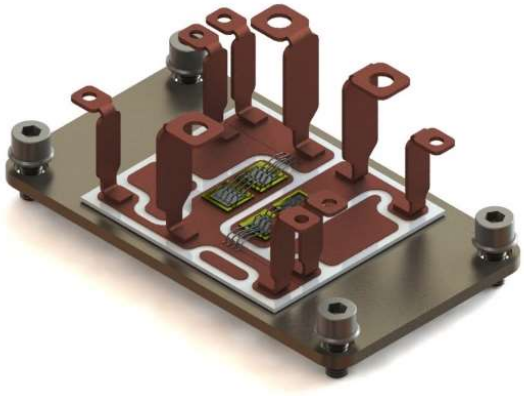

10kV SiC MOSFET Power Modules

MW turbines

Medium Voltage components and power converters first experiences

By: Stig Munk-Nielsen, Professor, smn@energy.aau.dk

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INTRODUCTION

- **MV power transistors**
- **MV power converters and challenges**
- **50kVA and 500kVA MV power test results and status**

MW MV Power Electronics

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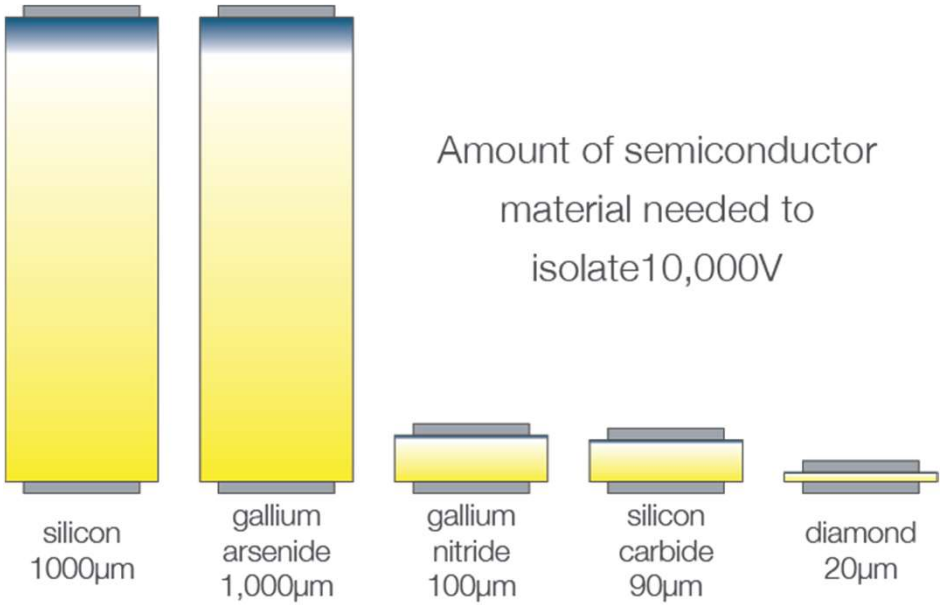
MV power transistors



http://www.evincetechnology.com/why_diamond.html

Si	**MOSFET** (commercial)	**12 V - 1200 V**
	IGBT (commercial)	**650 V - 6.5 kV**
SiC	**MOSFET** (commercial)	**1.7 kV (3.3 kV)**
	MOSFET (non-commercial)	**10 kV and 15V**
	IGBT (non-commercial)	**up to 25 kV** (expected)

