LOW VOLTAGE SIC-MOSFET BASED MEDIUM VOLTAGE CONVERTER

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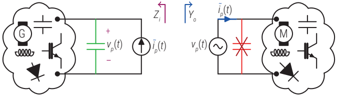
PEL RESEARCH FOCUS

MVDC Technologies and Systems

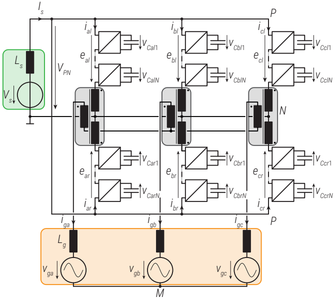
- **System Stability**
- Protection Coordination
- Power Electronic Converters

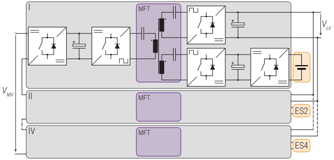
MVDC
ENERGY CONVERSION TECHNOLOGIES AND SYSTEMS



Power Electronics Conversion

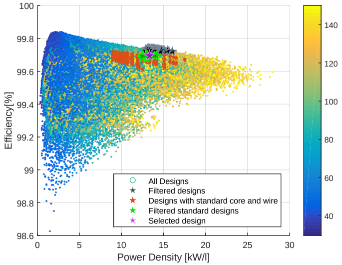
- Multilevel Converters
- Solid State Transformers
- Medium Frequency Conversion

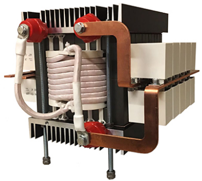




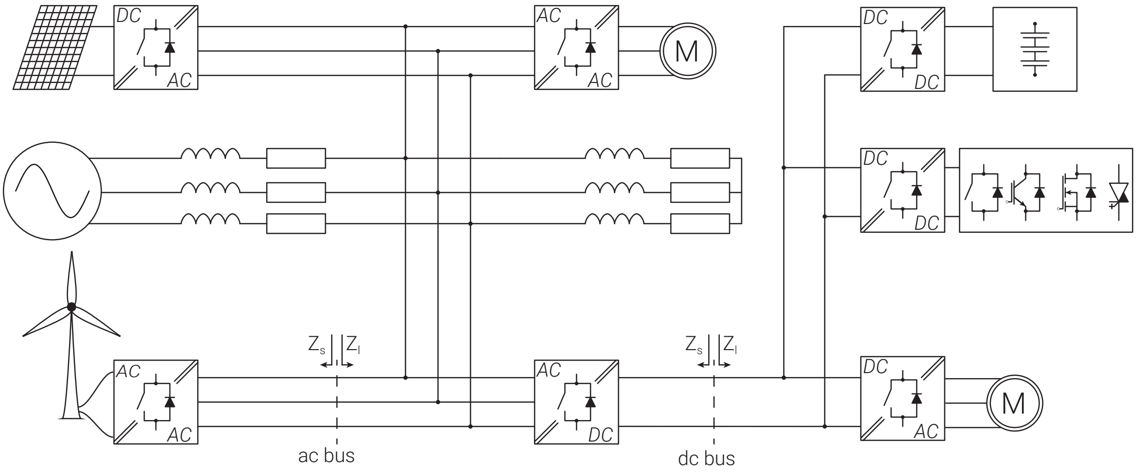
Components

- Semiconductors
- Magnetics
- **Characterization**





IMPEDANCE/ADMITTANCE MEASUREMENTS AT MEDIUM VOLTAGE



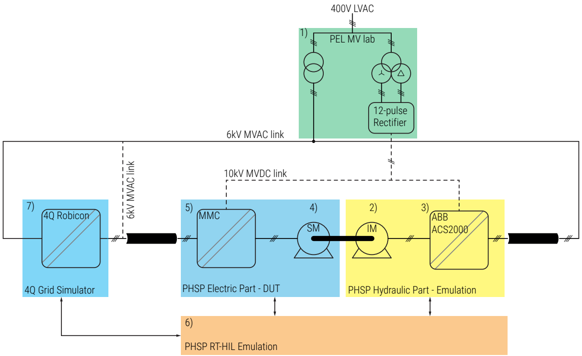
▲ AD/DC distributed power system

- Power electronics dominated energy system require careful design and stability studies
- System identification is challenging at medium voltage level [1]

MV GRID EMULATOR FOR PHSP RT-HIL

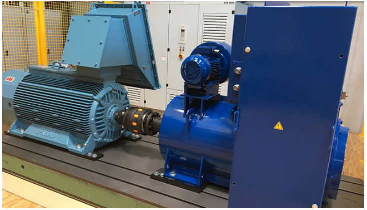
Medium Voltage Research Platform - MV Grid Emulator is needed!

