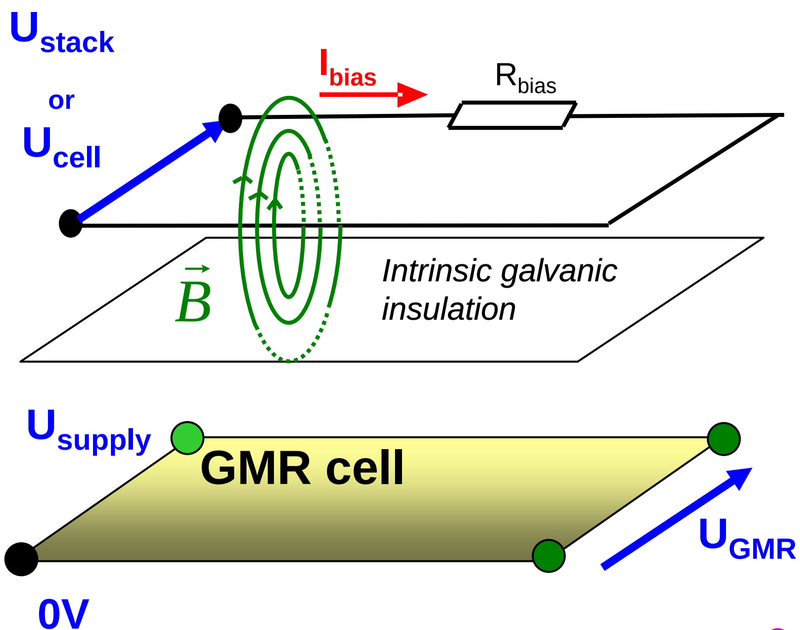
Stack



Acquisition cardboard

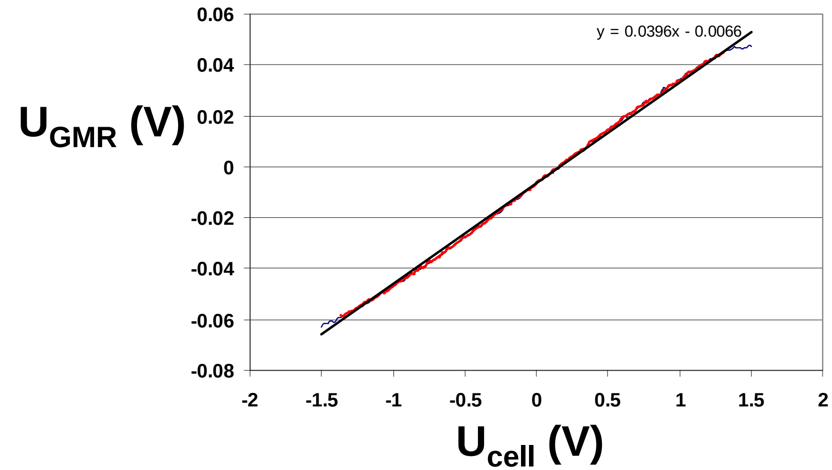
- ## Basic principle:

Generation of a bias current:



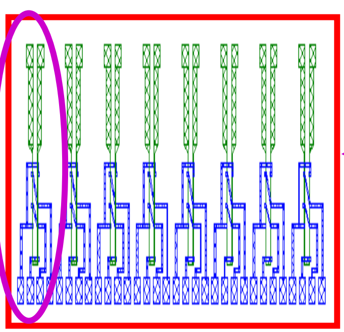
Measurement of UGMR similar with Wheatstone bridge principle

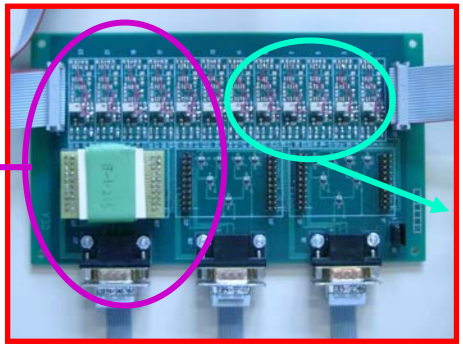
- ## GMR Performances:



Error < 1% (can be reduced but with sensitivity loss)

- ## Integration:





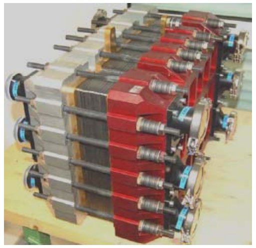
Amplifier & multiplexer

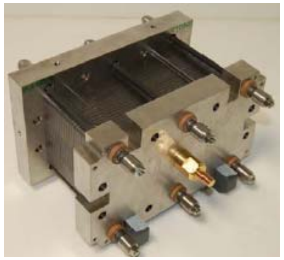
Outline

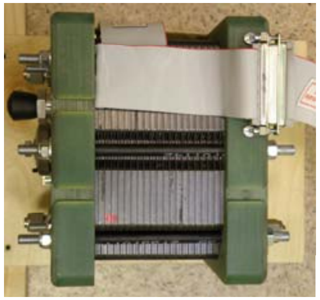
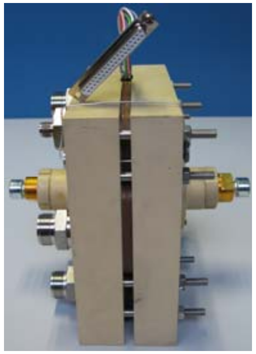
- Introduction
- Developpement of new measurement tools
- Stacks characterization
- Developped algorithm
- Conclusions and future work

