FORSCHUNGS CAMPUS
öffentlich-private Partnerschaft für Innovationen

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FORSCHUNGSCAMPUS
FLEXIBLE ELEKTRISCHE NETZE

Gleichstromversorgung im Nieder- und Mittelspannungsnetz

Wo macht was Sinn?

VDE Thüringen

Prof. Dr. ir. Dr. h.c. R. W. De Doncker

12.11.2020

Outline

- Introduction – RWTH Aachen University
  - E.ON ERC
  - ISEA and PGS
  - Research CAMPUS Flexible Electrical Networks
- Background – Energy Transition and Flexible Grids
  - Renewables and decentralized power generation impact grid structures
  - Flexible DC Distribution grids and sector coupling
  - eMobility impact on distribution grids
- Conclusions
  - Use cases where DC technology makes a lot of sense
  - DC technology never went away
  - Standardization activities
  - Urgency to drive the DC (r)evolution

RWTH Aachen University

- Founded in 1870; one of the largest technical universities in Europe
- 157 degree courses
  - **45,377** students (**57%** Engineering)
  - 7,165 graduates, 9,651 international students
- 9,264 employees
  - 547 professors (89 Junior Prof.)
  - 5,564 research associates
  - 2,786 non-scientific staff
  - 599 apprentices and interns
- **1.0 B€** Budget 2019
  - 500 M€ external project funds for R&D
- **4,833** Scientific Publications
- 25% of all Dr.-Ing. in Germany are from RWTH

E.ON ERC leads the RWTH CAMPUS Cluster Sustainable Energy
to accelerate innovation with industry partners

Production of Prototype EVs

Project space for SMEs

Research and Development

Training

IEM Institut für Elektrische Maschinen | RWTH AACHEN UNIVERSITY

ISEA | RWTH AACHEN UNIVERSITY

ISF WELDING AND JOINING INSTITUTE | RWTH AACHEN UNIVERSITY

PEM Chair of Production Engineering of E-Mobility Components | RWTH AACHEN UNIVERSITY

WZL | RWTH AACHEN UNIVERSITY

ELAB ELEKTROMOBILITÄTSLABOR

EUROPÄISCHE UNION
Investition in unsere Zukunft
Europäischer Fonds
für regionale Entwicklung

Ministerium für Wirtschaft, Energie, Industrie, Mittelstand und Handwerk des Landes Nordrhein-Westfalen