- Extending flexibility of pumped hydro storage plants
- Assessment of ancillary services
- Converter Fed Synchronous Machines - CFSM
- Doubly Fed Induction Generator - DFIG
- Novel power electronics conversion technologies [2]



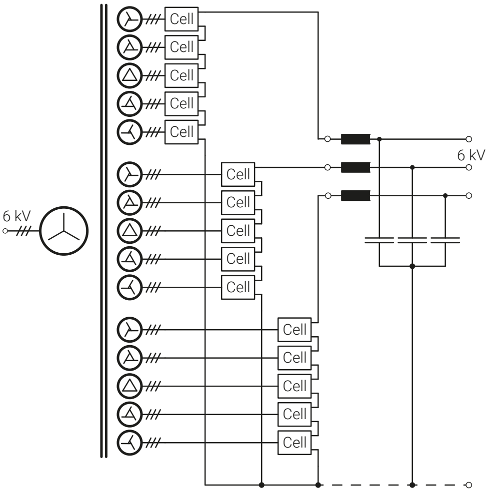
▲ Medium Voltage Pumped Hydro Storage Plant Emulation Platform (0.5MVA, 6kV)

▲ ACS2000: 1MW, 6kV, 4Q 5-level drive

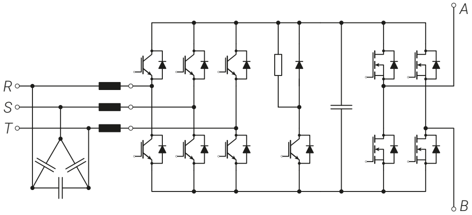


▲ IM (left) + SM (right): 0.5MVA, 6kV, 4p, 1500rpm

MEDIUM VOLTAGE GRID EMULATOR - 4Q ROBICON TOPOLOGY



▲ CHB topology with 15 LV cells and (small) output filter

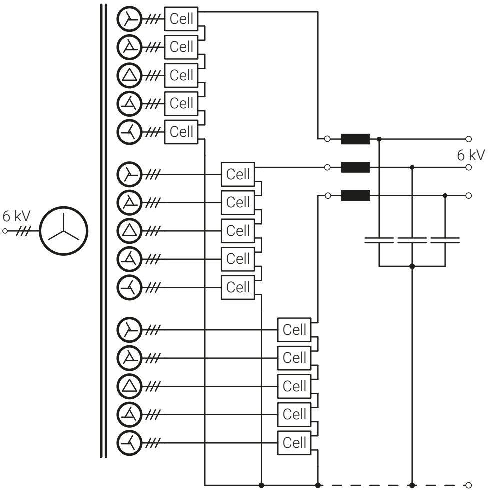


▲ Bidirectional CHB cell with input filter and overvoltage protection

Table 1 Grid Emulator Parameters

Parameter	Value
apparent power rating	1 MVA
transformer primary side line voltage	6 kV
transformer secondary side line voltage	710 V
maximum cell dc link voltage	1200 V
CHB output line voltage	0 to 6 kV ac or ±5 kV dc
switching frequency AFE	10 kHz
apparent switching frequency CHB	100 kHz

MEDIUM VOLTAGE GRID EMULATOR - 4Q ROBICON TOPOLOGY



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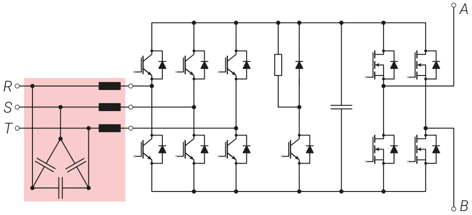

