Power Electronics in HVDC

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EC Workshop: Horizon 2050 power system and the role of HVDC technologies in a highly decentralised RES generation (Brussels, 4th of February 2020)

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Summary

- Types of converters of HVDC grids
- The functionality and durability of HVDC Systems are highly dependent of the use of reliable power devices
  - IGBTs devices in HVDC converters
  - potential of Wide Band Gap (WBG) devices for power transmission
- Multi-terminal HVDC system needs Protection
  - HVDC circuit breakers
- Call for advanced control and management.
  - condition and health monitoring towards predictive maintenance
  - further functionalities brought by the future high penetration of PE: flexibility, islanding, grid forming

Mitsubishi Electric LLC, Kii Channel HVDC Link in Japan

Siemens HVDC Plus for the COBRA converter stations.

ABB HVDC Light link Danish and German power grids, Press release | Zurich, Switzerland | 2016-03-10

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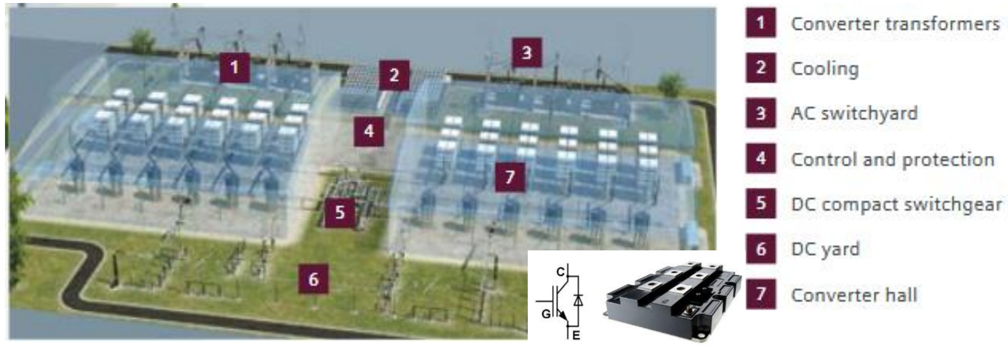
AC/DC Converters for HVDC

AC/DC VSC: Modular Multi-Level Converter (MMC) technology

- Robust and Flexible
  - can operate with weak grid
  - both active and reactive power exchange
  - black start capability
  - no reactive power compensation needed
  - small foot print, large AC filters are not required
- High modularity
  - easy to scale output voltages

- Big effort to produce suitable devices

Siemens HVDC Classic



Siemens HVDC PLUS VSC

ABB StakPAk VCE=4.5kV ;IC=3kA

Mitsubishi Electric X-Series HV IGBTs 4.5kV/1.2kA.

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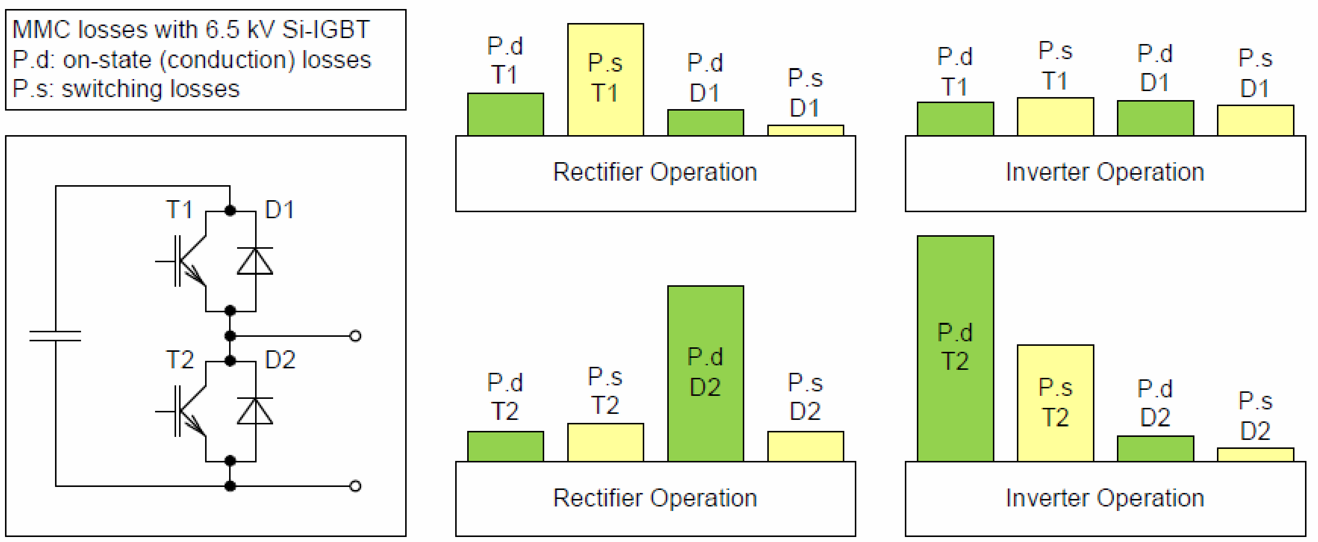
MMC for VSC-HVDC

