Representative research on power electronics in MVDC

Institute for Power Generation and Storage Systems
Flexible Electrical Network

Dr.-Ing. Shenghui Cui

Stromrichtertechnik und Elektrische Antriebe

E.ON Energy Research Center

Flexible Elektrische Netze

RWTH Aachen University

BMBF Forschungscampus „Flexible Electrical Networks”

Partners of FEN Research Campus*

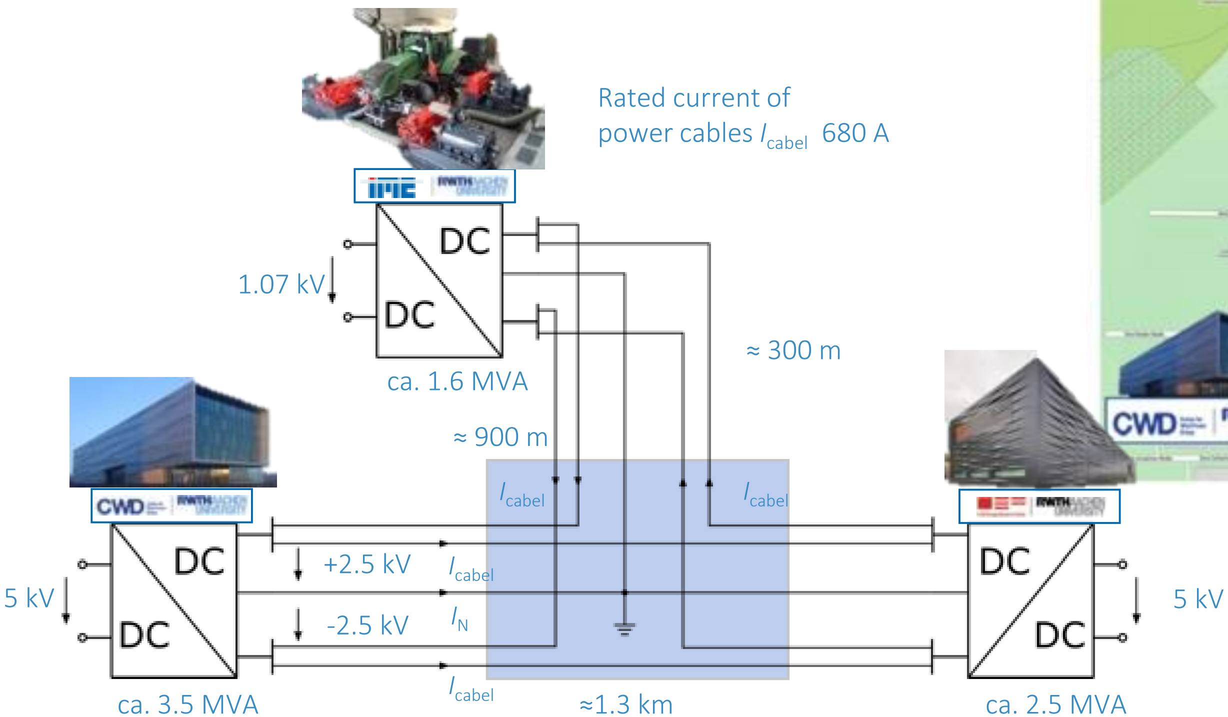
Flexible Electrical Networks
FEN Research Campus

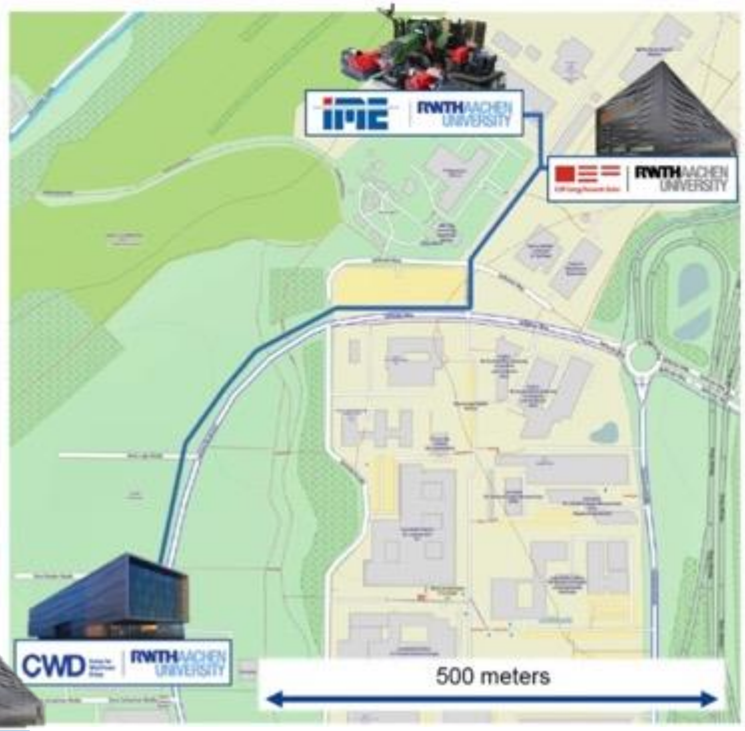
AixControl Ges. für leistungselektronische Systemlösungen mbH
e·on
EATON Powering Business Worldwide
HYOSUNG
infineon
LEADRIVE Technology Germany GmbH
MR
KIEPE ELECTRIC
OPAL-RT TECHNOLOGIES
schaffner energy efficiency and reliability
ESA GRIMMA ESA Elektroschaltanlagen Grimma GmbH
Fuji Electric
hager
HITACHI Inspire the Next
thyssenkrupp
MITSUBISHI ELECTRIC
ACS | FCN PGS | EBC GGE E.ON Energy Research Center
IAEW Institute of Power Systems and Power Economics
IAW Institute of Industrial Engineering and Ergonomics
IFHT Institute for High Voltage Technology
ISEA Power Electronics and Electrical Drives
RWTH AACHEN UNIVERSITY
UNIKLINIK RWTH AACHEN Institute of Occupational Medicine
städtebau
Institute of Landscape Architecture
Textlinguistics & Technical Communication
HCIC - Human-Computer Interaction Center
humtec
RWTH AACHEN UNIVERSITY
CWD Center for Wind Power Drives