▲ **One goal is to avoid need for these filters!**

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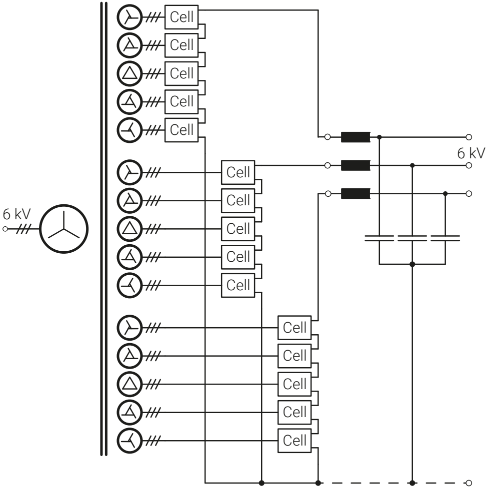
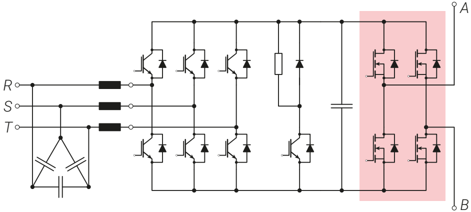


▲ CHB topology with 15 LV cells and (small) output filter



▲ **Another goal is to achieve high control bandwidth at the output!**

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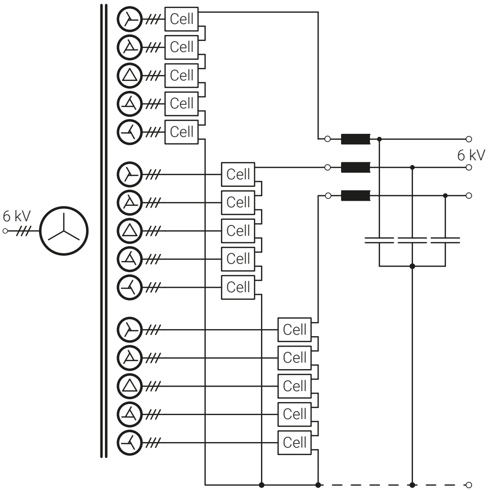
MEDIUM VOLTAGE GRID EMULATOR - 4Q ROBICON TOPOLOGY



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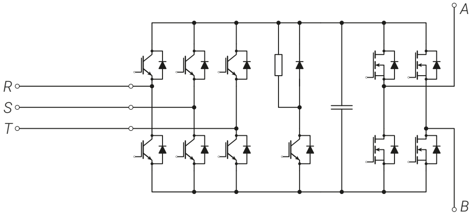

▲ Bidirectional CHB cell without input filter and with SiC output stage

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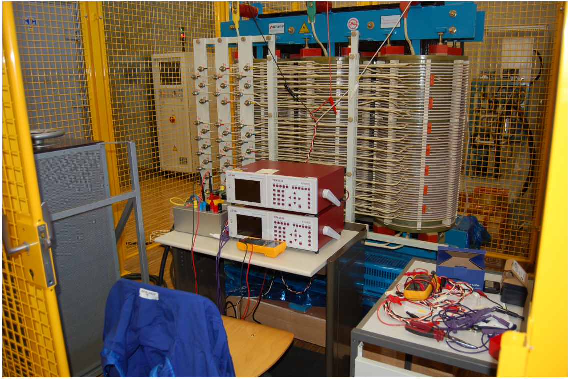
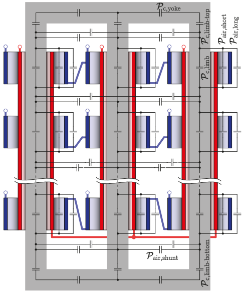
MULTIWINDING PHASE-SHIFT TRANSFORMER

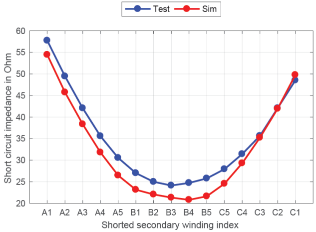
- 1MVA rated
- 6kV primary winding
- 15 x 710V secondary windings
- Complex but relatively cheap
- Not a symmetrical structure [3]
- Turns ratio and phase deviations