HVDC MMC equipped with 3.3 kV, 4.5 kV or 6.5 kV Si-IGBTs are the backbone of high power, long distance electrical energy transmission.

- A major design criterion: efficiency
- Low switching frequencies (<300Hz) of the MMC submodules
- Si-IGBT: on-state losses are dominant, but switching losses are not negligible.

Loss distribution in a MMC submodule for HVDC



ECPE Joint Research Programme 2017: VHV SiC IGBTs and Diodes: Potential and Challenges for HV Converters; Prof. Kaminski, University of Bremen and Prof. Eckel, University of Rostock

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SiC-based MMC for HVDC

Mitsubishi Electric: Technology Verification of MMC Cell for HVDC Transmission with SiC 3.3 kV

MMC switches at low f_{sw} and SiC-devices' switching losses are rather small.

To further reduce the losses, SiC MMC f_{sw} increased from 175 Hz to 350Hz.

Result SiC v.s. Si 3.3kV submodule prototype (*)

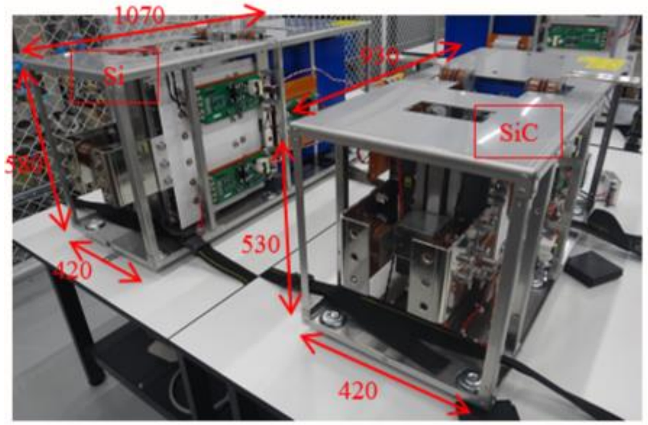
- 50% semiconductor loss reduction -> downsizing the heatsink
- 17% decrease of capacitance of submodules -> downsizing capacitors
- 21% lower volume
- 14% less weight

(*) (3.3kV/1.5kA) SiC-MOSFET/SiC-SBD v.s. Si: CM1500HC-66 R (3.3kV/1.5kA)

SPECIFICATION OF ASSUMED HVDC TRANSMISSION SYSTEM

Capacity	576 MW
DC voltage	±250 KV
AC voltage	380KV, 50Hz

300kVA SiC prototype submodule /Si IGBT



COMPONENT WEIGHT OF CHOPPER CELL

Parts	Weight [kg]		Diff. [kg]	Ratio
	Si	SiC		
Cell capacitor	46.5	39.5	7	84.9%
Bus bar	23.2	19.3	3.9	83.2%
Heatsink	10.0	7.2	2.8	72.0%
Module	9.6	9.2	0.4	95.8%
Others	50.9	45.1	5.8	88.6%
Total	140.2	120.3	19.9	85.8%

Y. Ishii, T. Jimichi, "Verification of SiC based Modular Multilevel Cascade Converter (MMCC) for HVDC Transmission Systems", the 2018 International Power Electronics Conference