Status: September 2020

* Member of CIGRE C6.31 MVDC Feasibility Study and DKE LVDC Std. Committee

FEN Medium-voltage (5 kV) DC CAMPUS grid

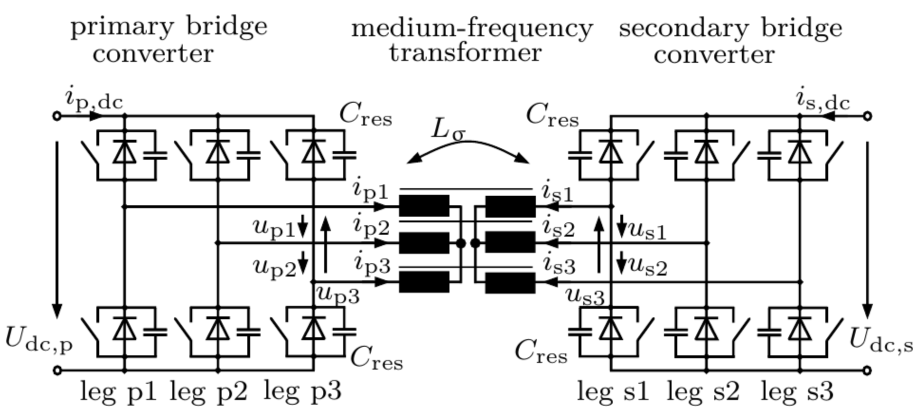


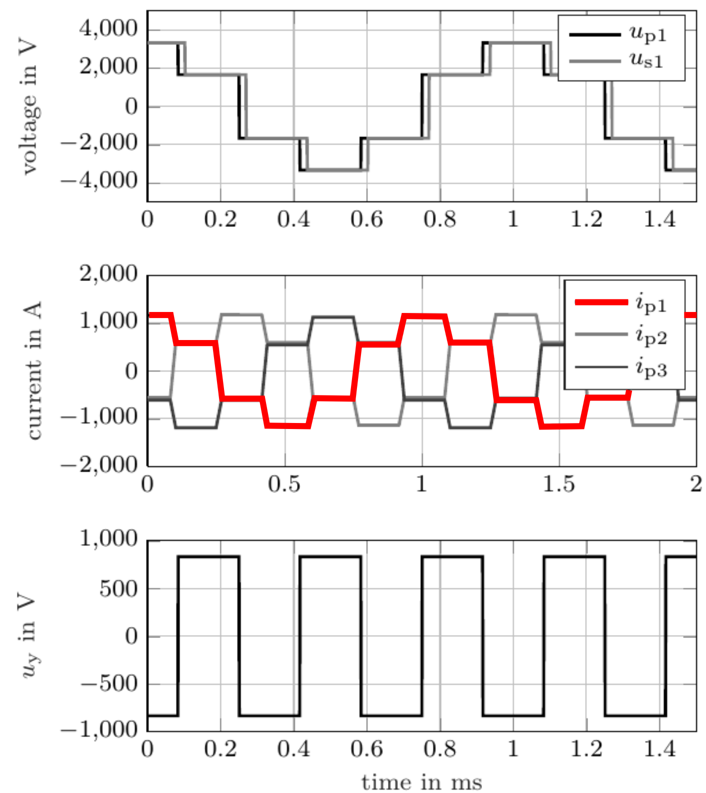


M. Stieneker, J. Butz, S. Rabiee, H. Stagge and R. W. D. Doncker, "Medium-Voltage DC Research Grid Aachen," *International ETG Congress 2015; Die Energiewende - Blueprints for the new energy age; Proceedings of*, Bonn, Germany, 2015, pp. 1-7.

IGCT-based High-Power DC-DC Converter

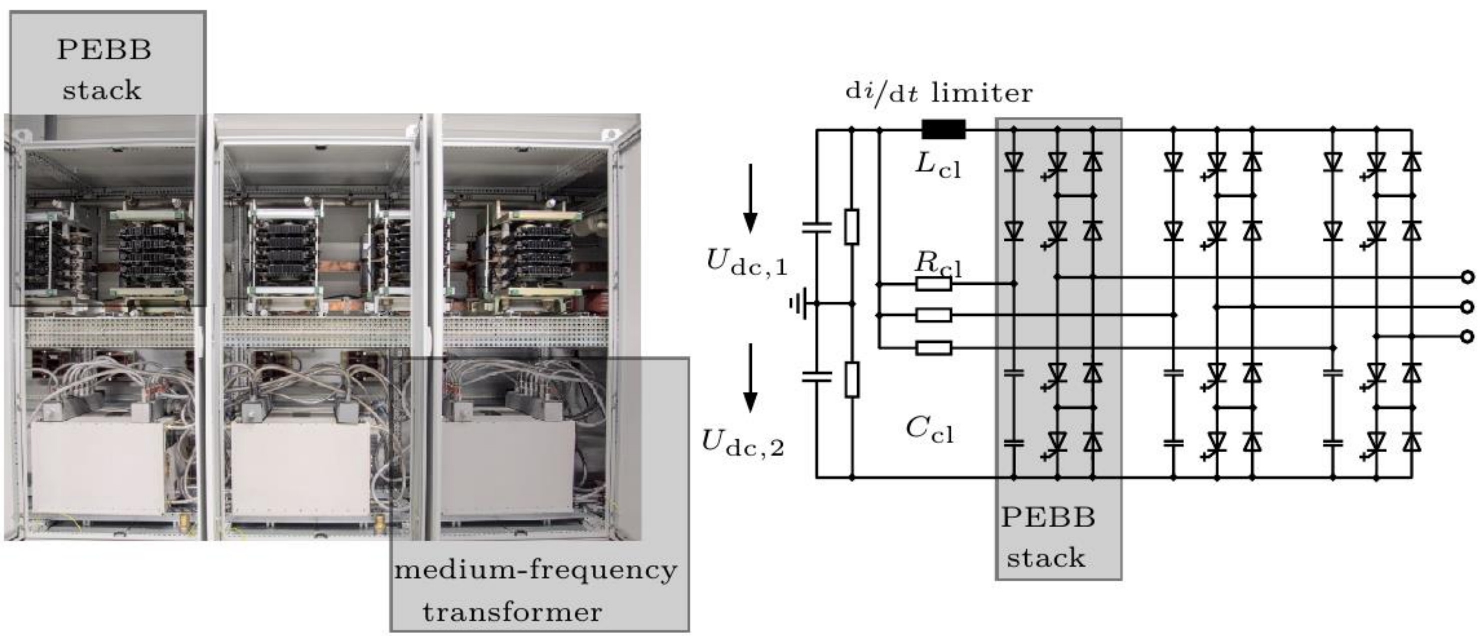
- Key component for DC Grids:
  Robust, efficient high-power converter
- Demonstrator, dual-active bridge concept
  - wide soft-switching operation area
  - Power > 5 MW
  - Input and output ratio up to 5 kV
  - 3 single-phase transformers each rated for 2.2 MVA (600 kg/transformer)