▲ 1MVA, 6kV multiwinding transformer

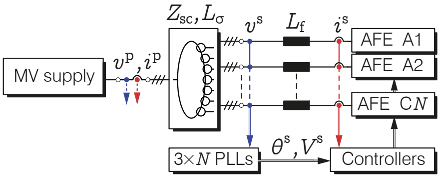


▲ Detailed and accurate PLECS simulation model is available

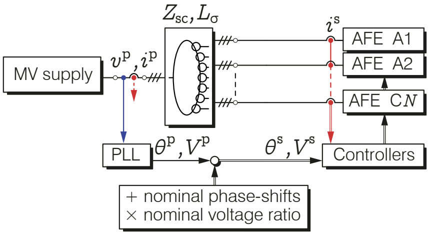


▲ Measured and simulated short circuit impedances

GRID SYNCHRONIZATION - PLL VOLTAGE SENSING LOCATION?



▲ Multiple secondary side PLLs

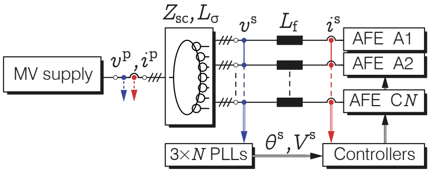


▲ Single primary side PLL

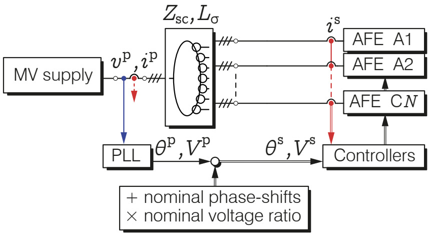
- Transformer secondary winding voltage as source
- Local PLL on each cell
- Transformer parameters mismatch not relevant
- Discrete filters are needed in front of the AFE - bulky!
- Straightforward solution

- Grid voltage as source
- Transformer leakage inductances used as filter
- Transformer nameplate parameters used (ratio, phase)
- No discrete filters are needed in front of the AFE - savings!
- Preferred solution [4]

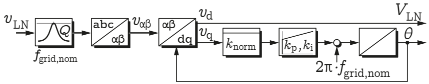
CONTROL IMPLEMENTATION



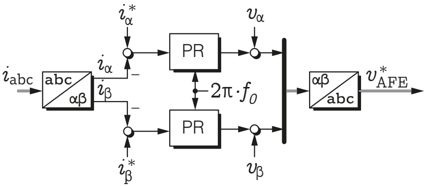
▲ Multiple secondary side PLLs



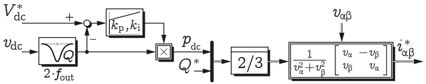
▲ Single primary side PLL



▲ SRF PLL is used for both cases



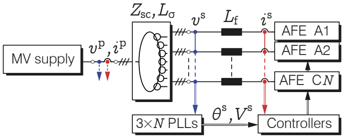
▲ AFE input current controller in SRF



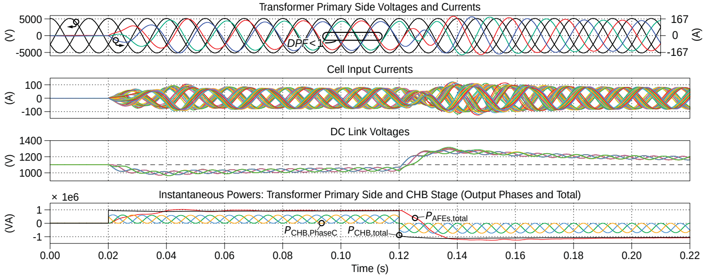
▲ AFE DC link voltage controller

- PR controllers in SRF for AFE input current control
- PI DC link voltage controller
- CHB operation causes 2nd harmonic ripple
- Notch filter on measured DC link voltage
- PSC PWM
- Controller parameters are available in [4]

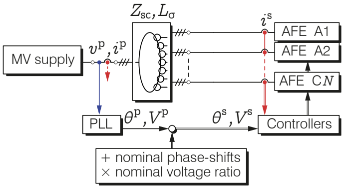
SIMULATION RESULTS...



