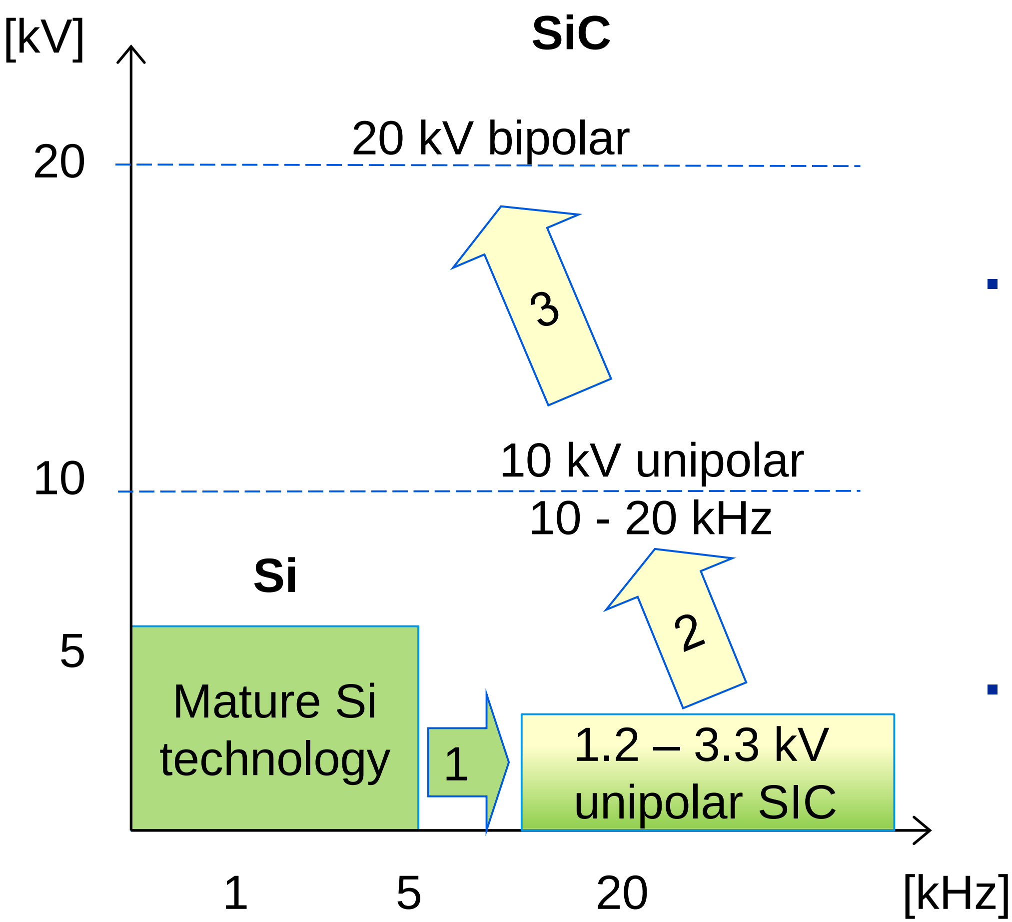
Peter K. Steimer, ABB Switzerland Ltd., Corporate Research Fellow, NIST/DOE Workshop, April 15, 2016

MV WBG Power Electronics for Advanced Distribution Grids

1. HV Power Semiconductors
2. MV Power Conversion
3. Opportunities for SiC
4. Conclusions

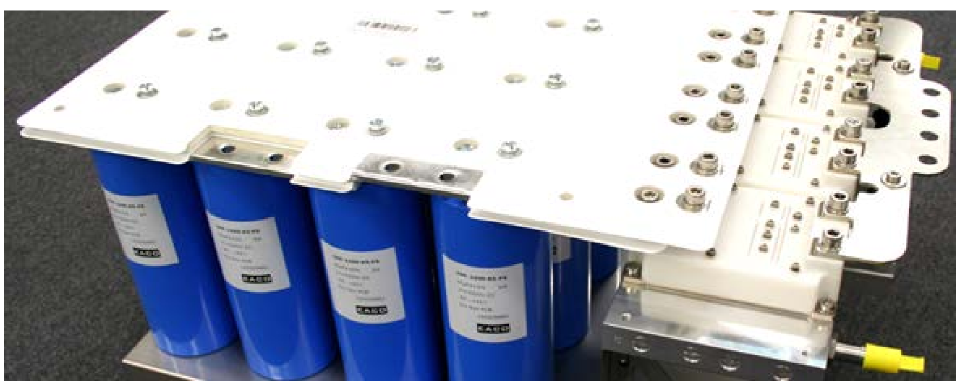
Power Semiconductors
SiC technology

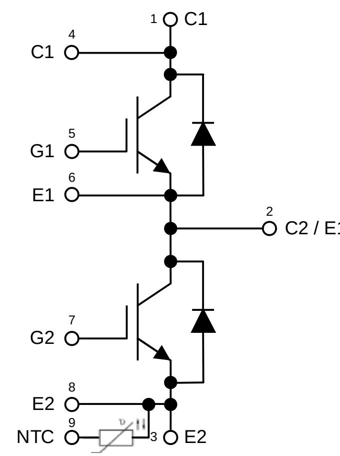


- Silicon devices up to 6.5 kV
  - Enhanced Trench SPT+ IGBT
  - 50% more power per Si area with Bi-mode devices (BIGT, BGCT)
- Wide band gap SiC devices
  1. Unipolar 1.2 kV -3.3 kV devices
  2. Unipolar 10 kV devices
     Up to 10 - 20 kHz
  3. Bipolar 20 kV (and higher) devices
- Packaging
  - Higher temperature and
  - Higher voltage packaging

