Power Electronics - Key Enabling Technology for a CO_2 Neutral Energy Supply Linking HVDC and MVDC Grids

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BMBF FEN Research Campus, ISEA and PGS|EONERC of RWTH Aachen University







EU Horizon 2050 – HVDC Workshop

Brussels, February 4, 2020

Overview

- Introduction - Driving Innovation at R&D at RWTH Aachen Research CAMPUS Flexible Electrical Networks (FEN Consortium)
- Electrical Grids for a CO_2 Neutral Energy Supply System
- Multi-terminal HVDC Transmission and MVDC Distribution grids
- Solutions to link HVDC and MVDC – Intelligent DC Substation
- Why we should urgently demonstrate Intelligent DC Substations

Flexible Electrical Networks (FEN) Research Campus

Academia and Industry work together under one roof to accelerate innovation

Forschungscampus
Flexible Elektrische Netze FEN

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
Fuji Electric
hager
HITACHI Inspire the Next
thyssenkrupp
MITSUBISHI ELECTRIC

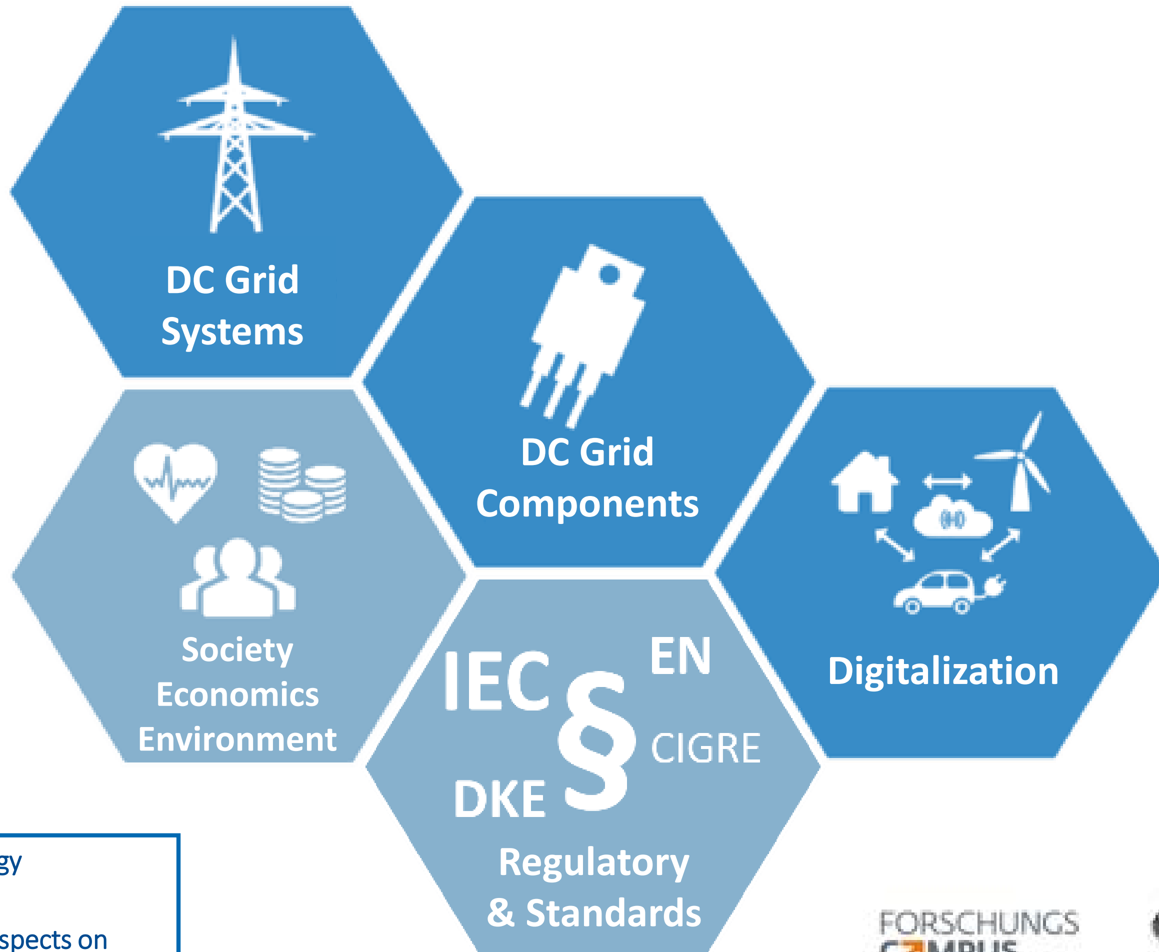
ACS | FCN | PGS | EBC | GGE – E.ON Energy Research Center
IAEW Institute of Power Systems and Power Economics
IAW Institute of Industrial Engineering and Ergonomics
IFHT Institute for High Voltage Technology
ISEA Power Electronics and Electrical Drives
RWTH AACHEN UNIVERSITY

UNIKLINIK RWTH AACHEN Institute of Occupational Medicine
städtebau
Institute of Landscape Architecture
Textlinguistics & Technical Communication
HCIC - Human-Computer Interaction Center
humtec
RWTH AACHEN UNIVERSITY

Status: Oktober 2019

Flexible Electrical Networks (FEN) Research Campus

Research Divisions focus on DC Grids, Planning, Automation, Acceptance and Standards



Research on energy technology

Interdisciplinary aspects on energy research

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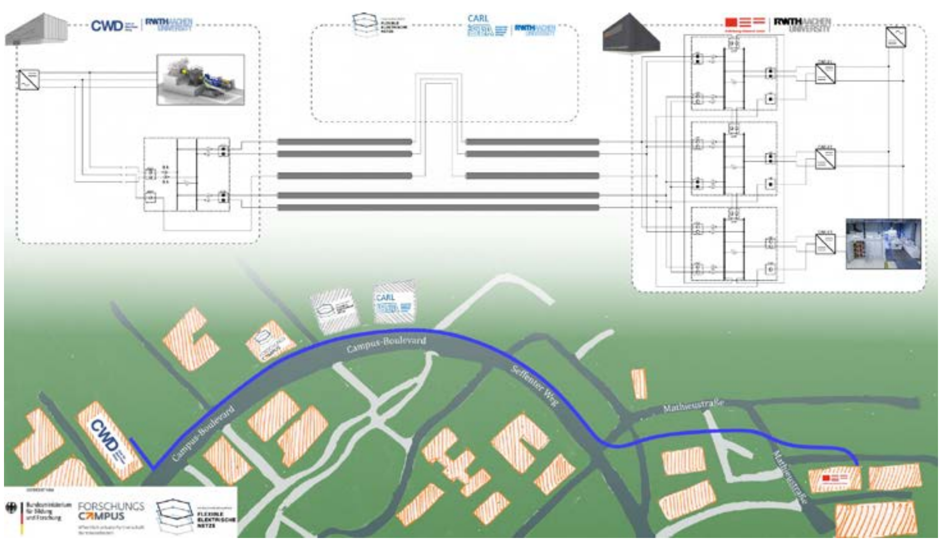
FEN-MVDC-Research Grid at RWTH Campus Melaten

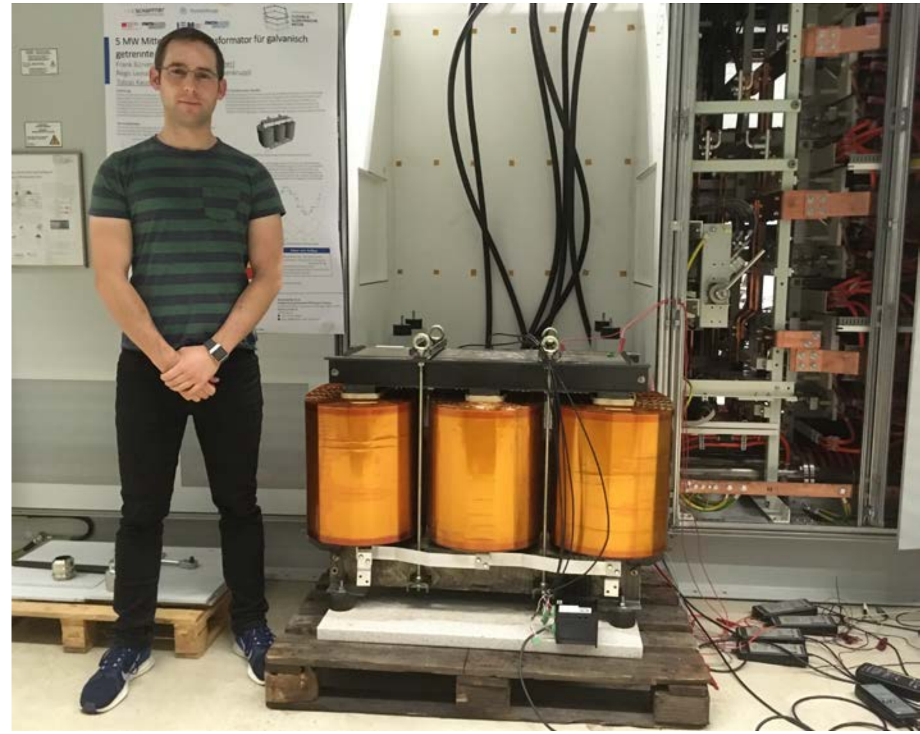
Taking in operation the 5 kV/3 MW MVDC Grid on 19.11.2019



