International Symposium on
DIAGNOSTIC TOOLS FOR FUEL CELL TECHNOLOGIES

ONLINE PEMFC STACK MONITORING WITH “THDA“

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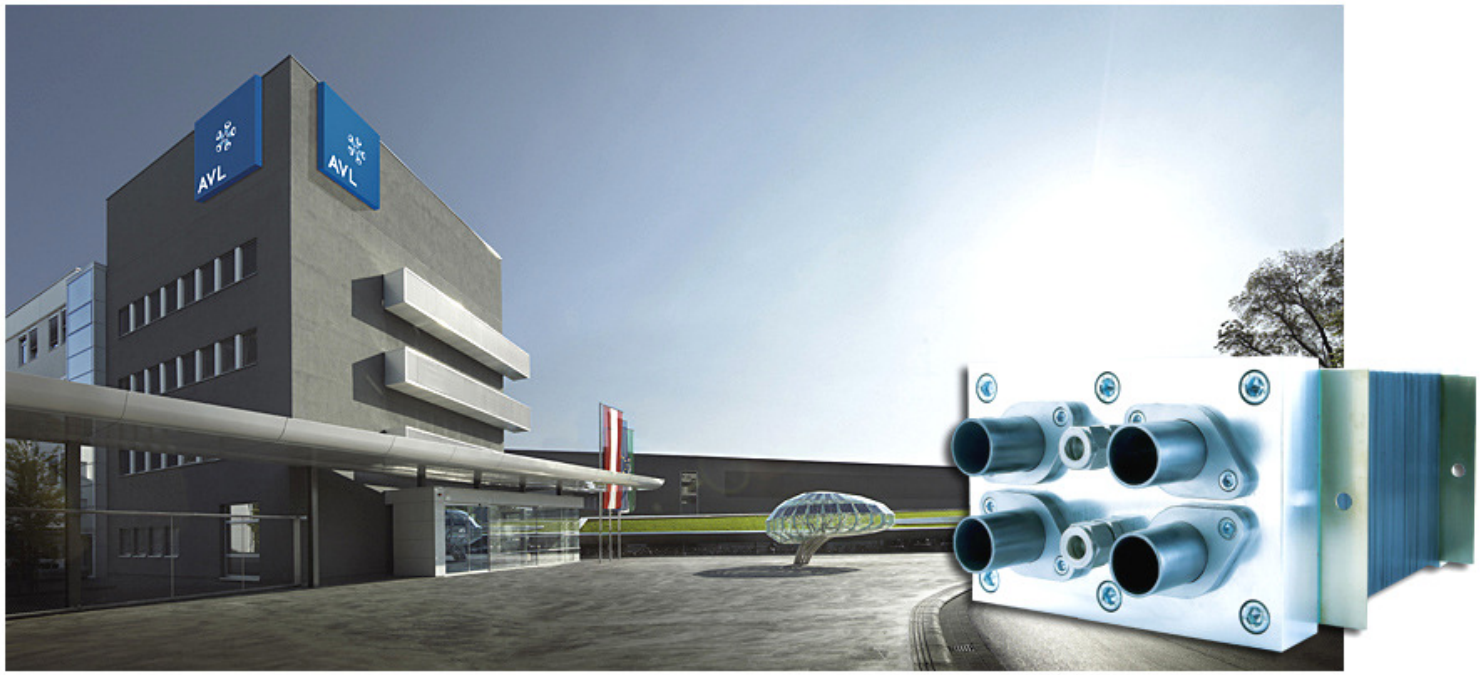
Trondheim, 23rd – 24th June 2009



BASICS OF THE APPROACH “AVL THDA”

EFFECTS RESULTING FROM VOLTAGE DRIFTS ARE ANALYZED INSTEAD OF VOLTAGE DRIFT MEASUREMENT ITSELF

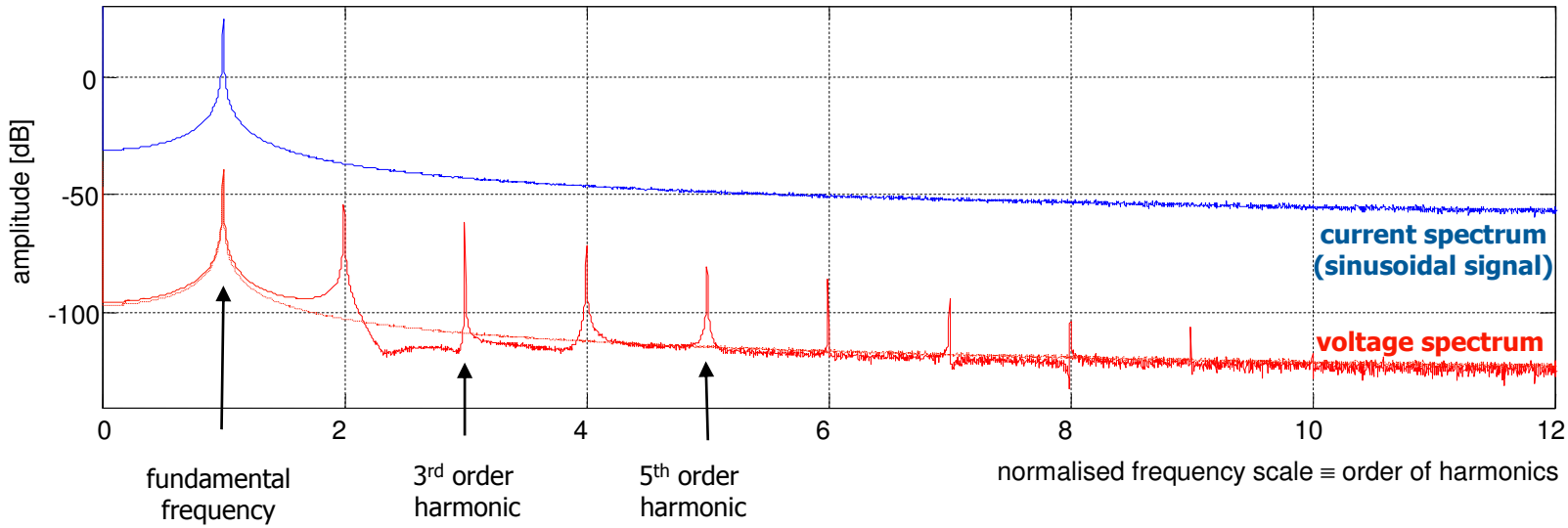
If defects or critical conditions occur in one or few cells, time variant conditions or local non-linearities in the transfer function distort a superimposed signal and form harmonics