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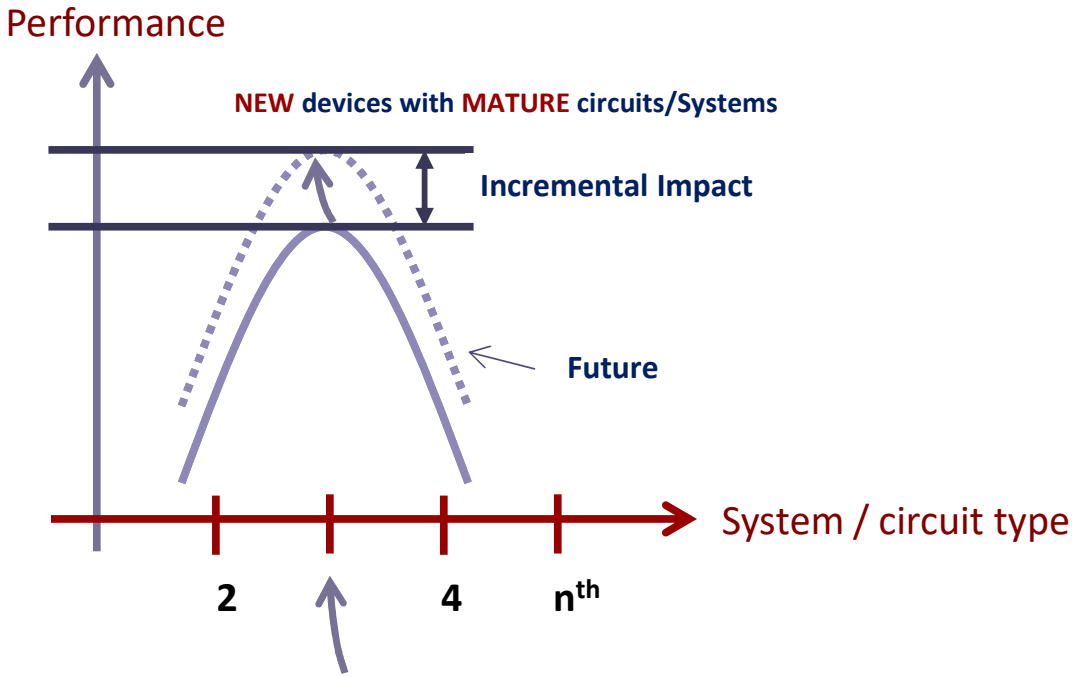
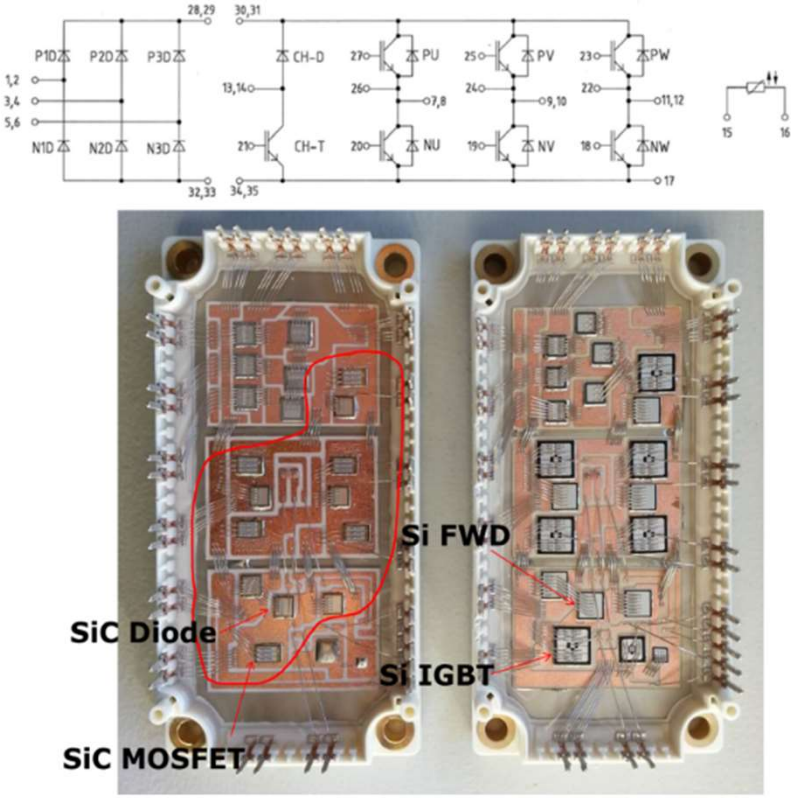
Next-Generation Power Device: opportunities



The “winner” circuit/solution.
Identified by the MARKET



www.iepe.et.aau.dk/electronic/motor-drive-sic-mosfets/

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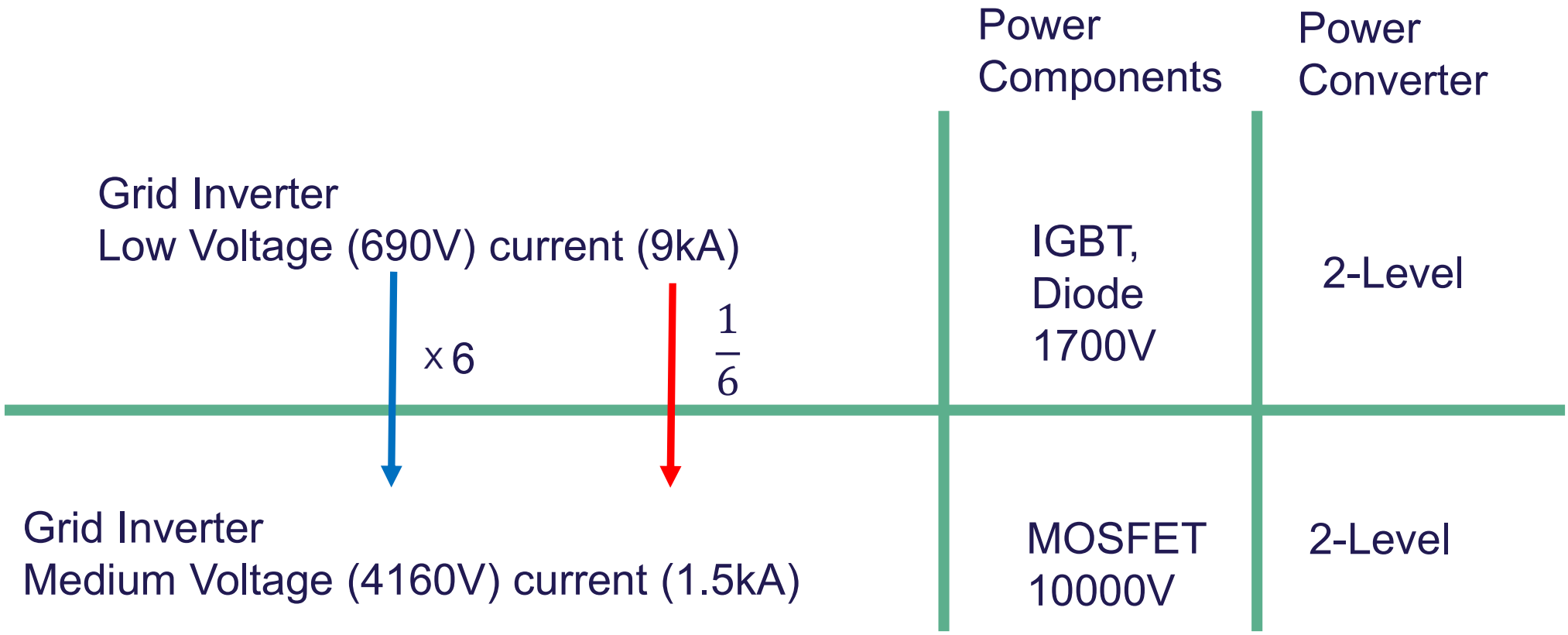
Aalborg EPE 2023 Conference