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)



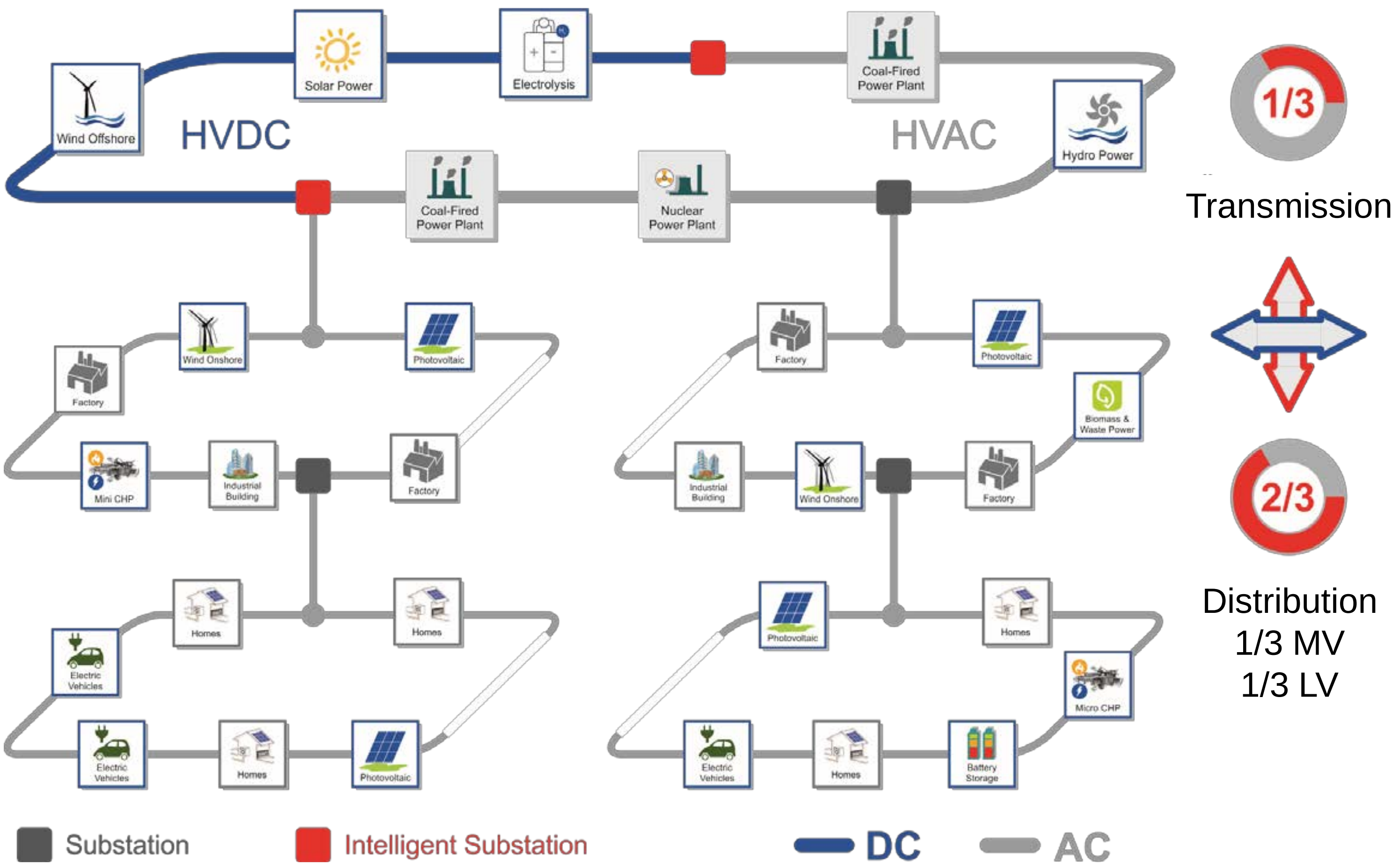
5,0 MVA, 1.000 Hz Transformator
675 kg (0,14 kg/kVA)

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

Bottleneck of electrical supply in AC grids

Increased REN, decentralized power generation and sector coupling leads to the „1/3 Rule“



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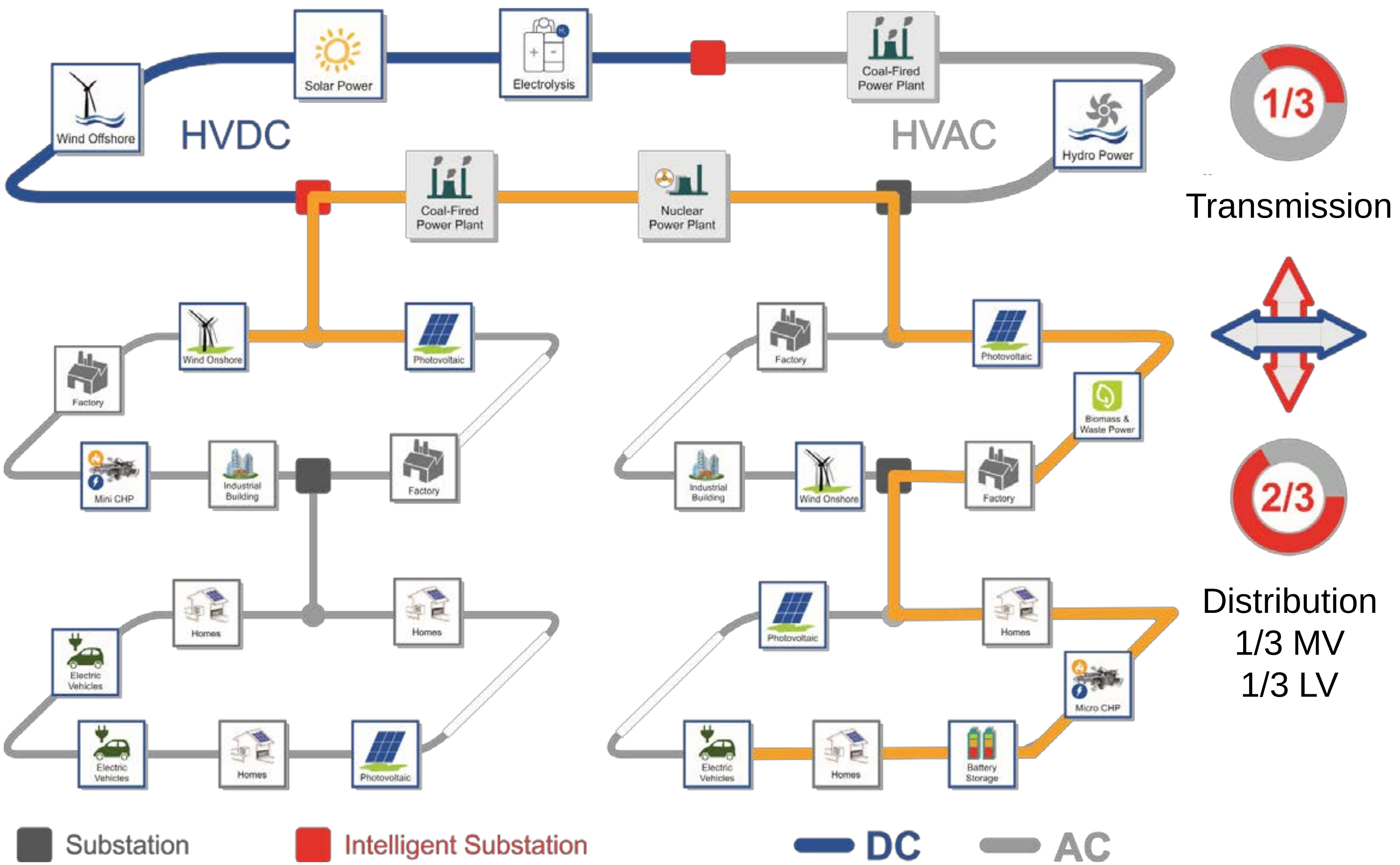
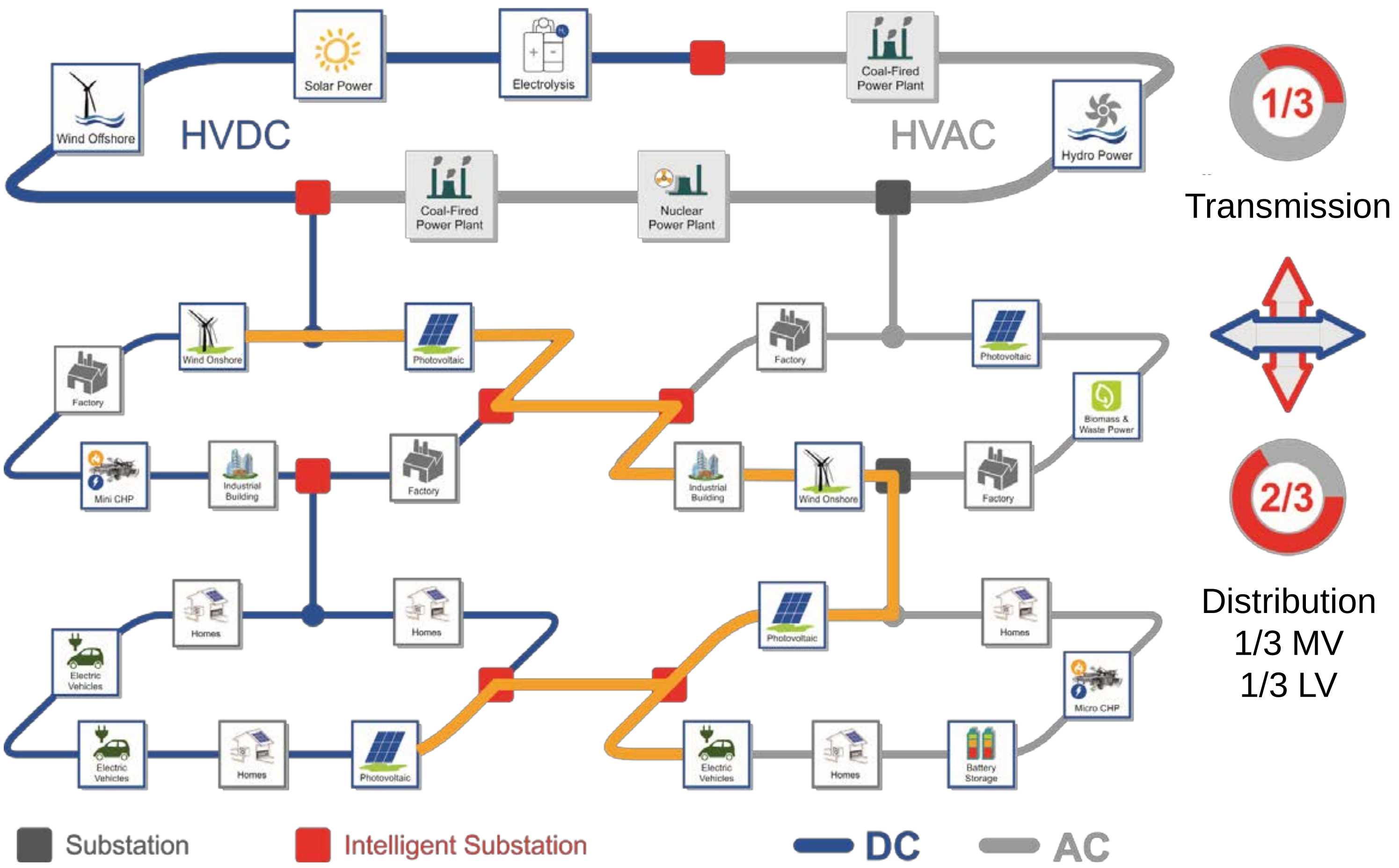
Bottleneck of electrical supply in AC grids