- Extra spectral components (i.e. harmonics) are detectable in the stack voltage – no cell voltage measurement required
- Reduced measurement effort: stack voltage & stack current only
- COST EFFICIENT APPROACH

“THDA™” – Total Harmonic Distortion Analysis*

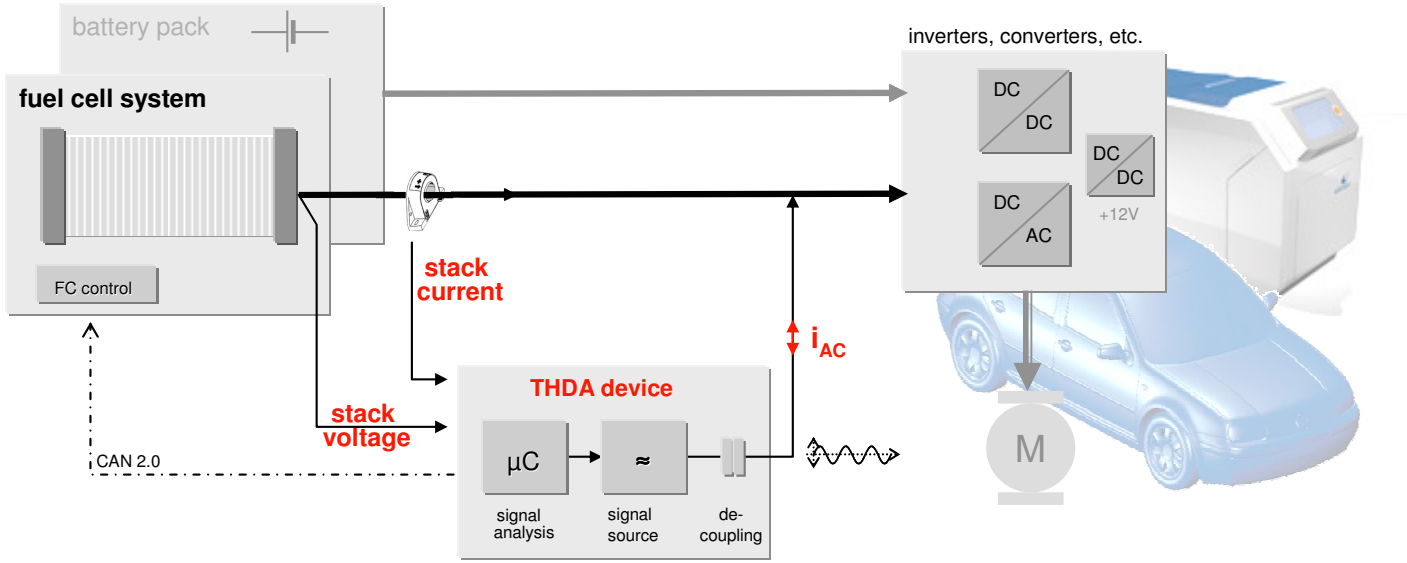
*AVL patent, registered trademark

BRIEF BACKGROUND OF HARMONIC DISTORTION



- Signal distortion forms extra components in the frequency spectrum. Harmonics can be detected at integer multiplies of the fundamental frequency
- Occurrence of extra spectral components is measured
- Quantification: “Klirrfactor” or “THD”, [%] [dB]

THDA INSTRUMENTATION PRINCIPLE

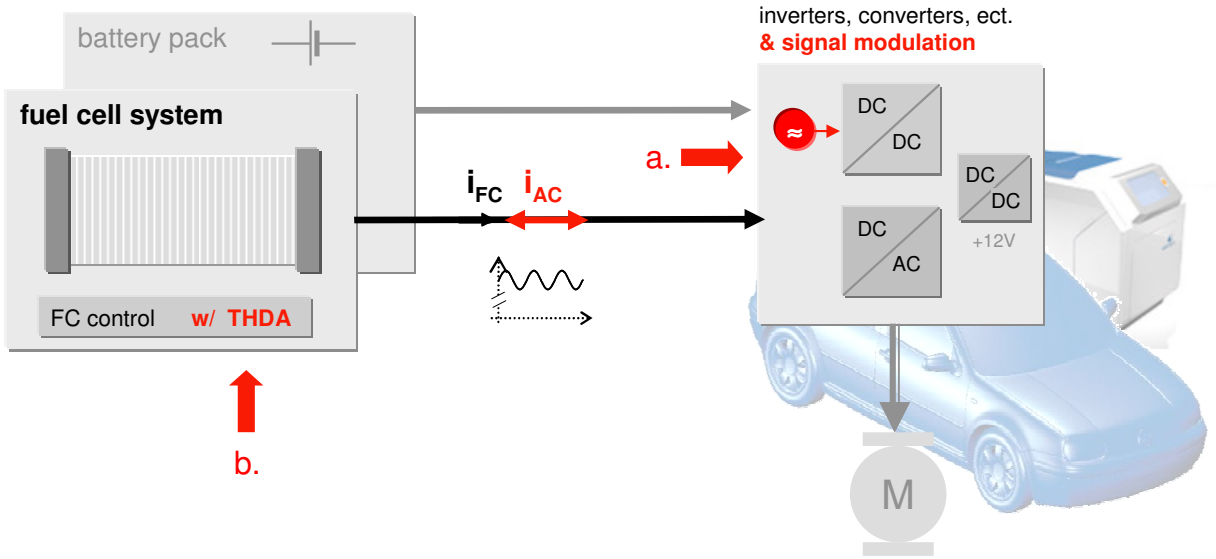


STAND ALONE APPROACH

- Superimposition of a small AC signal*
- (Spectral-)Analysis of voltage in terms of extra spectral components i.e. harmonic distortion