Wind offshore 10MW LV vs. MV



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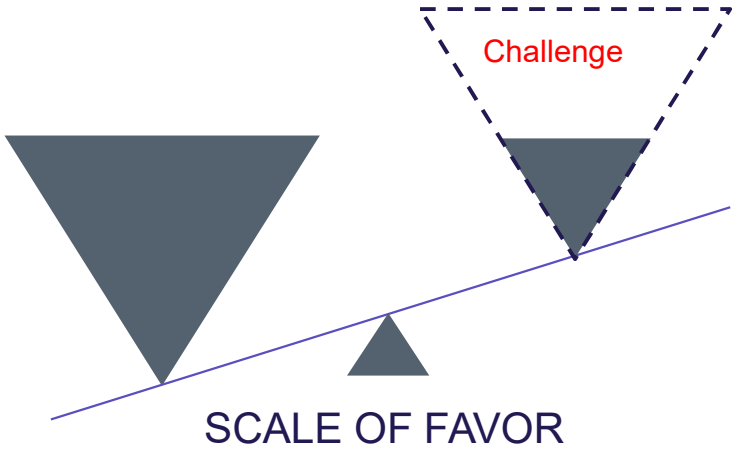
Next-Generation Power Device : Challenges

Silicon Power Devices:

- Cheap
- Stable supply chain
- Mature
- Low risk



Next-Generation Power Devices:

- Expensive
- Need strong supply chain
- Design and application challenges
- Higher risk

Challenges of next-generation power devices to fill the gap:

- High voltage
- Fast switching

→ Partial discharge → Low lifespan

→ High di/dt and high dv/dt → EMI & common-mode current

→ Sensitive to parasitic → "Ringing" switching

→ **Optimized Design & Guideline**

New Concerns in Medium Voltage power modules

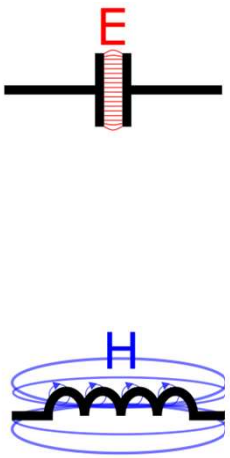
New parasitic paradigm

- Capacitive effects can dominate in medium voltage applications

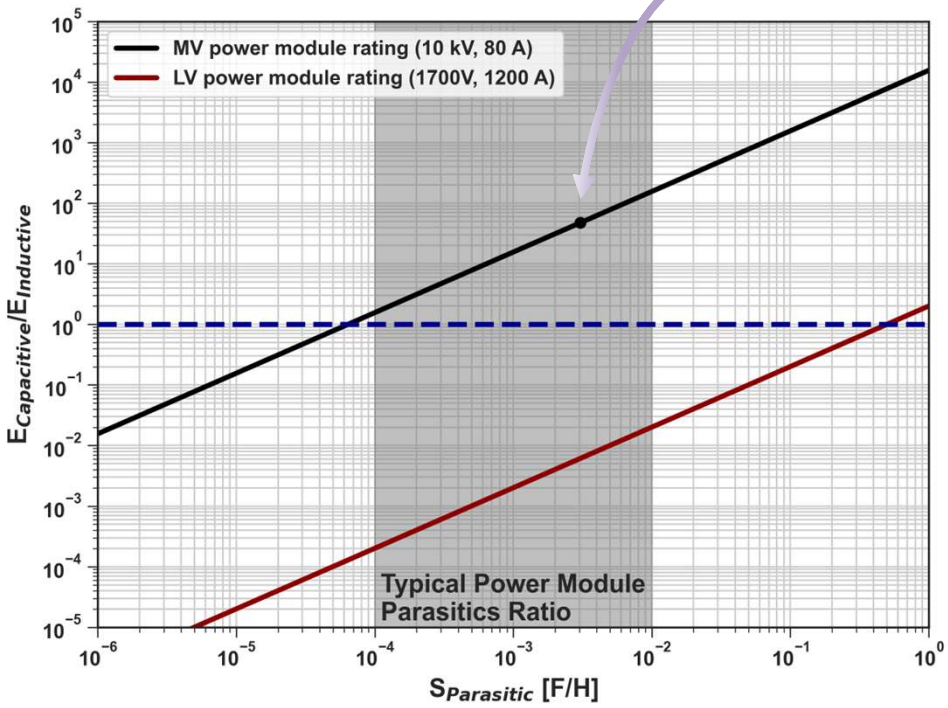
$$\frac{E_{\text{capacitive}}}{E_{\text{inductive}}} = \frac{C_{\text{parasitic}}}{L_{\text{parasitic}}} \cdot \frac{v^2}{i^2} = S_{\text{parasitic}} \cdot \left(\frac{v^2}{i^2}\right)$$

Size/application-type scale

"Electric" scale



M5x-series



Source:

J. K. Jørgensen et al., "Multi-chip Medium Voltage SiC MOSFET Power Module with Focus on Low Parasitic Capacitance," *in Proc. 11th International Conference on Integrated Power Electronics Systems*, 2020, pp. 1-6.