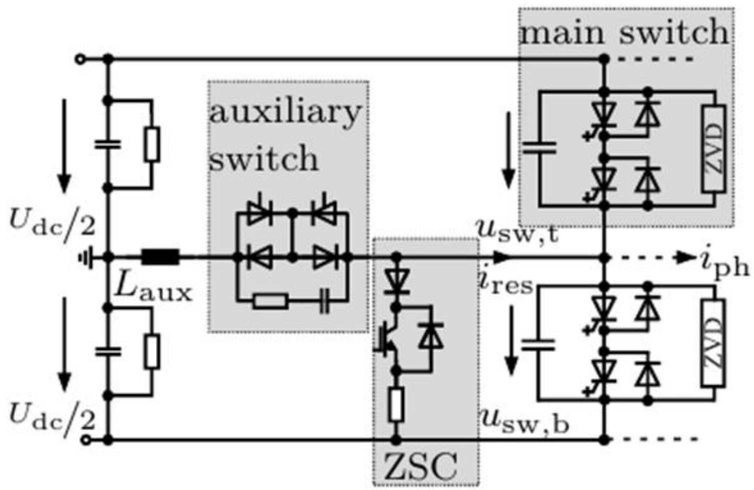
IGCT-based High-Power DC-DC Converter

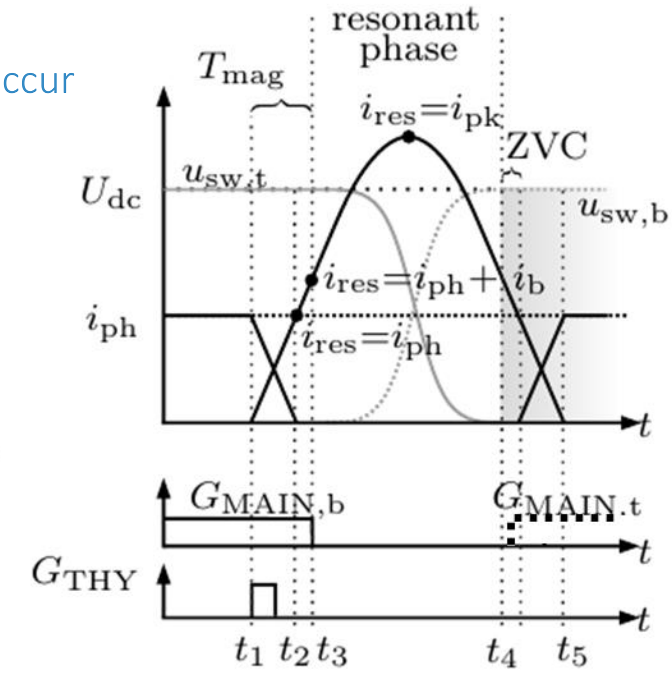
- Key Elements for DC Grids: High-Power Dual-Active Bridge
  - IGCTs require clamping circuits to limit di/dt, which increase the losses
  - Alternative: Soft switching
  - Must be unconditional
  - Accidental hard-switching is absolutely not allowed



IGCT-based High-Power DC-DC Converter

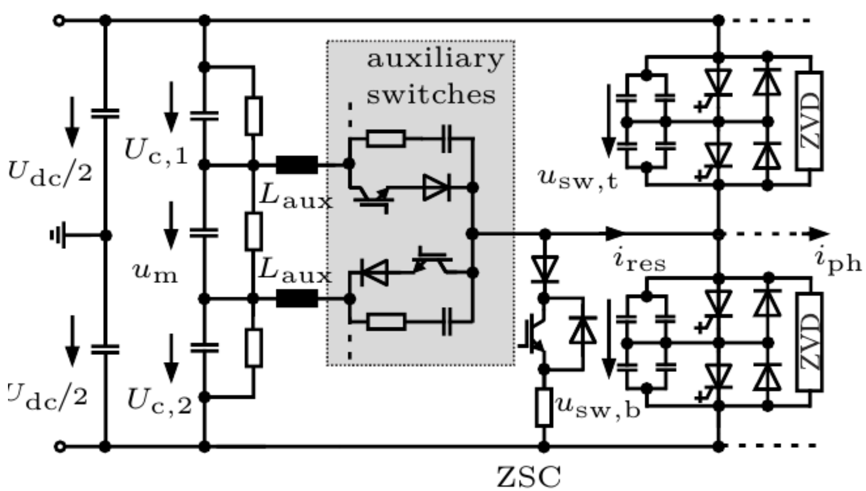
- Classic Auxiliary-Resonant Commutated-Pole (ARCP)
  - Quasi resonant switching for zero-voltage switching at operating conditions
  - Expected loss savings up to 90 kW
  - Challenging control of correct boost current
    - Sensitive to control and device delays
    - Very little margin for i_b and after t_4
    - Otherwise hard-switching/snubber dump may occur

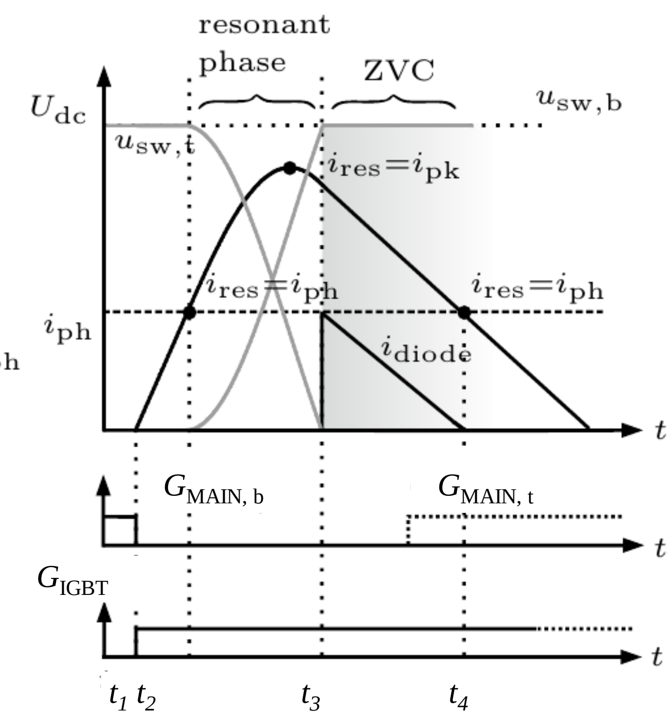




IGCT-based High-Power DC-DC Converter

- Modified Auxiliary-Resonant Commutated Pole
  - Splitting the center node creates margin for complete resonant transition
  - Split voltage u_m set for capacitive load capability, control and switching delays
  - Zero-voltage detection across the IGCT, inhibiting IGCT turn-on, prevents from accidental snubber dump





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IGCT-based High-Power DC-DC Converter

