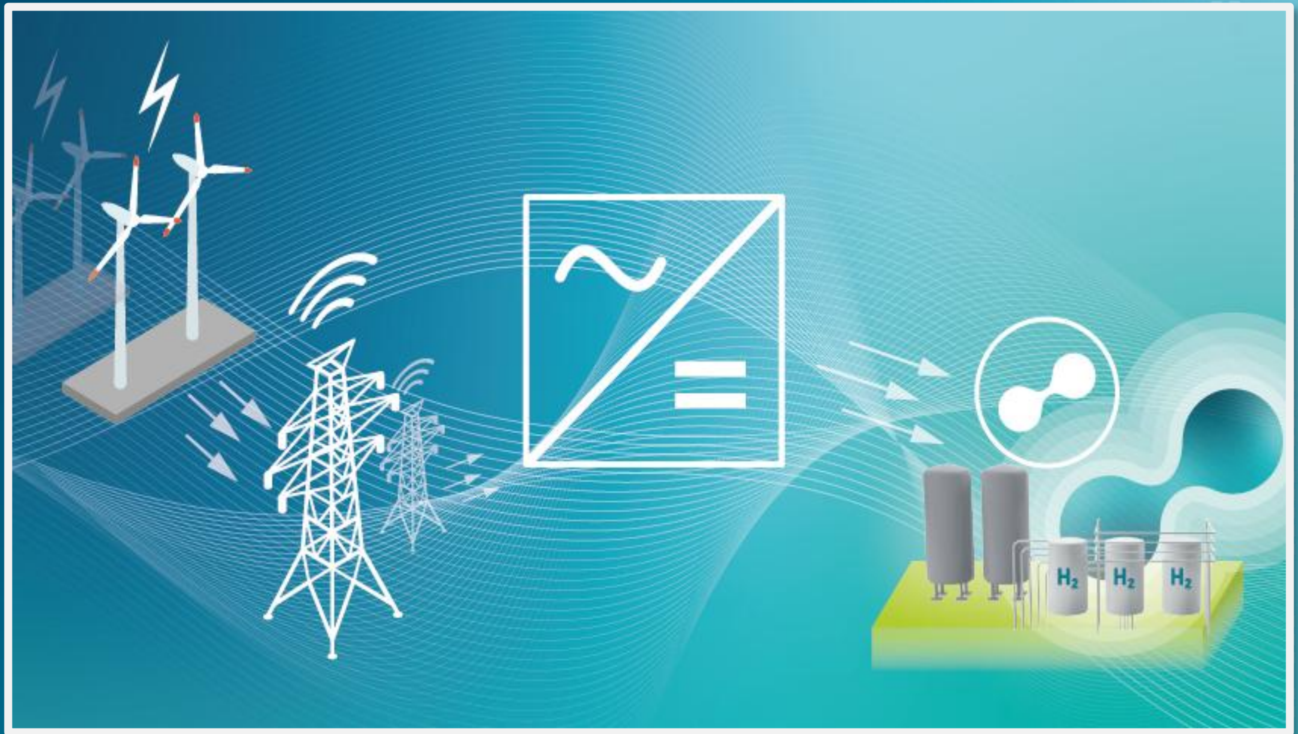


Fraunhofer IEE

DERlab
European Distributed Energy Resources Laboratories

Workshop, 04. August 2025

Welcome to the workshop: Challenges of Electrolysis Systems at Relatively Weak Connection Points

Workshop

Modeling of electrolysis plants on component and system level

Agenda	

13:00 – 13:15	Welcome
	▪ Welcome and a short introduction of DERlab (Mohammed Al-Saadi, DERlab. 5min)
	▪ Opening Remarks and Moderation (Norbert Henze, Fraunhofer IEE, Germany)
	    ▪ Aims and Motivation of this Workshop
	    ▪ Introduction to the HyLeiT Project. Cost-optimized system technology and grid integration of systems for the production of green hydrogen