DSO sees long paths to redistribute energy and REN overload locally transmission system



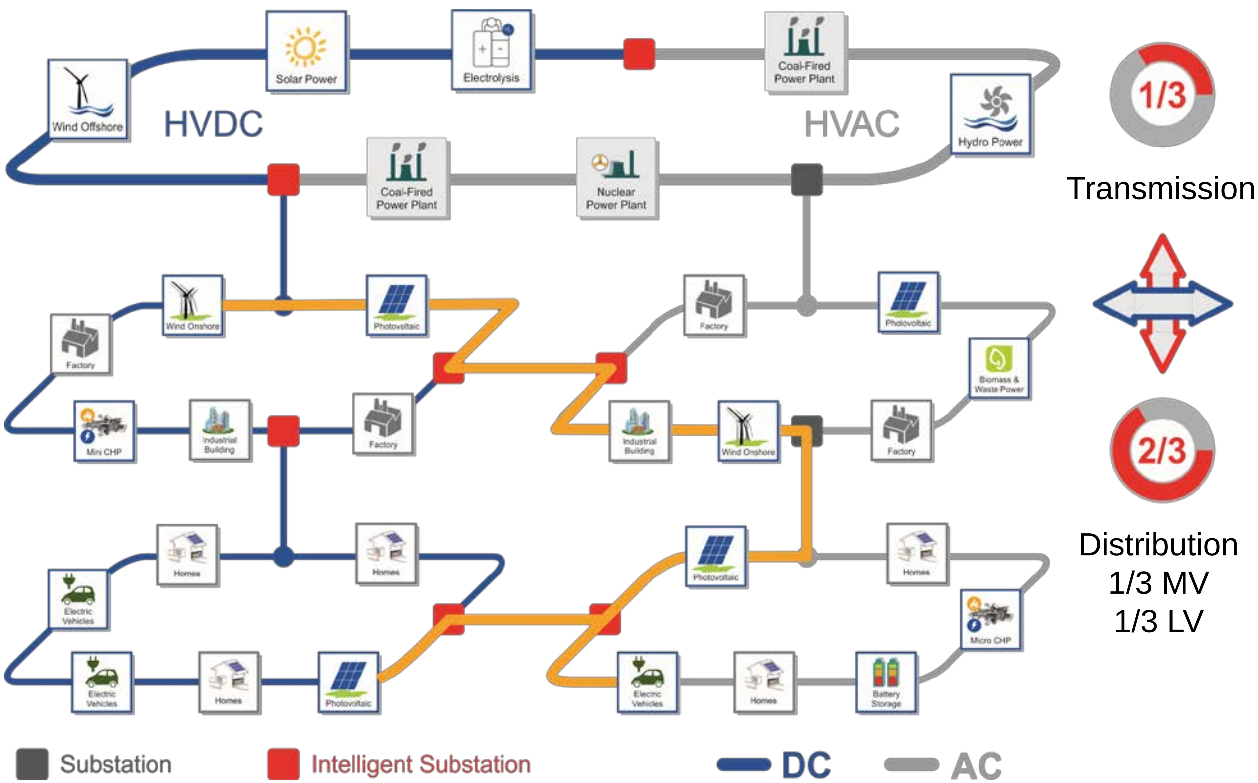
Bottleneck of electrical supply

MVDC and LVDC interconnections avoid bottlenecks & provide higher efficiency and flexibility



Bottleneck of electrical supply

Compared to classical AC grids, HVDC and MVDC grids are more

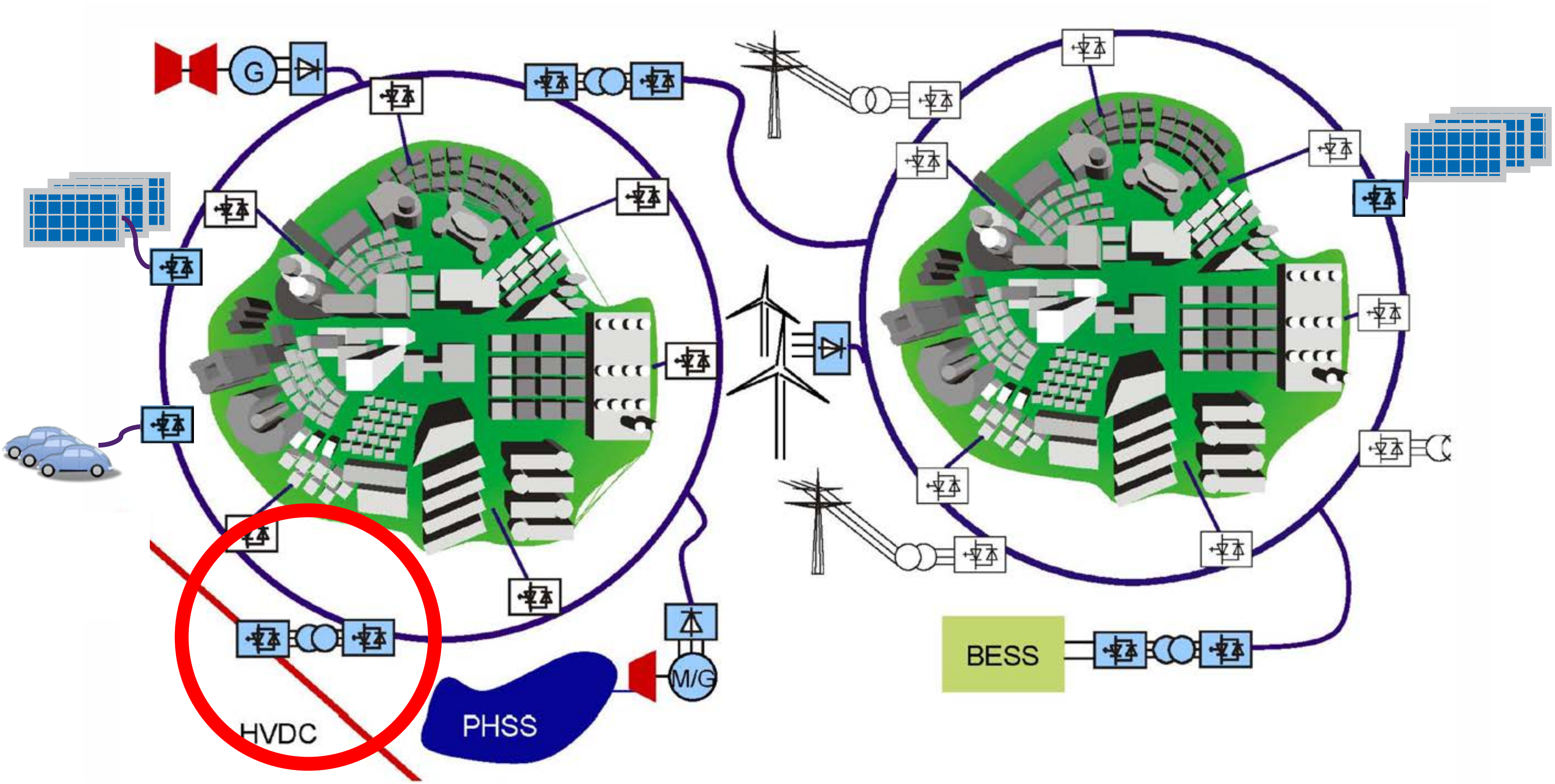


1. **Reliable**
2. **Efficient**
3. **Cost effective**
4. **Material savings**

Power Electronic DC Solid State Transformers are key enabling components to realize the next generation grids