* i_{AC} = typ. 1A (→1mV/cell, sinusoidal, low frequency)

FULLY INTEGRATED INSTRUMENTATION PRINCIPLE

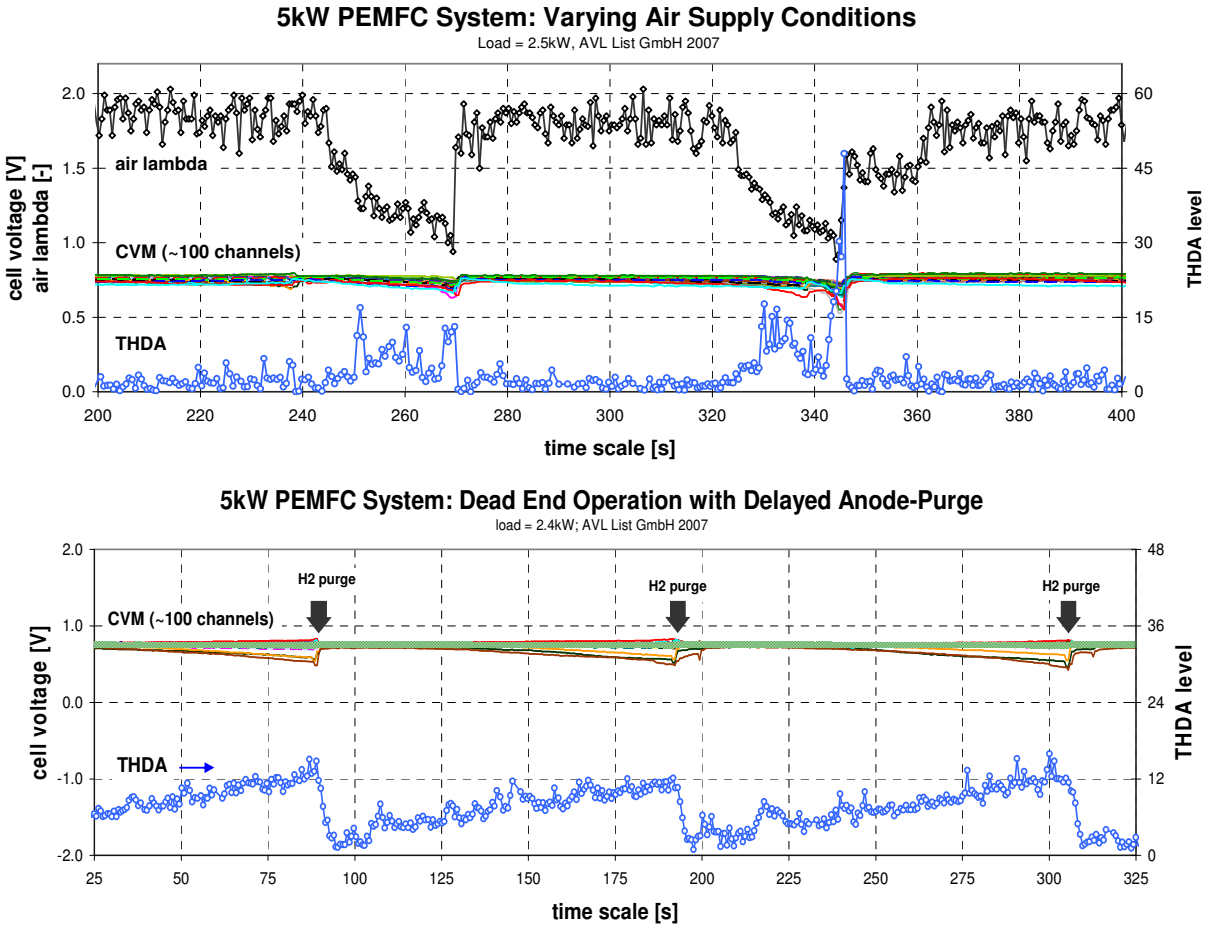


COST EFFICIENT APPROACH

a. Modulation of specific current signal pattern by **converter**

b. Embedded signal distortion analysis by **existing FC controller** (SW function)

THDA OPERATION EXAMPLE (PEMFC SYSTEM)



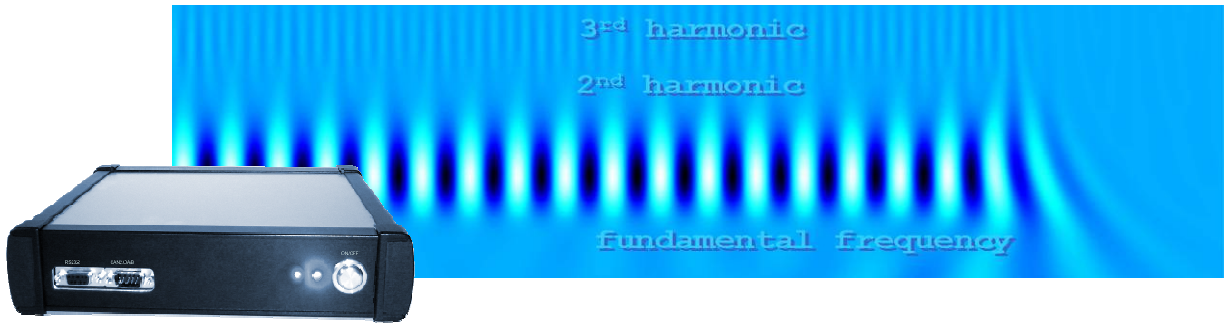
„THDA level“ is indicating on-line critical voltage drifts (somewhere) in the stack