13:15 – 15:00	Presentations
13:15 – 13:35	Grid-Friendly Hydrogen (Alexander Unru, SMA Altenso GmbH, Germany)
13:35 – 13:55	Challenges with Grid / without Grid (Thomas Schwabe, Siemens Gamesa Renewable Energy Deutschland GmbH, Germany)
13:55 – 14:15	Green Hydrogen Electrolysers in Forming Future Grids – Power Electronics Perspective (Michael Fette, Fette Dynamics GmbH, Germany)
14:15 – 14:20	*Short Break*
14:20 – 14:40	Hydrogen Integration and its Implications for Weak Grid Infrastructure (Jakob Hainyemba, Namibia Energy Institute – Center for Renewable Energy and Energy Efficiency, Namibia
14:40 – 15:00	Impact of Large-Scale Electrolysers on Power Grids (Antonio Iliceto, CIGRE, France; ENTSO-E, Belgium)
15:00 – 15:20	Discussion
15:20 – 15:30	Conclusions and end of meeting

Workshop

Challenges of Electrolysis Systems at Relatively Weak

Motivation

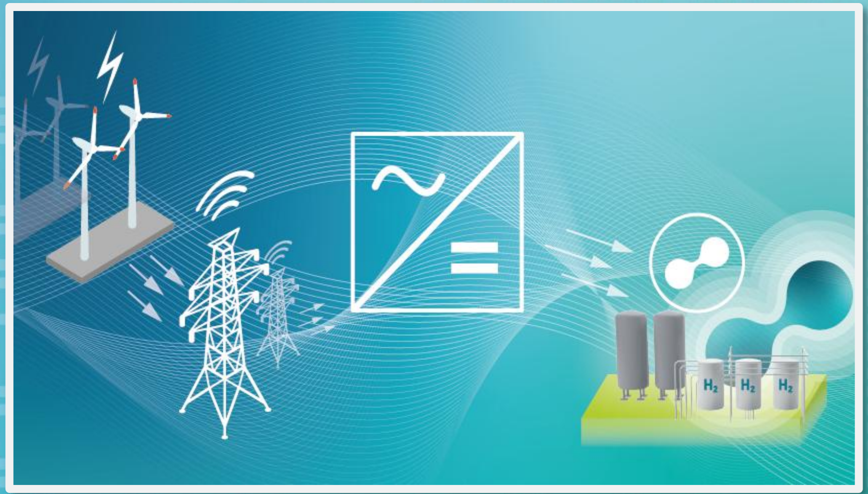
- The scale up of green hydrogen production (Germany: 10 GW electrolysis capacity in 2030) requires a large amount of renewable energies.
- Facilities for green-hydrogen production are expected be connected often to weak or islanded grids, where the available short-circuit power is not sufficiently
- Effects in weak grids: Voltage, power and frequency fluctuations, disconnections, reduces stability, sub/super synchronous oscillations (in inverter dominated grids)
- Even under weak grid conditions the system stability must be maintained and the impact on the electrolysis plant minimized

Aim of the workshop

- How can electrolysis systems be operated under short circuit ratio conditions?
- What are the challenges of connecting water electrolysers for green hydrogen in week grids?
- How can electrolysis be made grid-friendly?

Project HyLeiT

Cost-optimsed system technology and grid integration of systems for the production of green hydrogen



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Project HyLeiT

Cost-optimised system technology and grid integration of systems for the production of green hydrogen

Profile

- Funding: Federal Ministry of Research, Technology and Space (BMFTR)
- Part of the flagship project H2Giga: Serial Production of Electrolysers
- Duration: 01.04.2021 – 30.09.2025
- Project Partner
  - Fraunhofer IEE (Project lead)
  - SMA Technologies AG
  - Infineon AG
  - Technical University Dresden
  - University Bonn-Rhein-Sieg

Content and objectives

- Project content
  - Development of system-optimised rectifiers
  - Investigation of electrolysis stacks to build real-time simulation models for optimal power converter design
  - Grid integration of electrolysis plants (grid support, system services)
- Key objectives
  - New generation of power inverters for electrolysis plants
  - Cost reduction in system technology
  - Better DC power quality for the electrolyser
  - Grid compatibility and options for system services
  - Embedding in scenarios with renewable energy