Experimentals

- 3 stacks technologies:





AREVA
HELION
HYDROGEN POWER

3M

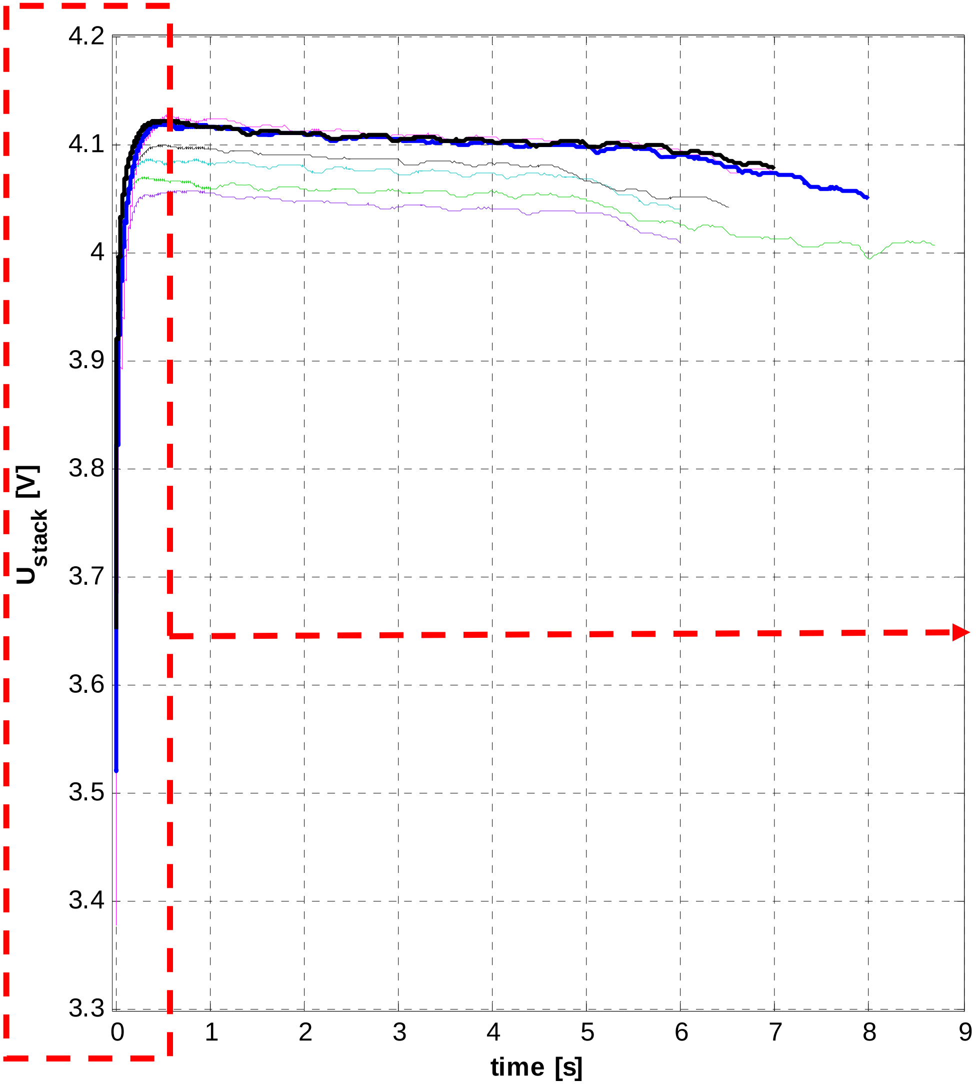
cea

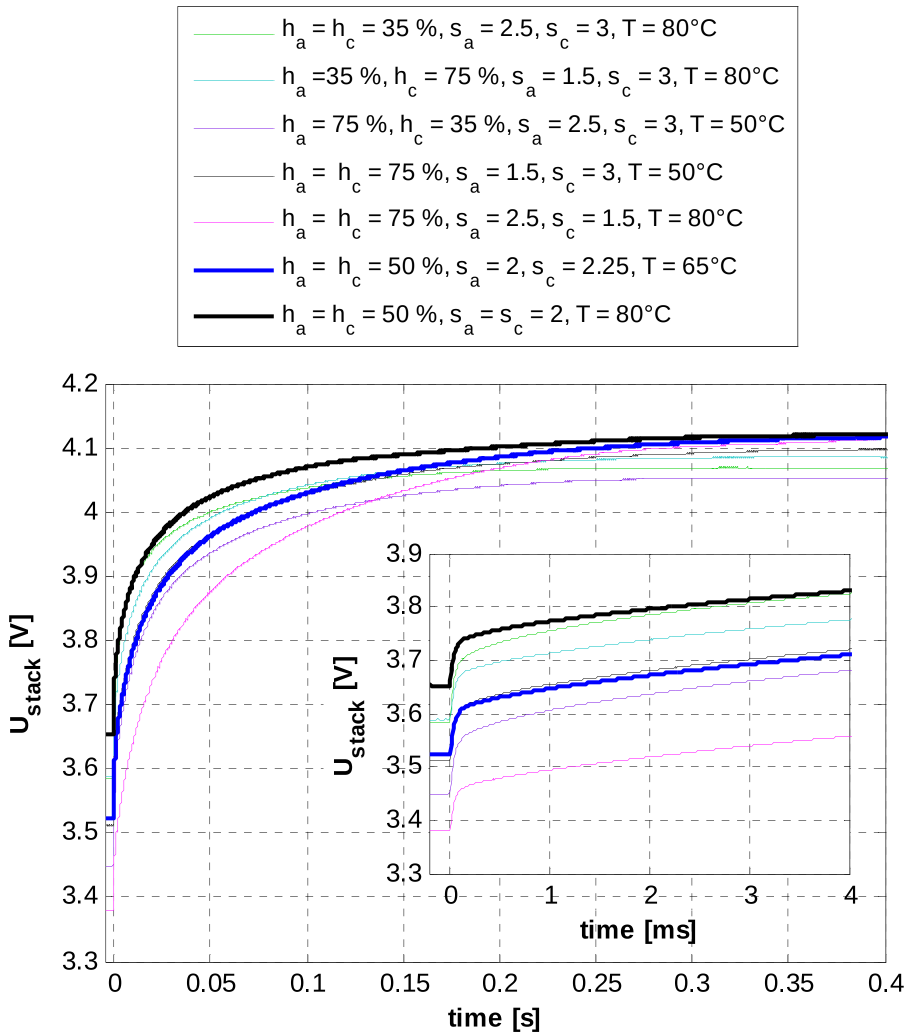
- Design of experiment methodology:
  - 6 parameters: anodic and cathodic overstoichiometric ratios, fuel and oxident relative humidities, fuel CO content, stack temperature.
  - 2^{6-2} (16 experiments) design of experiments, with aliases.

- Characterisations:
  - Current steps profile:
    - ✓ Current + Individual and total stack voltages: 100 kHz during 5 to 10s.
    - ✓ Process regulation parameters + pressure drops: 1 Hz.
  - EIS.

