Test Setup for Aging Investigations on PEM Cells

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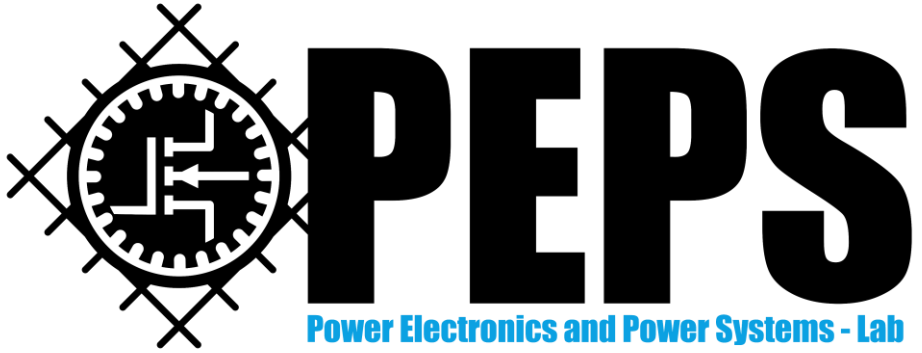
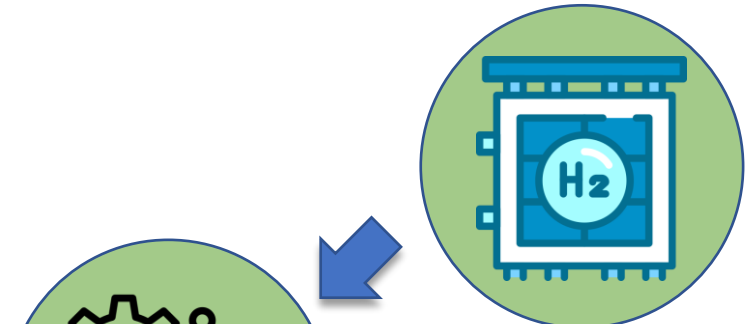
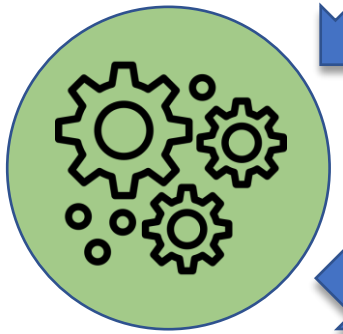


