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Flagship Project H_2Giga
Federal Ministry of Research, Technology and Space
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New Inverter Technologies for Large Electrolyzer Systems

HyLeiT / DERlab Workshop

26.09.2025

Dr. Ralf Juchem, SMA Solar Technology AG / Dr. Stefan Wettengel, TU Dresden

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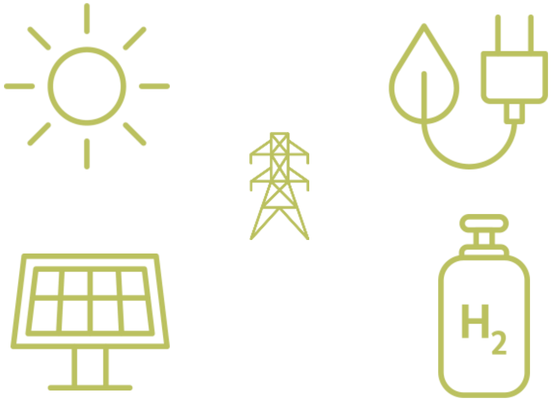
SMA

New Inverter Technologies for Large Electrolyzer Systems



- Agenda
  - Scope
  - Key findings in H2Giga / HyLeiT project
    - Basic Technology decision
    - Steps to higher power density and lower cost
  - Power Electronics (TU Dresden, Dr. Wettengel)
  - Outlook
  - Market Perspective

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Scope

- Engineering of a power supply for large electrolyzers
  - >> 10 MW
- Utilizing SMA high volume series product manufacturing experience from PV and Battery applications
- Easy grid integration (turn key solution)
- Grid support functionality

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Basic technology decision

- Currently, Thyristor technology is the state-of-the art power electronics technology for high power rectifiers
  - We conducted deep and thorough investigations in the Pros and Cons of Thyristor- vs. Transistor- (Mosfet) Technology with TU Dresden, Chair of Power Electronics

- Conclusion:
  - Transistor beats Thyristor mainly because of these reasons:
    - Much easier grid integration and even grid supporting functionality
    - Highly reduced project specific engineering (turn key solution, software focus)

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Steps to higher power density and lower cost

- Improved cooling
  - Better heat transfer from power semiconductors to heat sink
    - Investigation of new layer-materials for a better heat transfer
  - Improved heat sink performance
  - Air cooling with optimized air streaming (noise reduction as a nice side effect)

- Using higher voltages above 1500 V
  - Improved efficiency
  - Higher power density

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SMA

Power Electronics

- Presentation of Stefan Wettengel, TU Dresden

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Outlook

- Further research is ongoing
  - SMA-internal- and new public funded projects to be started
- Continuous transfer of project results to series product development

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Current SMA perspective on the Hydrogen market (1/2)

- Currently the Hydrogen market experiences a significant slow down
  - Cost of green Hydrogen is still too high (higher than promised?)
  - Political reasons (US and EU government, focus shift to military tech)
  - Some electrolyzer companies (especially PEM) are in financial troubled waters
    - Market shake-out is expected
- Benefits from using active frontend rectifiers to support the grid are still not well known in the industry
  - Still a low awareness for grid related challenges when ramping up electrolytic hydrogen

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Current SMA perspective on the Hydrogen market (2/2)

- The trend to higher voltages is currently weak
  - But SMA is quite confident about this on the medium-term

- We see a trend to large electrolyzer plants (> 100 MW) and also one towards small scale applications (< 10 MW) for filling stations

- SMA is still optimistic about the future Hydrogen market
  - Resuming market growth from 2027 on with more Chinese electrolyzer technology
  - Green ammonia and green steel production will become an important future field of activity for many countries

Thank you!