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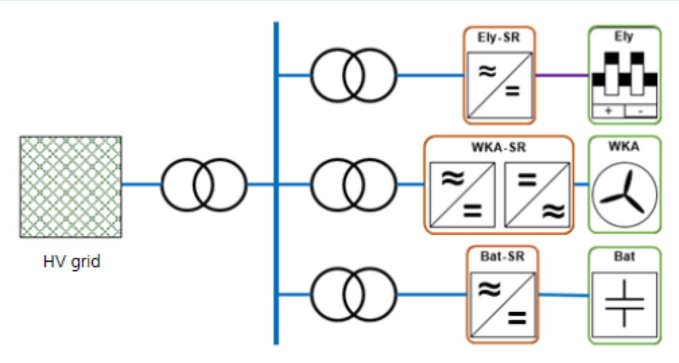
Summary: Solutions for electrolysis plants by Fraunhofer IEE

Grid integration of electrolysis plants
- Assessment of grid stability
- Dynamic system modelling

Modular power supply for electrolysers
- P_N = 200 kVA per Module
- Voltage Range DC: 0 - 500 V

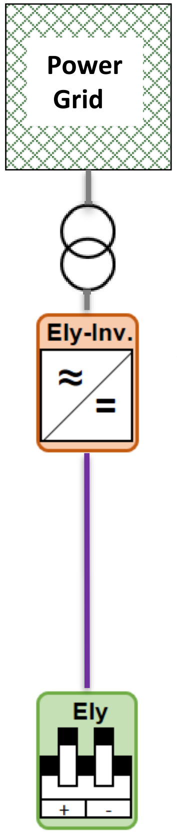
PEM cell models
- Based on electro-chemical processes
- Customized real-time model



Electrolyser Park with Battery Storage and Wind Power Plant

Inverter with SiC Trench MOSFET

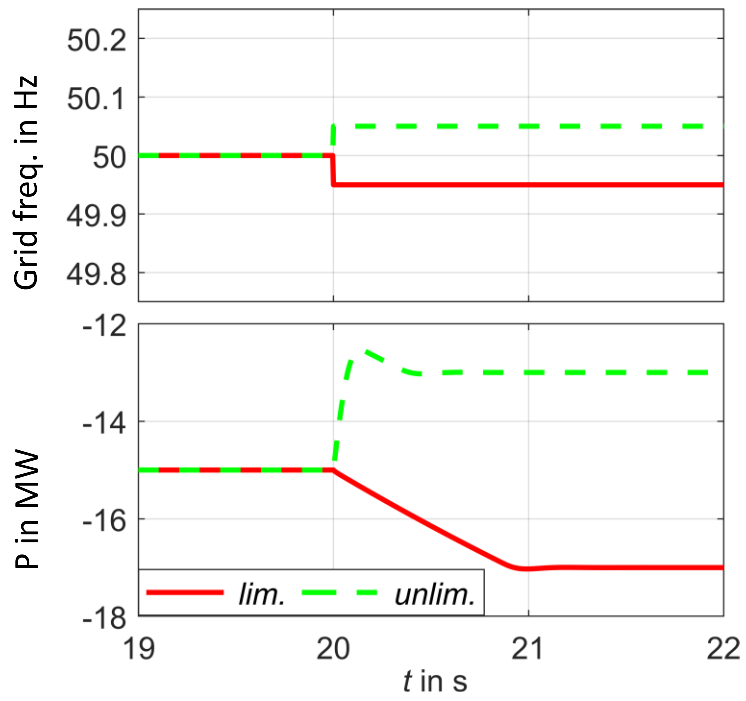
HyLeiT results - Solutions for electrolysis plants



- 10 GW in 2030: Electrolysis plants are a relevant factor for securing system stability
  - HyLeiT solution: Grid forming control of electrolysis plants and dynamic models to assess the interaction of electrolysis plants (including battery storage, wind power etc.) on the power system
- Innovative electric power supply to meet challenges that arise from
  - …demand for cost-efficient multi-MW rectifiers (→ large-scale production)
  - …increased grid integration requirements on rectifiers (→ provision of ancillary services)
- Measures to increase reliability of electrolysers:
  - Optimised high current connections
  - Fault detection and protection systems in electrolysis systems.
- Electro-chemical real-time models of cells and stacks
  - Test environment for deep analysis of PEM cells, model parameter extraction, precise performance prediction