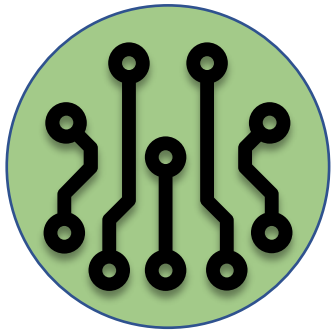
Agenda



PEM electrolyzer



Aging effects



PEM test bench

Measurement results

Structure of an electrolyzer

General structure of an electrolyzer

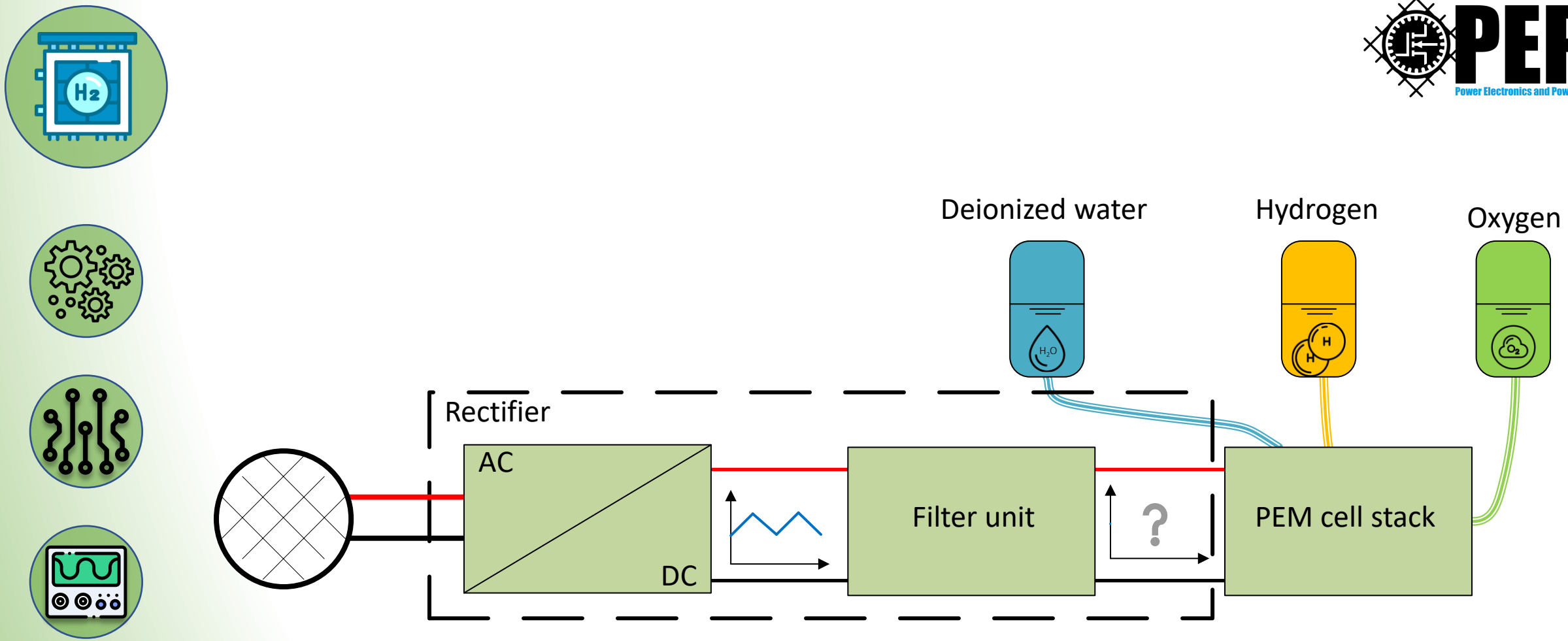


Figure 1: Components of an electrolyzer

Aging effects of a PEM cell

Overvoltages of a PEM cell

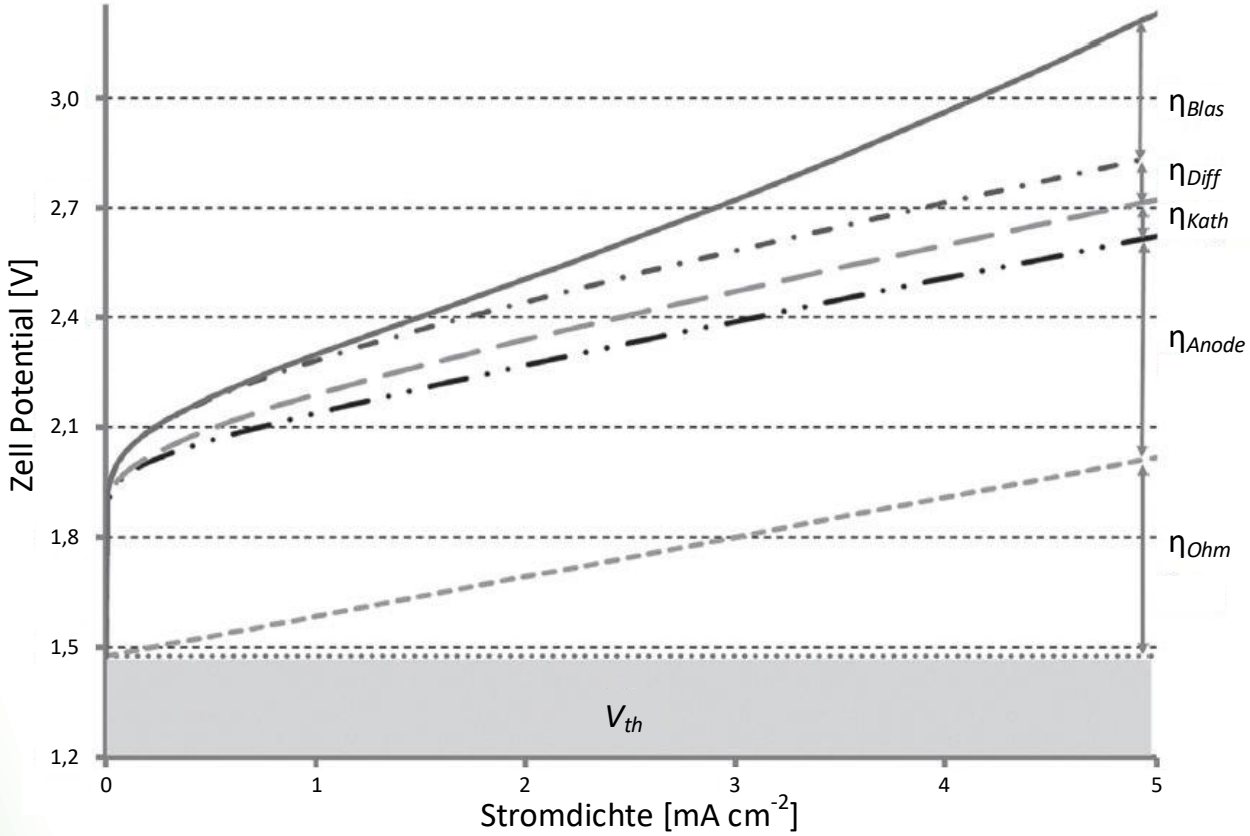


Figure 2 : Cell voltage as a function of current density
Source**:** *PEM electrolysis for hydrogen production: Principles and applications,* D. G. Bessarabov u. a., Hrsg.

$$V_{Zelle} = V_{th} + \eta_{Ohm} + \eta_{Anode} + \eta_{Kath} + \eta_{Diff} + \eta_{Blas}$$