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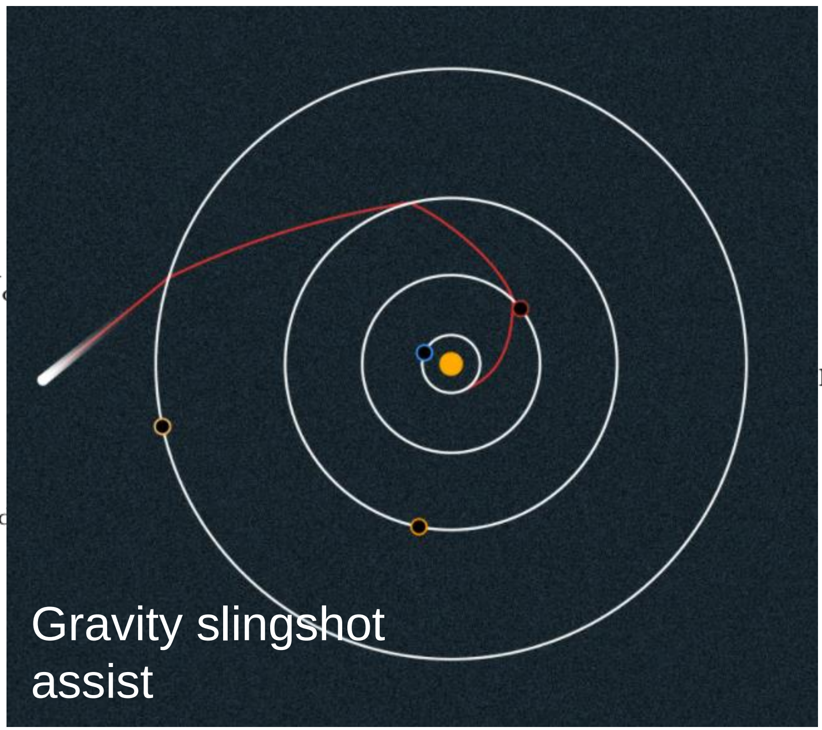

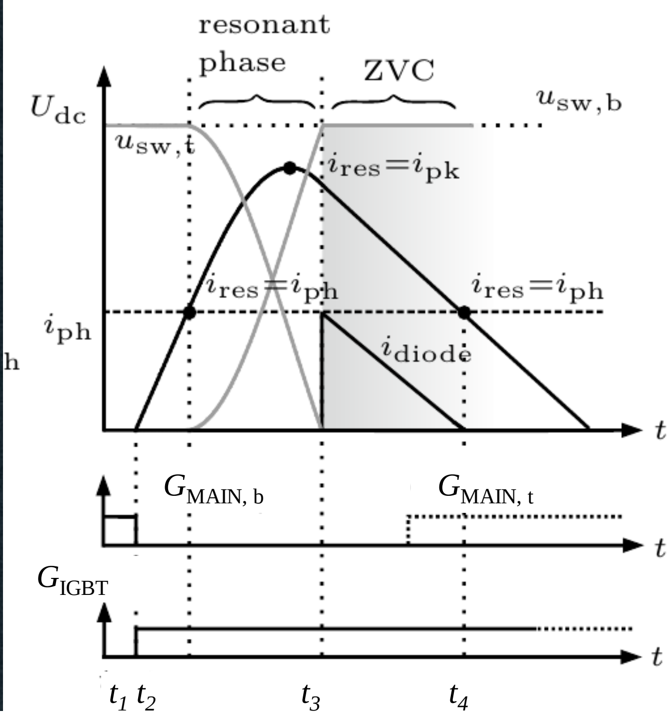

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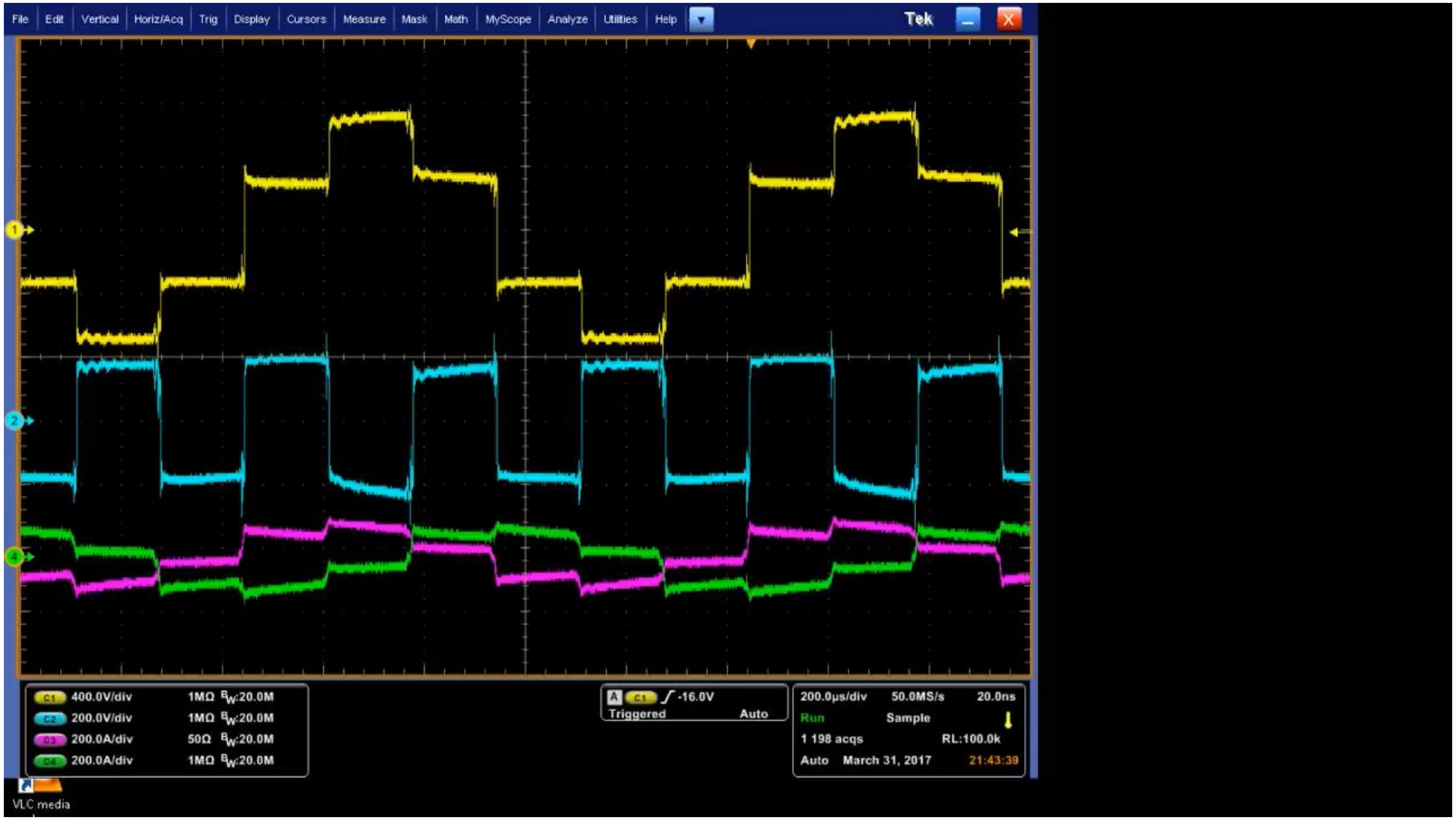
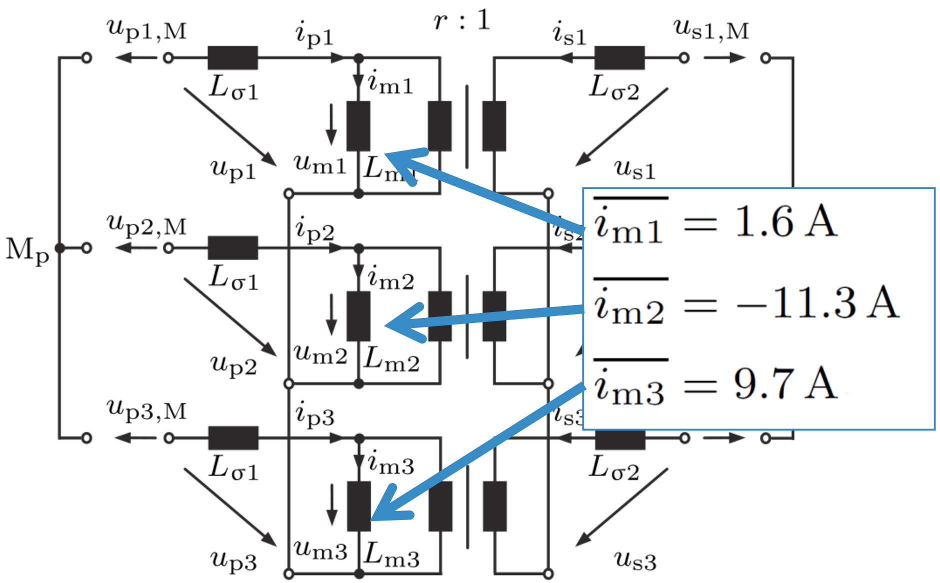
Appearance of the Saturation in the High-Power Setup