Grid Integration of Electrolysis Plants

- Dynamic electrolyser models
- Conducting system integration studies
- Evaluation of system stability / grid support by electrolysers
- Consideration e.g. of wind power and batteries in electrolyser parks
- Consideration of grid forming in electrolysis plant control
- Assessment e.g. of
  - LVRT (Low voltage ride through)
  - LFSM (Limited frequency sensitive mode)
  - Reactive power provision
  - Provision of asymmetric inertia



Exemplary active power response on frequency changes

Modular Power Supply for Electrolysers

Dimension

- Height: 9 units (445 mm)
- Depth: 800 mm
- Width: 19 Inch-Rack
- Weight: ca. 80 kg

19‘‘-Rack

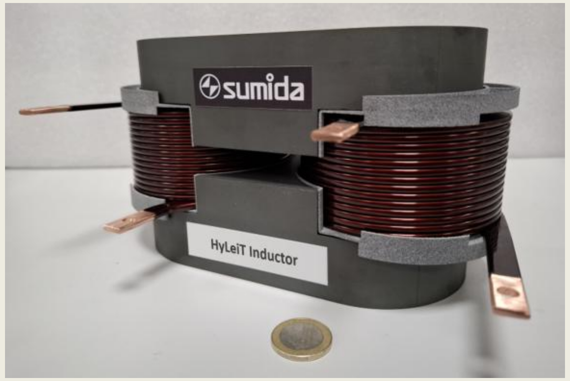
- Multiple inverters in one 19‘‘- rack
- Electrical DC connection in series or parallel
- Safety functions
- Power scale up by electrical series or parallel connection

Basic Design Parameter

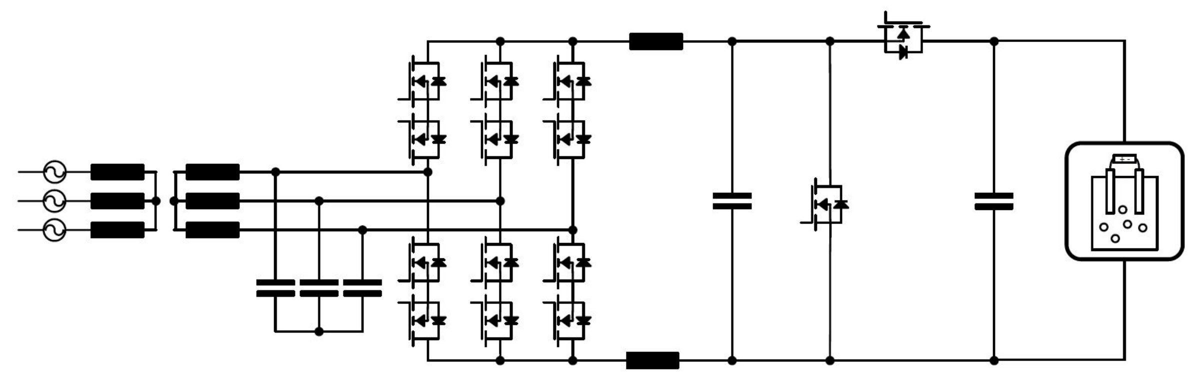
- AC rated apparent power 200 kVA
- AC rated voltage AC 520 V_{LL}
- AC rated current AC 225 A
- Phase angle -30° bis 30°
- DC voltage range 0 - 500 V
- DC rated current 0 - 400 A

Modular Power Supply for Electrolysers

HyLeiT



- Significat reduction in size, weight and costs of magnetic componentes
- Only one magnetic component for PFC/Rectifier stage and DC-DC stage



- Six-Switch-Buck Topology with boost stage
- Interleaved operation to minimize DC ripple
- pure reactive power provision
- Dynamic grid support acc. common grid codes
- Fault-Ride-Through capability
- Electrolyzer supply during grid faults

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HyLeiT
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Cell model development - From cell to stack to BoP

Balance of plant (BoP) level	Stack level	Cell level	Curr. collector, membrane, electrolyte	cell level	particle

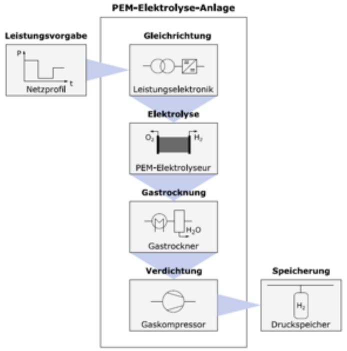


Figure – 6 from [2]