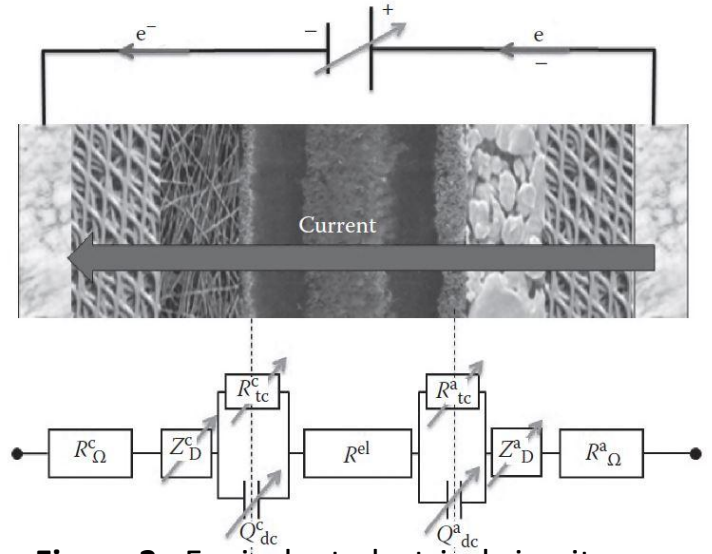


Figure 3: Equivalent electrical circuit
Source**:** *same as Fig. 2*

Aging effects:

- Membrane aging
- Catalyst degradation
- Increase in ohmic resistance

PEM cell test bench

PEM cells test bench - key features

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- Water circuit with integrated water treatment system for cleaning and reusing the water
- Hydrogen sensor measures the hydrogen concentration in the system to ensure safety
- A compressor supplies compressed air
- Function generators produce a reference signal for current supply
- Desktop PC for control and data backup