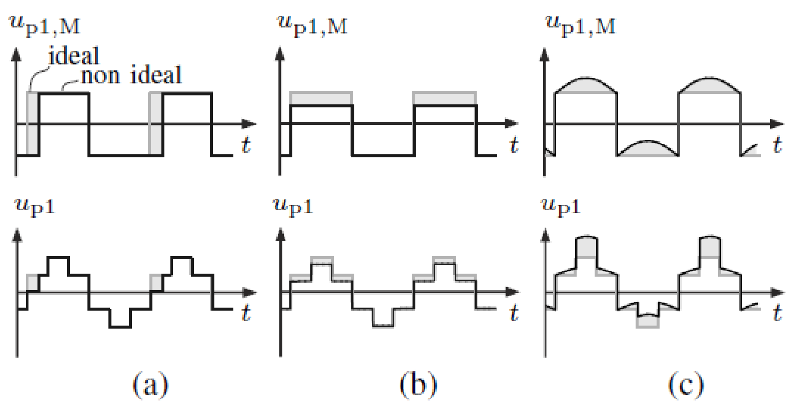
2 years ago with conventional IGCT clamping circuit at dc-link voltage of 1.2 kV:



Appearance of the Saturation in the High-Power Setup

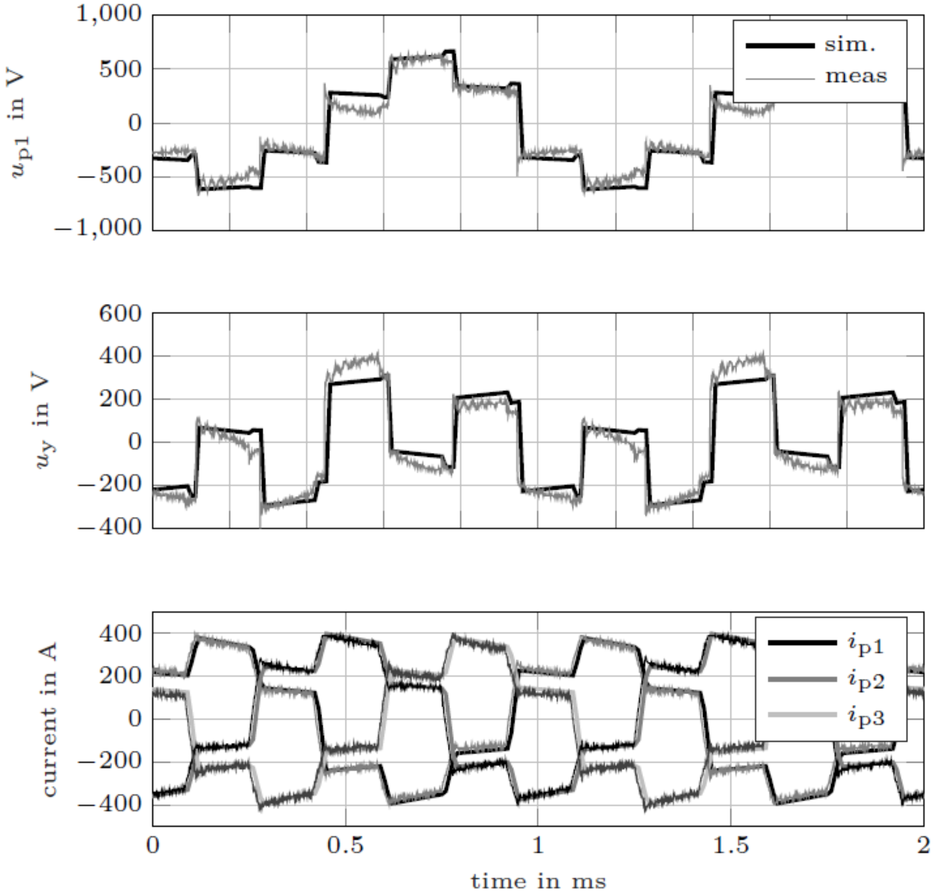
- DC-offsets in magnetizing currents measured
- Various effects can cause saturation
- Unequal in volt-seconds per switching cycle





Estimation of DC-Magnetizing Currents

- Simulation with inductance depending on magnetizing current
- Hysteresis effect neglected
- Accurancy high enough between simulation and hysteresis
- Langevin approach matches most



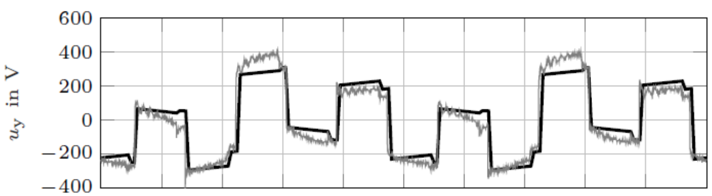
Estimation of DC-Magnetizing Currents

- **Space vector** representation with Clarke transformation:

$$\overline{i_{\mathrm{m1}}} = 1.6\,\mathrm{A}$$
$$\overline{i_{\mathrm{m2}}} = -11.3\,\mathrm{A}$$
$$\overline{i_{\mathrm{m3}}} = 9.7\,\mathrm{A}$$

$$\rightarrow \quad {}^{2}/_{3}\left(\overline{i_{\mathrm{m1}}} + \underline{a}\cdot\overline{i_{\mathrm{m2}}} + \underline{a}^2\cdot\overline{i_{\mathrm{m3}}}\right) \quad \text{with} \quad \underline{a} = \mathrm{e}^{\mathrm{j}120^\circ} \quad \rightarrow \quad \underline{i}_{\mathrm{m,dc}}$$