▲ Multiple secondary side PLLs



▲ Performances during load change - with discrete filters and multiple PLLs on the secondary side



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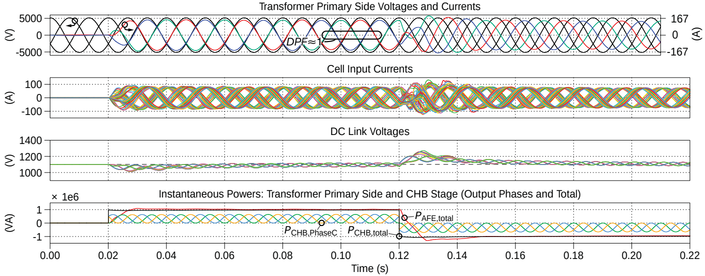
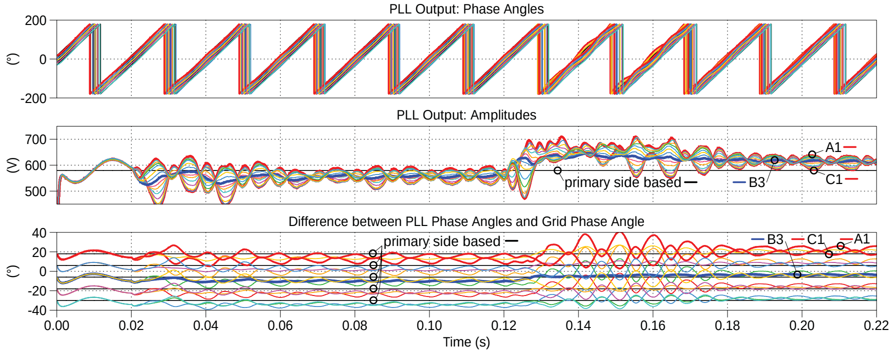
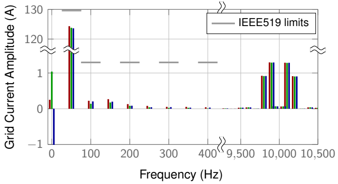


▲ Performances during load change - without discrete filters and with single PLLs on the primary side

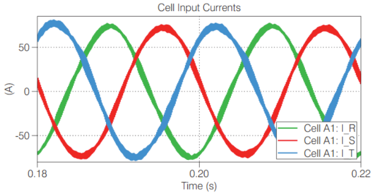
SIMULATION RESULTS



▲ PLL performances: primary side based (black) and secondary side based (colored)

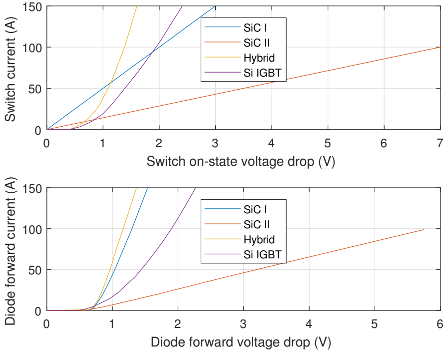


▲ Grid side current spectrum

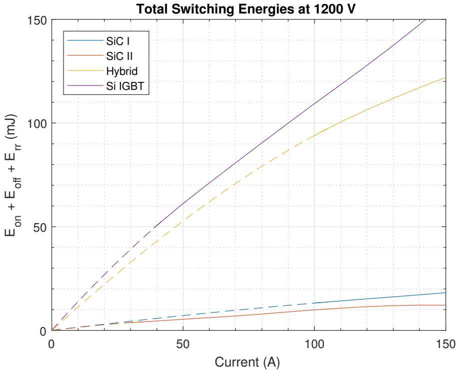


▲ AFE current waveforms

SEMICONDUCTOR CONSIDERATIONS?