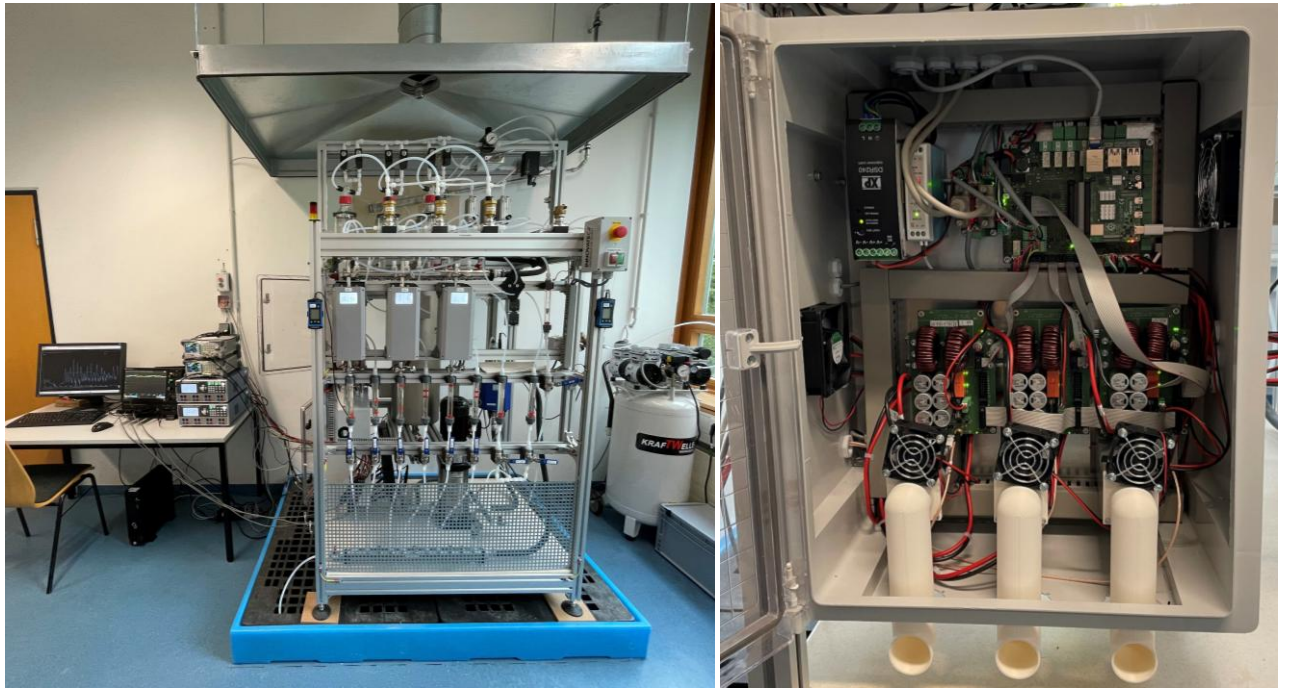

Figure 4: PEM cell test bench

Features:

- Up to three PEM cells are supplied with a DC mean current of 10 A each
- Superposition of different current waveforms possible, e.g., triangular, rectangular, or sinusoidal current [1]
- With a frequency of up to 50 kHz [1]
- Adjustable ripple factor of up to 150% [1]