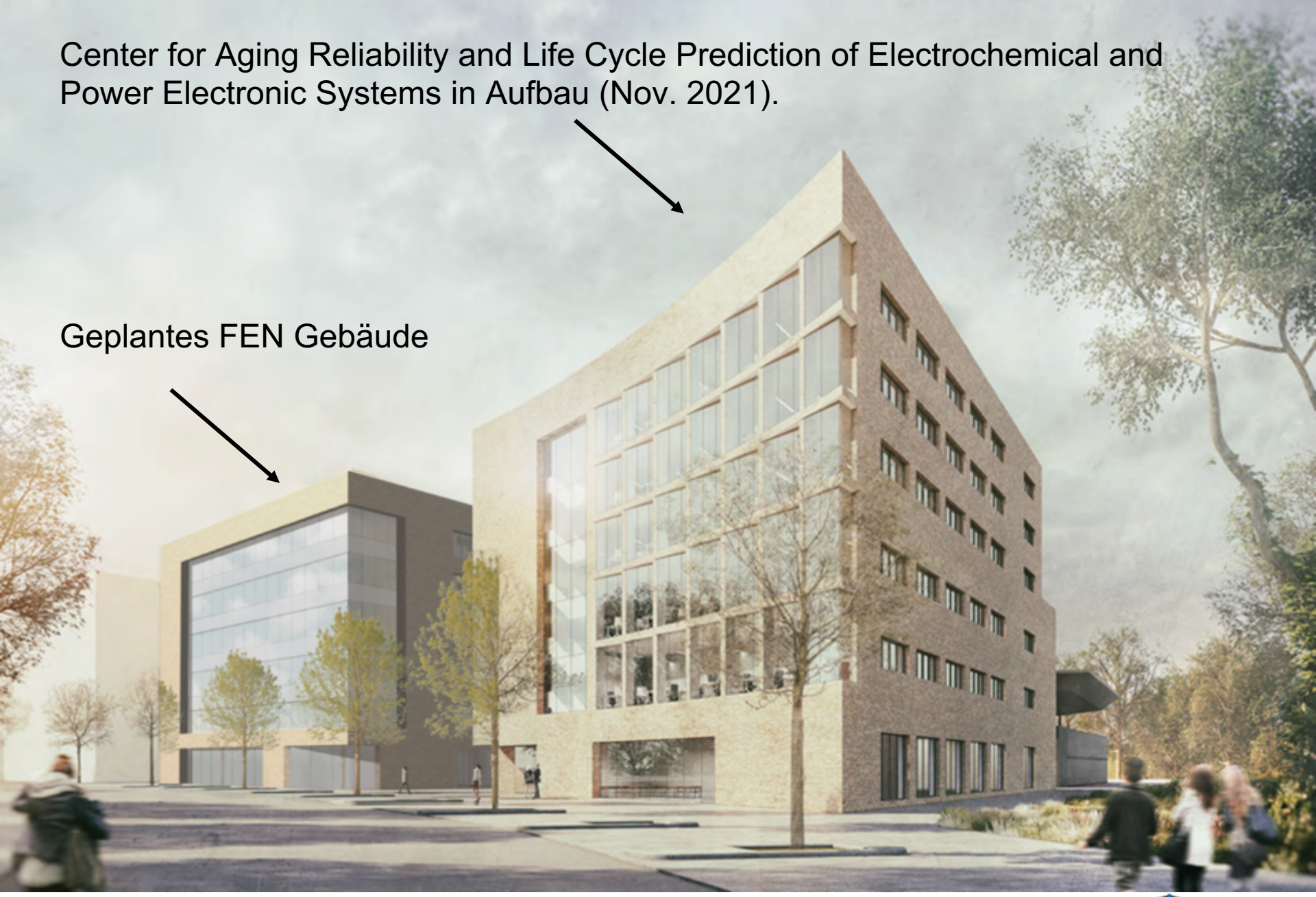
Ziel2.NRW
Regionale Wettbewerbsfähigkeit und Beschäftigung

I³ Research Center for Wind Power Drives

CWD – Center for Wind Power Drives

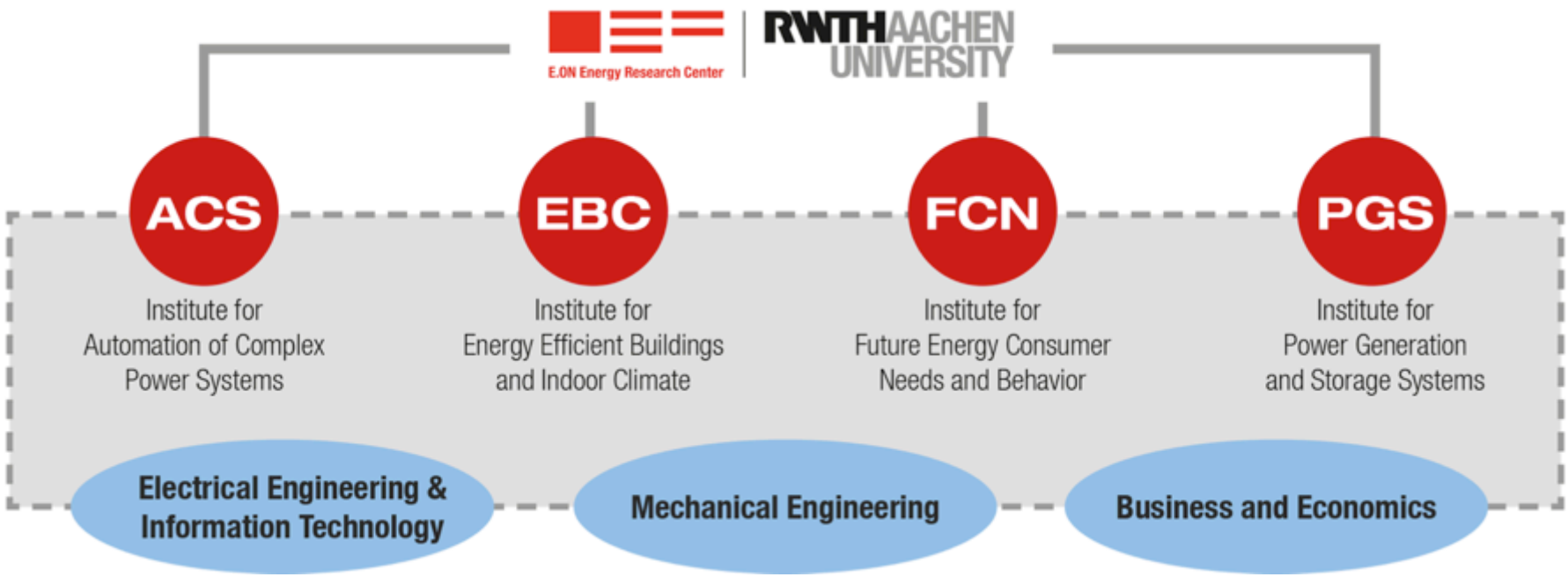
4 MW test bench for mechanical and electrical research and characterization of wind turbines