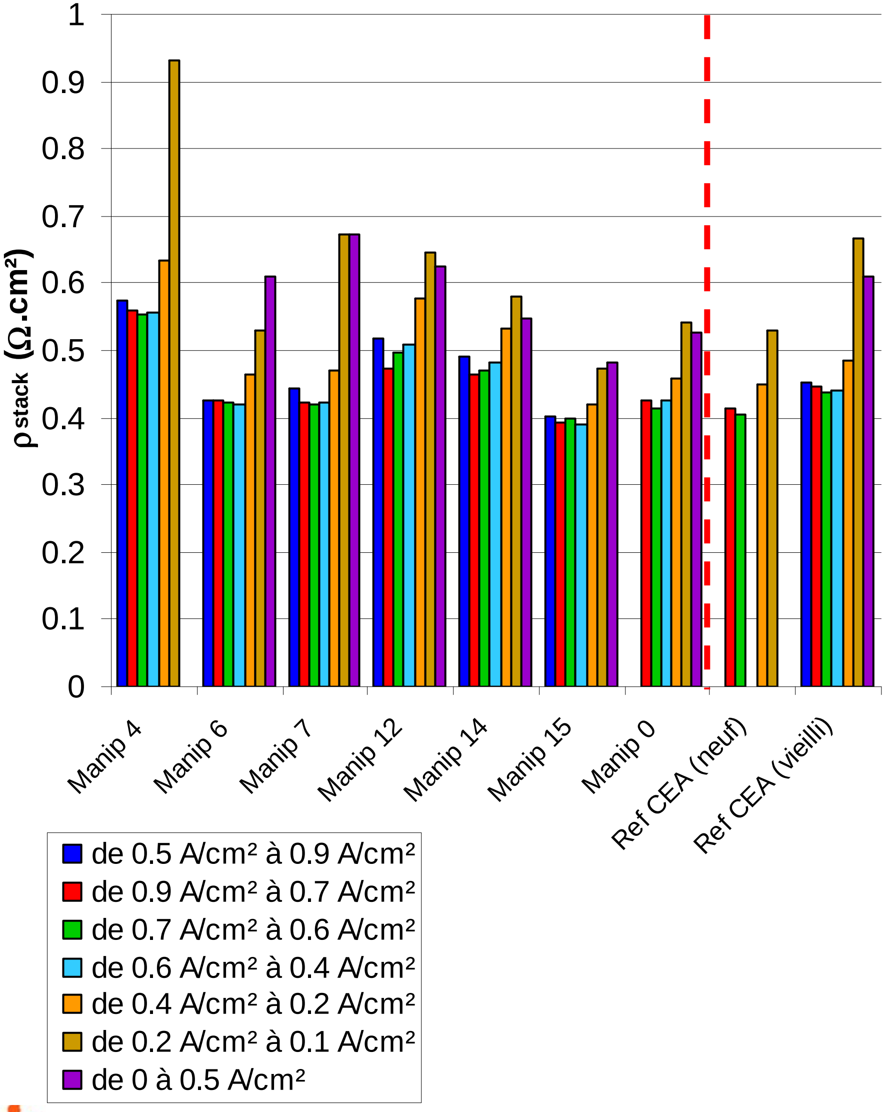
EDF

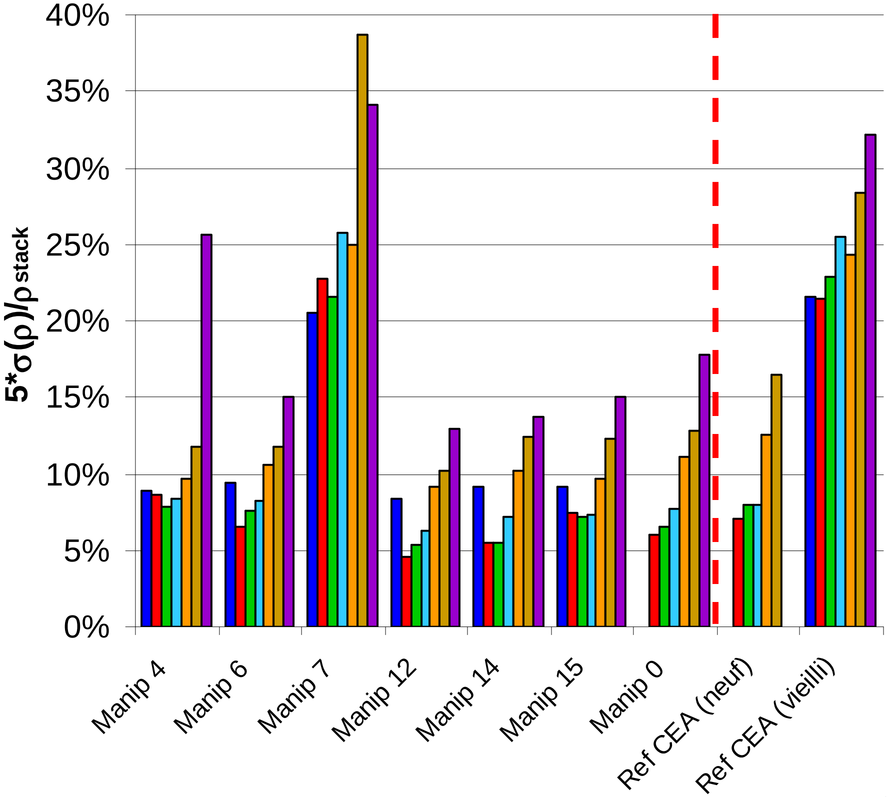
Transient behavior of CEA 5 cells stack during current step from 0.4 A/cm² to 0.2 A/cm²