Name Dr. Ralf Juchem

Phone: +49 561 9522-4723 • Mail: Ralf.Juchem@sma.de

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New Inverter Technologies for Large Electrolyzer Systems

8th HyLeiT Workshop • 26. September 2025

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Agenda: New Inverter Technologies for Large Electrolyzer Systems

- Transistor-Based Rectifier for Electrolysis
  - Introduction
  - Test Setup
  - Oscillations & Damping
  - Full-Scale Demonstrator

- TUD: Chair of Power Electronics
  - HyLeiT Publication List
  - Power Semiconductor Laboratories

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Introduction: Transistor-Based Rectifier

No usage of thyristors

- Investigated in a past publication[1]
- Require substantial reactive power compensation + filtering → large, expensive
- Also: insufficient for grid support

Future grids will require large loads to actively support and stabilize the grid

Rectifier:	Thyristor	MOSFET
Efficiency	+	+
Power Density*	-	+
System Cost (CAPEX)	+	+
Grid Compatibility / Grid Services	-	+
Modularity*	-	+

* Including: grid filter, PCC connection and expected planning effort per plant

1: S. Puteanus, S. Wettengel, M. Meißner and S. Bernet, "Multipulse Rectifiers for Large Scale Water-Electrolysis - Reactive Power and Harmonics," *ECCE Europe 2024*, Darmstadt, Germany, 2024, pp. 1-8

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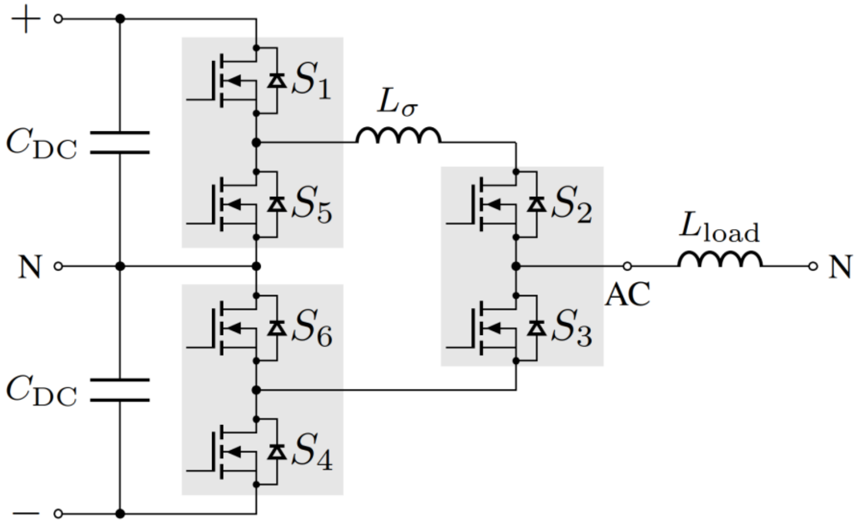
Introduction: Transistor-Based Rectifier

SiC-MOSFET based, active rectifier

- Employing novel 2.3 kV SiC MOSFETs
- Two main options:
  - Two-Level Voltage-Source-Converter (2L-VSC)
  - Three-Level Active-Neutral-Point-Clamped Voltage-Source-Converter (3L-ANPC-VSC)

    → Challenge: using half-bridges in a three-level configuration + fast switching



Example: 3L-ANPC-VSC phase leg

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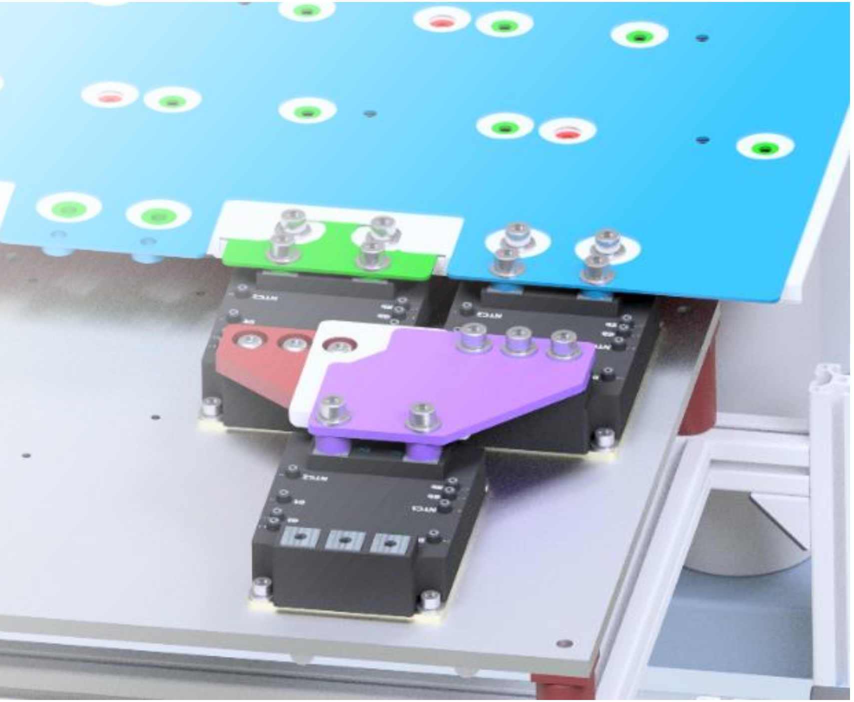
Test Setup: 3L-ANPC-VSC