- **Prof. Abel** — IRTT
- **Prof. Brecher** — WZL
- **Prof. De Doncker** — E.ON Energy Research Center
- **Prof. Hameyer** — IEM
- **Prof. Jacobs** — IME
- **Prof. Monti** — E.ON Energy Research Center
- **Prof. Schröder** — AIA


Center for Aging Reliability and Life Cycle Prediction of Electrochemical and Power Electronic Systems in Aufbau (Nov. 2021).
Geplantes FEN Gebäude

E.ON ERC at RWTH Aachen University

Energy savings, energy efficiency and sustainable energy supply in the urban environment



Two chairs – two institutes ISEA and PGS

	Institut für Stromrichtertechnik und Elektrische Antriebe RWTH AACHEN	E.ON Energy Research Center PGS | Institute for Power Generation and Storage Systems
Chair for Power Electronics and Electrical Drives – LEA/PED Prof. De Doncker	Power electronics and drives systems with a voltage < 1000 V	Power electronics and drives systems with a voltage > 1000 V
Chair for Electrochemical Energy Conversion and Storage Systems – ESS Prof. Sauer	Mobile energy storage systems	Stationary energy storage systems

Research areas and staff at ISEA and PGS

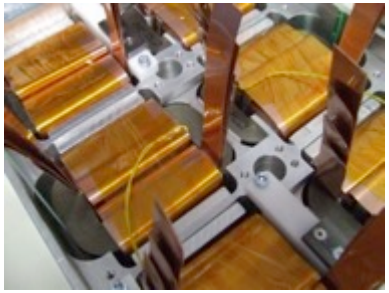
Univ.-Prof. Dr. ir. Dr. h. c. Rik De Doncker
Power Electronics
Electrical Drives
Electronic Devices, Switched Mode Power Supplies

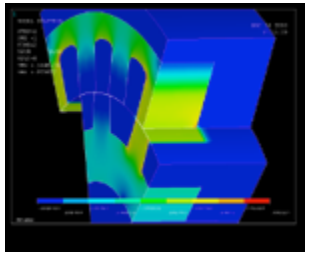
Univ.-Prof. Dr. rer. nat. Dirk Uwe Sauer
Electrochemical Energy Conversion and Storage Systems