- **Phasor** represenation of second harmonic of the star-point voltage:



$$\rightarrow \quad \frac{1}{T}\int_0^T \left(u_{\mathrm{y}}(t)\mathrm{e}^{\mathrm{j}2\omega t}\right)\mathrm{d}t \quad \rightarrow \quad \underline{u}_{2\mathrm{y}}$$

Estimation of DC-Magentizing Currents

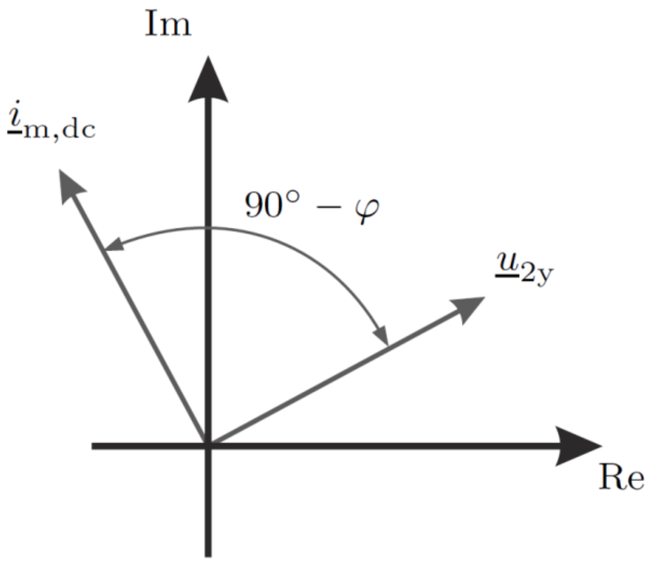
Parameter sweep in simulation brought up following relationships:

- Absolut values depend:

$$|\underline{i}_{\mathrm{m,dc}}| \approx c_{\mathrm{amp}} \cdot |\underline{u}_{\mathrm{2y}}|$$

- Arguments have linear relationships:

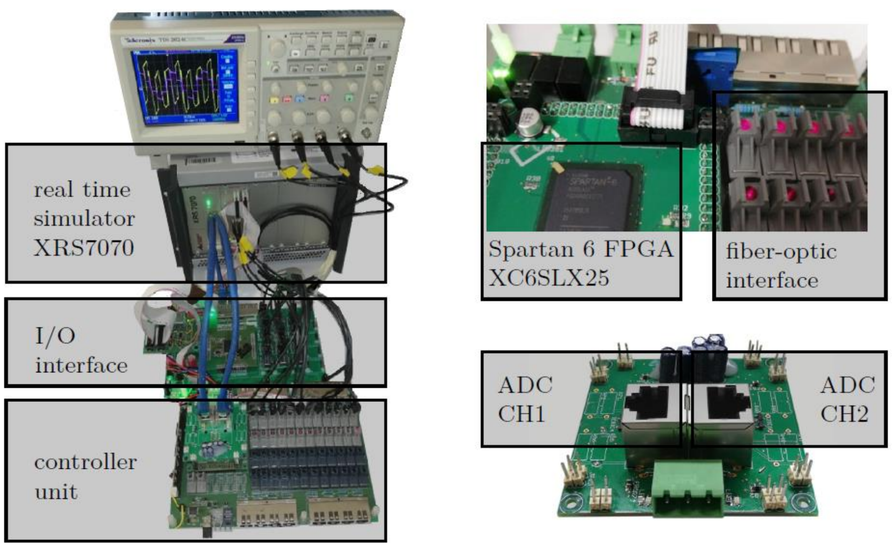
$$\arg(\underline{i}_{\mathrm{m,dc}}) \approx \arg(\underline{u}_{\mathrm{2y}}) + 90^\circ - \varphi$$

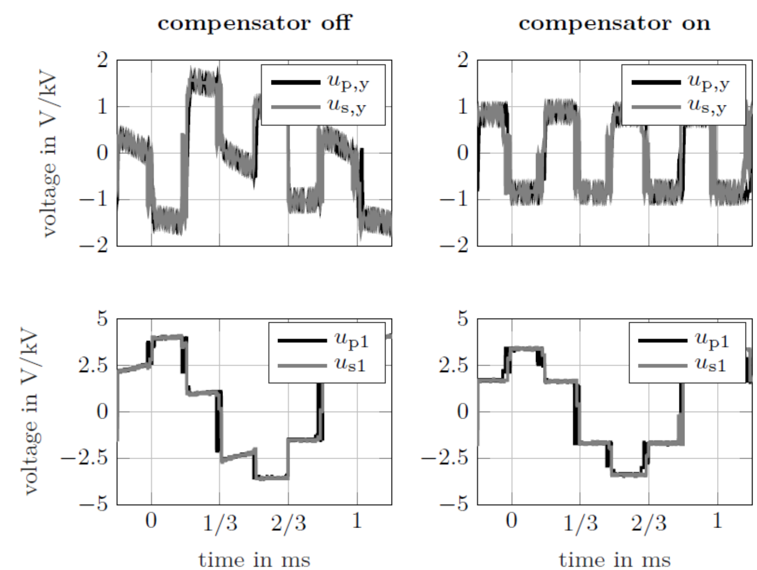


With the star-point voltage dc-magnetizing currents can be estimated!