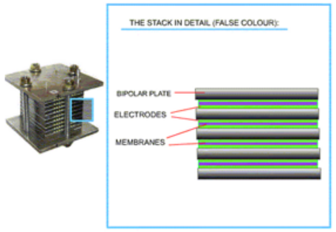


Figure – from [4]

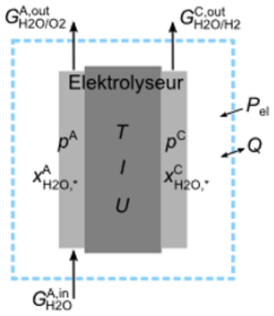


Figure – 4.2 von [3]

$U, T, ...$

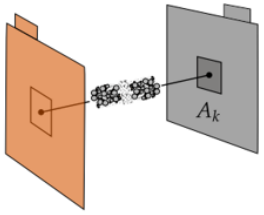


Figure – 5.2 from [3]

$i_{tot}, \phi, A, T, L,$
$\dot{N}_{H_2O}, \dot{N}_H, \dot{N}_O, ...$

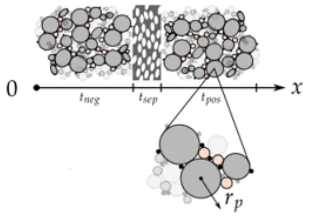


Figure 5.2 from [2]

$\mu_H, \mu_{H_2O}, \mu_O,$
$\phi, c_H^{Bulk}, c_O^{Bulk},$
$c_{H_2O}^{Bulk}, i_e^{Bulk}$ ...

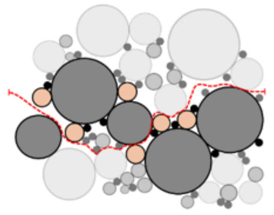


Figure 3.7 from [2]

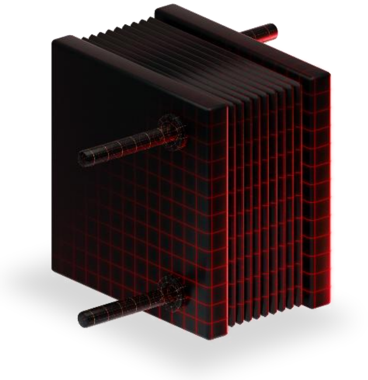
$\eta, i_e, i_s, a_v^{act,cat}$
$a_v^{act,an}, j_{bv}^{cat}, j_{bv}^{an},$
$\mu^{H^+}, c_H^{agg},$
$c_{H_2O}^{agg}, c_O^{agg}, \varepsilon, ...$

Sources:
[1] Entwicklung und Integration neuartiger Komponenten für Polymerelektrolytmembran- (PEM) Elektrolyseure - Philipp Lettenmeier, Promotion Arbeit, Institut für Energiespeicherung (IES) der Universität Stuttgart , 2018, Online: https://elib.uni-stuttgart.de/handle/11682/9706)
[2] PEM-Elektrolyse-Systeme zur Anwendung in Power-to-Gas Anlagen, Geert Tjarks Forschungszentrum Jülich GmbH, Institut für Energie- und Klimaforschung Elektrochemische Verfahrenstechnik (online: https://publications.rwth-aachen.de/record/689617/files/689617.pdf)
[3] Systemanalyse der Druckwasser-Elektrolyse im Kontext von Power-to-Gas-Anwendungen , Boris Bensmann, , Promotion Arbeit, Fakultät für Verfahrens- und Systemtechnik der Otto-von-Guericke-Universität Magdeburg, 2017, Online: https://pure.mpg.de/rest/items/item_2506307/component/file_2520739/content
[4] DoITPoMS Teaching and Learning Packages, University of Cambridge (Online: https://www.doitpoms.ac.uk/tlplib/fuel-cells/low_temp_pem.php)

Cell model development - From cell to stack to BoP

Model Highlights

- Prediction of the terminal behavior of arbitrary operating states
- Detailed insights into the internal processes
- Simulation of dynamic short-term processes and aging effects
- Complete individual parameterization of cells
- Total package - software and parameter data set