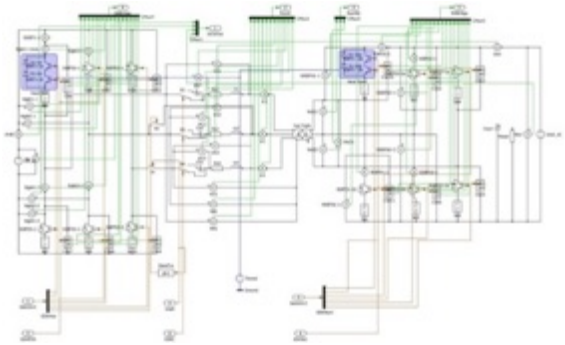
Univ.-Prof. Dr. rer. nat. Egbert Figgemeier
Ageing Processes and Lifetime Prediction of Batteries (Helmholtz - FZJ)

- 14 Chief Engineers
- 1 Adjunct Professor, 2 Lecturers
- 102 Research Associates
- ca. 90 Student Co-Workers
- ca. 150 Graduate Students per Year
- 30 Permanent Staff
- 9 Apprentices

Power Electronics and Drives Division







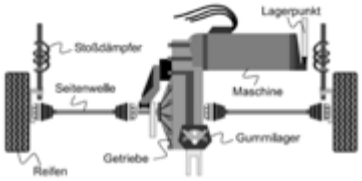
Device & Component Analysis

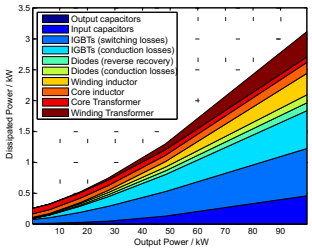
Component & Converter Design

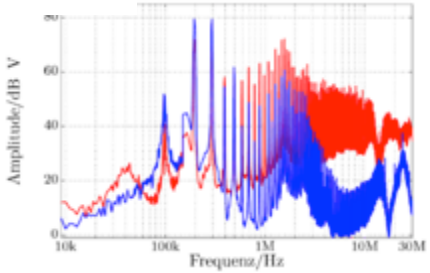
Modeling & Control

Demonstrator Development

System Integration







PGS|E.ONERC - Electrochemical Storage Systems Division

M5BAT

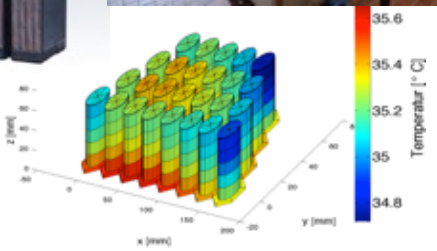