Power semiconductprs
New High Power Module Standard

- Dual Module Concept, 10 nH stray inductance
- Ratings (100mm x 140 mm)
  - typical 1.7 kV ratings up to 2 x 1000A
  - typical 3.3 kV ratings up to 2 x 500A
  - typical 6.5 kV ratings up to 2 x 250A
- Designed to accommodate Si and SiC Chips
- No derating for parallel connection





Reference: LinPak, a new low-inductive phaseleg IGBT module with easy paralleling for high power
R. Schnell, S. Hartmann, D. Trüssel, F. Fischer, A. Baschnagel. M. Rahimo, PCIM 2015

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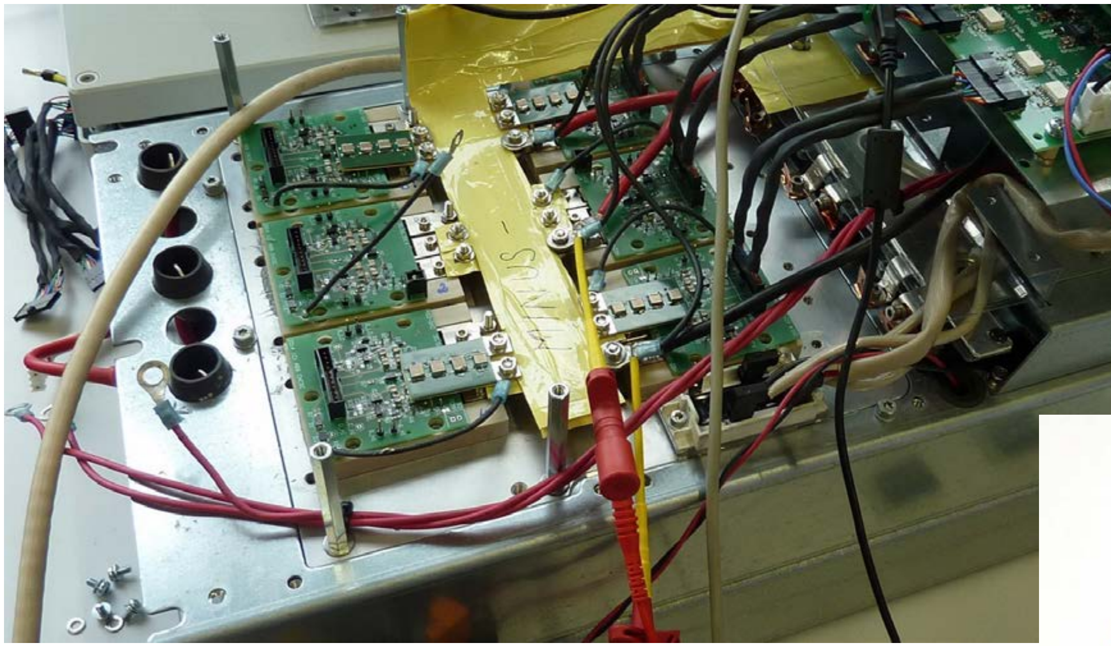
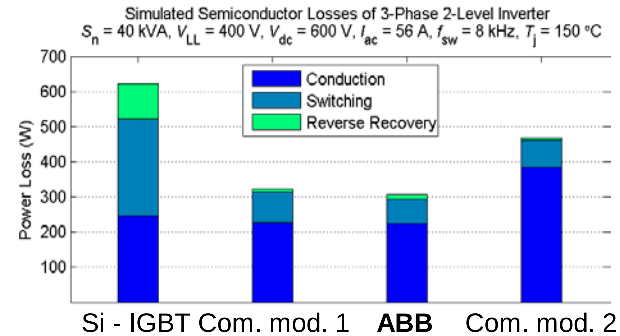
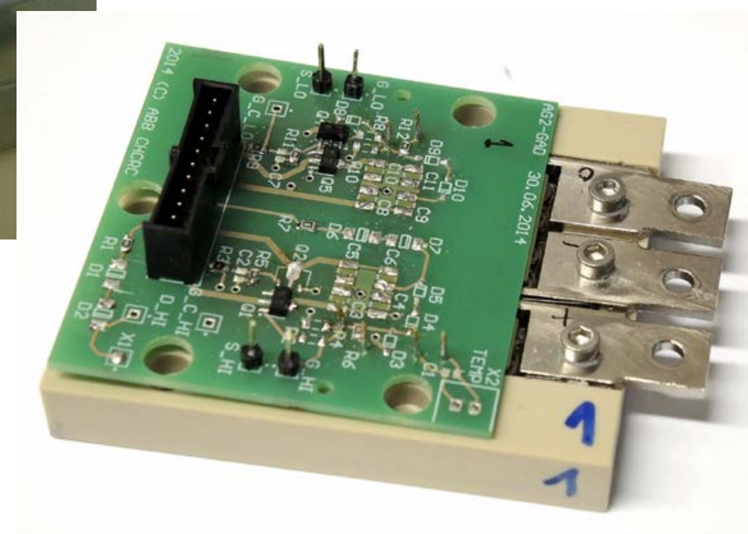
LV Power Conversion
SiC Module in a LV Converter