BaSiS HYO
Electrolyzer Model

Technical advantages

- Real-time capability / HiL use (individual emulator control)
- Adjustable accuracy and calculation speed
- Available for common operating systems
- Further interfaces: MATLAB® / SIMULINK®, Functional Mock-up Interface, Python

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Cell model development - From cell to stack to BoP

- Determination of highly detailed model parameters in our laboratory
- Electrical testing of PEM electrolyses cells and short stacks, up to:
  - 10 V / 1 200 A applied voltage and current
  - 50 bar(a) applied pressure on anode and cathode
  - 100 °C DUT temperature
- Independent anode/cathode operation and circulation
- Cell voltage monitoring
- Integrated electrochemical impedance spectroscopy (EIS), up to:
  - 30 A modulation current (@ +20 / -2.5 V)
  - 10 µHz – 100 kHz modulation frequency
  - 8 independent channels

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Test bench for lifetime testing of PEM electrolysis cells

- Supplying up to three PEM-Cells with a DC average current of 10 A
- Superimposition of different current waveforms (e.g., triangular, square, sinusoidal)
- Operating frequency of up to 50 kHz
- Adjustable ripple factor up to 200%

- Objective of this test bench:
  - *Do ripple currents from a power converter impact the lifespan of PEM cells?*

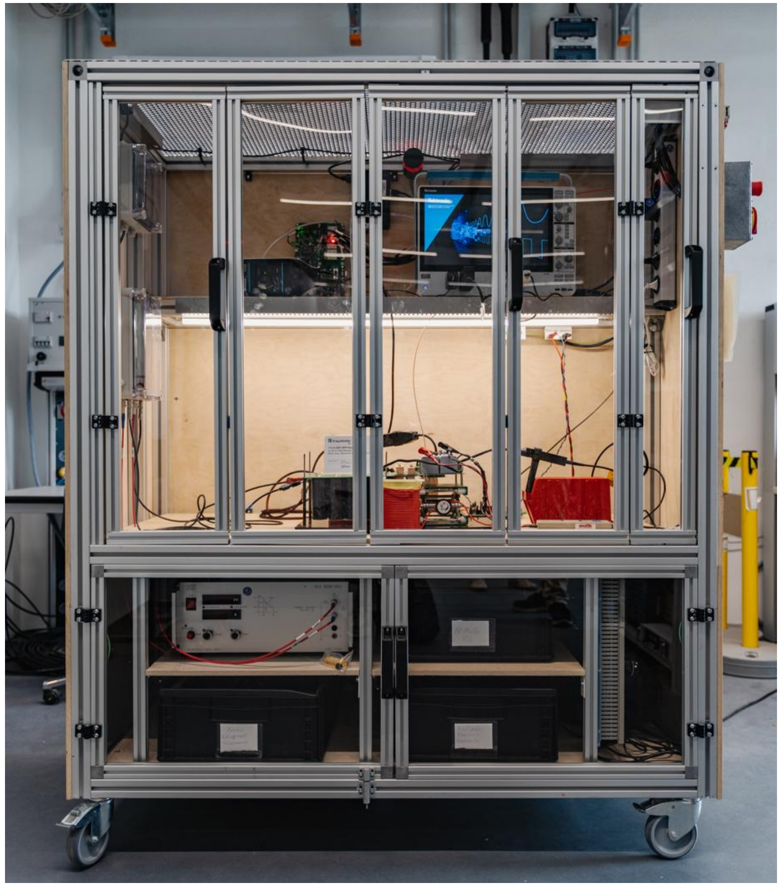
Calorimeter based power dissipation measurement

- Single and double chamber approach
- Determination of power loss by measuring the heat flow
- Measurement for different ambient temperatures of the DUT
- High accuracy of power loss measurement
  - *For magnetic components*
  - *For systems with very high efficiencies*
  - *Systems with high frequencies operating conditions*
  - *Automated measuring process*

Ambient temperature	$T_{amb} = 15°C\ up\ to\ 30°C$
Chamber Temp.-Range	$T_{in} = 15°C\ up\ to\ 85°C$
Measurable power loss	$up\ to\ \dot{Q}_{DUT} = 1000\ W$
System accuracy	$>= 95\%$
Max. test frequency	$f_{DUT} = 25\ kHz$
Max. current supply	$I_{DUT} = 500\ A$