EXTENDED DIAGNOSIS FUNCTIONS: CLASSIFICATION OF CRITICAL CONDITIONS

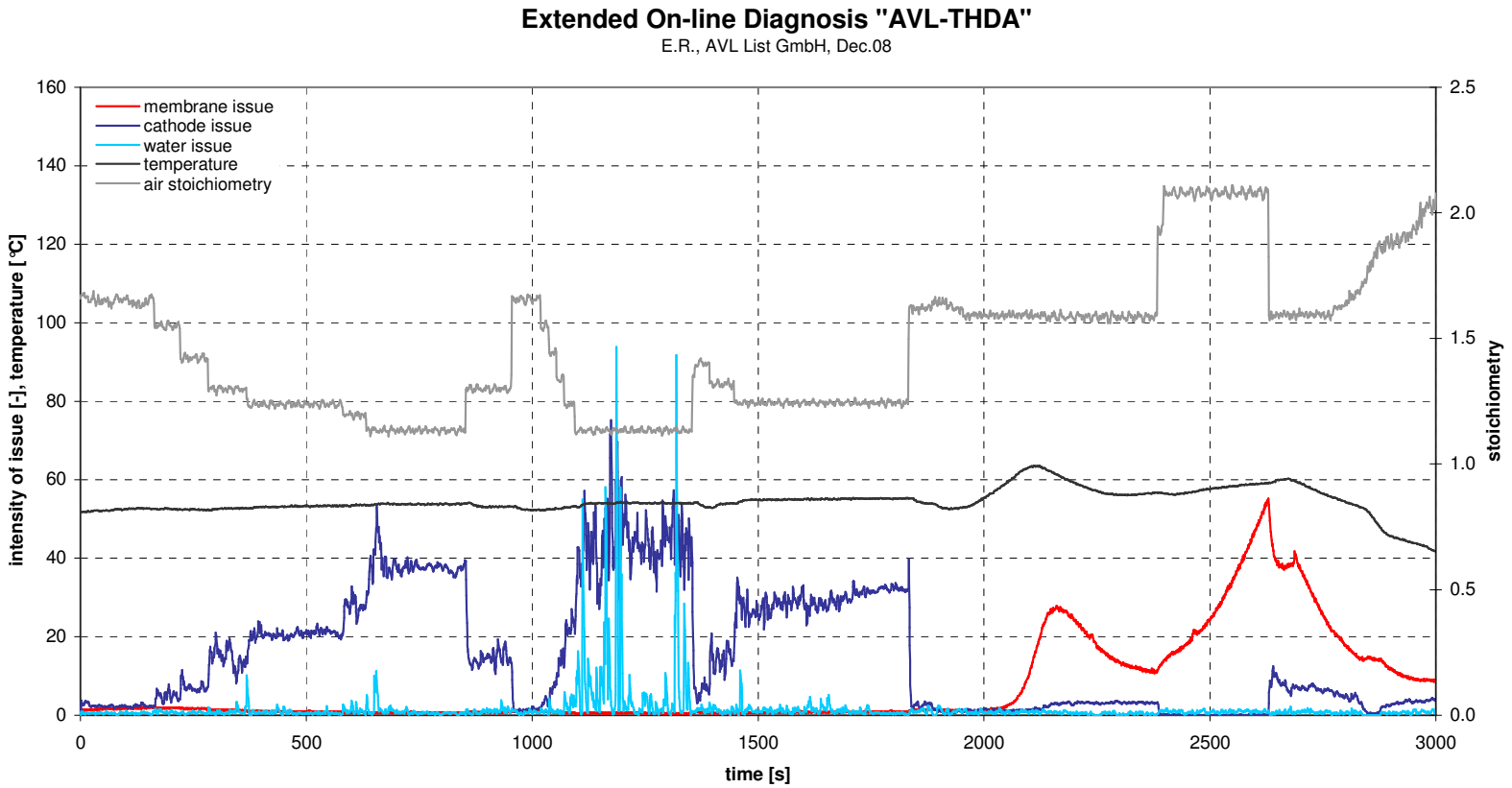
On-line determination of causes for detected critical cell voltage drops/drifts:

- **Water issues (flooding – drying)**
- **Low media supply issues (cathode – anode)**

Usage of same hardware and same instrumentation principle
i.e. continuing cost efficient 2 channel approach



ON-LINE DETECTION OF CRITICAL WATER ISSUES



ISSUES:

continous air reduction
>> insufficient O2 supply

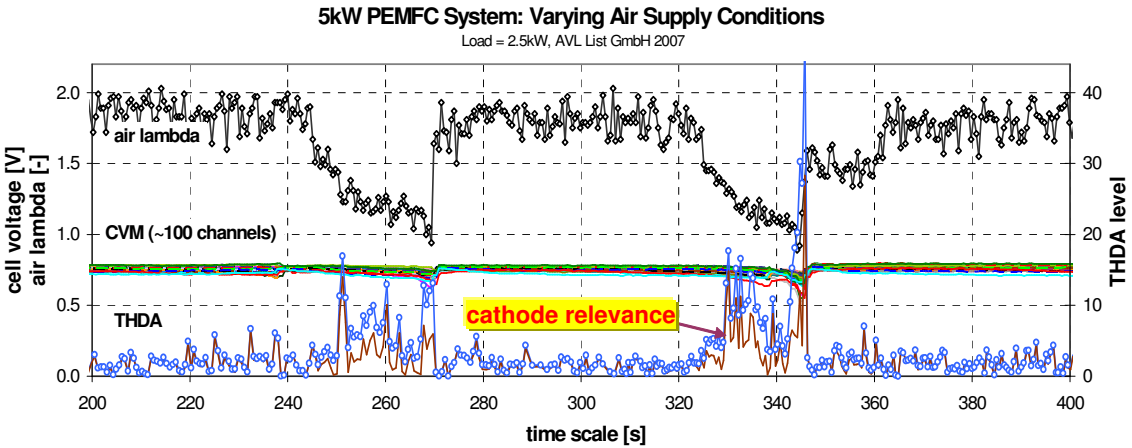
too fast air reduction
>> blocking through
remaining water