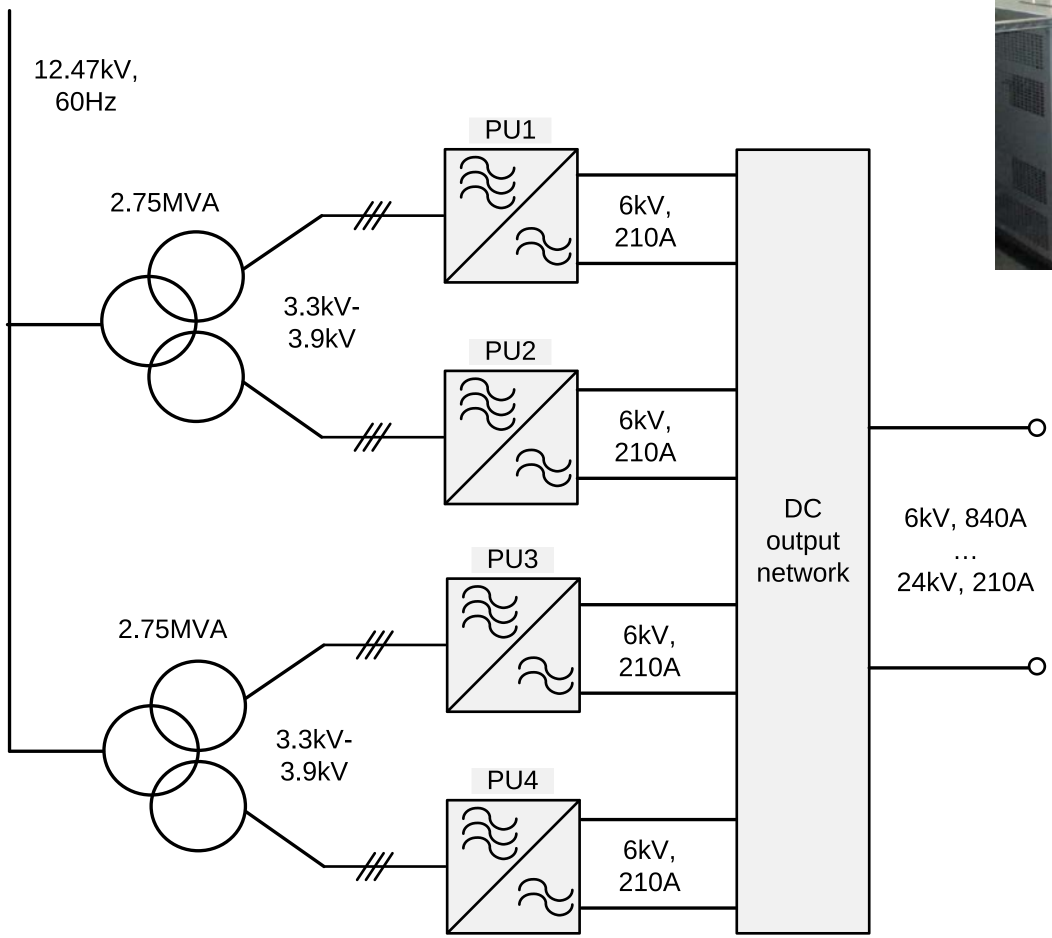






- $L\sigma$ ~ 16nH
- Max gate coupling < 200 pH
- Long-term reliable operation confirming expected performance of the module prototype

MV Power Conversion
MMC Demonstrator

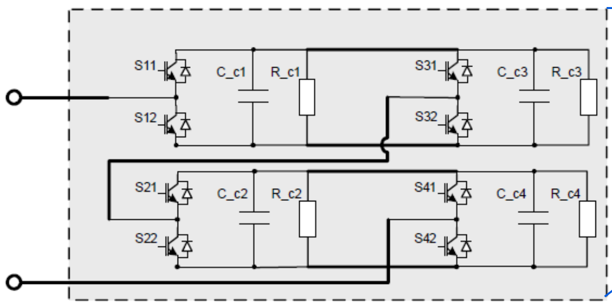


- Four MMC Demonstrator units
  - each rated 6 kVDC
  - 1.25MW
  - connected to 12.47kV, 60Hz grid
  - dc link configurable
    - 6kV, 840A
    - 12kV, 420A
    - 24kV, 210A

Reference: M. Steuer, et al., “Multifunctional Megawatt Scale Medium Voltage DC Test Bed based on Modular Multilevel Converter (MMC) Technologys”, ESARS 2015