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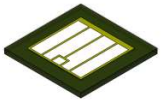
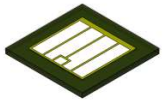
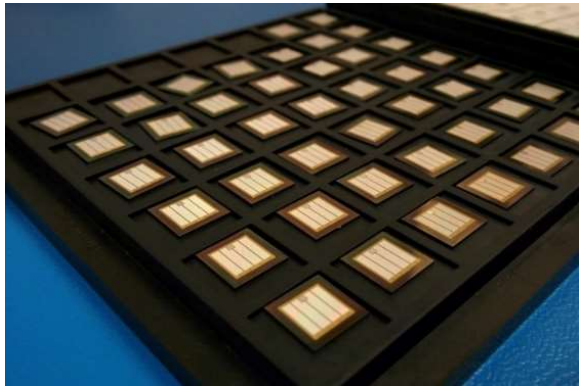
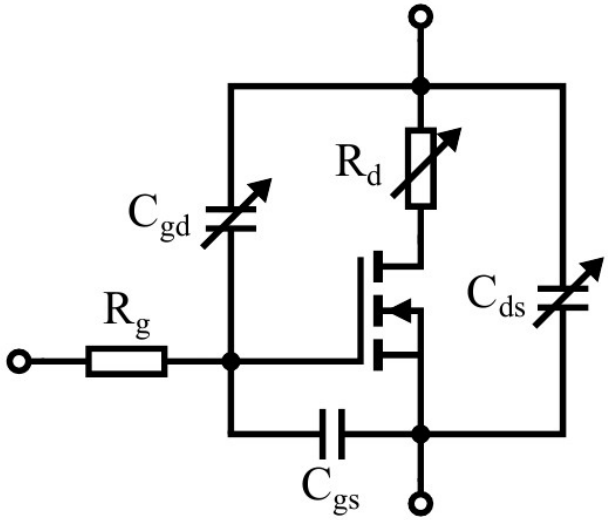
SiC MOSFET semiconductor model



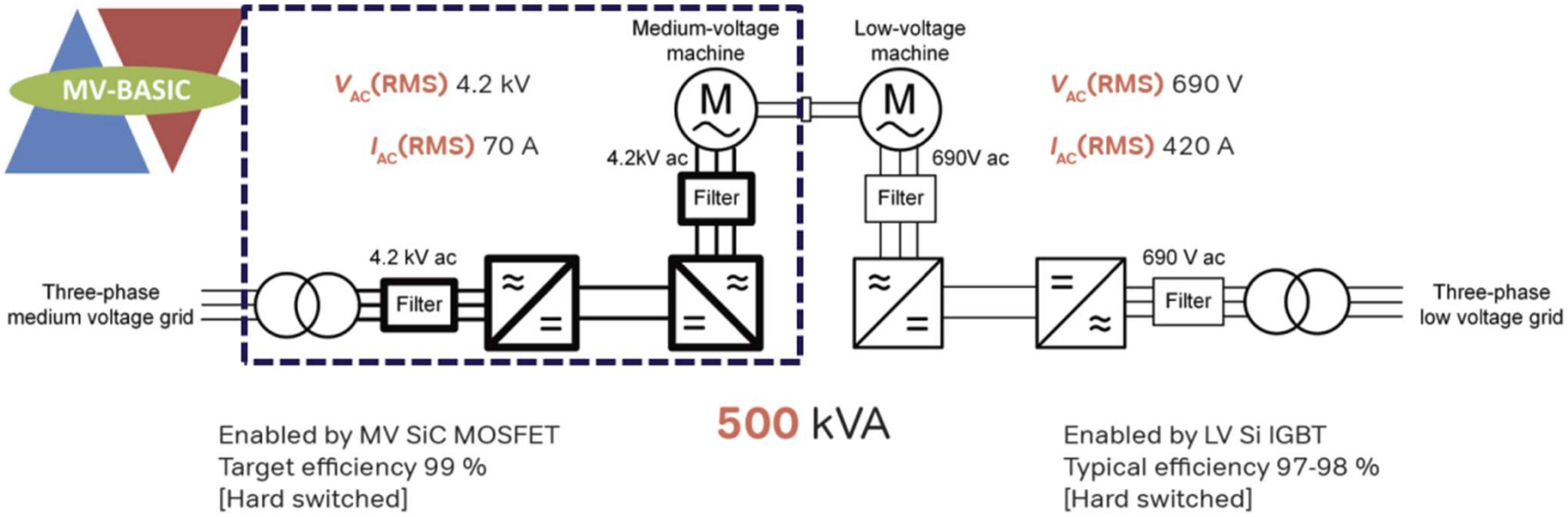


- Bare 10/15 kV SiC MOSFET die's from Wolfspeed





500kVA demonstrator 2-level converter MV and LV



Prospective benefits:

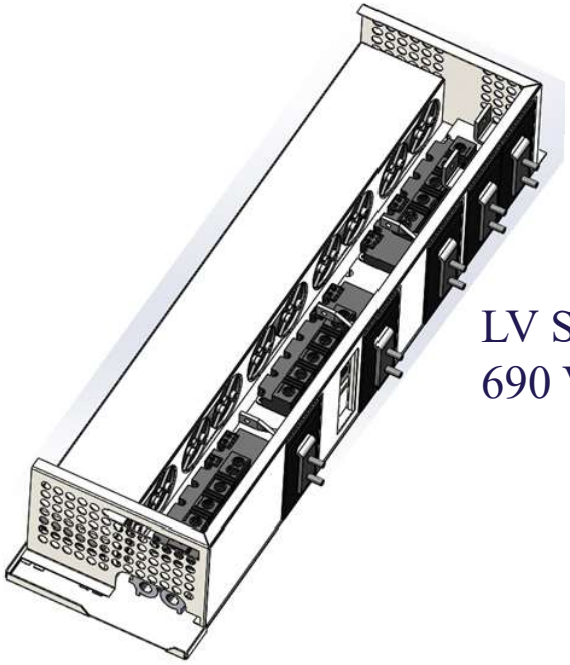
- Higher switching frequency: 5 kHz - 10 kHz
- Higher efficiency: 1-2% more than Si IGBT
- Less copper: 17 % rated current compared to IGBT

Major challenges and research problems:

- High dv/dt: 30 kV/µs - 80 kV/µs
- Higher insulation requirement: 10 kV level
- Design of magnetics with reduced parasitic

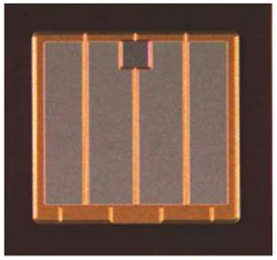
We use LV hardware as platform for our MV converters