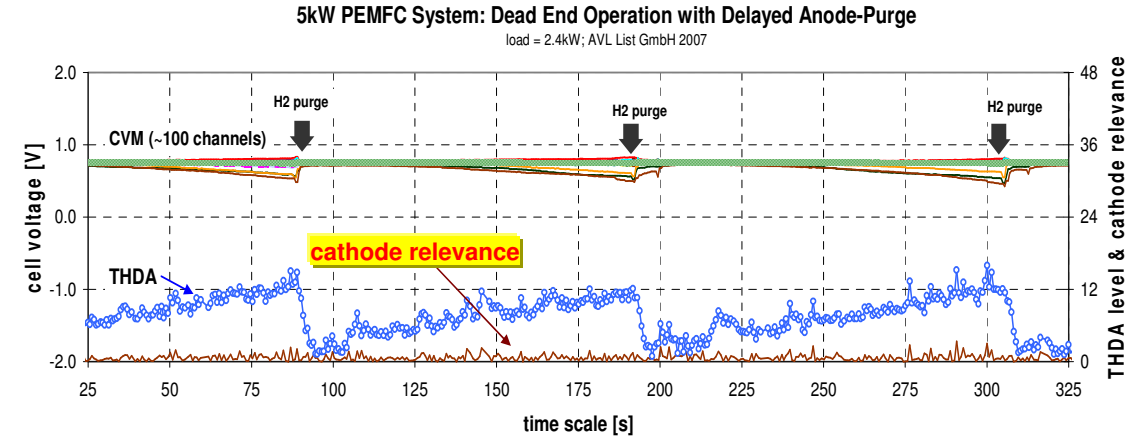
temperature
increase
>> dryout

high air flow
>> dryout

air supply issue | **liquid water** | **drying issue**

DETERMINATION INTO ANODE – CATHODE ISSUES

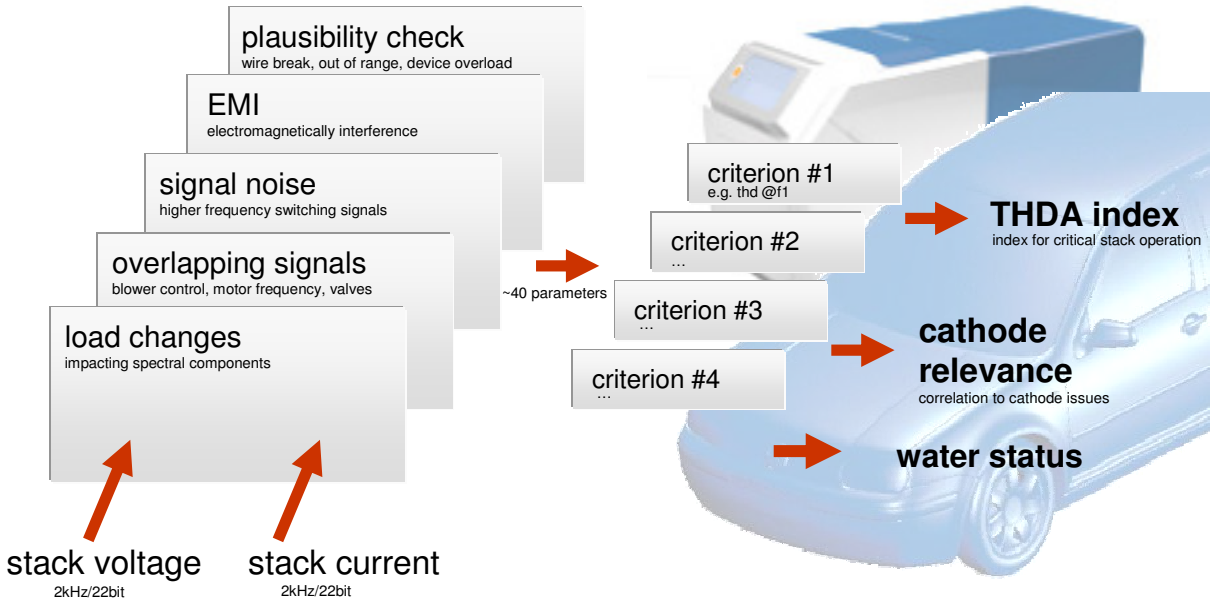




"THDA" indicates critical cell conditions

PLUS:
"CATHODE RELEVANCE" FOLLOWS "THDA" (cathode issue)
OR STAYS CLOSE ZERO (anode issue)