New Semiconductor Module:
2.3 kV SiC MOSFET half-bridge

- Datasheet values are nice → Tests are better!
- Double pulse test setup
- Tests of all comutation types possible

Target Parameters

- DC-link voltage: $V_{DC}/2 = 1350$ V
- Load current: $I_{load} \leq 1600$ A
- Temperature: $-20\ °C \leq T_{vj} \leq +150\ °C$



3D-CAD render of one 3L-ANPC-VSC phase leg and copper plates on a heat sink.

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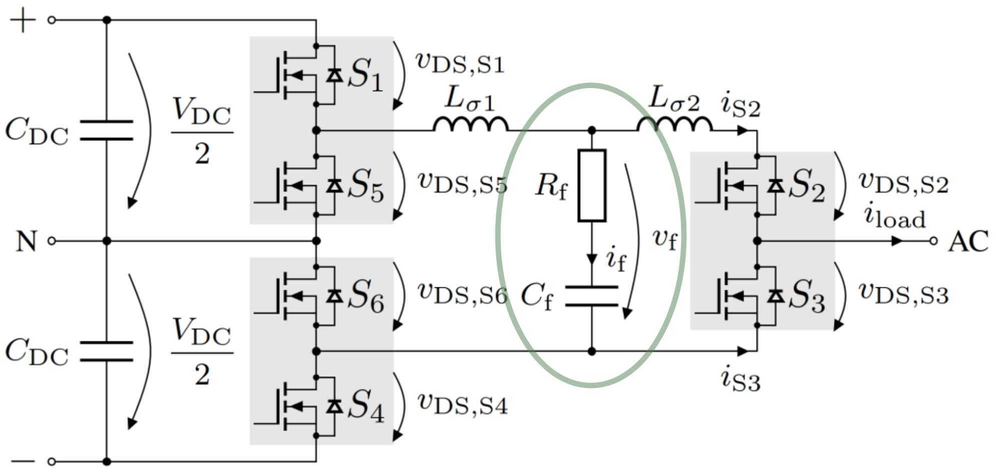
Damped Decoupling Circuit

- Required for overvoltage reduction
- Electrical dimensioning is straight-forward

Actual Challenge

- practical implementation
- limited space
- small stray inductance required
- high pulse current
- losses / cooling



See also: A. Höhnel, S. Wettengel, S. Puteanus, and S. Bernet, “Oscillation and overvoltage damping in an all-sic three level anpc,” in 2025 ECCE Europe. IEEE, Sep. 2025