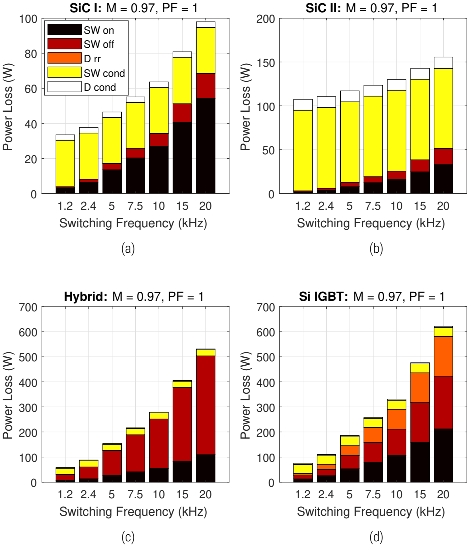
▲ Static characteristic of several considered modules



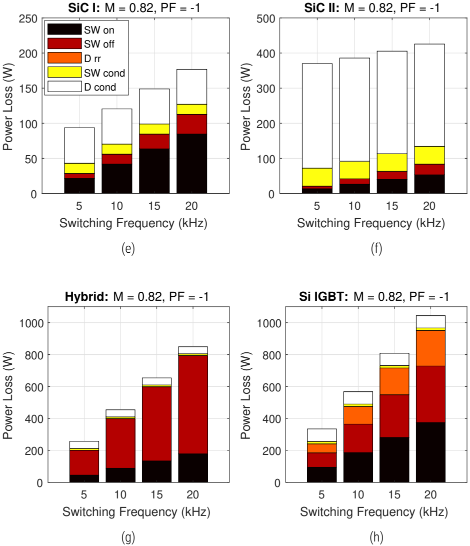
▲ Switching energies at 1200 V

Halfbridge Module	Short Designator	Package	Datasheet Parameters				
			$T_{j,SW}$	$T_{j,D}$	$R_{g,on}$	$R_{g,off}$	Ref.
CAS300M17BM2	SiC I	62 mm	150 °C	150 °C	2.5 Ω	2.5 Ω	[5]
APTMC170AM30CT1AG	SiC II	SP1	150 °C	175 °C	10 Ω	10 Ω	[6]
2MSI400VE-170-53	Hybrid	M277	150 °C	150 °C	1 Ω	0.5 Ω	[7]
SKM150GB17E4	Si IGBT	34 mm	150 °C	150 °C	2 Ω	2 Ω	[8]

SEMICONDUCTOR LOSSES

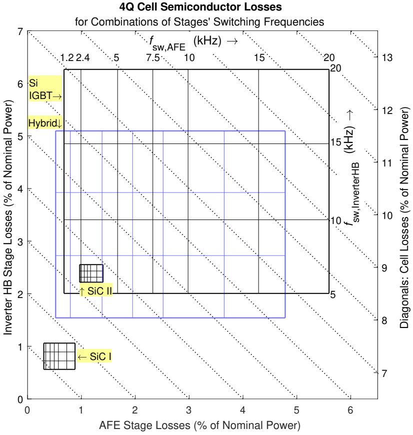


▲ AFE losses per switch, P = 1 MW.

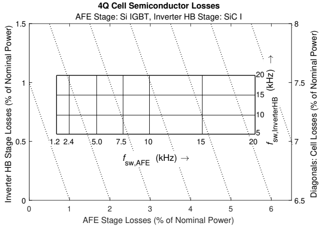


▲ Inverter losses per switch, P = 1 MW.

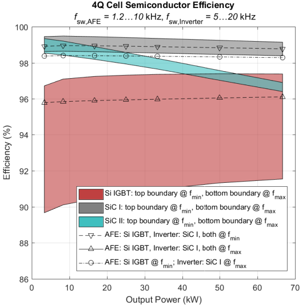
SEMICONDUCTOR LOSSES...



▲ 4Q cell losses for different f_{sw} with same modules in both stages



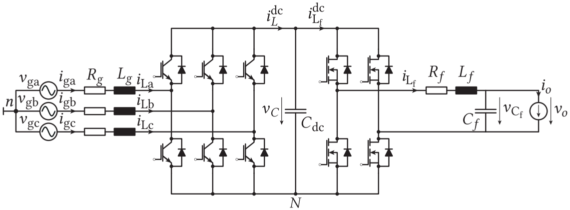
▲ 4Q cell losses for Si IGBT AFE and SiC I HB at different f_{sw}