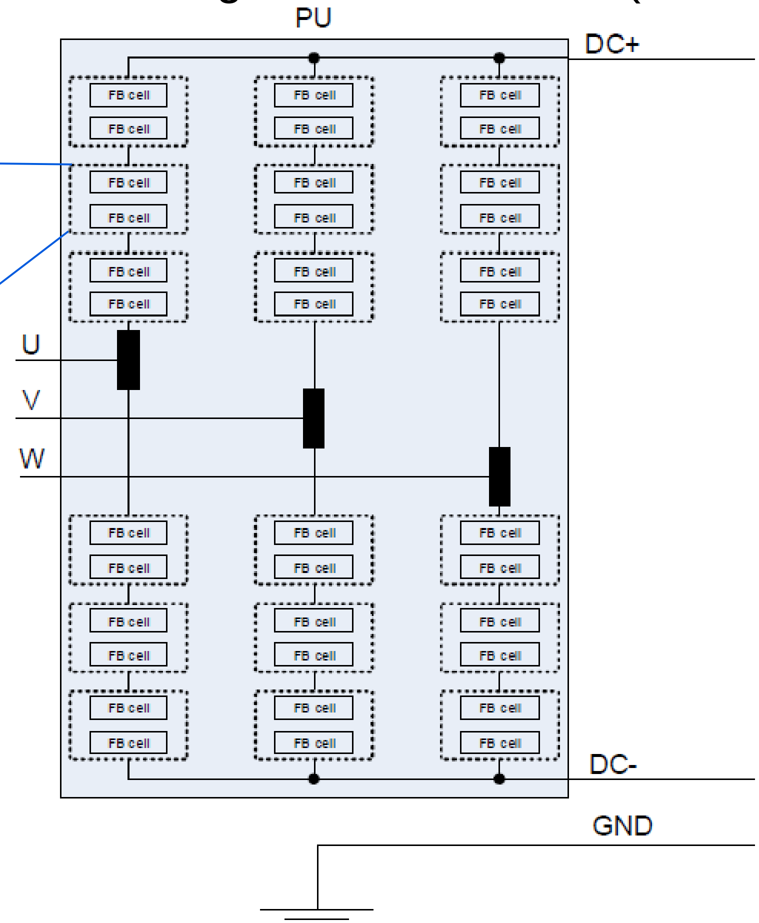
MMC Demonstrator
MMC Converter

- MMC PEBB
  - Power module with two series bipolar cells, based on 1700V, 2 x 300A IGBTs



  - Configurable PEBB (4 unipolar cells)

- Full-bridge MMC converter (18 PEBBs)

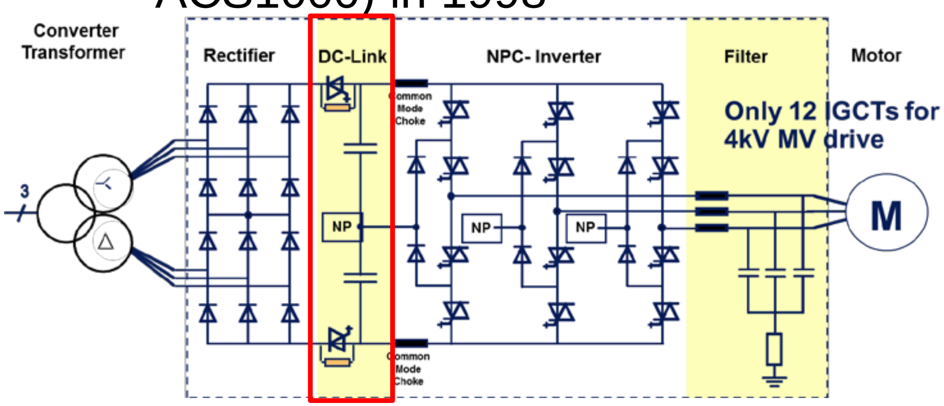


1.25 MW @ 6 kVdc

MVDC Distribution
Solid-State Protection Option

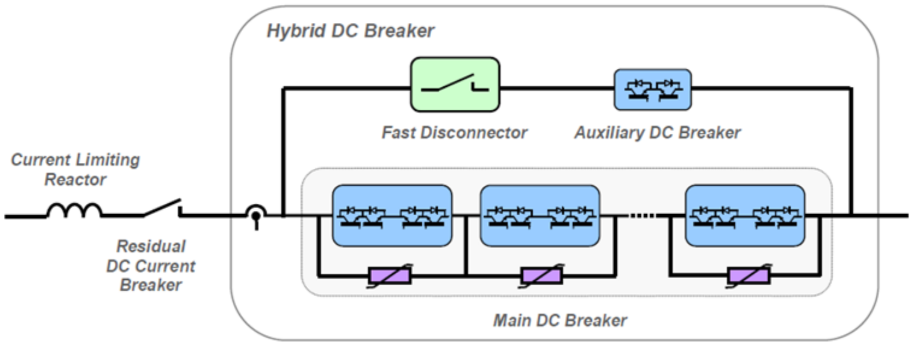
1. Integrated Solid State DC breaker
   - MMC with full bridge cells or equivalent circuits
   - Considerable losses, 1 pu PE