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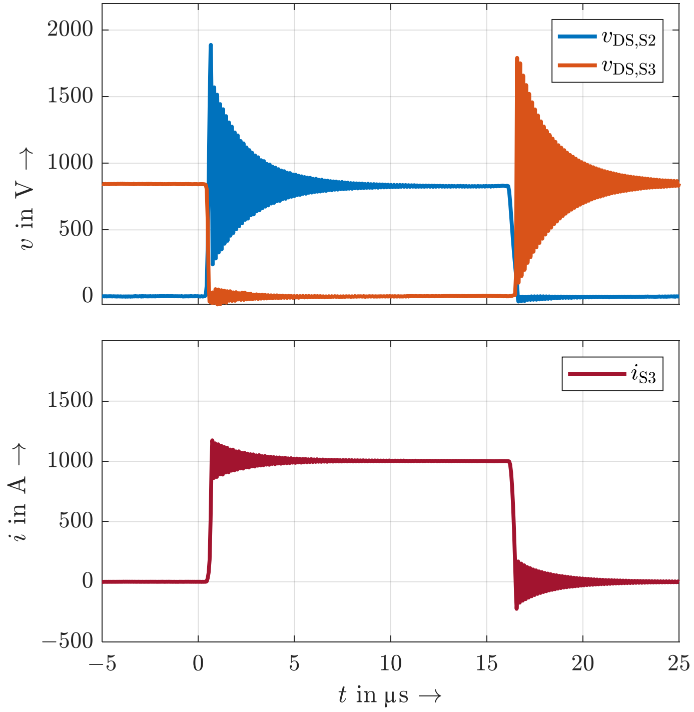
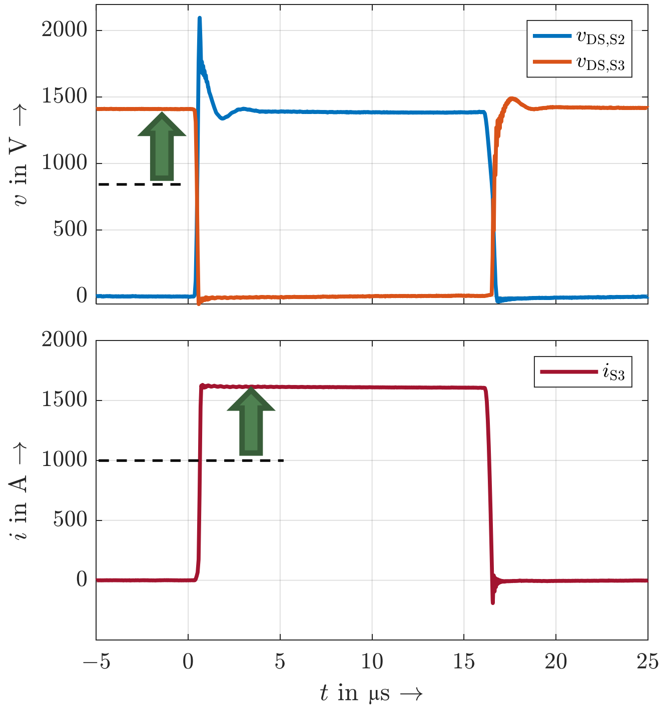
Damped Decoupling Circuit



- Reduced Overvoltage
- Reduced Oscillations
- Nominal Voltage and Current are reached



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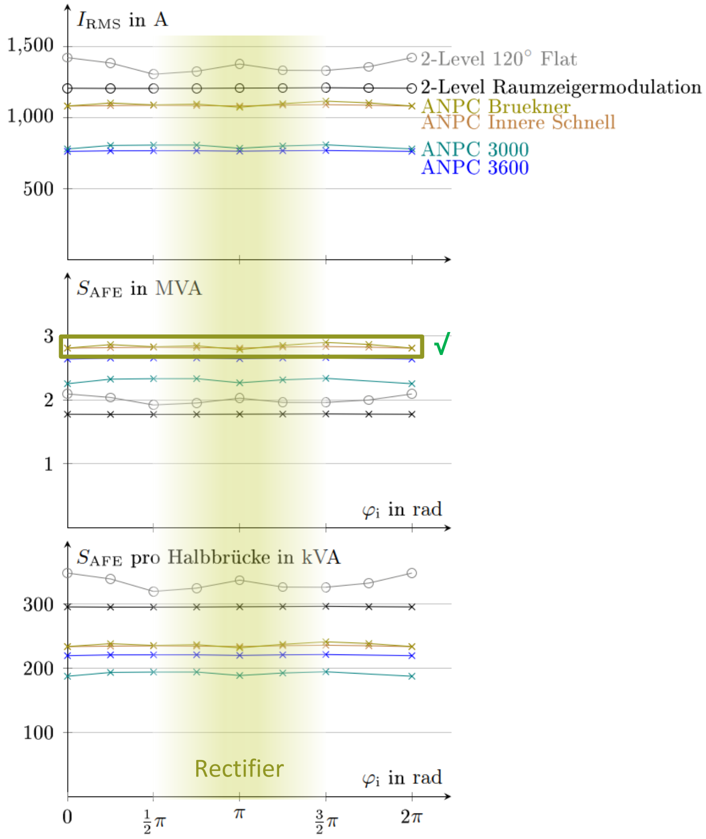
Simulation based on Experiments

Comparison

- Measurements of switching behavior
- Switching losses → Simulation

- Simulation compares e.g. Topology (2L, 3L) and different modulation schemes

- Favorite options are shown in diagram
- Full-Scale Demonstrator will be **3L-ANPC-VSC**