Simulation, Emulation and Control

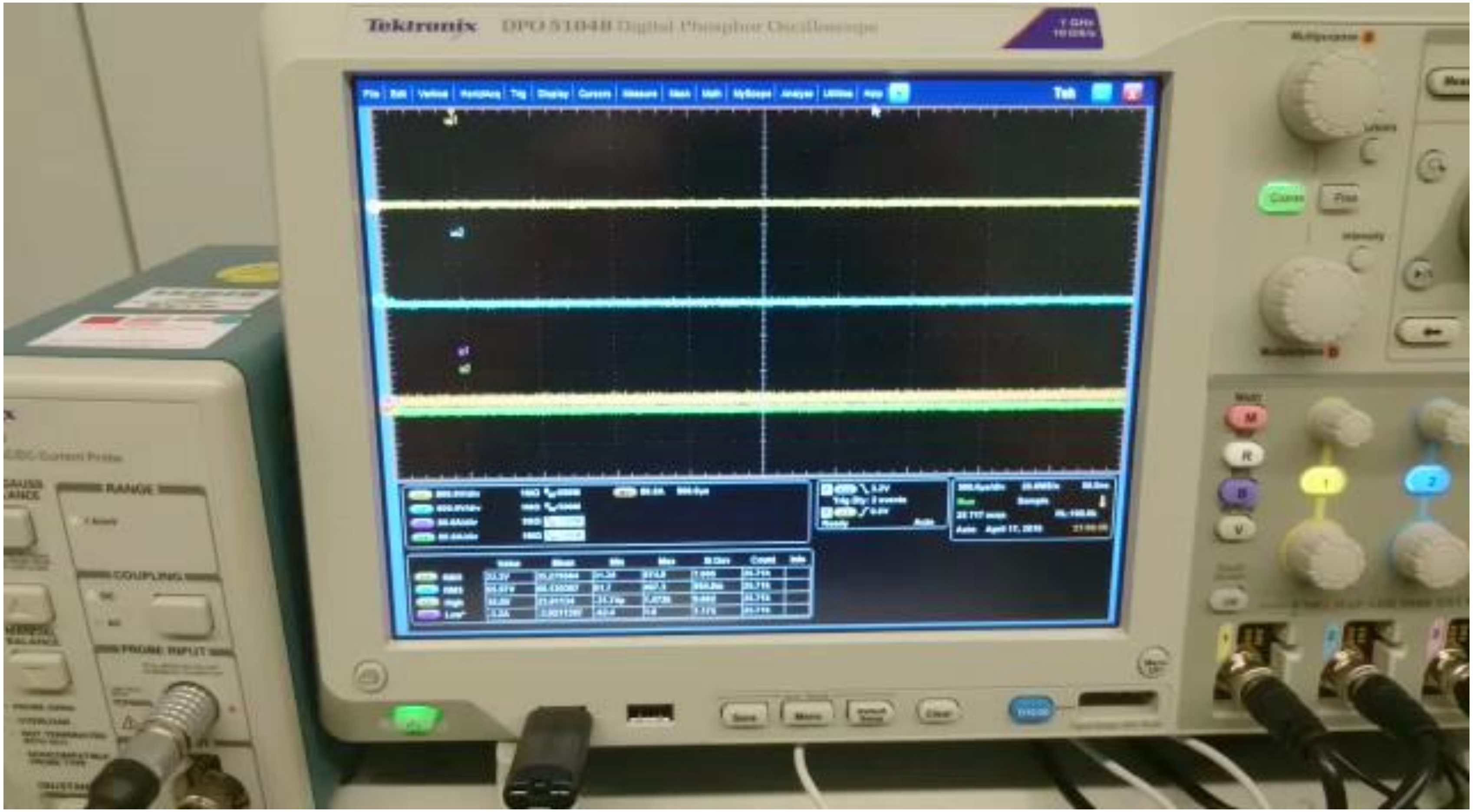
- Compensator embedded on controller platform (FGPA+DSP)
- Controller-in-the-loop test setup
- Controller unit proofs proper functionality of the unique compensation
- **Additional investment in hardware ~150 €**





Multi-Megawatt Three-Phase Dual-Active Bridge DC-DC Converter

Results of 3 years in 30 seconds



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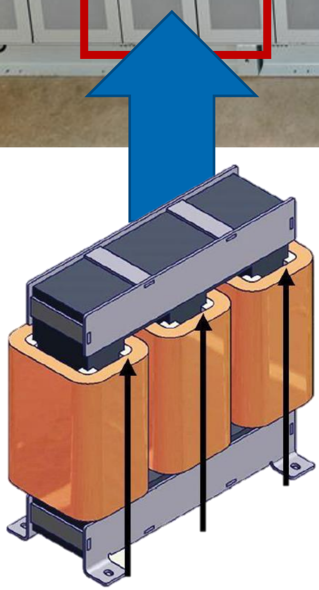
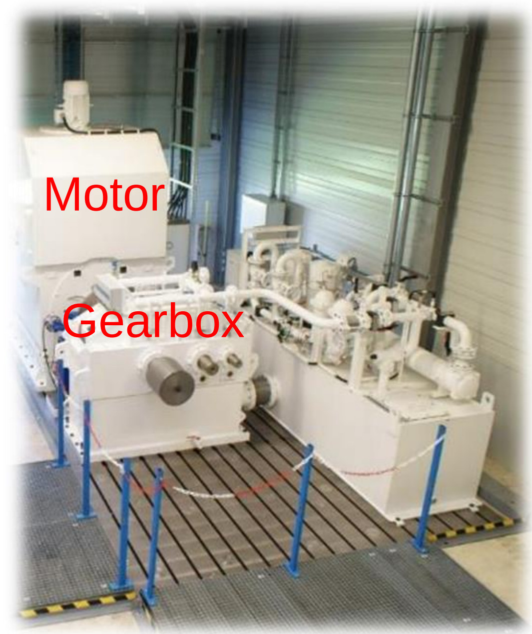
IEGT-based High-Power DC-DC Converter



5 MVA transformer
@ 1 kHz by Schaffner
and thyssenkrupp

Drive testbench
connected to MVDC
grid



IEGT-based High-Power DC-DC Converter

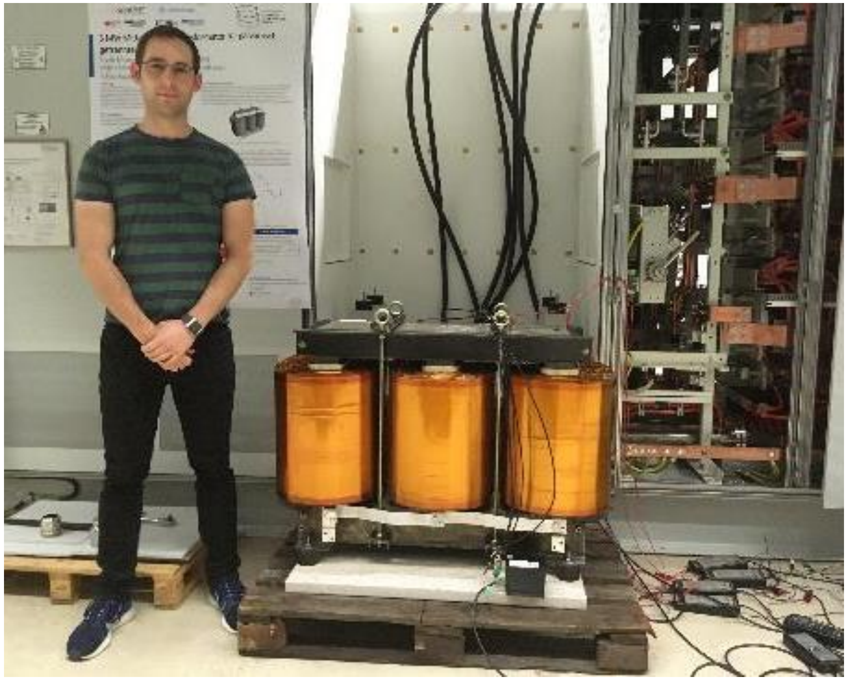
- 5 kV galvanic isolated bidirectional DC-DC converter
- Off-the shelf converter with new-developed 1 kHz medium-frequency transformer with 16x power density compared to 50 Hz state-of-the-art
- 5 MVA Transformer build with FEN partners (thyssen krupp electric steel and Schaffner GmbH)
- Key-component for smart energy distribution in coming DC grids

[1] Gravimetric power density of the transformator compared to 50 Hz dry transformers

DC Transition

Higher Efficiency, Saving Materials, Digital, Flexible, but also more Ecological!