▲ 4Q cell semiconductor efficiency for switching frequency ranges

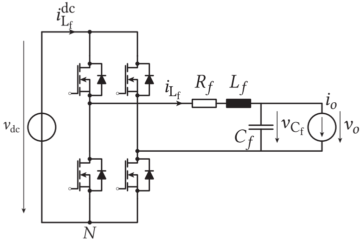
- Full SiC - nice, efficient, but not critical for AFE
- Hybrid solution seems more appropriate and cost effective
- AFE 10 kHz (Si) + CHB 20kHz (SiC)

SYSTEM IDENTIFICATION

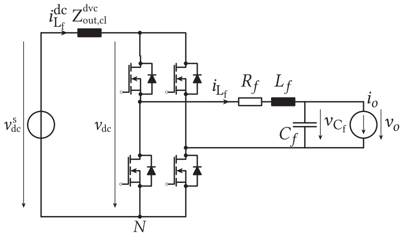


▲ Three-phase supplied Active Front End (AFE) interfaced to single phase inverter with an *LC* filter.

- AFE regulates DC link voltage
- Slower dynamics of AFE
- Impact on the CHB output?
- Source affected impedance
- Need to characterize source impedance?

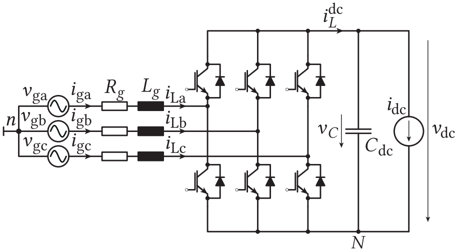


▲ HB inverter with an LC filter

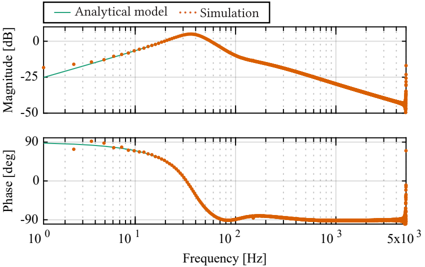


▲ HB inverter with an LC filter and internal Z_{source}

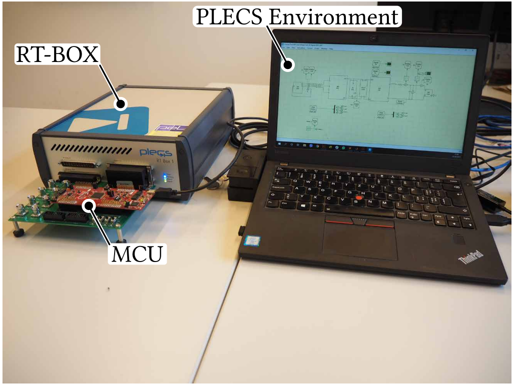
SYSTEM PERTURBATION AND IDENTIFICATION



▲ Three-phase AFE feeding a load.



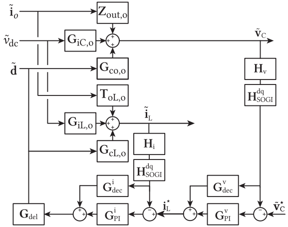
▲ Output, dc side, impedance of the AFE under the input current and output voltage control loops closed.



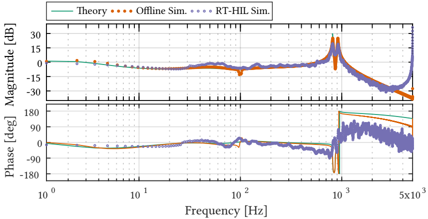
▲ Hardware in the loop system

- RT-Box based HIL
- Power hardware emulation
- Control on the DSP
- PRBS injection
- High flexibility in work

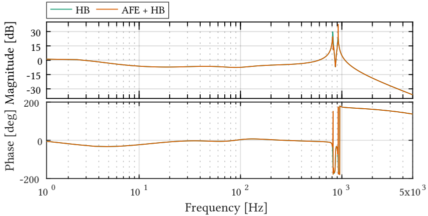
SYSTEM PERTURBATION AND IDENTIFICATION...