See also: S. Puteanus, S. Wettengel, A. Höhnel, and S. Bernet, "Performance Evaluation of Grid-Connected Active Front Ends using 2.3 kV SiC-MOSFET Half Bridges," in 2025 ECCE Europe. IEEE, Sep. 2025

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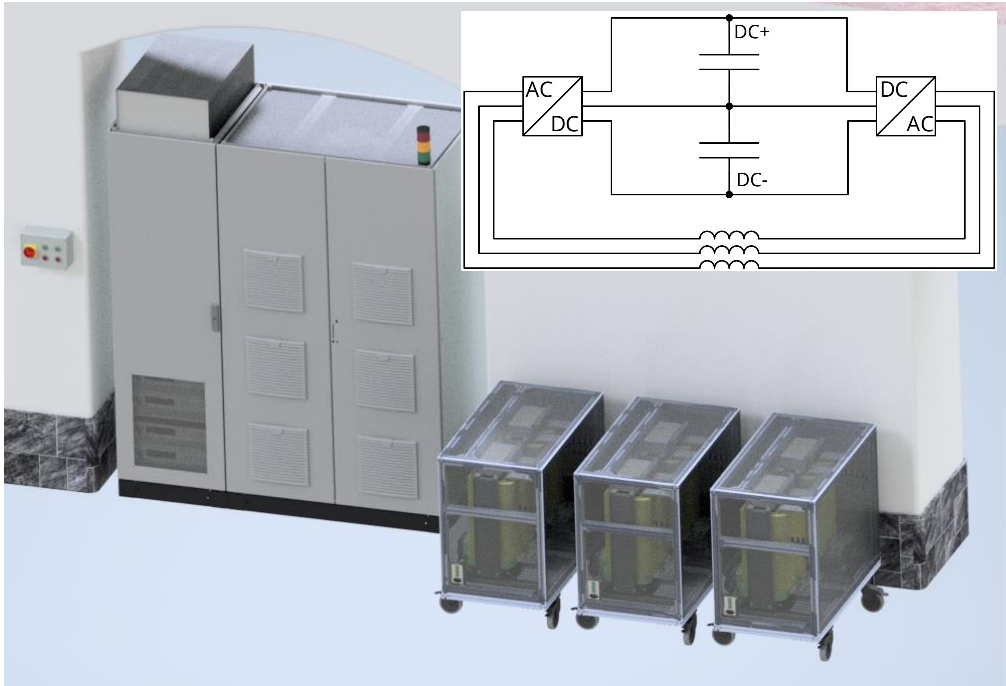
Full-Scale Demonstrator

- Test of two 3L-ANPC-VSCs in back-to-back configuration
- Construction in Görgesbau, TUD Dresden University of Technology
- Culmination of project HyLeiT from Chair of Power Electronics' point of view



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Full-Scale Demonstrator

Selection of technical parameters:

- DC voltage: ±1,350 V
- AC current: 1,000 A_{RMS}
- AC power: ≈2 MVA
- Loss estimation: <60 kW

Final steps:

- Full power test imminent
- Future publication planned

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HyLeiT Publications: TUD – Chair of Power Electronics

- S. Puteanus, S. Wettengel, A. Höhnel, S. Bernet:
  „Performance Evaluation of Grid-Connected Active Front Ends using 2.3 kV SiC-MOSFET Half Bridges“ (09/2025)
- A. Höhnel, S. Wettengel, S. Puteanus, S. Bernet:
  „Oscillation and Overvoltage Damping in an All-SiC Three-Level ANPC-VSC “ (09/2025)
- T. Miličić, S. Puteanus, X. Becker, S. Bernet, T. Vidaković-Koch:
  „Predicting electrolyzer performance under forced periodic operation using nonlinear frequency response method“, (06/2025)
- M. Bruhns, P. Schegner, M. Hehemann, R. Juchem, S. Wettengel: „Special Requirements on Protection Systems in Electrolysis plants“ (04/2025)
- S. Puteanus, T. Miličić, U. Feldmann, T. Vidaković-Koch: „Efficiency improvement by pulsed water electrolysis: An unjustified hope“ (03/2025)
- L. Jostes, S. Puteanus:
  „Using a Doubly Fed Induction Machine (DFIM) in an Active Filter for Grid Commutated Rectifiers - A Feasibility Study “ (10/2024)
- S. Puteanus, S. Wettengel, M. Meißner, S. Bernet:
  „Multipulse Rectifiers for Large Scale Water-Electrolysis - Reactive Power and Harmonics“ (09/2024)