5 cells stack resistivity and individual cell resistivity scattering

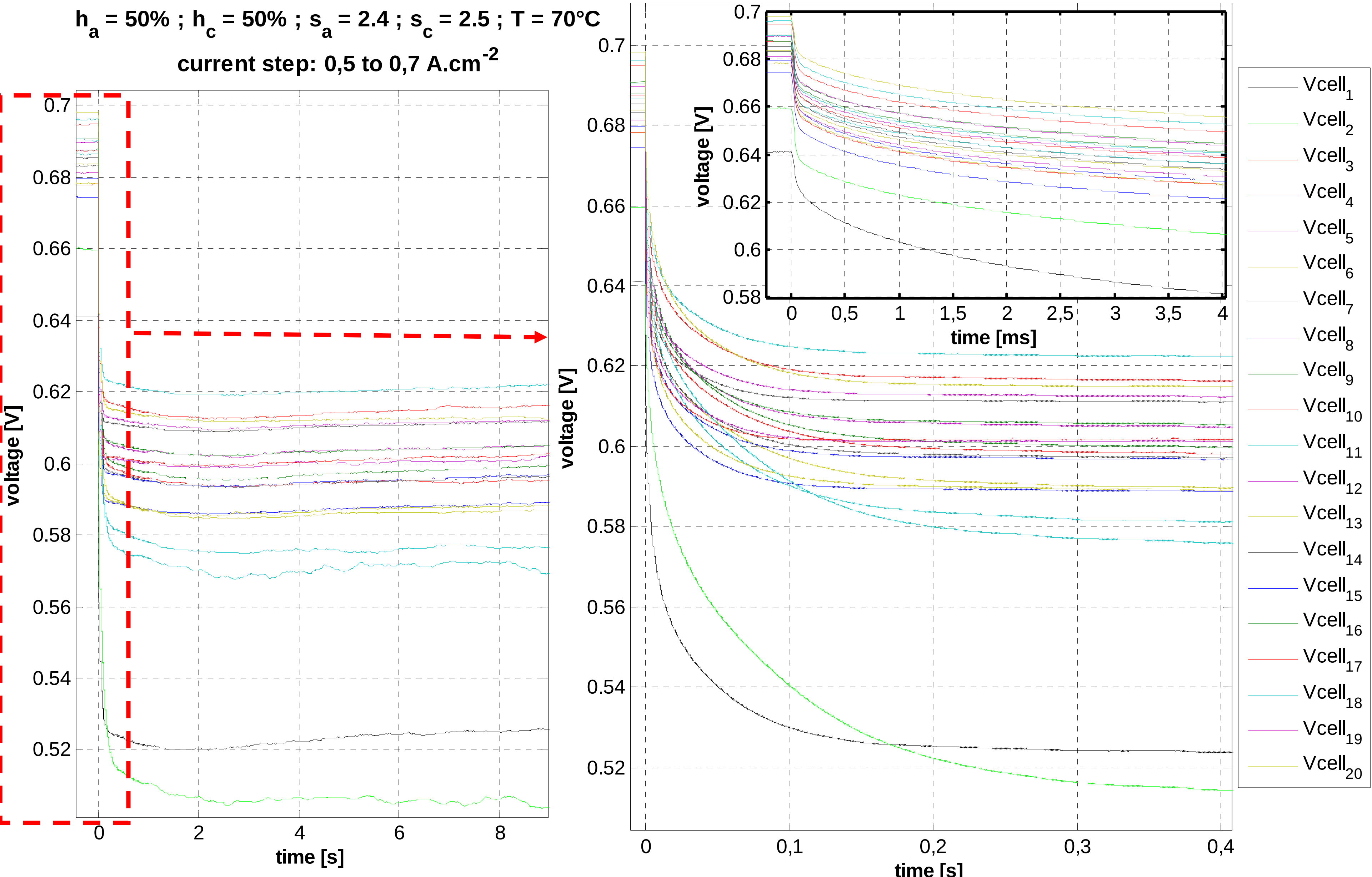




Manip 4	$h_a = h_c$ = 35%, s_a = 2.5, s_c = 3, T = 80°C
Manip 6	h_a = 35%, h_c = 75%, s_a = 1.5, s_c = 3, T = 80°C
Manip 7	h_a = 75%, h_c = 35%, $s_a = s_c$ = 1.8, T = 80°C
Manip 12	h_a = 75%, h_c = 35%, s_a = 2.5, s_c = 3, T = 50°C
Manip 14	$h_a = h_c$ = 75%, s_a = 1.5, s_c = 3, T = 50°C
Manip 15	$h_a = h_c$ = 75%, s_a = 2.5, s_c = 1.5, T = 80°C