PEM cell test bench - concept

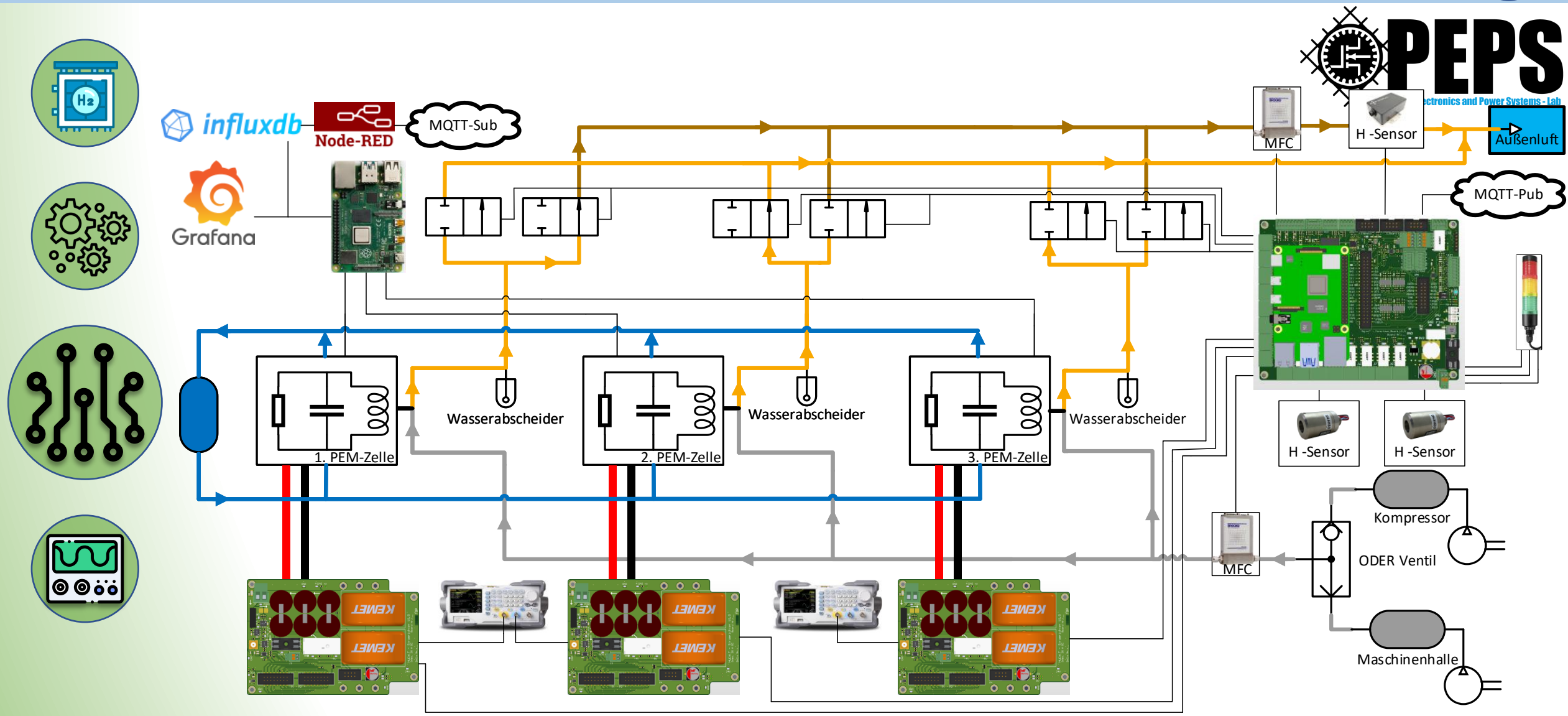

Figure 5: Concept of the PEM cell test bench

Measurement results and PEM model

Measurement result – Foreign ions in water

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Membrane failure (Short-circuit)

Figure 6: Bronze electrode: Discolorations and deposits on the front and back sides

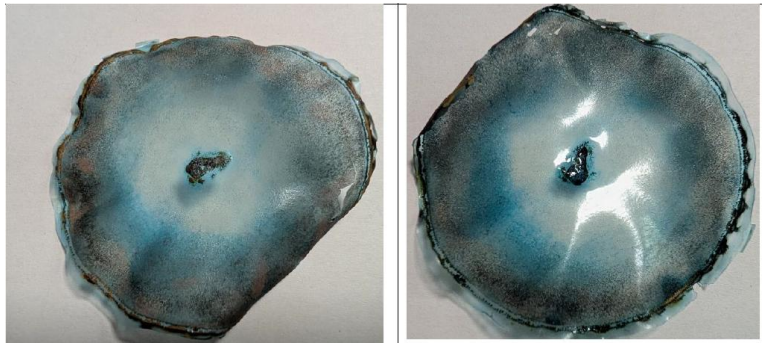

Figure 7: Nafion 117 membrane:
Front side: blue discoloration.
Back side: blue and brown discolorations and deposits, holes, white deposits in the center.