Standard 690V 500kVA
3Ø-IGBT converter

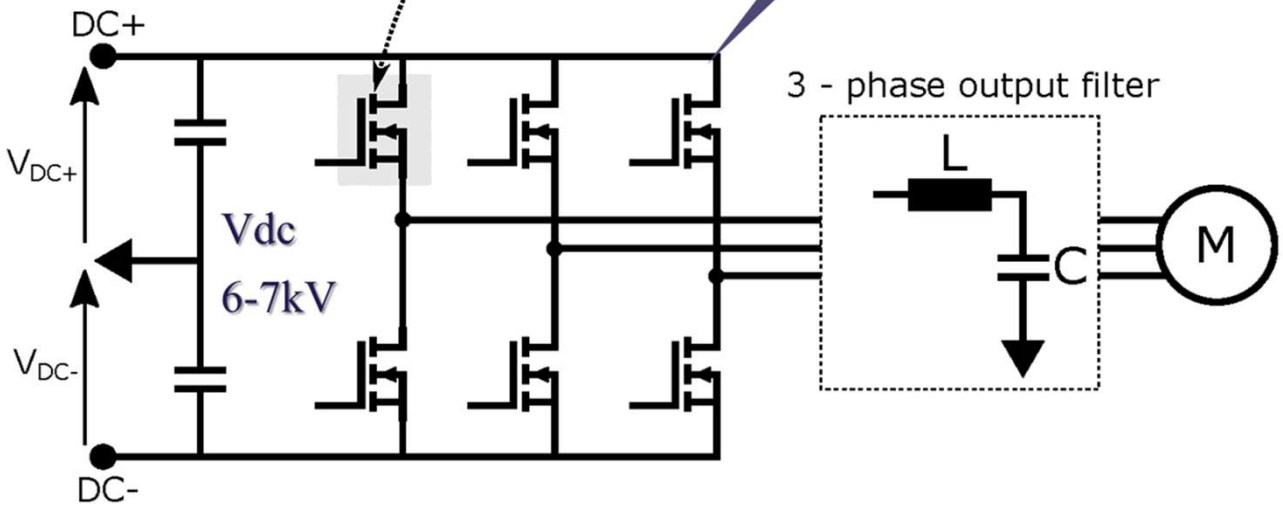


LV Si
690 V

MV SiC
4.16 kV



1 - 2 % target efficiency improvements



Road to demonstrator hardware test

2023

10kV 80A **2020**

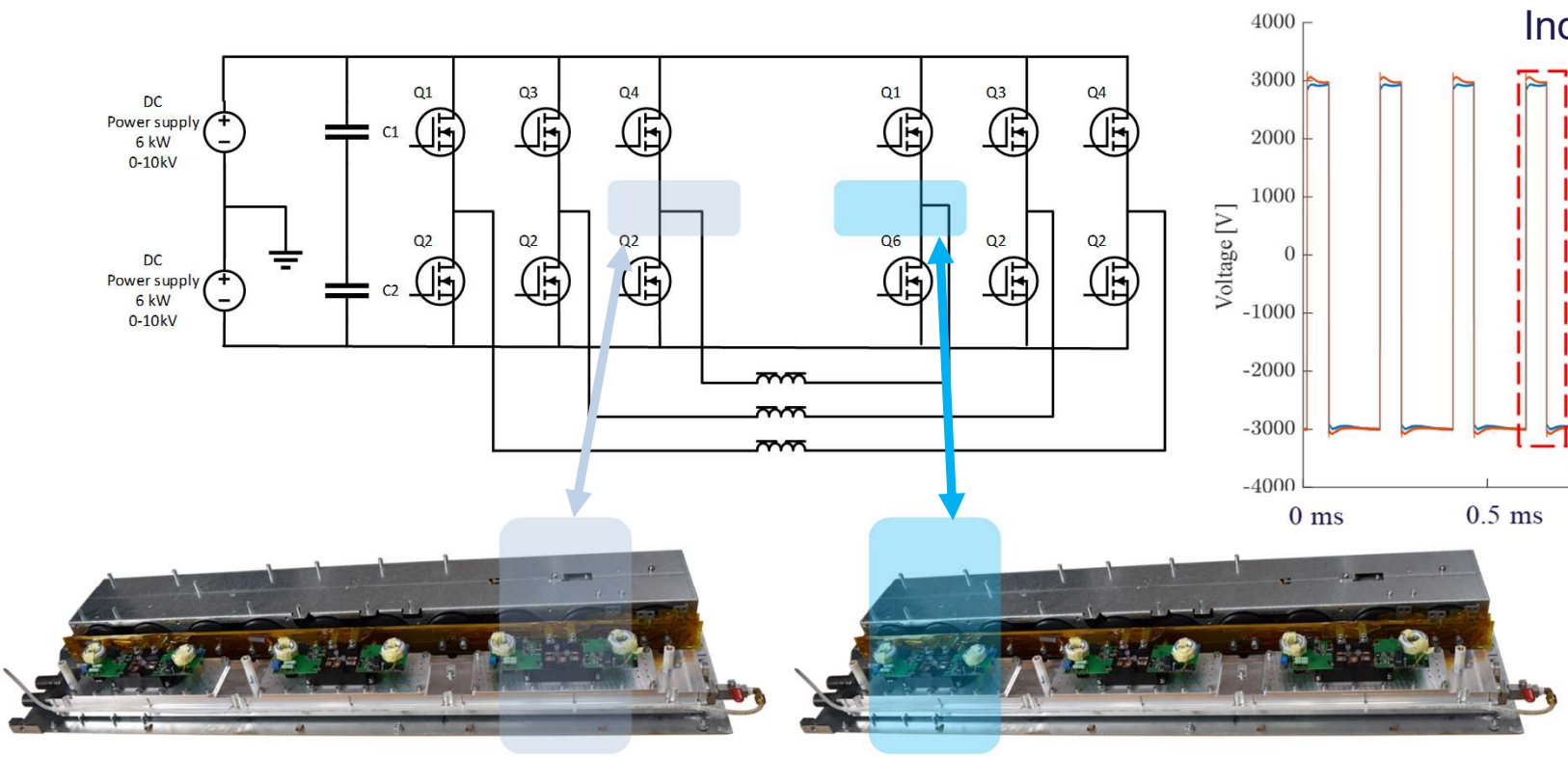
10kV 20A **2019**

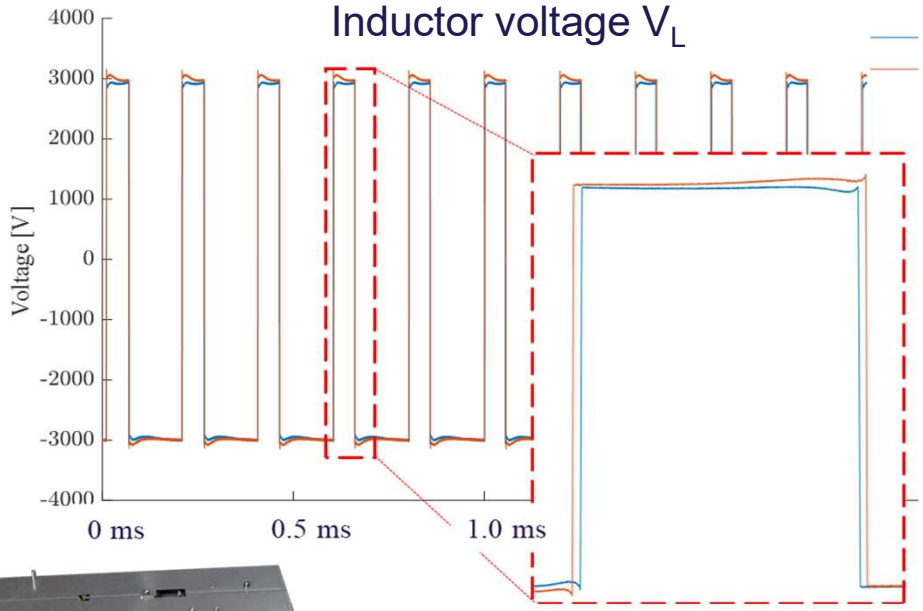
Demonstrator MV1: Medium voltage 80 kVA 3 phase power stack using single die 10 kV half bridge power module

Demonstrator MV2: Medium voltage 500 kVA 3 phase power stack using multi chip 10 kV half bridge power module

MV laboratory: Testing 500kVA of MV and LV power stacks. Key performance characteristics evaluation.