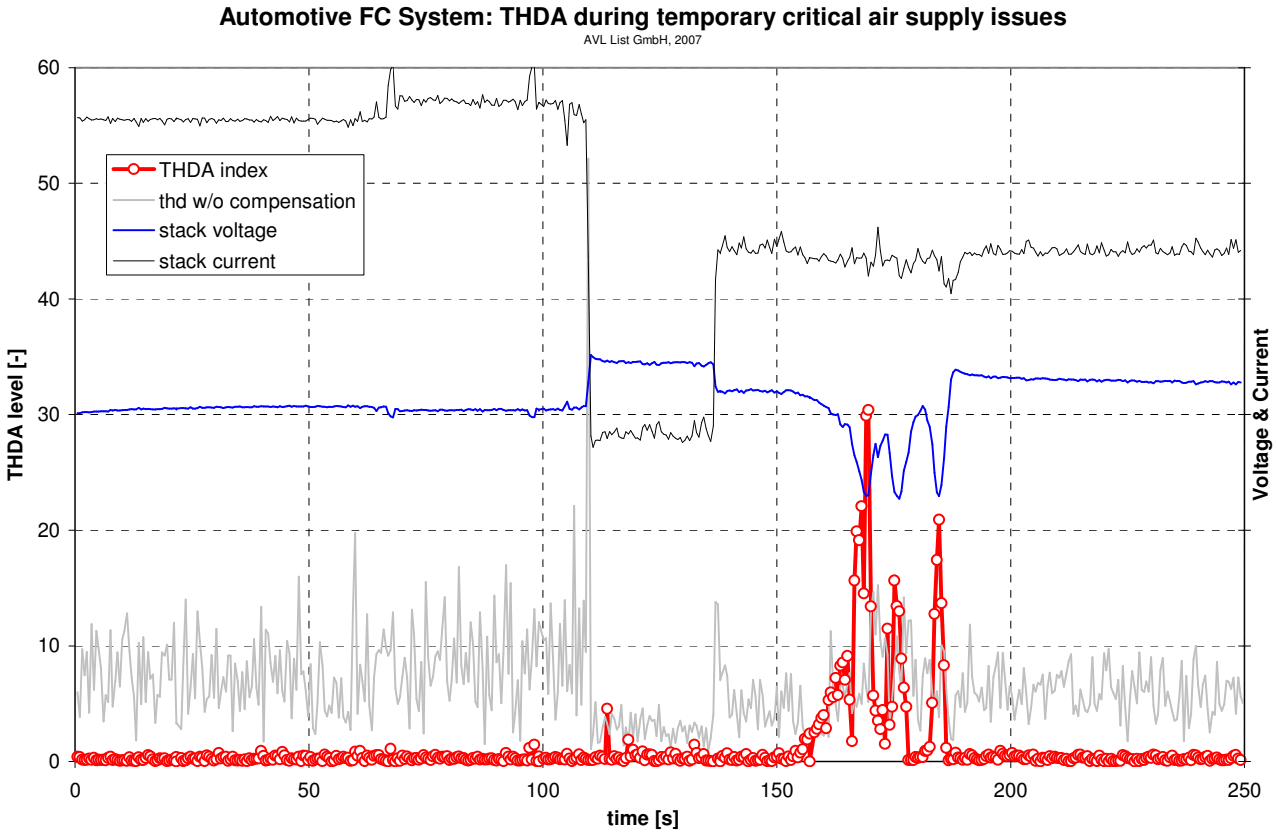
SYSTEM VIEW:
RELIABILITY & ROBUSTNESS



Criteria for stack monitoring with extended diagnosis functions are

- ROBUST within entire system environment due to special failure detection and compensation algorithm
- Still detectable without cell voltage monitoring (main criteria are harmonic distortion based)

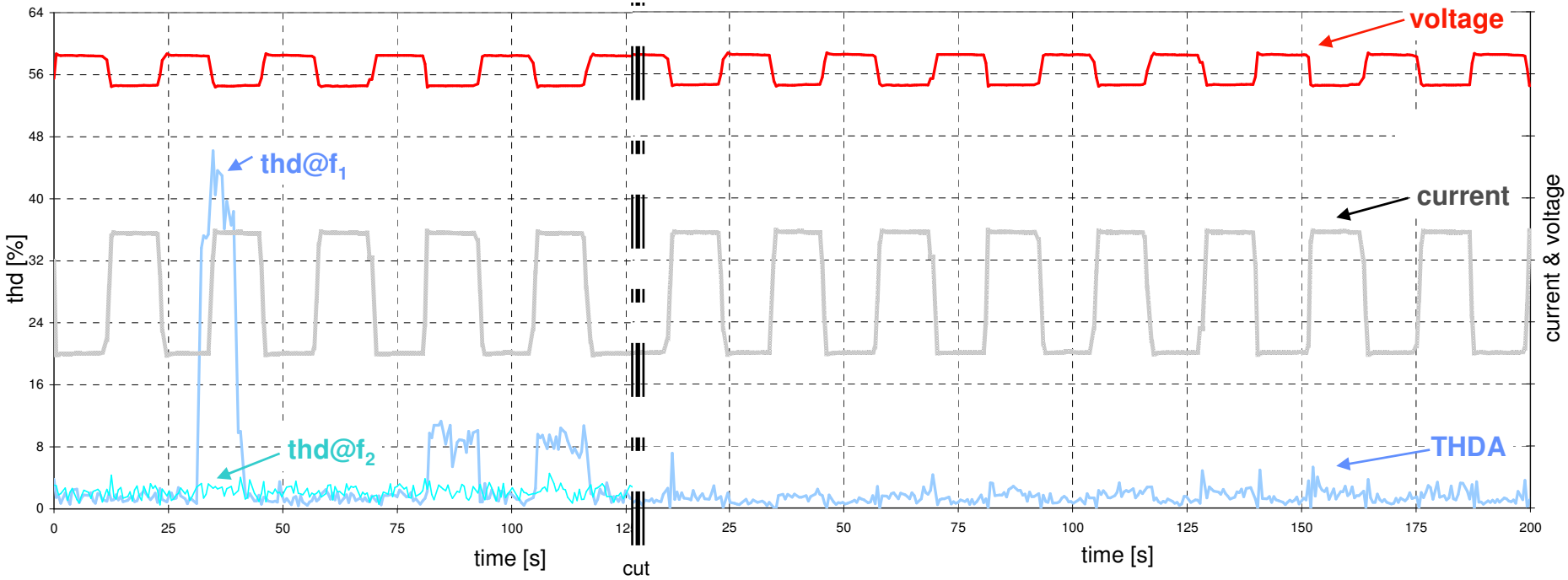
ROBUSTNESS: THDA OUTPUT EXAMPLE IN AN AUTOMOTIVE SYSTEM



Within automotive environment usually occur electromagnetic interferences (grey plot).
AVL has developed compensation algorithm for reliable THDA measurement (red plot)
→ critical issues are clearly indicated