Flexible Grids for Decentralized Power Generation

Cellular Grid Topologies, Sector coupling and HVDC/MVDC Intelligent Substations

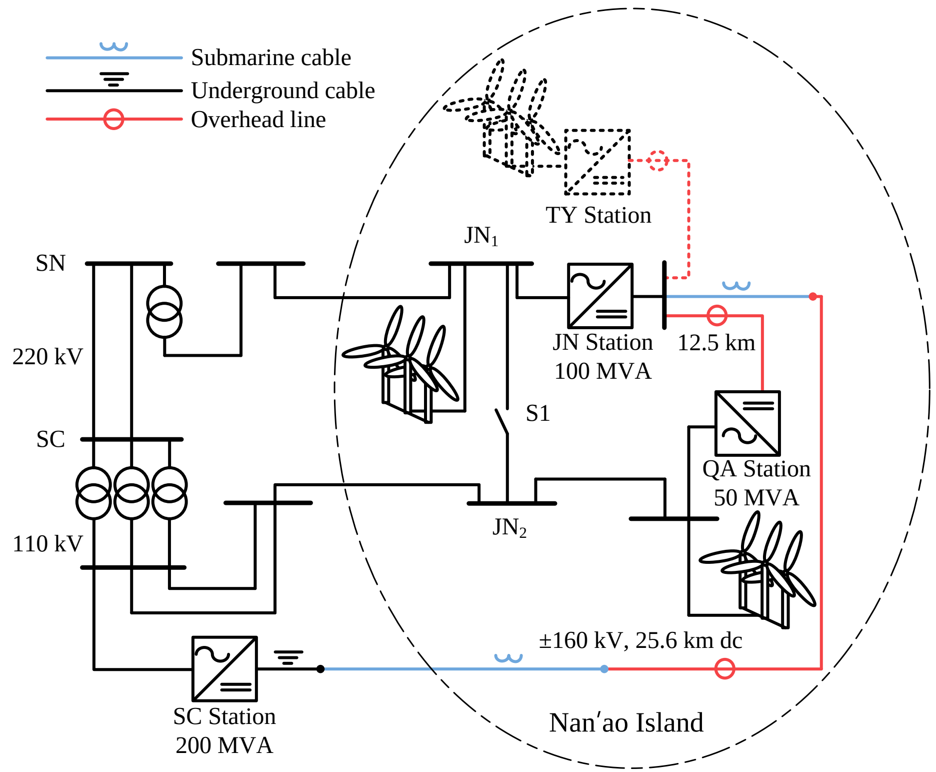


Multi-terminal HVDC Grid demonstrated in China

DC Transmission for far distance large scale power plants (example Nan'ao China)

Large central power plants and large scale wind & PV farms

- Integrated into the transmission grid
- HVDC multi-terminal transmission grid
  - Higher efficiency (partial load)
  - Higher flexibility



±160 kV Four-terminal HVDC grid in Nan'ao, China in operation since 2013

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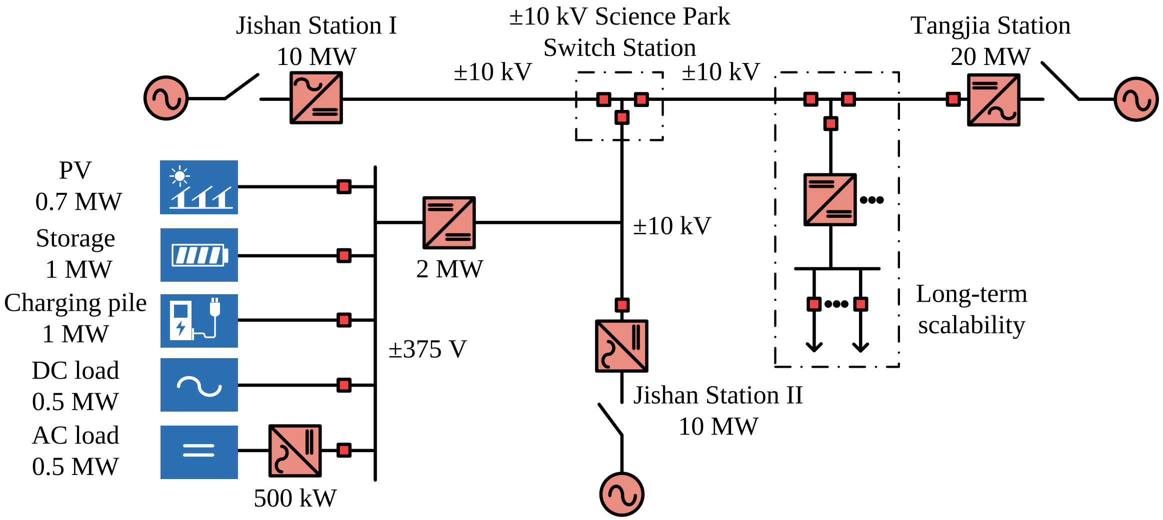
MVDC Multi-terminal Distribution Grid in operation in China

DC Distribution for small-scale distributed power plants, REN, prosumers and sector coupling

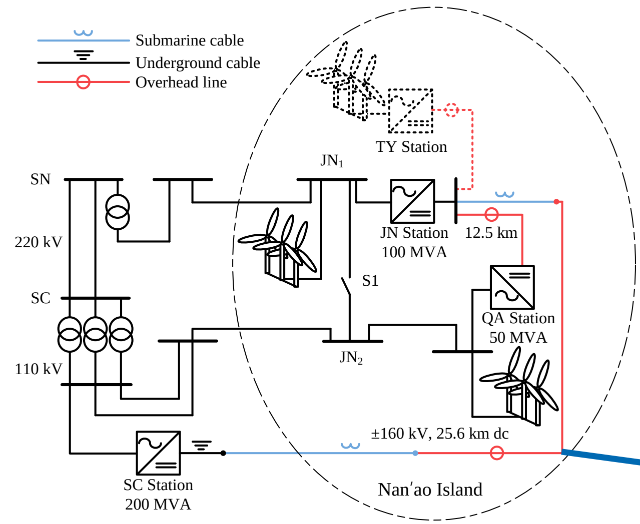
- Decentralized renewable generations
  - Integrated into the distribution grid
  - MVDC distribution grids
    - Higher efficiency
    - Simpler grid integration
    - Interoperability between renewable energy sources and storage systems, (all in DC)

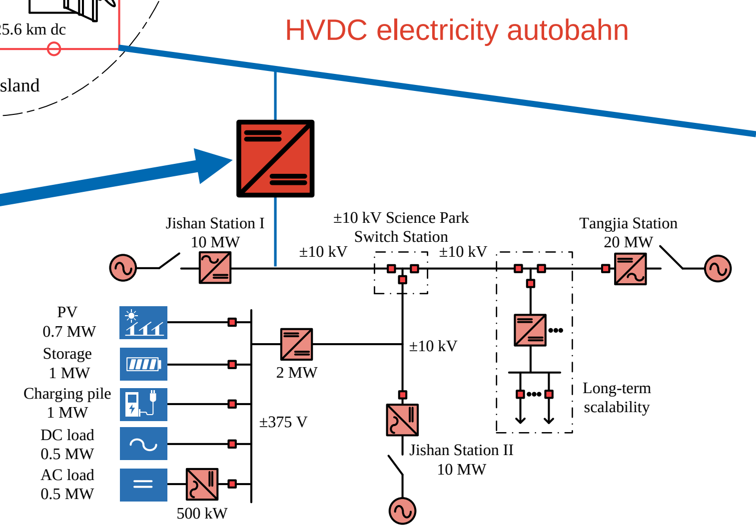


±10 kV MVDC distribution grid in Zhuhai, China in operation since 2018

Intelligent Substations – Missing Link

DC Converter Technology needed to link HVDC Transmission with MVDC Distribution



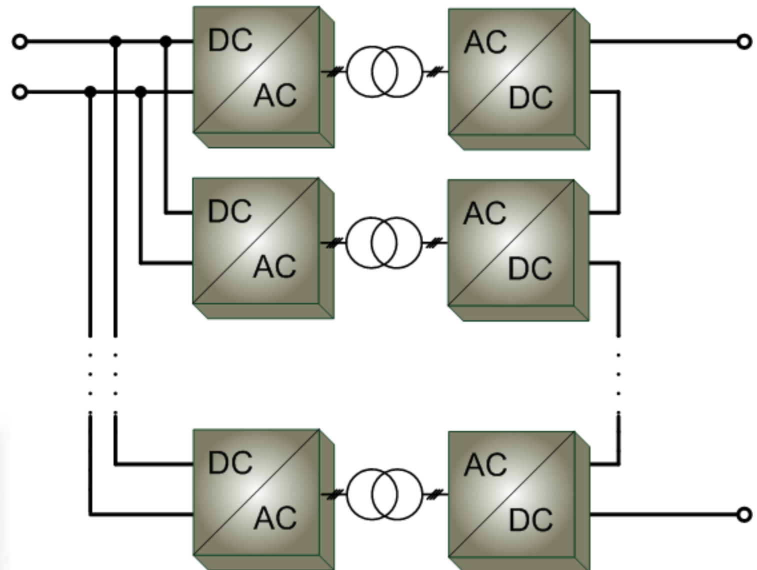


- DC Intelligent Substations using DC solid state transformers
  - Avoids 50 Hz transformers
  - Flexible power flow control
  - Dynamically stable
  - Higher efficiency
  - Less utilization of space and materials
  - Lower cost