2. Solid state DC breaker
   - As introduced for MV Drives (ABB's ACS1000) in 1998



   - Considerable losses, 0.2 pu PE

3. Hybrid DC breaker



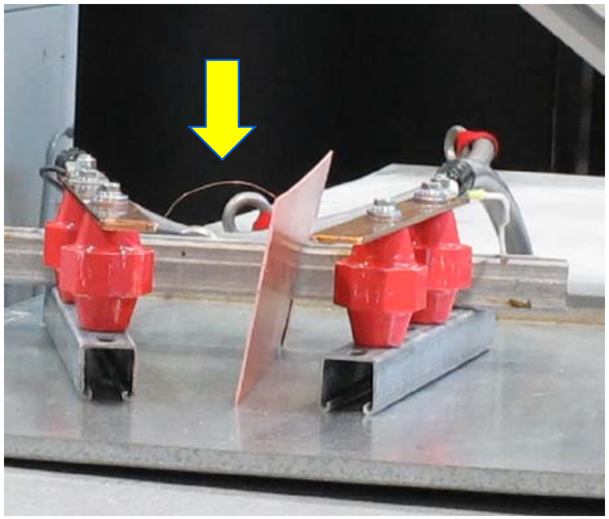
   - Very low losses, 0.2 pu PE
   - Needs fast mechanical disconnector

<u>Conclusion for MVDC</u>

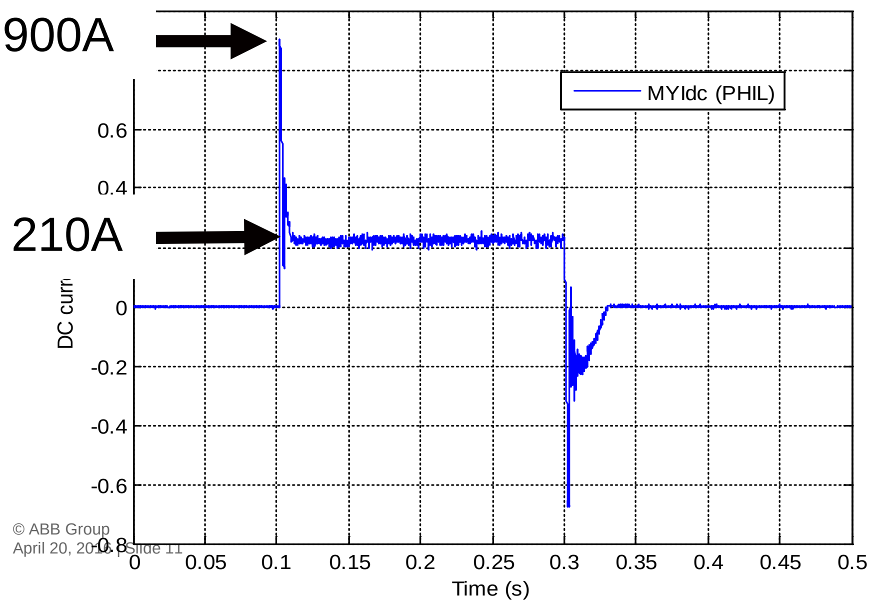
The solid-state breaker is expected to be preferred solution due to

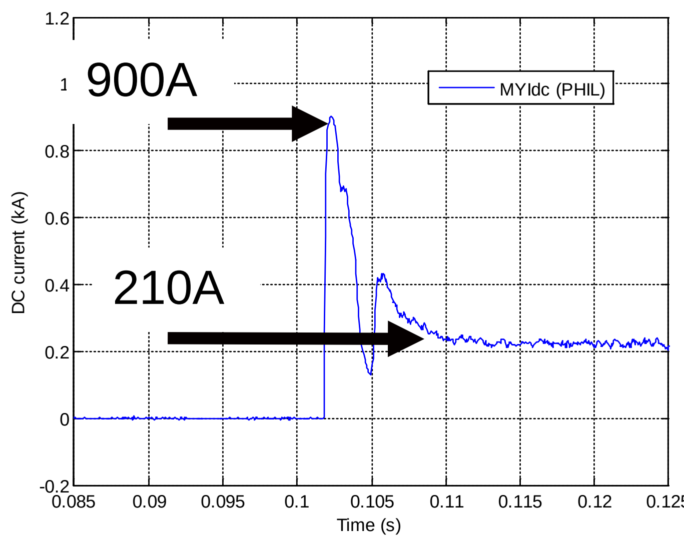
- Lowest PE effort
- Losses of 0.1%
- Si as benchmark