RELIABILITY: AUTOMATED ERROR DETECTION IN THE THDA CALCULATION

dynamic load test of stationary PEMFC system with THDA Monitoring

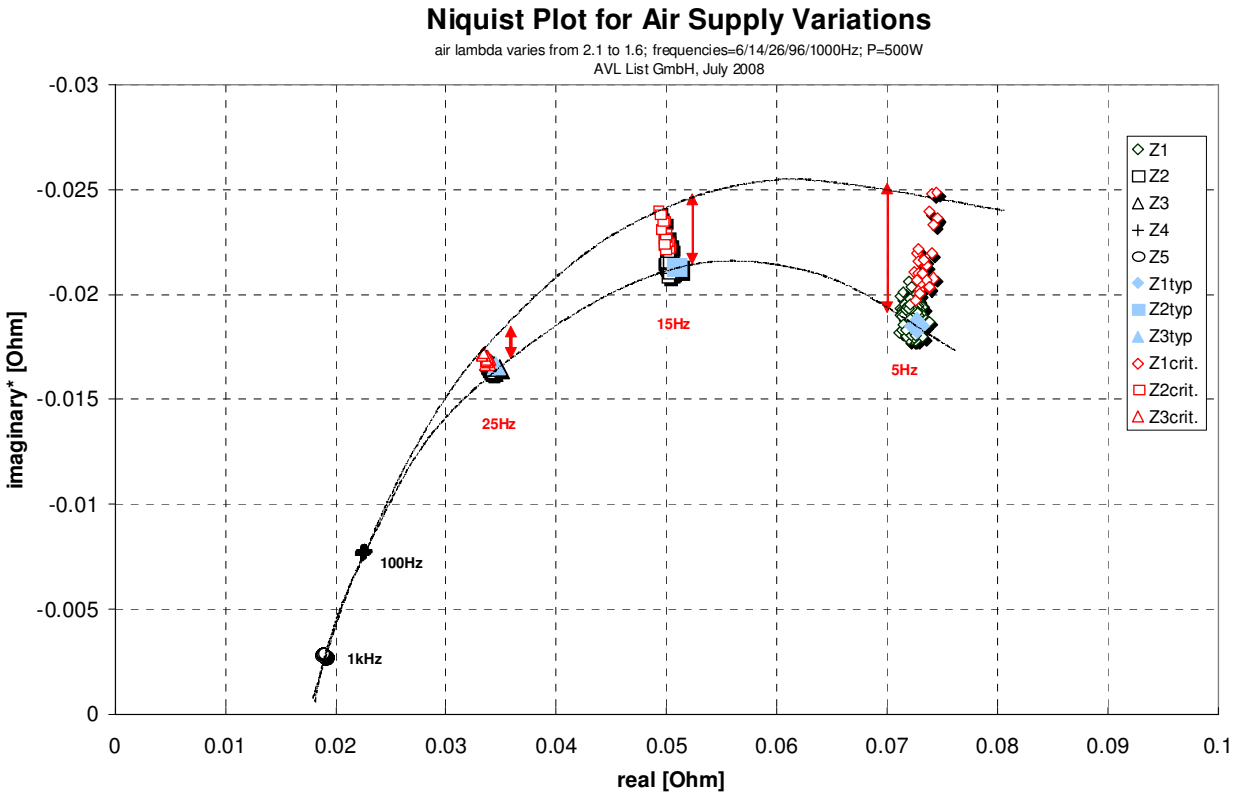


harmonic distortion measurement at two different frequencies: blower controller causes error
(controller uses same frequency as set for THDA)

→

THDA Index with automated error compensation

SPIN-OFF EFFECT: ONLINE FAST ELECTRICAL IMPEDANCE MEASUREMENT



Continously EIS scan every 0.5 sec.

shows **even time variant conditions** e.g. during water blocking issues

Conclusions from this example:

only imaginary fraction changes at lower frequencies

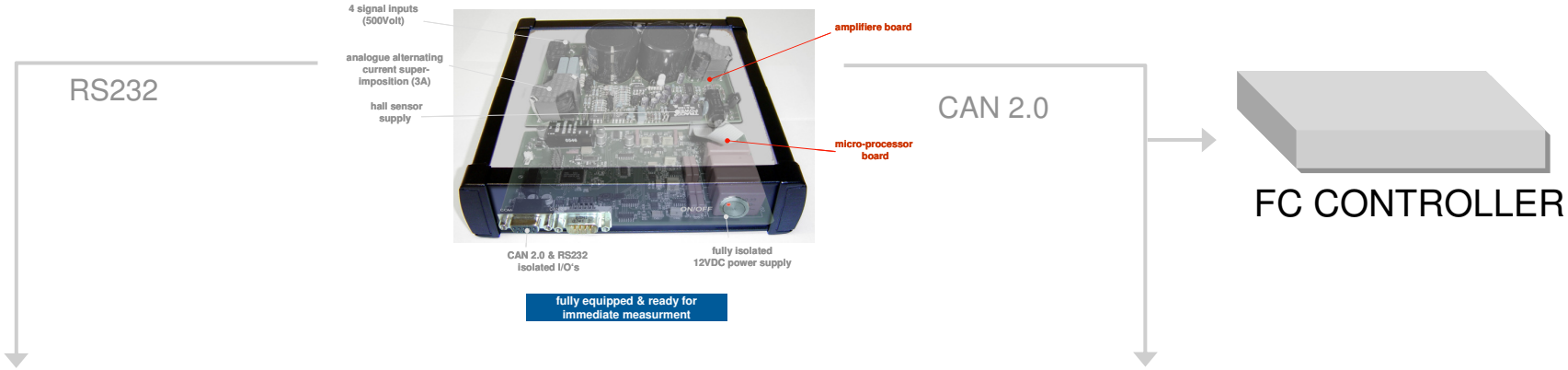
➔ **douple layer capacity** = constant & not important