Laboratories – TUD: Chair of Power Electronics

Medium Voltage Semiconductor Lab "*Room 25*"

- Test setup with two independent DC-links
  - In parallel for two-level topologies
  - In series for three-level topologies
- Tests on modules and press packs possible
- High level of automation through MATLAB

- Selection of technical parameters:
  - Max. voltage: ±6.5 kV
  - Max. current: 5 kA
  - Junctiontmp.: –40 °C to +150 °C

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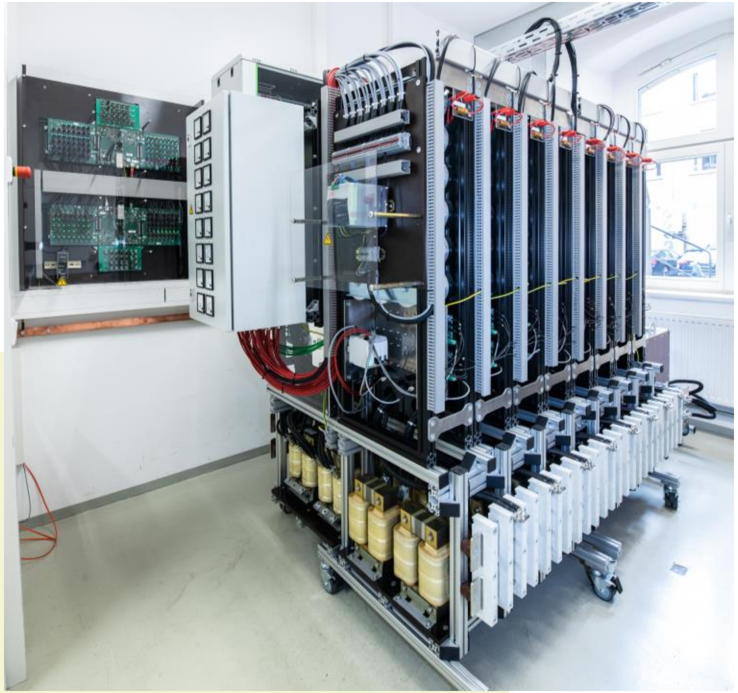

Surge Current Source “*SBGL*”

- Arbitrary surge current generator
- Modular system → 16 cells, 32 half-bridges
- High fault tolerance through arc detection

- Selection of technical parameters:
  - Max. energy: ~100 kJ
  - Max. voltage: 1,200 V
  - Max. current: 100 kA

See also: S. Wettengel, A. Hoffmann, J. Kienast, L. Lindenmüller and S. Bernet, "Topology, Design, and Characteristics of a Modular, Dynamic 100 kA Surge Current Source With Adjustable Current Shape," in *IEEE Open Journal of Industry Applications*, vol. 5, pp. 29-42, 2024, doi: 10.1109/OJIA.2024.3353328

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***Modular Multilevel Matrix Converter* (*M3C*)**

- Possible energy storage solution
  → Flywheel storage
- Research into novel control and protection algorithms
- Selection of technical parameters:
  - Grid voltage: 400 V, 50 Hz
  - # Submodules: 108 (12 per arm)
  - Power: 15 kVA

See also: J. Kienast, A. Hoffmann, M. Höer and S. Bernet, "Novel Distributed Control Platform and Algorithm for a Modular Multilevel Matrix Converter," in *IEEE Transactions on Power Electronics*, vol. 38, no. 7, pp. 8089-8101, July 2023, doi: 10.1109/TPEL.2023.3260241

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FPRC

***Free Programmable Real-time Control* (*FPRC*)**

- Based on *Xilinx Zynq 7015* SoC
- Employing “*Lab Analyzer*” open source control software

Honorary Mentions

- GaN semiconductor test bench
- Setup for thermal impedance measurements
- Drive converter test setup with 5 kW induction motor
- 6 kA surge current source
- *FlexGrid*: research on inverter-based grid

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Thank you for your attention!

Dr.-Ing. Stefan Wettengel

Tel.: 0351-463-34569 • E-Mail: stefan.wettengel@tu-dresden.de