Figure 8: Platinized titanium electrode:
Front and back side: spot formation. Source: [3]

Figure 9: PEM cell before the test

Measurement result – Foreign ions in water

Ex – Situ Analysis

- **MEA consists of platinum-coated titanium electrodes and Nafion 117 membrane**
- **Types/Methods of Investigation**
  - Computed tomography
  - LIBS analysis
  - X-ray fluorescence (XRF)
  - Water analysis, etc.
- **Results of the Investigation**
  - Foreign ion (Zn^{2+}, Cu^{2+}) deposits in electrodes
  - Short circuit due to damaged membrane
  - Increasing conductivity of water
  - Oxidized cathode

Figure 10: LIBS measurements on the membrane – deposits of copper oxides, chlorides, and hydroxides on the membrane

Table 1: Multi-point analysis [wt%]

Nr.	Assumed Material	F	O	Cl	Cu	Si	Ti	Ni	Zn	Sn	Pt
1	Fluoride compounds	50,0	25,6	14,7	9,7	0,0	0,0	0,0	0	0	0
2	Fluoride compounds	56,0	30,1	0,0	13,9	0,0	0,0	0,0	0	0	0
3	Fluoride compounds	57,9	30,4	0,0	11,7	0,0	0,0	0,0	0	0	0
4	Fluoride compounds	59,8	31,0	0,0	9,2	0,0	0,0	0,0	0	0	0