➔ **membrane characteristics** not changed

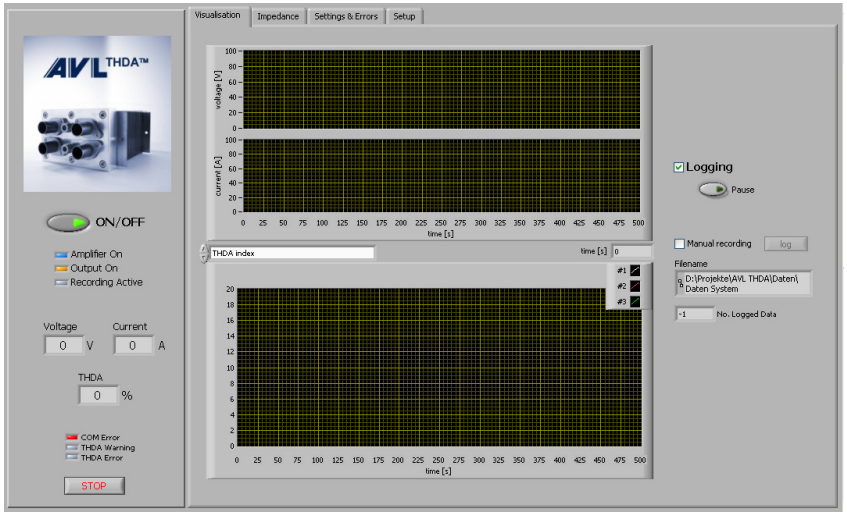
➔ **activation resistance** to be considered

➔ **harmonic distortion** effects for air supply issues below ~20Hz

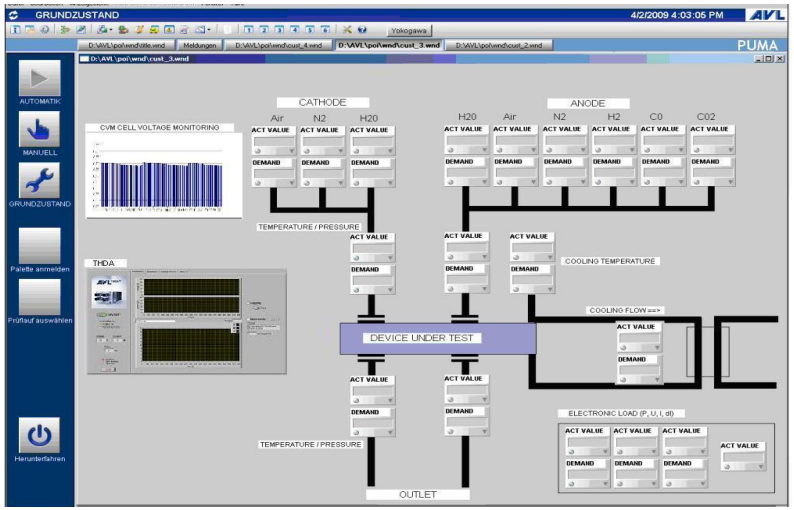
HW & SW EQUIPPMENT



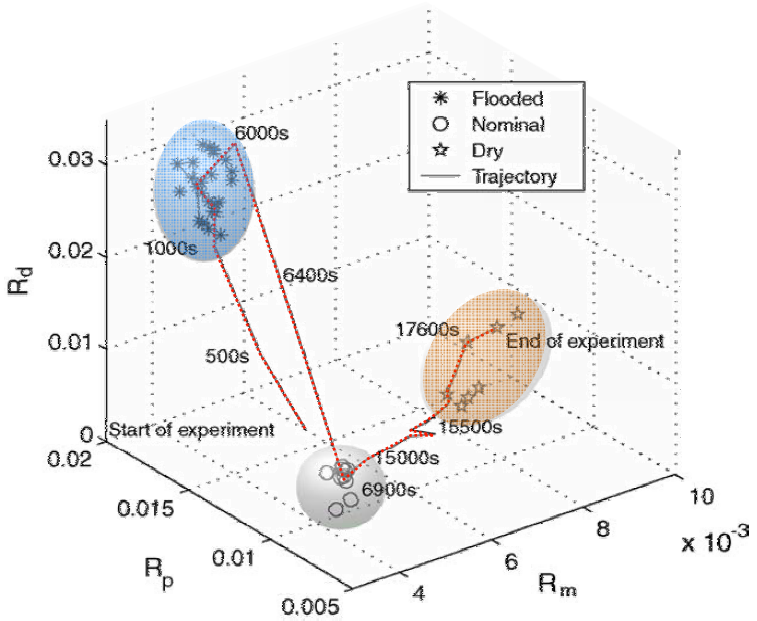
GUI for logging and visualisation



AVL PUMA FC TESTBENCH



OUTLOOK: LIFETIME MEASUREMENT



Evolution of the fuel cell state of health as a function of time
N.Fouquet et al /Journal of Power Sources, Volume 159, Issue 2, 22 September 2006, Pages 905-913

Online **STATE OF HEALTH MEASUREMENT** on basis of THDA approach including interpretation of certain electrical impedance parameters

TARGET is a powerful online monitoring technology including

- ✓ detection of **critical cell conditions**
- ✓ determination of **failure causes**
- ➢ **SOH** measurement

for increasing **system efficiency,**
fuel cell **lifetime and reliability** on
cost efficient HW approach

Cooperative project with partners

PSA PEUGEOT CITROËN

TU Graz

supported by bmvit Bundesministerium für Verkehr, Innovation und Technologie FFG

SUMMARY

AVL THDA is an **ONLINE STACK MONITORING TECHNOLOGY** based on analyzing harmonic distortion effects of voltage drifts instead of single cell voltage measurement

Standard THDA routines together with extended criteria give the **EXTRA INFORMATION FOR CLASSIFICATION** into cathode, anode or membrane effects

Two channel measurement (V_{FC}, I_{FC}) with **COST EFFECTIVE HARDWARE** components significantly reduces the instrumentation effort

THDA includes special algorithm for **ROBUSTNESS & RELIABILITY** within practical system application