The specifications depends on the construction

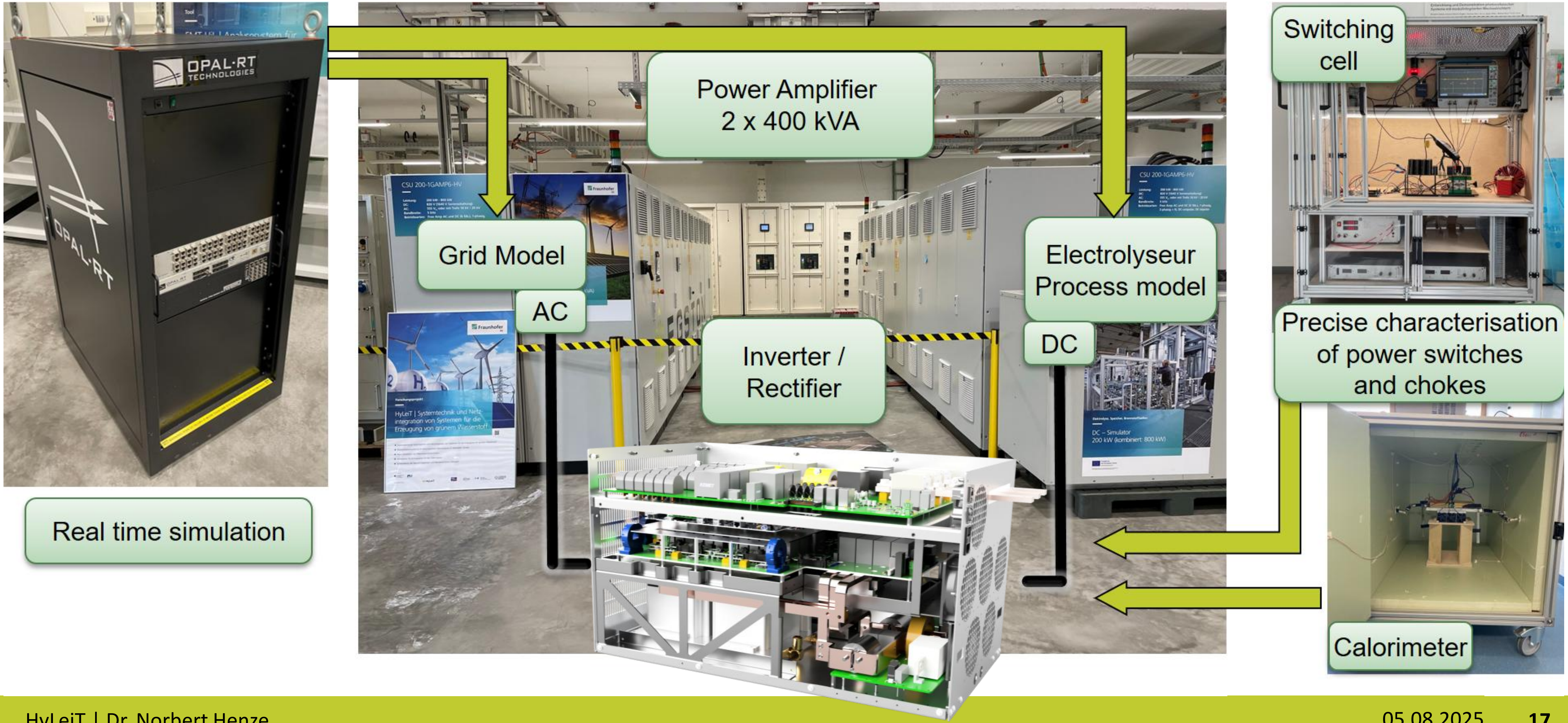
Automated Double Pulse Test Bench



- Simulations of application related semiconductor losses in power electronic systems are important tools for design
- Characterization of switching losses according to standards (IEC 60747-7/8/9) or custom limits
- Parameters that can be influenced
  - *Temperature: RT … +150 °C*
  - *Switching current: several kA*
  - *Power supply voltage: up to 3 kV*
  - *Gate-Voltage*
  - *Driver network*

Comprehensive analysis of switching losses leads to more realistic simulation results and supports circuit design in the early stage

P-HiL Test Environment



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