Back-to-back MV converter





First test results of back-to-back converters

10kV 20A SiC MOSFET

Switching Frequency 5kHz

6000V DC link voltage

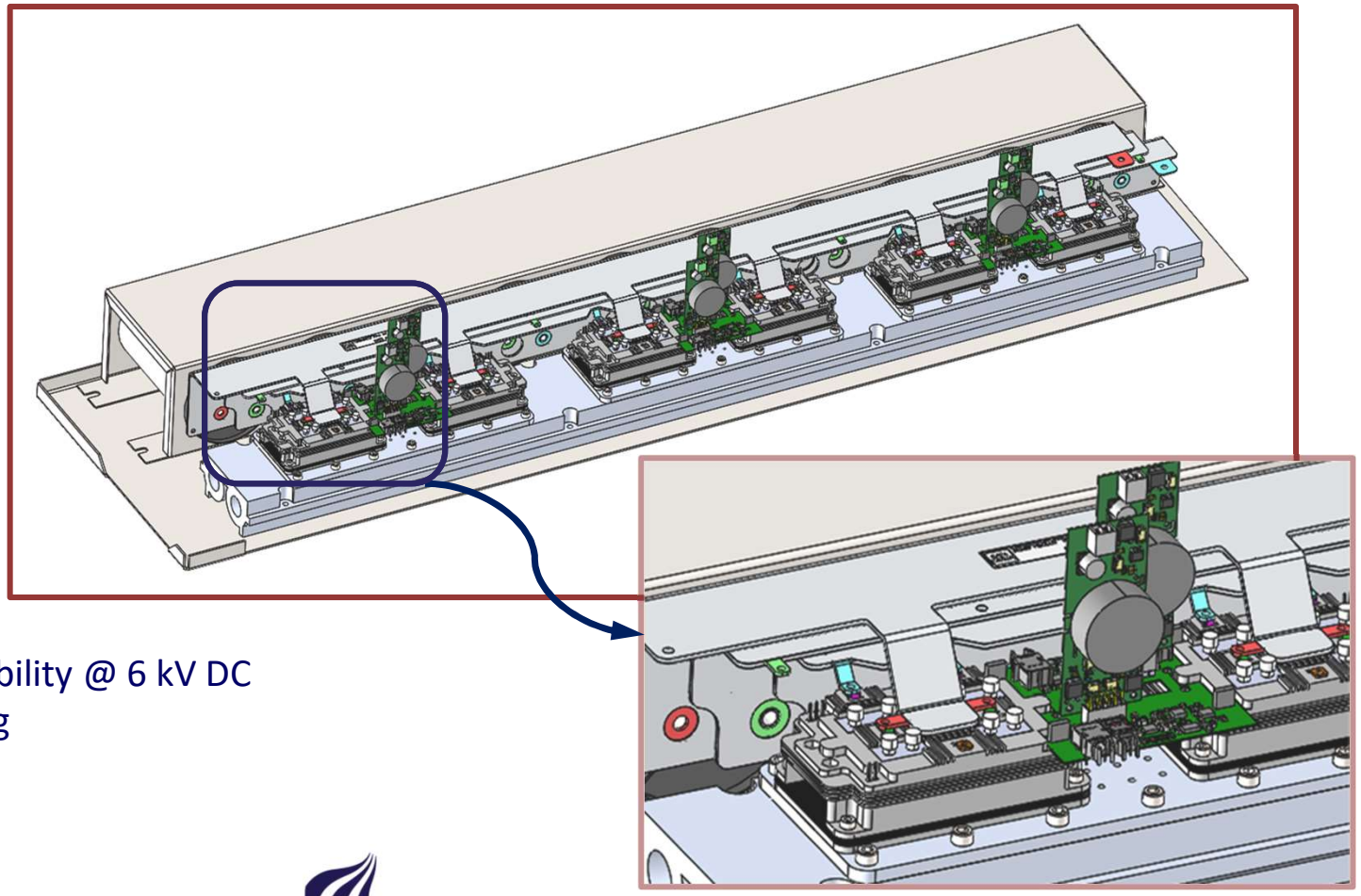
AC voltage: 4160Vrms

Line current: 6.6Arms

DESIGN OF A 500 KVA MEDIUM VOLTAGE CONVERTER

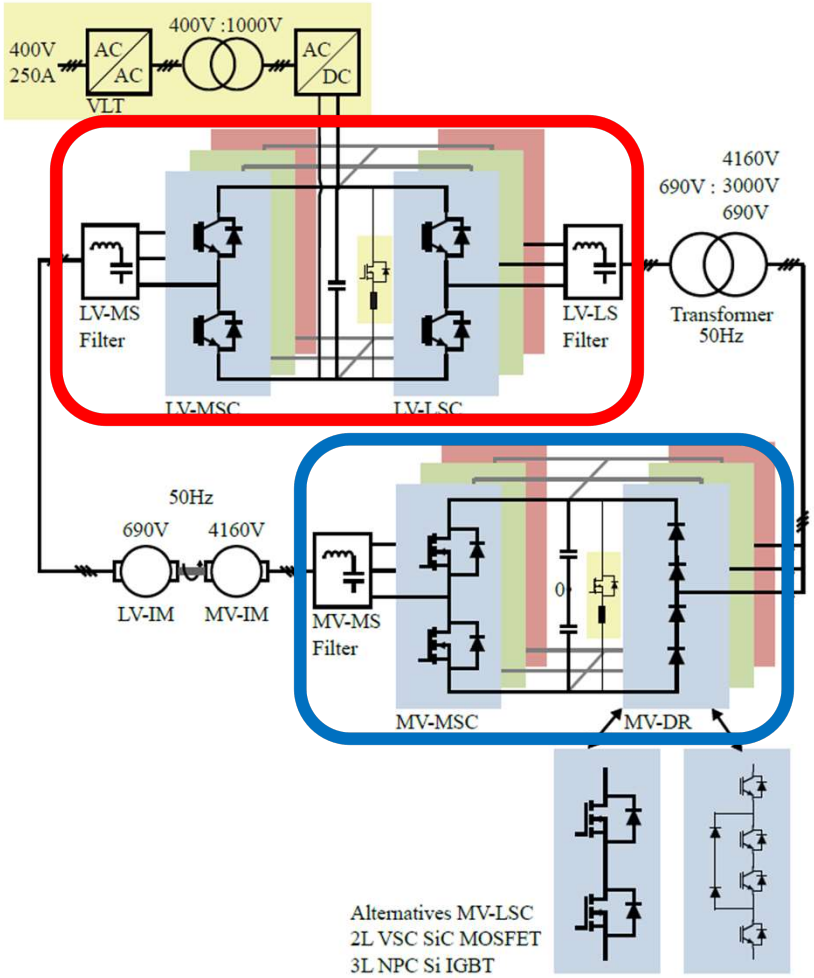
Converter stack

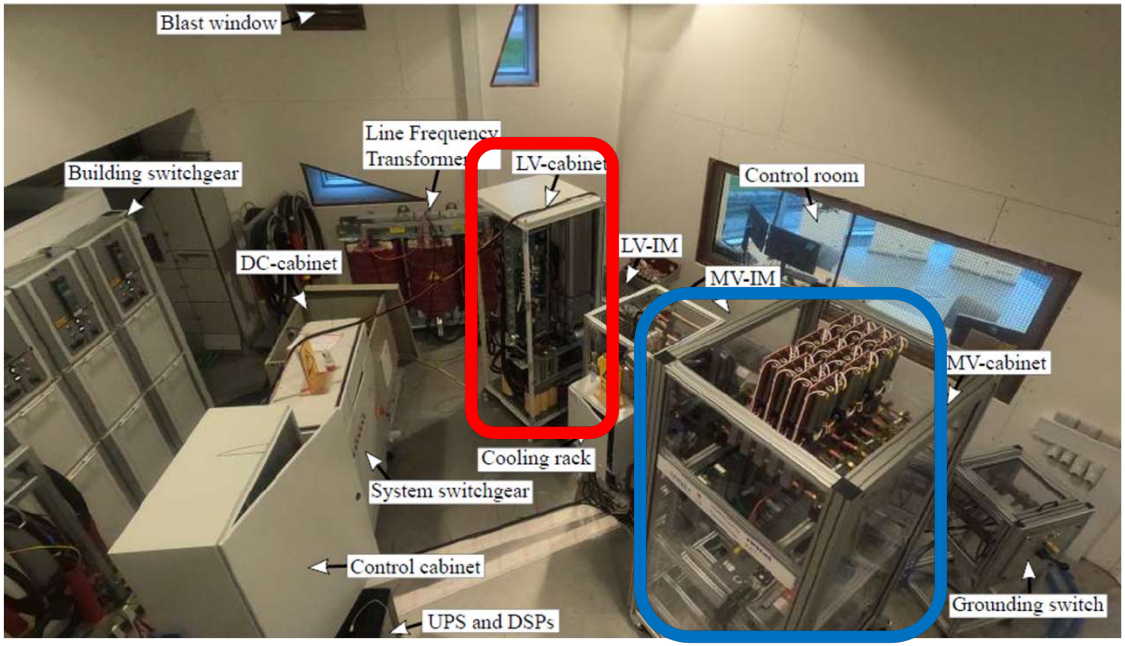
- 3-phase MV SiC MOSFET stack
- No. parallel modules/phase leg: 1 or 2
- 4 chips per switch position/module
- Water cooled cold plate
- Busbar with plus, minus and midpoint configuration – up to 10 kV



- Anticipated stack power handling capability @ 6 kV DC exceed 500 kVA for 1 module/phase leg

MV demonstrator 500kVA using 10kV SiC and 1.7kV Si technology





Summary

Possibility of next-generation power devices:

- LV development impact performance on MV power devices

Opportunity of using next-generation power devices:

- Reduced power loss, cooling requirement, footprint;

Challenges of using next-generation power devices:

- Need maturity: experimental converter-level validation.

Acknowledgement to Current Power Electronics Projects

MVOLT
POWER A BETTER FUTURE

2020 - 2024

- Design 2-level 500 kVA / 4.16 kV (AC) converter enabled by 10 kV SiC MOSFETs.
- Wind energy applications
- Module packaging, converter design, filter design, and system integration.

Innovation Fund Denmark

CODE

2021 - 2026

- Develop new digital design and product qualification processes allowing for higher efficiency and more compact power electronics systems.
- Only a single physical prototype has to be manufactured to achieve the specified performance.

POUL DUE JENSEN GRUNDFOS FOUNDATION

HEART PROJECT
ENGINEERING TOMORROW
Danfoss

2021 - 2024

- Commercial-level EV charger enabled by SiC

Innovation Fund Denmark

THANK YOU FOR YOUR ATTENTION

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