MMC Demonstrator
DC link short-circuit test



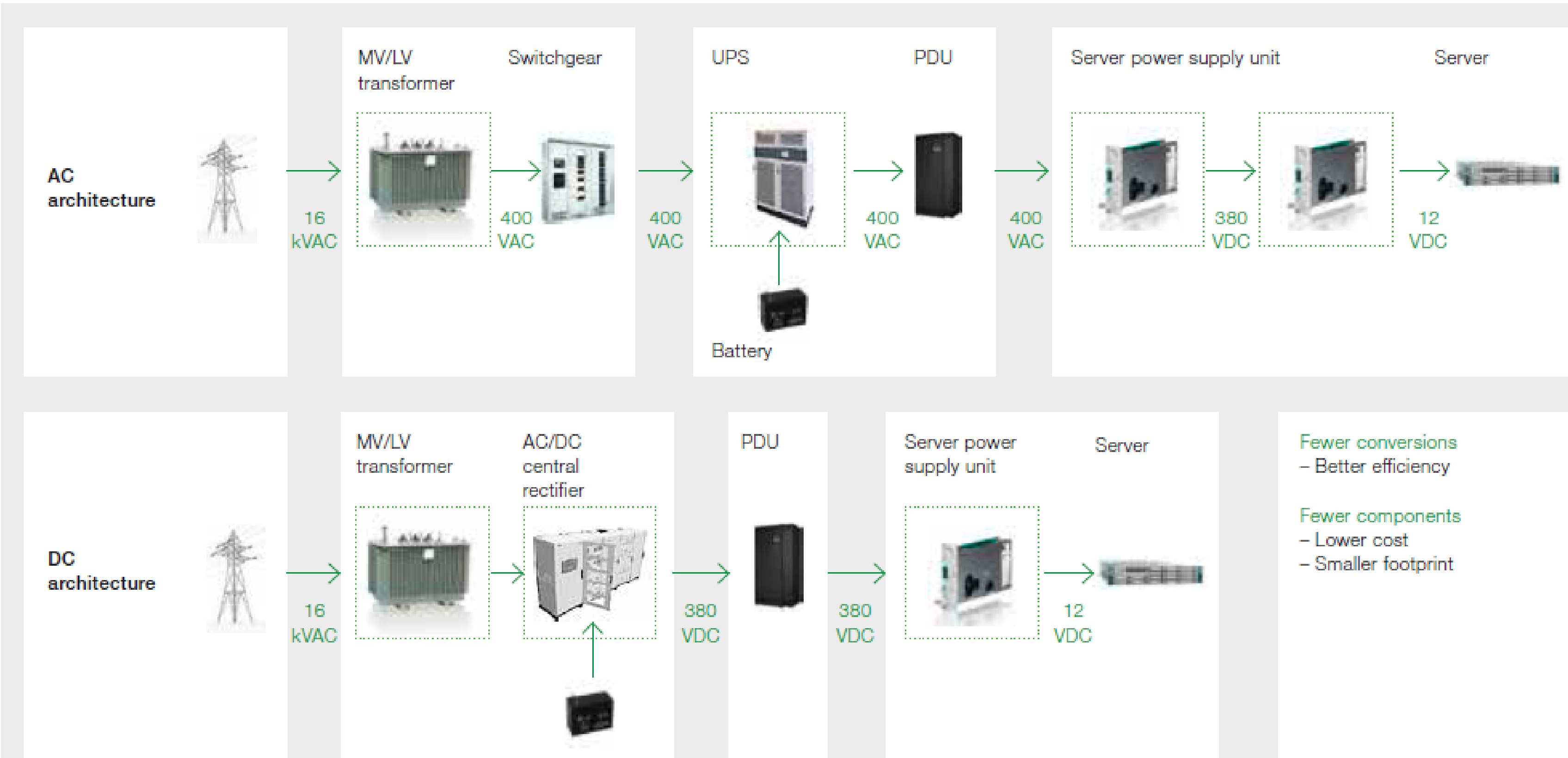
- Logic implemented to step DC voltage from 0 to 5.5kV and back to 0V after 200ms