Manip 0	$h_a = h_c$ = 50%, s_a = 2, s_c = 2.25, T = 65°C
Ref CEA	$h_a = h_c$ = 50%, $s_a = s_c$ = 2, T = 80°C

Transient behavior of 3M 20 cells stack during a current step from 0.5 A/cm² to 0.7 A/cm²

EIFER



Outline

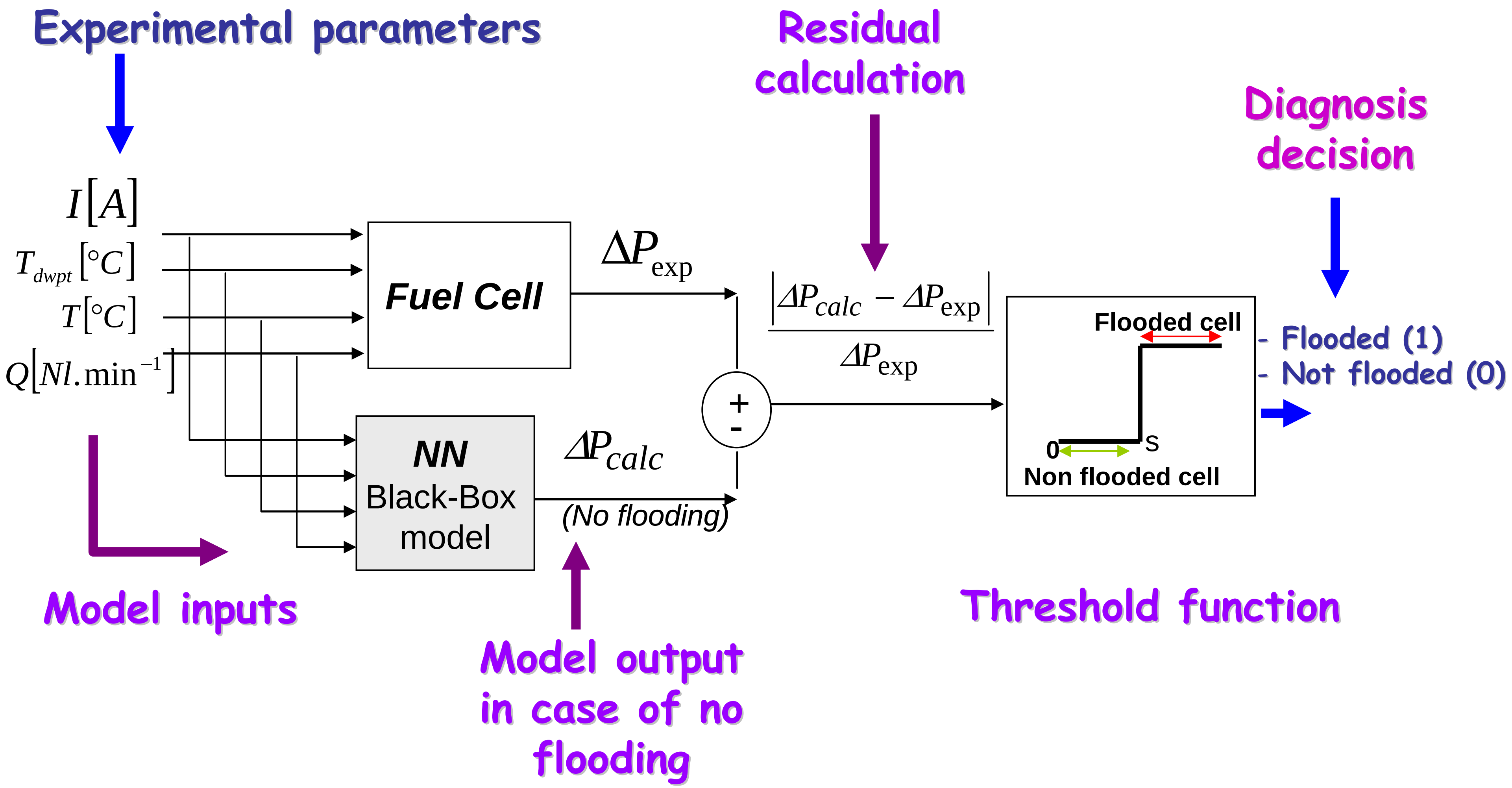
- Introduction
- Development of new measurement tools
- Stacks characterization
- Developped algorithms:
  - Physical model based.
  - Black box model based.
- Conclusions and future work