4,5 MVA, 50 Hz Transformator
11.500 kg (2,5 kg/kVA)



5,0 MVA, 1.000 Hz Transformator
675 kg (0,14 kg/kVA)

Solid State DC transformers reduce significantly our CO_2-foot print

Estimated Transformer use; AC@50 Hz >25,000 ton/GVA, DC@1 kHz Grid < 1,500 ton/GW

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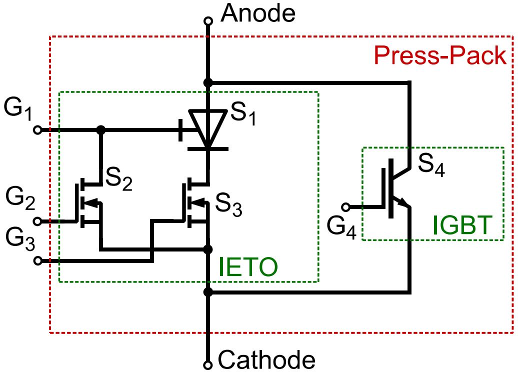
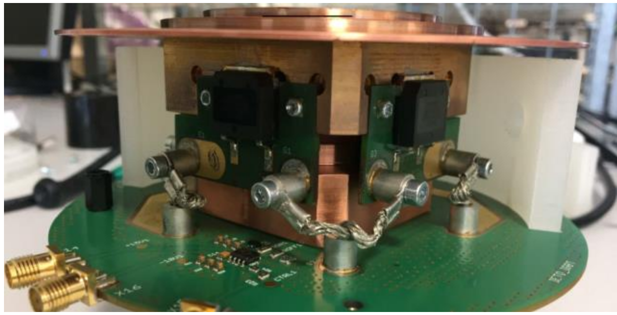
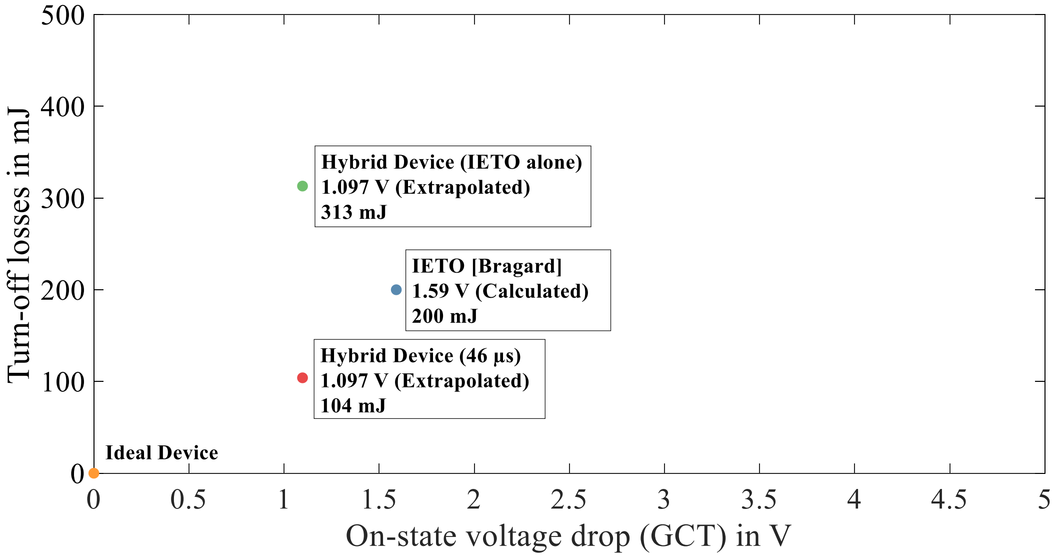
IETO-IGBT Hybrid Switch

- Turn-off thyristor
  - Lower on-state voltage
- IGBT
  - Lower turn-off loss

- Hybrid concept
  - Shifting technology curve towards optimized overall performance

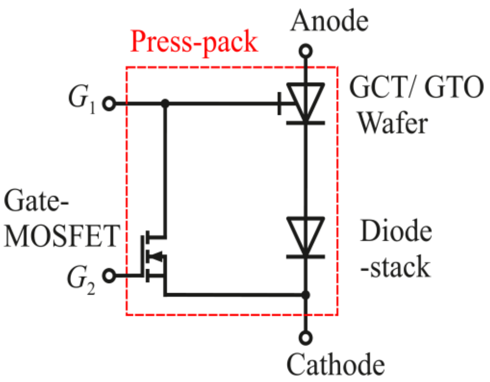


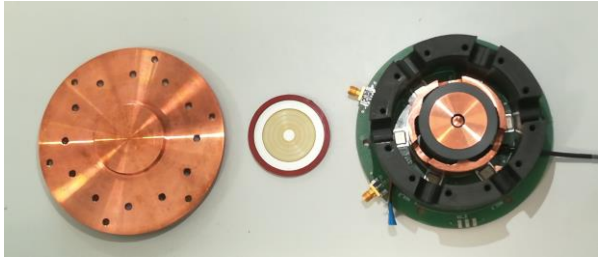


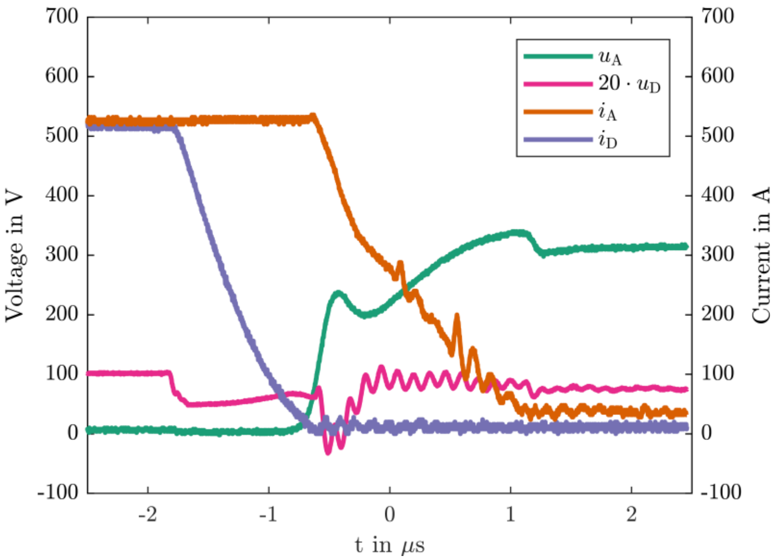


Diode Assisted Gate Commutated Thyristor (DAGCT)

- For DC circuit breaker application
- Lower cost than IGCT
  - Simplified gate driver circuit







Representative research on MVDC at Institute PGS & FEN

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