Intelligent Substations – Dual Active Bridge DC-DC Converter

Promising but series connection for HVDC above 100 kV is transformer insulation challenge

- P = 7 MW, VDC = 5 kV ±10 %
- Efficiency up to 99.2 %
- Ultimately air-cooled devices are an option
- DC substation at 1/3 weight of 50 Hz transformer



Picture: EONERC: ABB IGCT Stack

R. Lenke, „A Contribution to the Design of Isolated DC-DC Converters for Utility Applications“, Diss. RWTH Aachen University, E.ON ERC, 2012

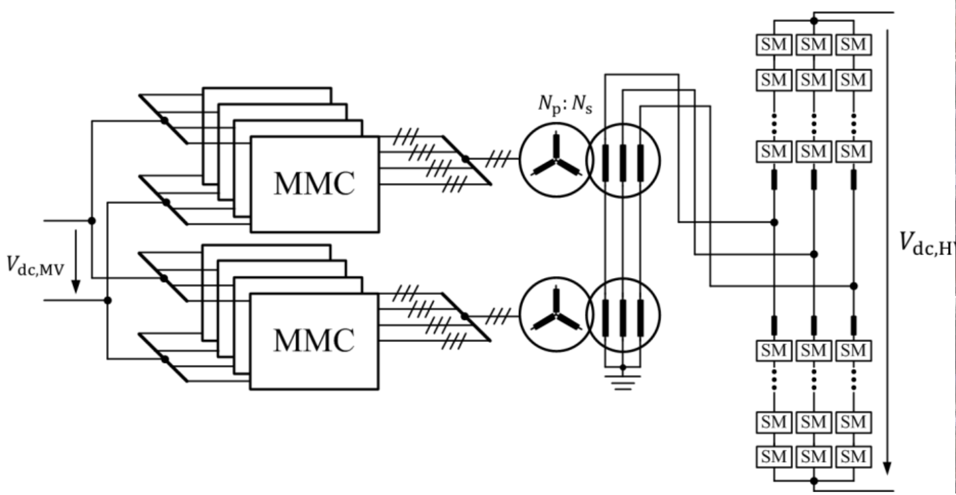
N. Soltau, „High-power medium-voltage DC-DC converters : design, control and demonstration”, Diss., RWTH Aachen University, E.ON ERC, 2017

Intelligent Substations – Multi-level Modular Converter

Back-to-back with isolation is a major challenge in capacitor costs

	MMC-FTF Converter (Conventional)
Converter on HV side	Identical
Semiconductors on the HV side	2400× 4.5 kV, 1.2 kA IGBTs
Number of converters on MV side	8
Semiconductors on the MV side	**2400**× 4.5 kV, 1.2 kA IGBTs
Capacitive energy on the MV side	3.28 MJ

Large volume of capacitors



Picture: Siemens; HVDC PLUS –the decisive step ahead Stabilized power flows improve transmission grid performance, Article No. EMTS-B10016-00-7600

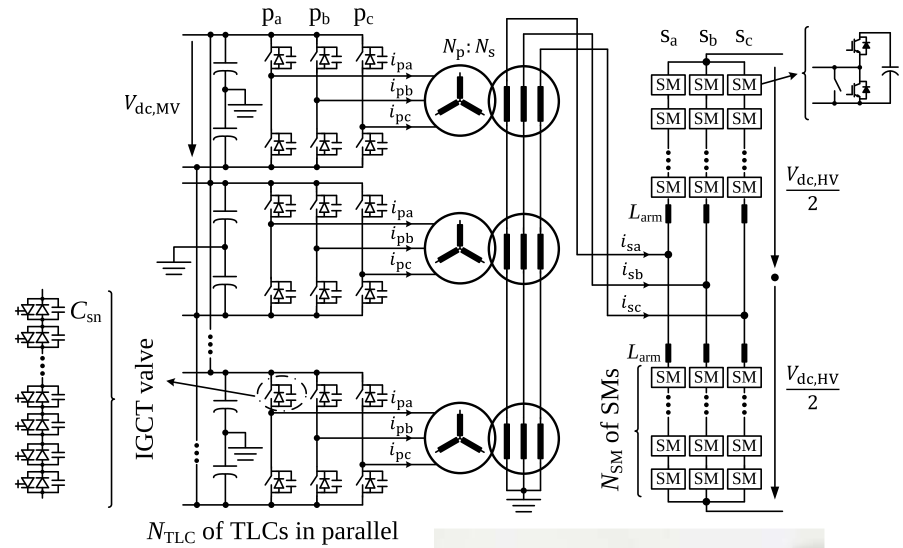
DC Substation based on TLC-MMC Dual Active Bridge Converter

Solution based on existing proven power electronic building blocks

- HV side – Multi-level Modular lConverter (MMC) uses compact IGBT stacks
  - provides reactive power for ZVS of MV side
  - Medium frequency (200 – 400 Hz) significantly reduces amount of capacitors

- MV side – Standard Two-Level Converters (TLCs) in parallel
  - Less amount of devices
  - Smaller dc-link capacitors
  - Series connection of IGCTs
    - Directly reach MV-side dc-link voltage
    - Snubber capacitors in parallel for ZVS

- Medium Frequency Transformer (200 – 400 Hz)
  - Secondary sides are connected in series
  - Proven technology in first generation STATCOMs



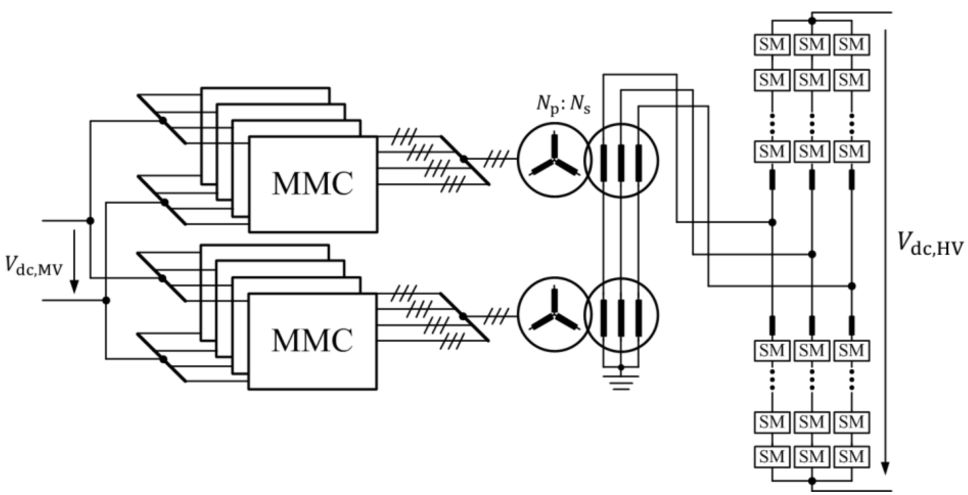
Source: Series connection of MV IGBTs, *Source*: ABB

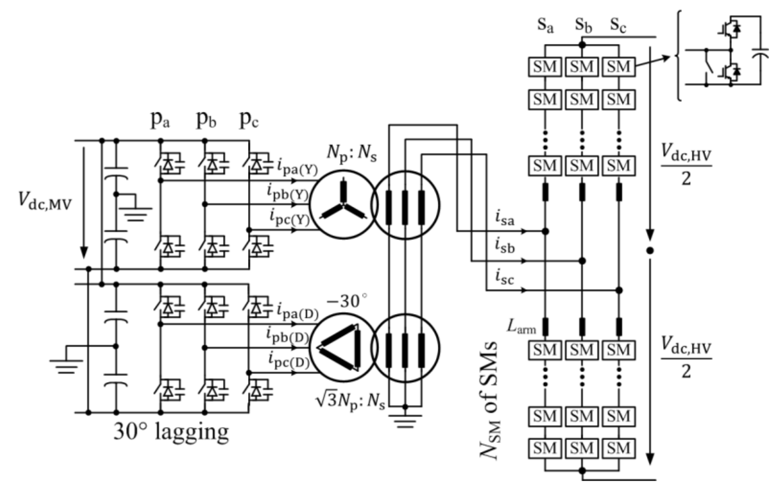
Access dissertation Shengui Cui via -
URL: http://publications.rwth-aachen.de/record/762795