Physical model

- Input variables:
  - H_2O, H_2, O_2 and CO partial pressures, H^+ concentration.
  - fraction of catalytic sites poisoned by CO.
  - water content in membrane and GDLs.
- 1D (⊥ to MEA plane) model taking into account:
  - kinetics of electrochemical reactions.
  - diffusion-migration (mass conservation equation).
  - water balance in each compartment : GC, GDL, membrane,…(cf. Benziger et al.)
- Model simplification by :
  - discretization for approximation of conservation equations (via orthogonal collocation method).
  - Analysis of the different time-scales phenomena (in adsorption/desorption, water diffusion)

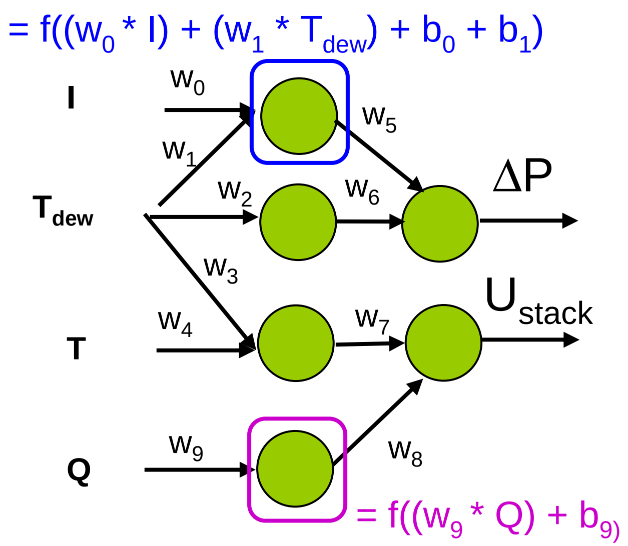
  ⇒Reduced 0D model describing I-U relation in various operating conditions.
- Serie-parallel "assembly" of the model to simulate a cell heterogeneity and a stack.
- Output: polarization and EIS curves, are determined analytically

Flooding diagnosis algorithm



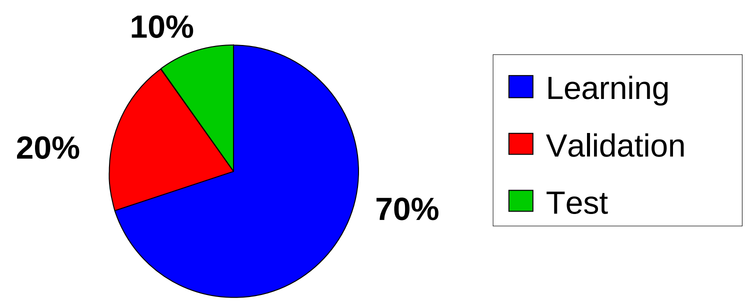
Neural network ?...

- **Definitions:**
  - Neuron = succession of 2 mathematical functions: multiparameter linear combination + other (e.g. identity, sigmoid, linear,...)
  - Layer = group of unconnected neurons.

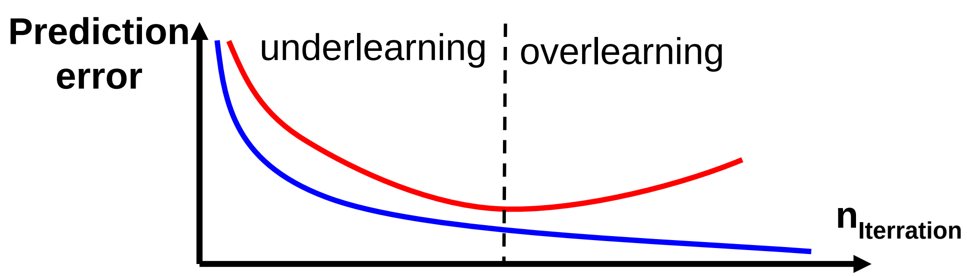


w_i ⇔ coefficients of multiparameter linear combination function

- **How is it build (3 steps) ?**
  - Architecture definition:
    - ✓ Inputs = experimental parameters.
    - ✓ Number of layers ≥ 2.
    - ✓ Number of neuron/layer ⇔ compromise risks of overlearning and underlearning.
  - Database random spliting:



  - Learning + Validation:
    - ✓ determination of w_i and b_i by iterative interpolation.
    - ✓ optimization of iteration number on learning:



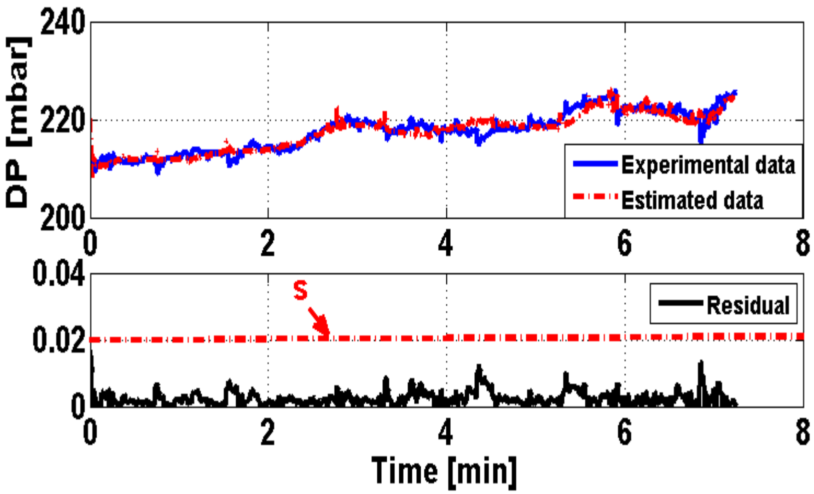
  - Test ⇔ the network ability to predict the output

Results: Neural network build-up

Database:

T [°C]	∈ [35-40]
Tdwpt [°C]	∈ [25-50]
I [A]	∈ [0-35]
Q [Nl.min^{-1}]	∈ [30-55]

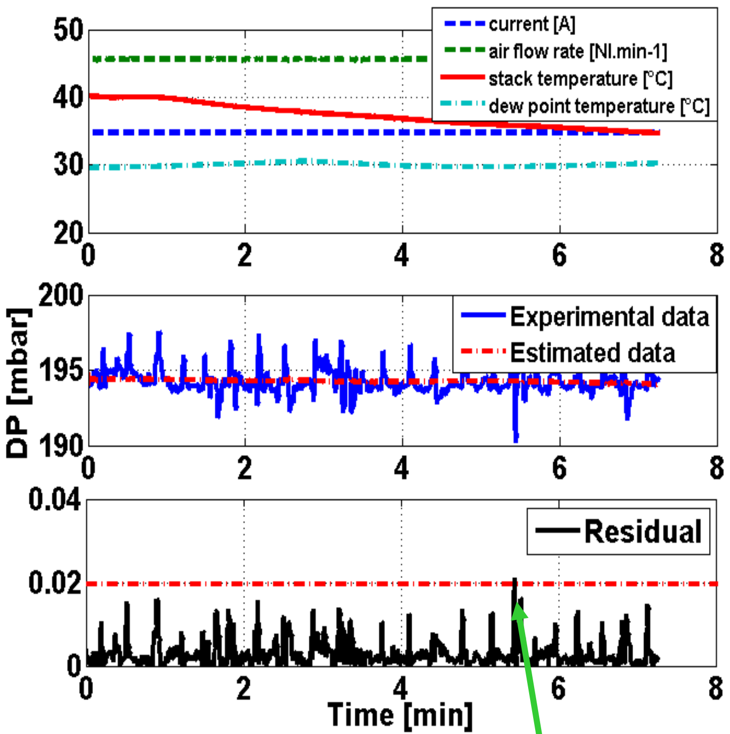
Learning on DP = f(t):



Threshold definition:
s = 3*|σ(residual)|

Test:

Not flooded cell, data not previously seen by the Neural Network

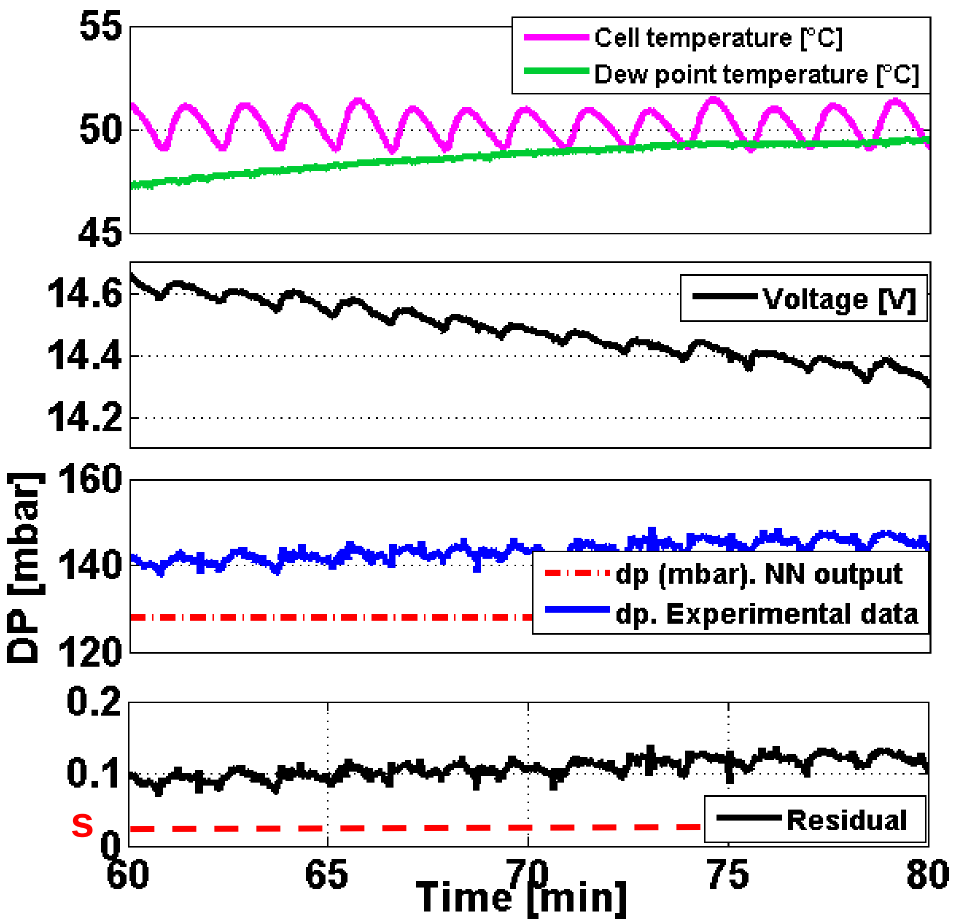


One punctual wrong alarm

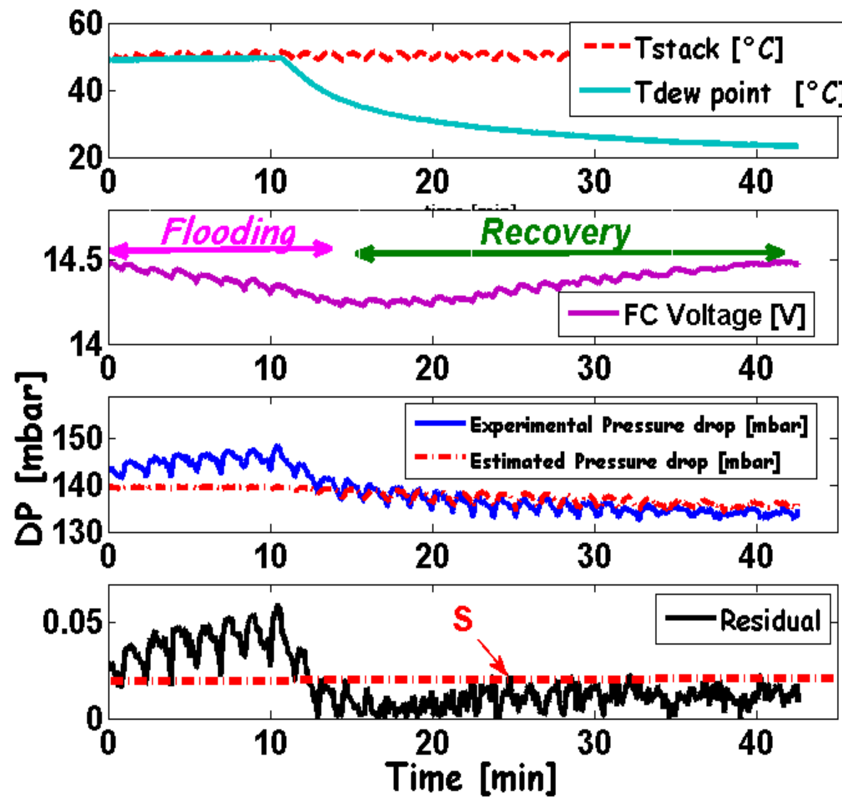
$2x\sigma$

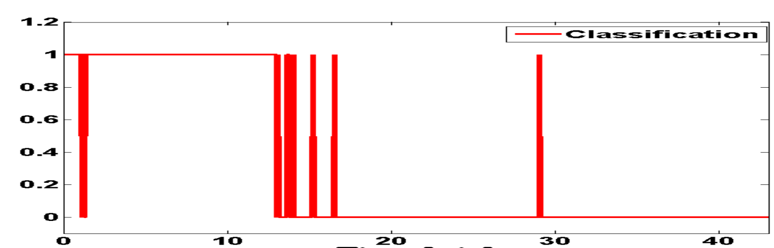
Results: Model application to flooding diagnosis

Flooding detection:



Detection of flooding and recovery:





Conclusions & next steps

- Main achievements:
  - Developments of:
    - ✓ A diagnosis model for water management issues.
    - ✓ A new EIS system for operation at high stack voltages (up to 300 V).
    - ✓ A hardware for acquisition, treatment and storage of system data during operation.
- Next steps:
  - Design of experiment analysis on different 20 cells stacks by EIS and current steps *(in progress).*
  - Extend diagnosis model to CO poisoning detection *(in progress).*
  - Generalize the diagnosis model to different PEMFC stack technologies *(in progress).*
  - Interface the diagnosis model with the hardware in a diagnosis tool to be validated on a 20 cells stack.
  - **Export the methodology to develop a tool for other fuel cells technologies: FCH-JU JTI CP 2008 "GENIUS" project for SOFCs.**