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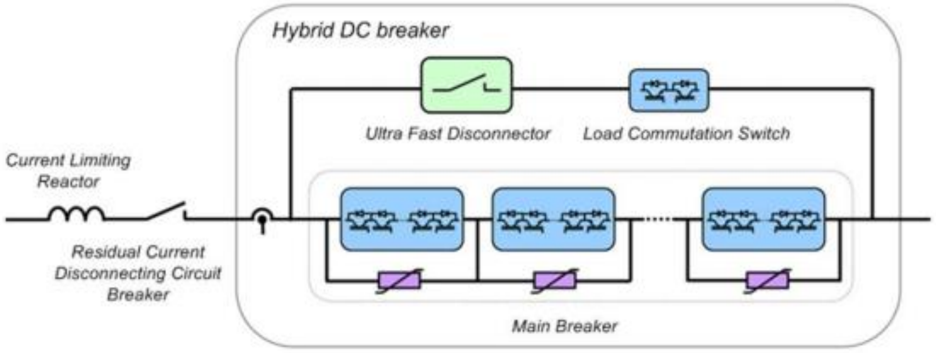
DC grid protection devices

- Selective, fast fault blocking of the DC fault can be realized by:
  - MMC with Full Bridge submodules
  - Electronic or Hybrid DC-Circuit Breakers (DCCB) at the DC-side of the converter

- Criteria for DCCBs: HV, interruption peak fault current (>16 kA), fast fault clearing <8ms, low loss, high temperature operation, robustness



DCCB development with PE:

- GE: Hybrid DC CB using thyristor-based valves
- ABB
  - 2011: Hybrid DCCB, using IGBT-based valves
  - 2015: Hybrid DCCB, using RC-IGBT-based valves (PCIM 2015)

- Implementing WBG semiconductor devices for DC circuit breakers:

  -> SiC would provide lower losses, higher power density to reduce the size and weight

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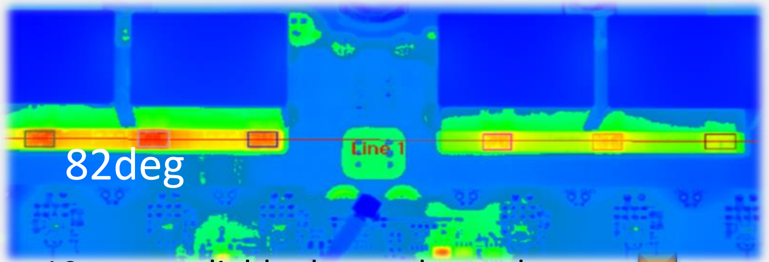
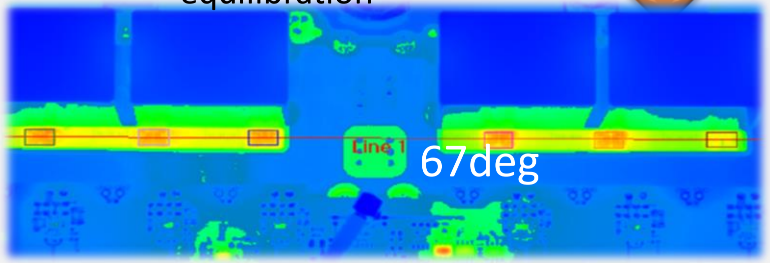
More available, cost-effective PE systems

- Long operation hours under harsh environments.
- Power semiconductor modules are the major failure source in the products (1).
- General objective: to improve the safety, the longevity, and the life-cycle cost of PE devices.



~ 10 more reliable due to thermal equilibration



The enabling technology is (also) **Condition and Health Monitoring** (2) which implies:

- estimate State-of-Health
- estimate End-of-Life
- optimised maintenance actions and possibility for max. usage before failure
- safer handling of severe events
- active stress management

(1) ECPE Joint Research Programme 2016, Investigation of reliability issues in power electronics, P. Zacharias - Uni Kassel, M. Lissere - Uni Kiel
(2) J. Brandelero, J. Ewanchuk, N. Degrenne, S. Mollov, ”Lifetime extension through Tj equalisation by use of intelligent gate driver with multi-chip power module,”

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PE in HVDC: additional functionalities