Comparison MMC versus TLC-MMC Dual Active Bridge

State-of-the-Art Solution - ±25 kV / ±200 kV, 400 MW System

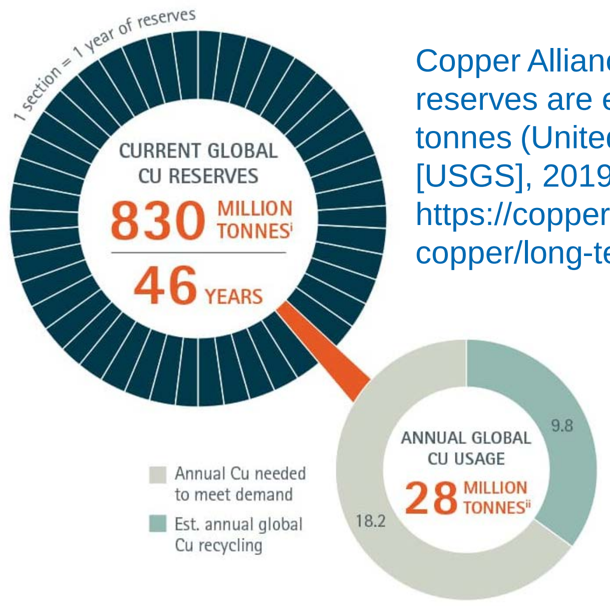
	MMC-FTF Converter (Conventional)	TLC-MMC Converter (Proposed)
Converter on HV side	Identical	Identical
Semiconductors on the HV side	2400× 4.5 kV, 1.2 kA IGBTs	2400× 4.5 kV, 1.2 kA IGBTs
Number of converters on MV side	8	2
Semiconductors on the MV side	**2400**× 4.5 kV, 1.2 kA IGBTs	**300**× 4.5 kV, 1.4 kA IGCTs
Capacitive energy on the MV side	3.28 MJ	**49 kJ (1.5 % of the conv.)**





Urgency to develop/demonstrate DC Intelligent Substations

- Saving material resources using PEL and higher frequencies in DC solid state transformers is needed to reach climate goals
  - Recycling
  - New technologies



Copper Alliance,based on Global copper reserves are estimated at 830 million tonnes (United States Geological Survey [USGS], 2019) https://copperalliance.org/about-copper/long-term-availability/

- EU leading companies are selling key technologies as transition is too slow
- Electrification of developing countries must be our goal for geopolitical stability
- China State Grid is deploying soon this technology and is considering a “Electrical Silk Route” of > +/- 1 MV. Do we need to worry about dependency both on electricity (China) and gas (Russia)?

IEEE eGRID Workshop, Aachen, Nov. 2-4, 2020

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Conference Deadlines

Deadlines for abstract submissions
— July 3, 2020

Notification of acceptance
— August 14, 2020

Deadline for final manuscripts
— September 25, 2020

Early Bird Regristation
— September 25, 2020

eGrid2020

For more detailed information on what to expect from the workshop, paper submissions and registration, please visit the website **www.egrid2020.org**, which will be accessible soon.

Organizers

E.ON Energy Research Center | RWTH AACHEN UNIVERSITY

E.ON Energy Research Center at RWTH Aachen University

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Flexible Electrical Networks (FEN) Research Campus

Contact

info@egrid2020.org will be activated in June 2019.
You can also contact the organizers:

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Sascha Falkner
Public relations
Flexible Electrical Networks (FEN) Research Campus
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eGrid2020

November 2-4, 2020
Eurogress, Aachen

5th IEEE Workshop on the Electronic Grid 2020

More information and regristation: **www.egrid2020.org**

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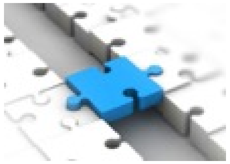


Thank you for your attention

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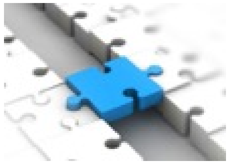
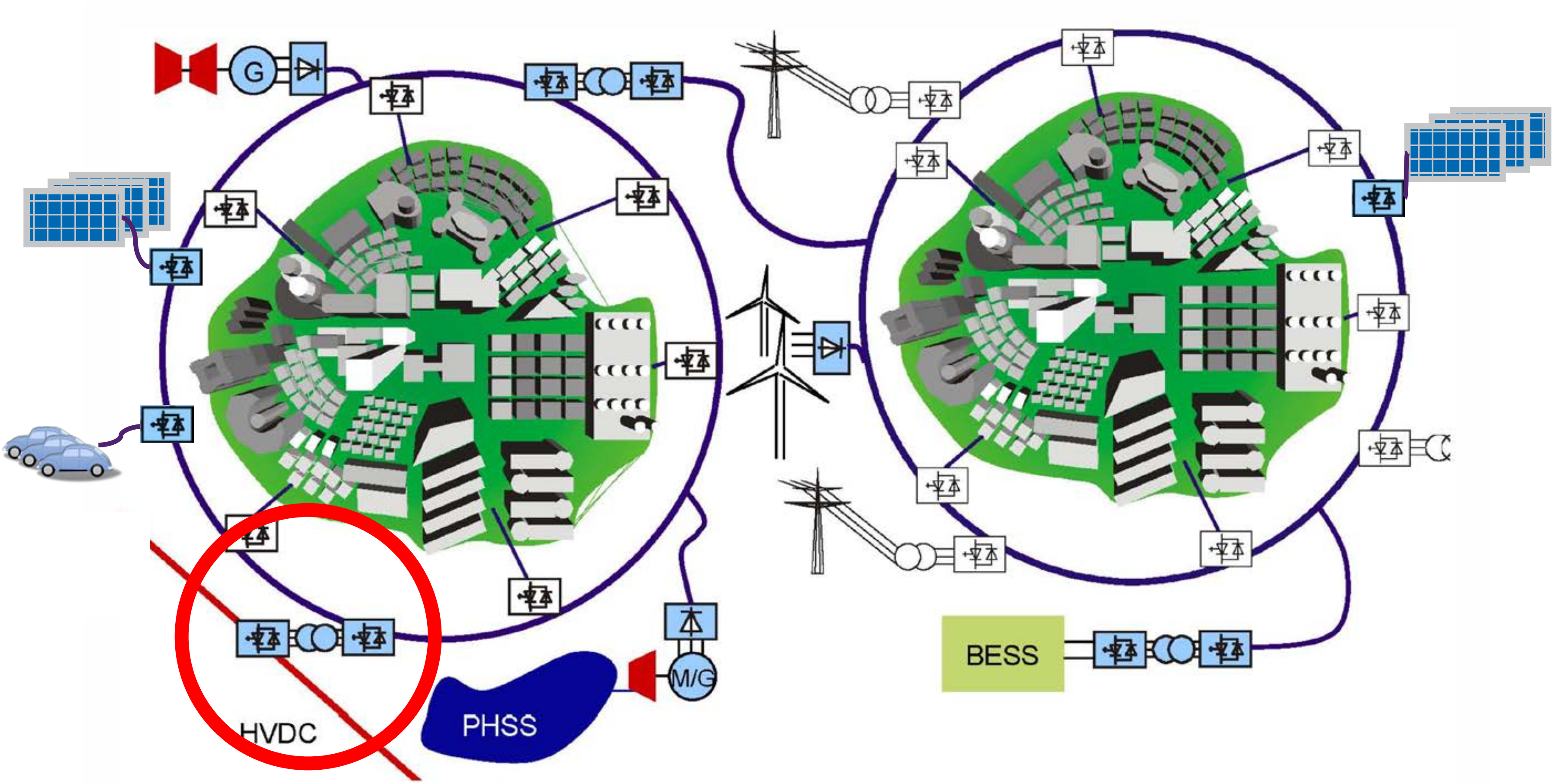


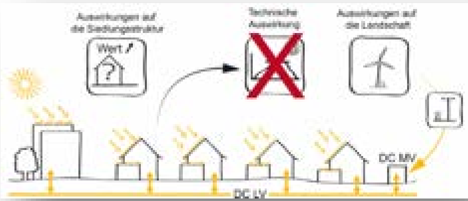

Panel Notes

Flexible Grids for Decentralized Power Generation
Cellular Grid Topologies, Sector coupling and HVDC/MVDC Intelligent Substations