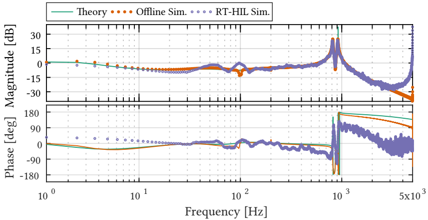
▲ Closed-loop dynamics of the HB inverter with cascaded inductor current and capacitor voltage control.



▲ *d*-axis control-to-output characteristics $G_{co,cl,dd}^{CVC}$ of the HB-inverter supplied from ideal DC source.



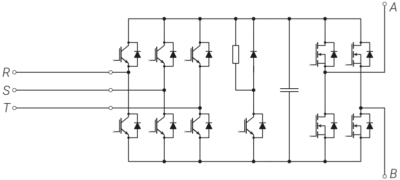
▲ Comparison of control-to-output $G_{co,cl}^{CVC}$ characteristics of a HB operating with an ideal dc link voltage and with AFE as an input stage controlling the dc-link voltage.



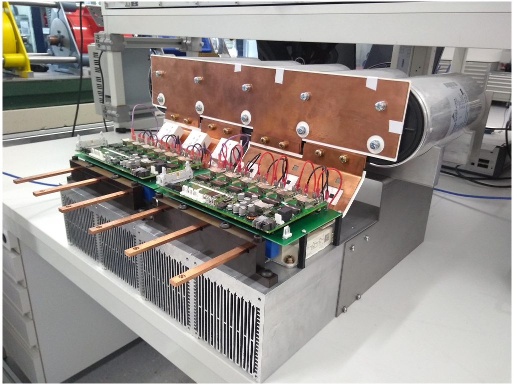
▲ *d*-axis control-to-output characteristics $G_{co,cl,dd}^{CVC}$ of the HB-inverter operated with AFE as the input stage.

ONGOING HW DESIGN

- 1.7kV Si IGBT (62mm package)
- 1.7kV SiC MOSFET (samples from Mitsubishi Electric)
- Cost design optimization of HW
- ABB AC 800PEC as main controller
- Communication, measurements, protection
- Mechanical design...



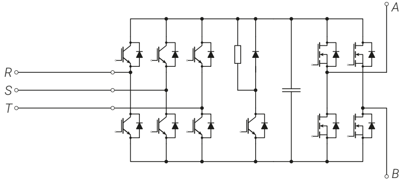
▲ 4Q PEBB under testing (communication)

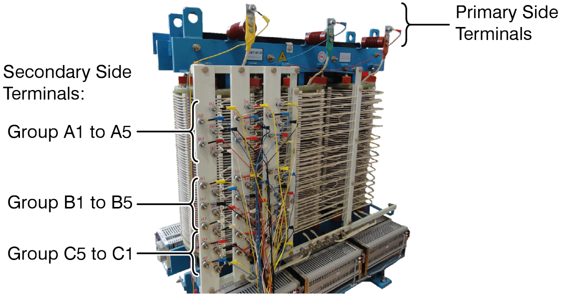


▲ 4Q PEBB - present design

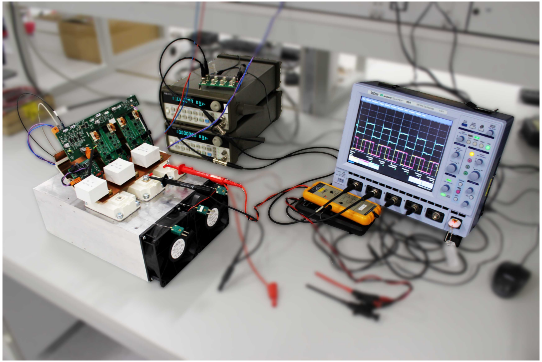
SUMMARY

- 4Q Robicon based Grid Emulator
- Hybrid design: AFE (Si), CHB (SiC)
- Perturbation Injection Converter for system identification
- Primary side PLL allow for significant cost savings
- Robust control despite transformer asymmetries
- SiC devices enabling high output control bandwidth!





▲ 1MVA, 6kV multiwinding transformer



▲ SiC PEBB during gate driver testing

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THANK YOU FOR YOUR ATTENTION

LOW VOLTAGE SIC-MOSFET BASED MEDIUM VOLTAGE CONVERTER

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