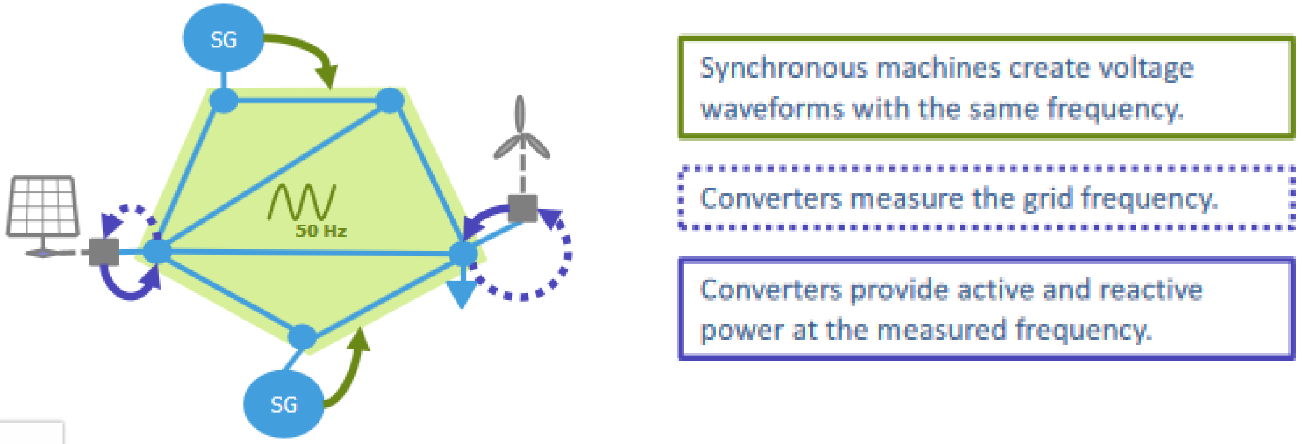
MIGRATE : Massive InteGRATion of Power Electronic device

Horizon 2020

Looking at technically feasible pathway towards stable 100% PE networks

Increasing levels of PE penetration will significantly change the stability and dynamics of a power networks

PE interfaced generators will have to actively take part in power system control



MIGRATE findings :

- a maximum PE penetration of 68 % if we continue installing grid following PE units only
- the maximum PE penetration can be increased with grid forming control

Massive PE penetration can improve grid reliability, providing city in-feeds and powering islands

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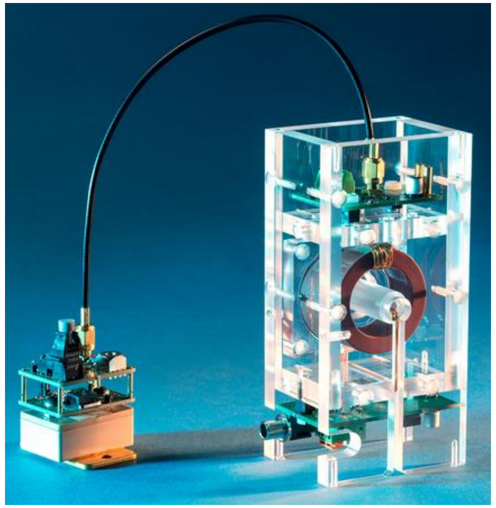
Opportunities

Evolution in HVDC regarding PE

- Device evolution in advanced packaging solutions: reliability, HV
  - SiC is starting to replace Si devices – will it propagate to HVDC?
  - SiC devices: significant research effort to push it to HV & power applications (reliability, reducing conduction losses, cost)
- Advancement in control and management:
  - stability issues need to be addressed
  - new control functions enabled: grid forming for city infeed, islanding
- Condition Monitoring and Prognostics
  - for an efficient predictive maintenance of components / cells
  - more efficient & available service



15 kV SiC MOSFET with mounted gate driver and galvanically isolated supply.

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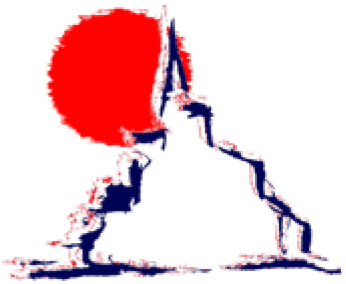
Changes for the Better

Thank you for your attention



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