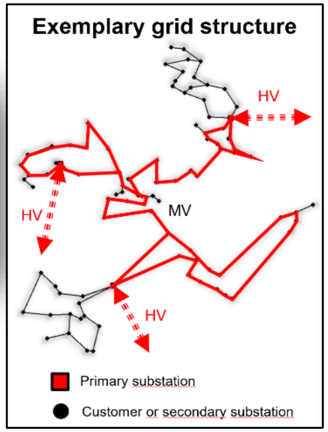


FEN Landmark Projects

Medium-voltage DC CAMPUS Grid, Design Tools & Real Time Emulators

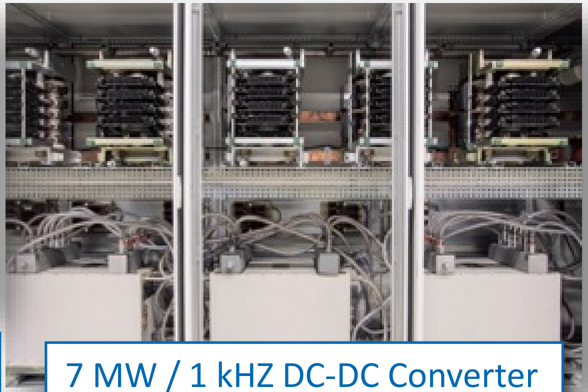


Landscape Architecture

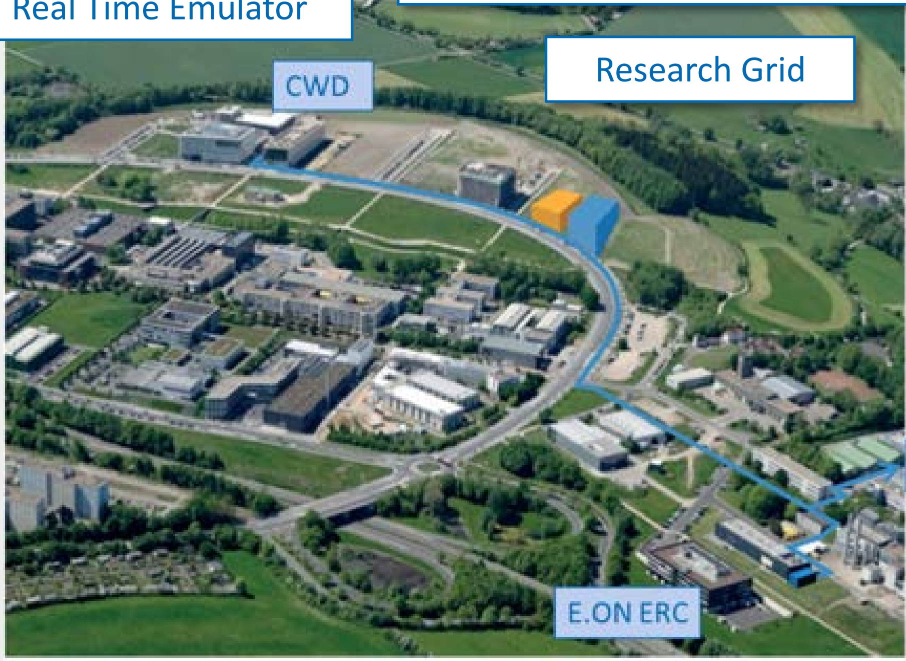


DC Grid Planning Tool

AixControl XRS7070
Real Time Emulator



7 MW / 1 kHZ DC-DC Converter

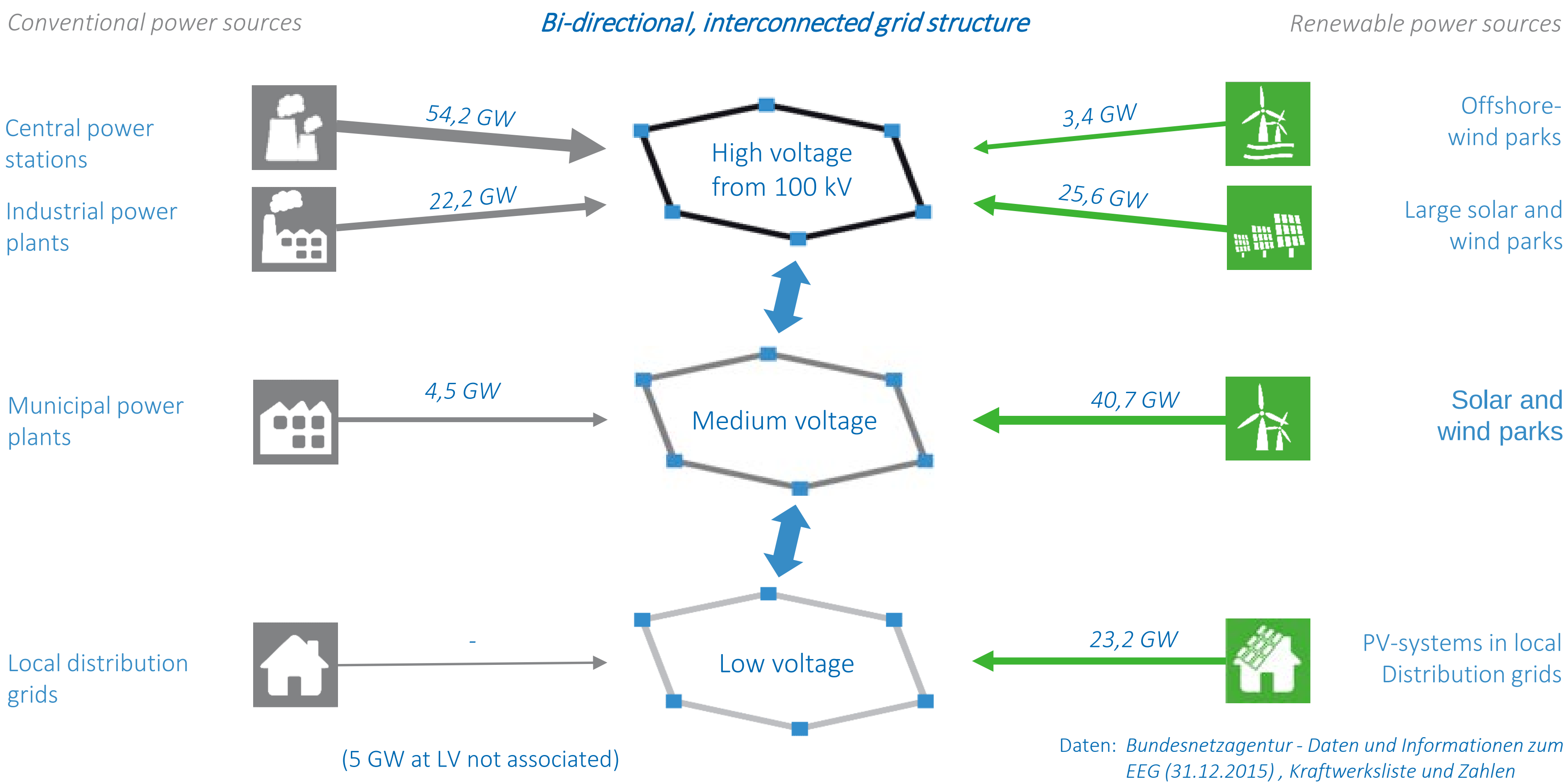


Research Grid

Medium
Frequency
Transformers

The 1/3 rule already applies in Germany to the installed capacities

Meshed distribution grids are indispensable for renewables and CHP in urban areas

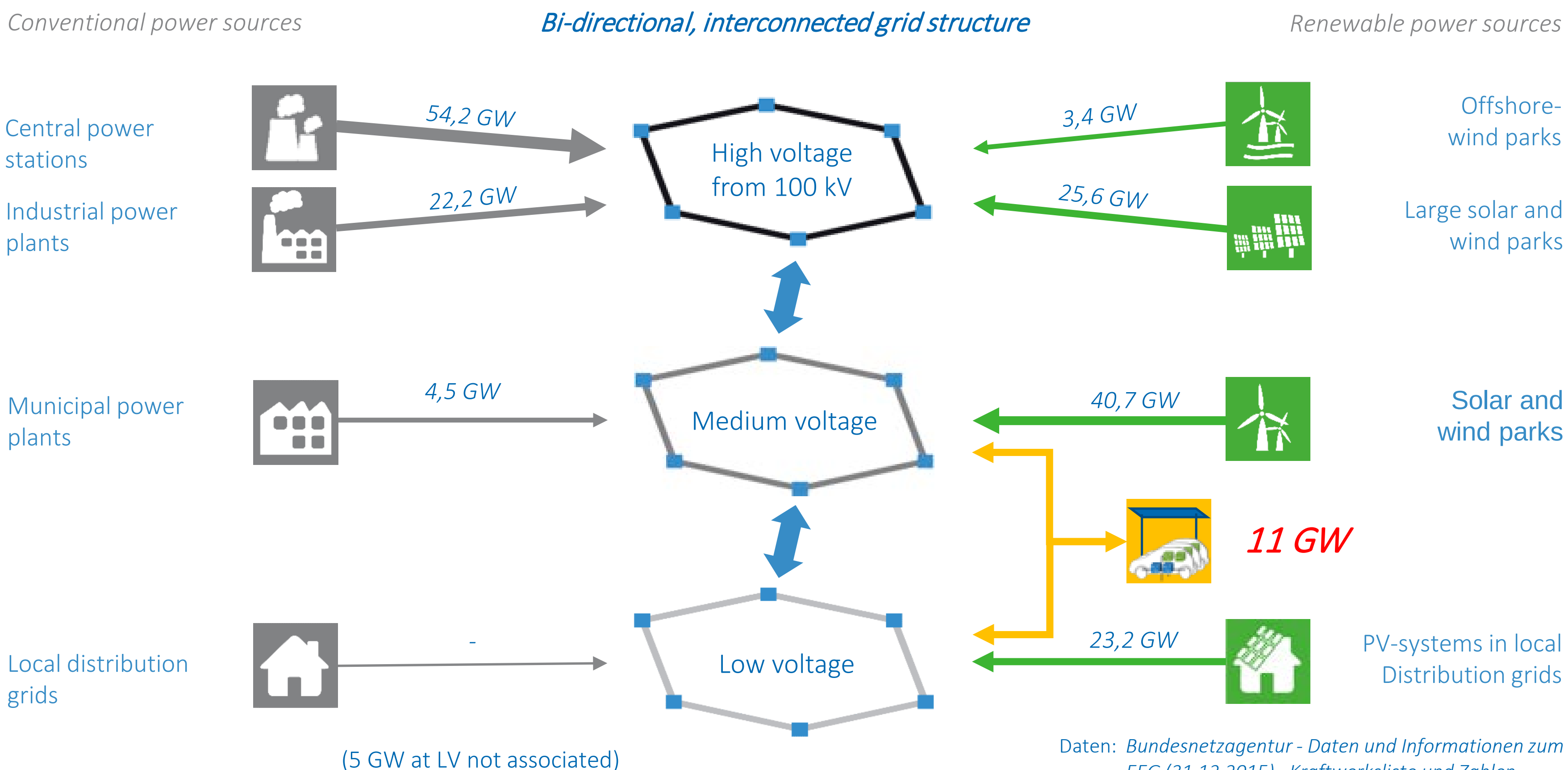


Daten: *Bundesnetzagentur - Daten und Informationen zum EEG (31.12.2015) , Kraftwerksliste und Zahlen (10.06.2016, Status 2015)*