Measurement result – Foreign ions in water

Voltage – current plot

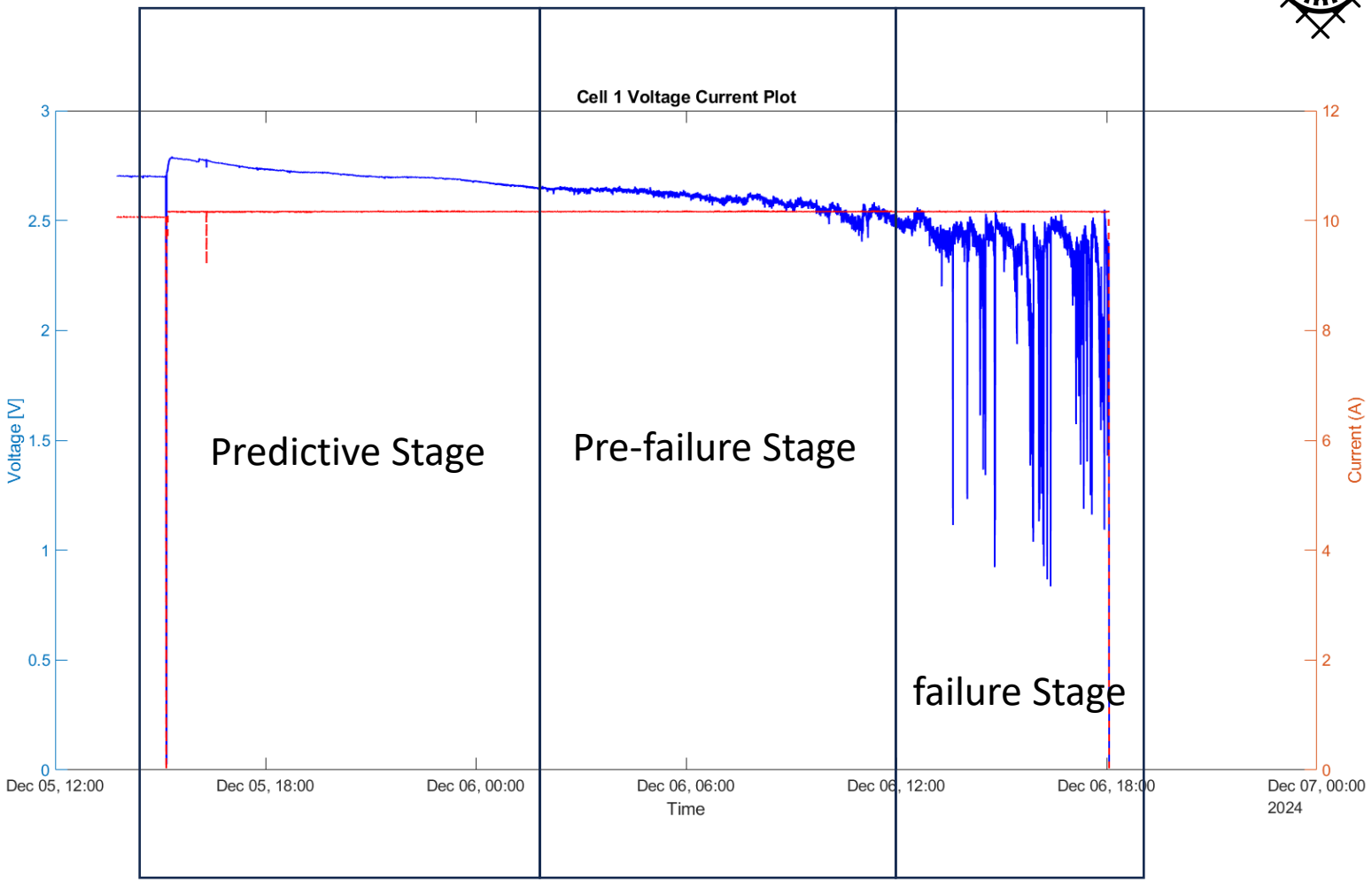

Figure 11: Voltage and current plot over time of a damaged PEM cell

Electrochemical Cell Monitoring and Characterization

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Analysis

EKF

EIS

Determination of cell electrochemical state and aging

Cell Parameter

Measurement

- Electrochemical Impedance (EIS)
- Steady-state Measurement (SS)

Cell characterising

- Membrane resistance
- Exchange Current (anode and cathode)
- Double layer capacitance
- Electrochemical active area
- …

Validated in every 1000Std operation or in case of anomaly

Electrochemical state

Measurement (Sensor data)

- Potential, Current
- Temperature
- H_2 generation (kg/s)
- O_2 generation (kg/s)

State-Space Model

- Membrane water content
- Overpotential
- Temperature

- Electrochemically active surface
- Ohmic Resistance
- Exchange Current
- …

Monitoring
Prediction

Future measurement result

Do ripple currents from a power converter have an impact on the lifetime of PEM cells?

?

To be continued…

Table 3: current configuration

		Cell 1	Cell 2	Cell 3
Frequency	f_{max}	24 kHz	24 kHz	-
DC supply current	I_{DC}	10 A	10 A	10 A
Ripple factor	γ	100 %	50 %	-

Summary & Outlook

Testing PEM cells under different current waveforms → Acquisition of measurement data → Investigation of PEM cells regarding aging effects → Possible cost, volume, and weight optimization of the rectifier filter

Table 4: Possible operating conditions of the PEM test bench

Frequenzbereich	f_{max}	=	50 kHz
max. DC PEM-Zellen Strom	I_{DC}	=	10 A
max. Rippelfaktor	γ	=	100 %
Current waveforms	*rectangle, triangel and sine*		

References

- [1] M. Mondre, J. Kirchhof, B. Sah and M. Jung, "Design of a Current Control System for Generating Various Current Forms," PELSS 2024; Power Electronics Student Summit, Kassel, Germany, 2024, pp. 75-80.
- [2] N. Wiese, D. Ghosh, P. Kretschmer, S. Eberlein and D. Strauß-Mincu, "Grid-Forming Controlled Electrolyzer with LVRT Capability and Asymmetric Inertia Provision," *2024 International Conference on Smart Energy Systems and Technologies (SEST)*, Torino, Italy, 2024, pp. 1-6, doi: 10.1109/SEST61601.2024.10694072
- [3] Moritz Mondre, Debraj Ghosh, Marco Jung, and Steffen Witzleben. Untersuchungder alterungseffekte von elektrolysezellen durch hochfrequente stromanteile. H2Giga-Abschlusskonferenz, Juli 2025. Frankfurt, Deutschland