LVDC Distribution

ABB LV DC pilot project for Green Datacenter

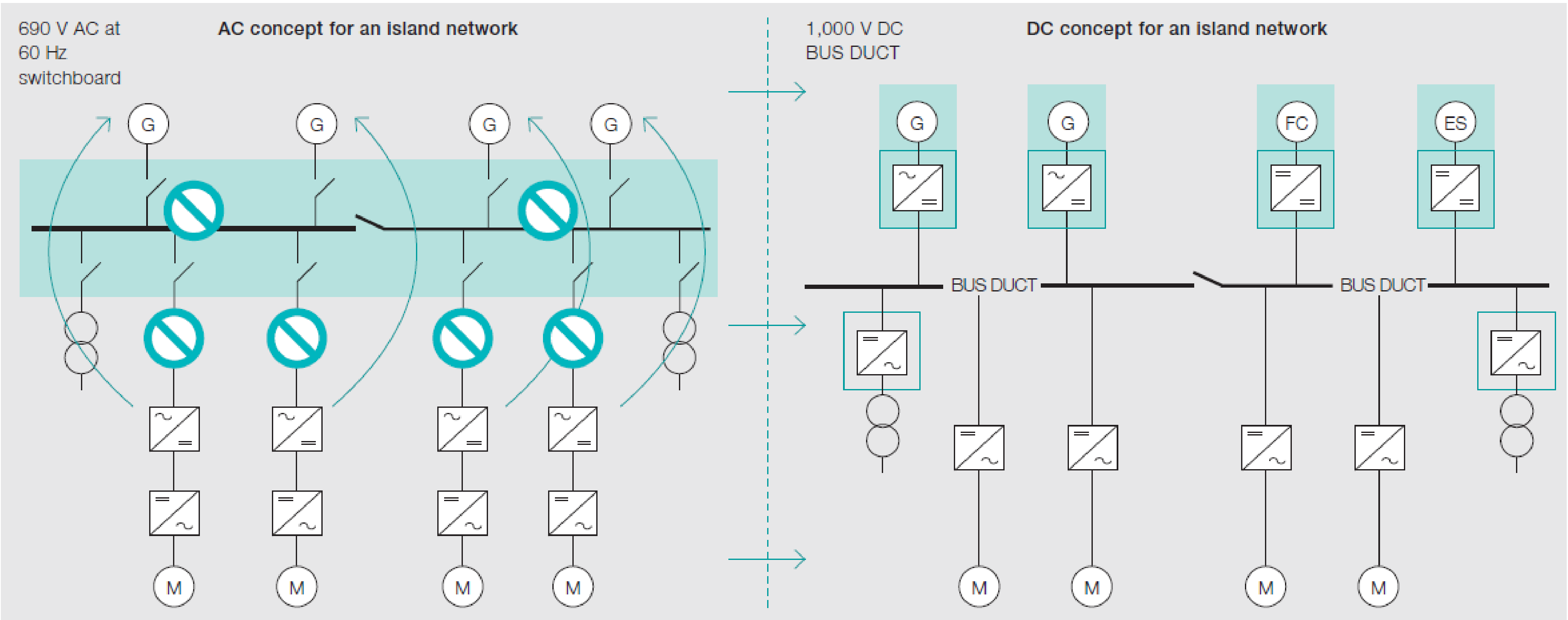


- Efficiency: 10 percent improvement (not counting the reduced need for cooling in the IT room).
- Costs: 15 percent lower costs related to the electrical components for the data center power supply.
- Footprint: 25 percent less space required for the electrical components for the data center power supply.

<u>Higher voltage</u> and <u>DC</u> brings efficiency benefits. Future is MVDC!

LVDC Distribution

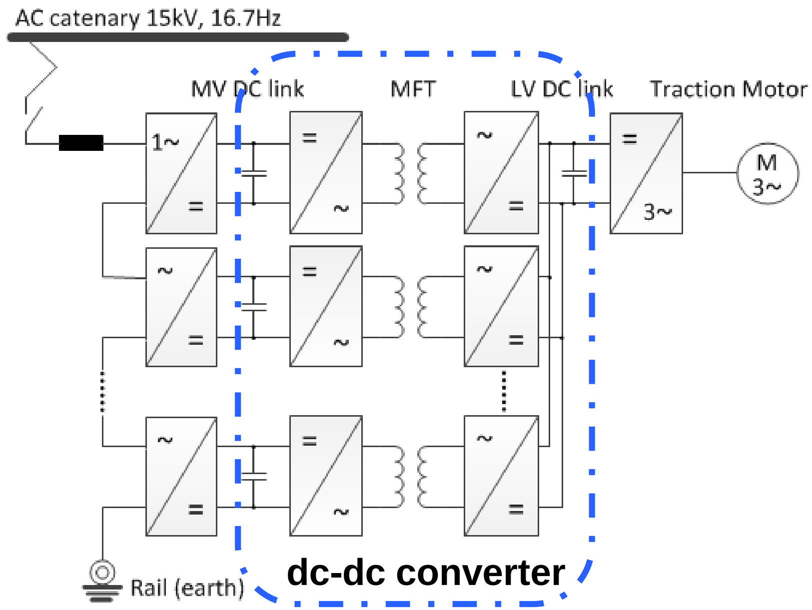
ABB’s On-board DC Grid System



- Efficiency: Up to 20% fuel saving if taking full advantage of all features including energy storage and variable speed engines.
- Footprint: Increased space for payload through lower footprint of electrical plant and more flexible placement of electrical components.
- Service: Reduced maintenance of engines by more efficient operation

<u>Higher voltage </u>and <u>DC</u> brings efficiency benefits. Future is MVDC!

MV DC/DC Power Conversion
1.2 MVA PET Protoype for Field Trial



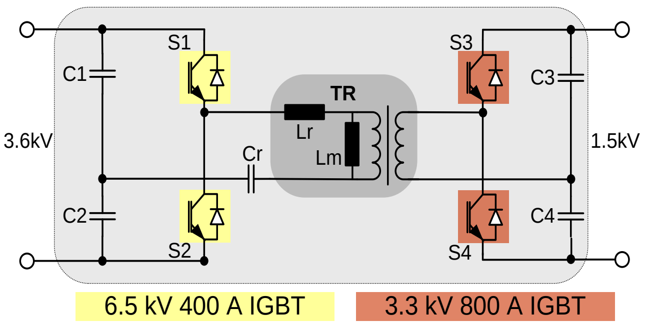
10,000 Km of operation

PETT traction pilot

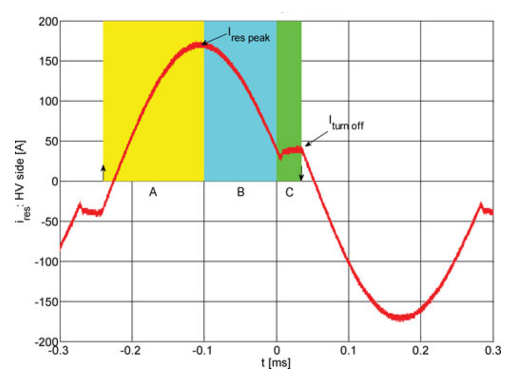
- pilot installation Q1 2012
- MV dc link (3.3kV DC)
- LV dc link (1.5kV DC)
- 1.2MVA
- Resonant operation, fs = 1.8kHz