Future grids cannot ignore the energy feed-in in medium- and low-voltage distribution grids and must become interconnected

The 1/3 rule already applies in Germany to the installed capacities

Meshed distribution grids are indispensable for Emobility in urban areas



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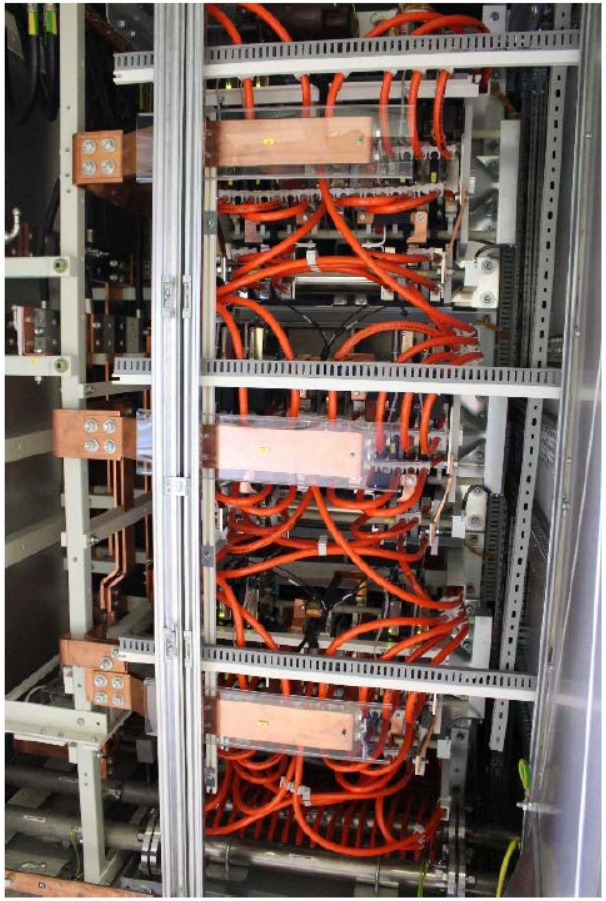
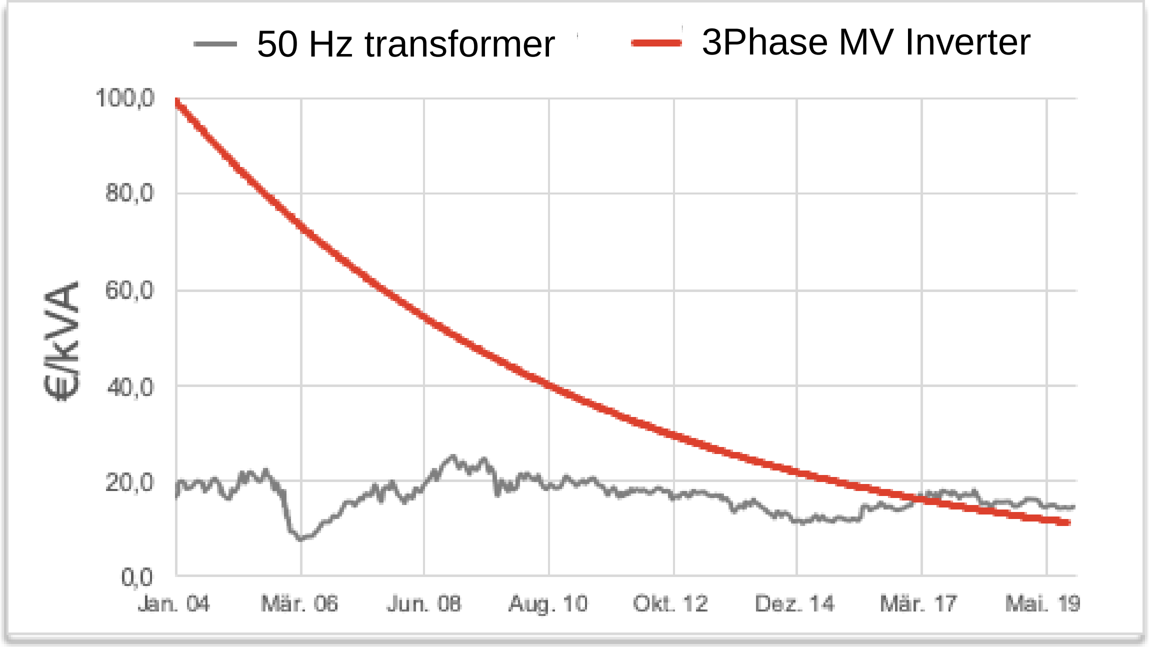
Future grids cannot ignore the energy feed-in in medium- and low-voltage distribution grids and e-Mobility and must become interconnected

Driving factor

Power electronic inverters are progressively having lower cost than 50 Hz transformers





Estimated cost for 2020

Automotive inverter 3 €/kVA

DC Solid-State Transformer 9 €/kVA

Modular Multilevel DC-DC Converters Interconnecting High-Voltage and Medium-Voltage DC Grids

Access dissertation via -
URL: http://publications.rwth-aachen.de/record/762795
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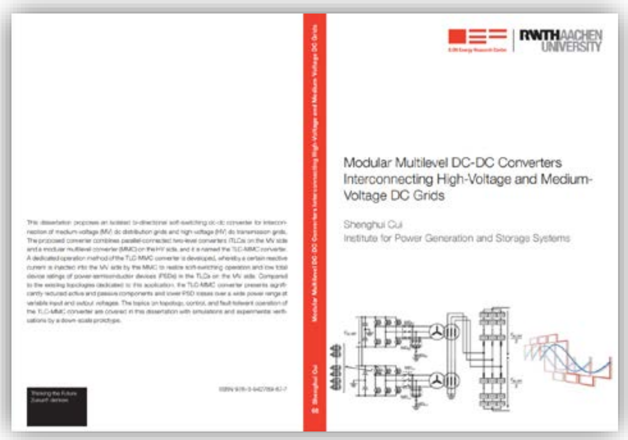

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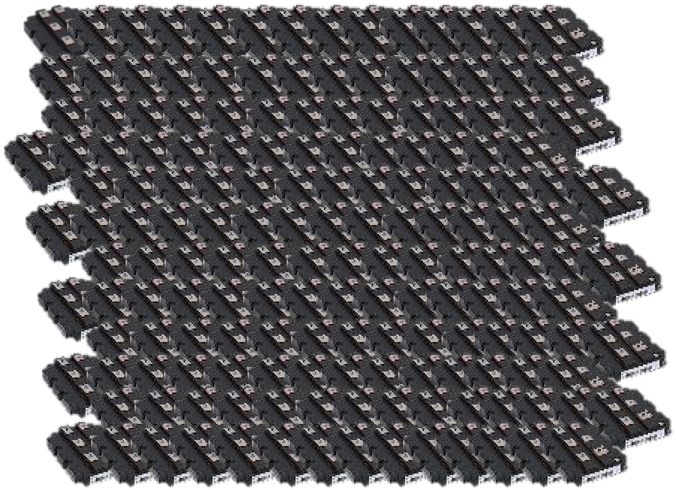
Comparison MMC versus TLC-MMC Dual Active Bridge

State-of-the-Art Solution - ±25 kV / ±200 kV, 400 MW System

Modular Multilevel DC-DC Converters Interconnecting High-Voltage and Medium-Voltage DC Grids

Performance Improvement - A 400 MW Converter

- Power semiconductor devices
  - 4800 → 2700, reduced by 44%



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- Power semiconductor devices
  - 4800 → 2700, reduced by 44%
- Power capacitors
  - 2400 capacitors in state-of-the-art topology, each 40 kg
  - 2400 → 1300, reduced by 46%

Source: EPCOS

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- Power capacitors
  - 2400 capacitors in state-of-the-art topology, each 40 kg
  - 2400 → 1300, reduced by 46%
- Conversion Losses
  - 30~40% loss reduction over entire operation ranges