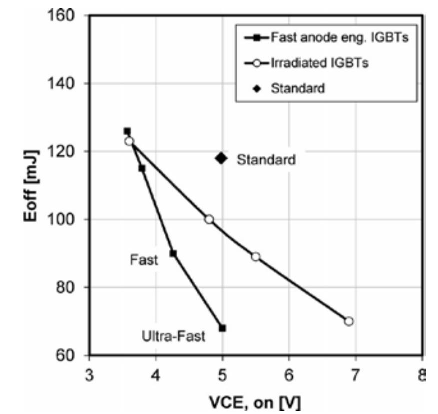
MV DC/DC Power Conversion
Semiconductor Technology – Main Challengers

PE Topologies/Architectures

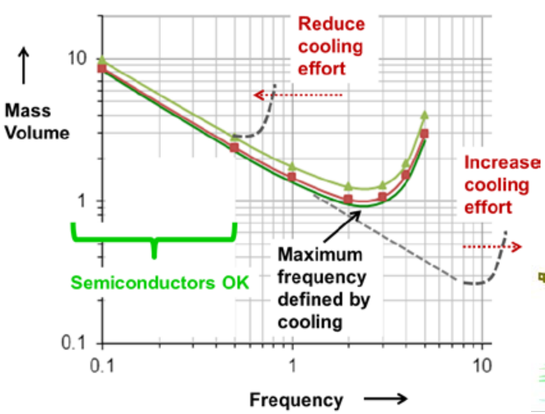


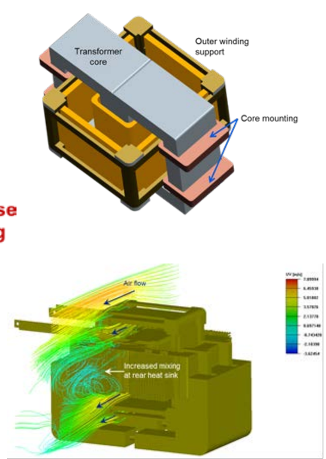
HV Si IGBT Devices – Resonant Operation





High Frequency Transformer





Main Challenges

- High voltage bipolar devices optimal for low frequency operation - < 1KHz
- Despite off soft-switching, turn-off losses still high – limiting switching frequency – 2kHz
- Better trade-off between turn-off and switching losses by anode engineering – but still not optimal Fs – 5kHz
- SiC as enabler for higher frequencies

20 kVdc /1 kVdc isolated DC/DC enabled by SiC needed for MVDC

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MV Power Conversion
Higher Voltage Grid connection

Grid connection options for 4.16 up to 13.8 kVAC:

1. Cell-based converters with 1.7 kV SiC MOSFETs – mainly higher dynamics

4.16 kV	9L	8 x 1 kVdc	1.7 kV Si IGBT → 1.7 kV SiC MOSFET
13.8 kV	25L	24 x 1 kVdc	1.7 kV Si IGBT → 1.7 kV SiC MOSFET

2. Switch-based converters with HV SiC MOSFETs / IGBTs – back to simple topology

4.16 kV	3L	2 x 3.6 kVdc	6.5 kV SiC MOSFET
13.8 kV	3L	2 x 12 kVdc	10 kV SiC MOSFETs, ns=2 20 kV SiC IGBT (as future option)

The game changer is the most simple 13.8 kV grid converter (3L and filtering)

- Higher voltage leads to higher efficiency
- To introduce focus on low currents (i.e. LinPak SiC Module: 20 kV, 2x 85A)

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MV WBG Power Eletronics for Distribution Grids
Outlook

<u>HV WBG Power Semiconductors</u>

- HV unipolar (i.e. 6.5 kV) as 1st step to enable HV and HF power semiconductors
- HV bipolar (i.e. 20 kV) as 2nd step for higher voltages

<u>MV Power Conversion</u>

- HV and HF WBG power semiconductors enable transformerless switch-based 3L MV converters with much higher voltages, i.e. up to 13.8 kVac
- HV and HF WBG power semiconductors enables galvanically isolated MVDC to LVDC power conversion to replace bulky grid transformers (60 Hz)

<u>MV Distribution</u>

- MVDC distribution enables highest efficient Integrated Power Systems (Marine, Renewables, Data centers) and will benefit from the above progress in MV power conversion (higher voltage, PE Xfrms)
- Solid-state breaker as prefered protection element for MVDC

ABB

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