Battery Testing

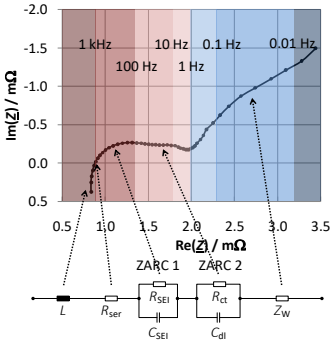
Laboratory Analysis

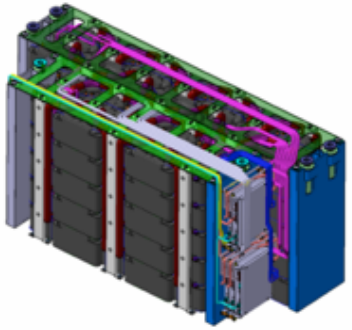
Modeling & Lifetime Prediction

System Integration

Monitoring & Management







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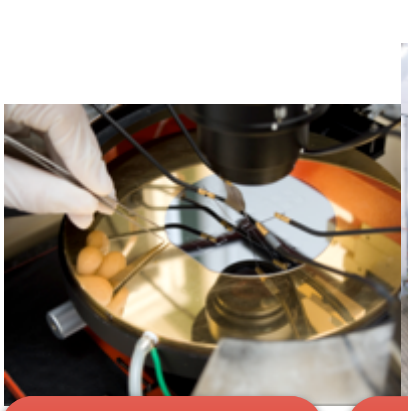
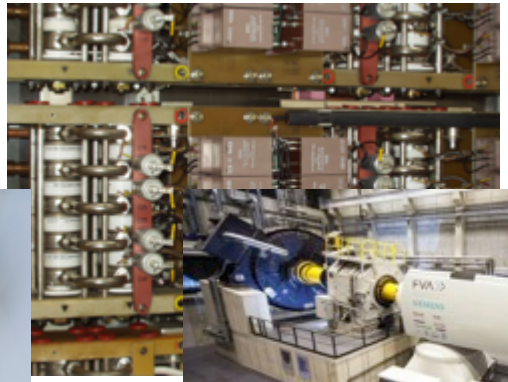
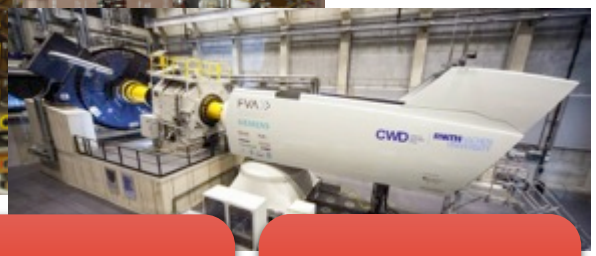
High Power Electronics and Drives (PGS)



Device & Component Analysis

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Demonstrator Development

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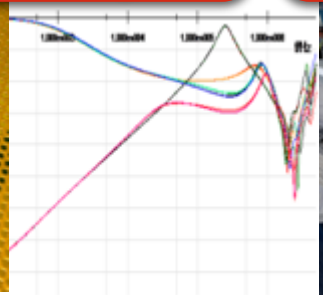
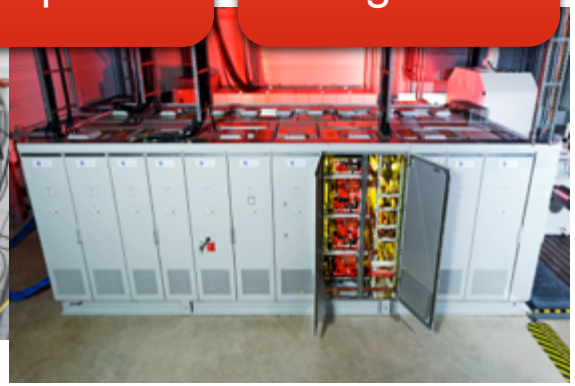
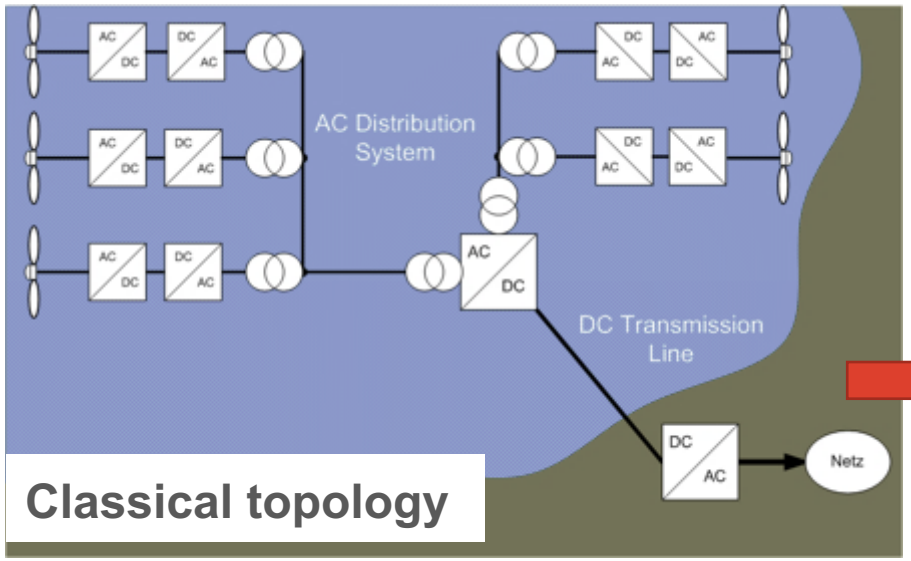
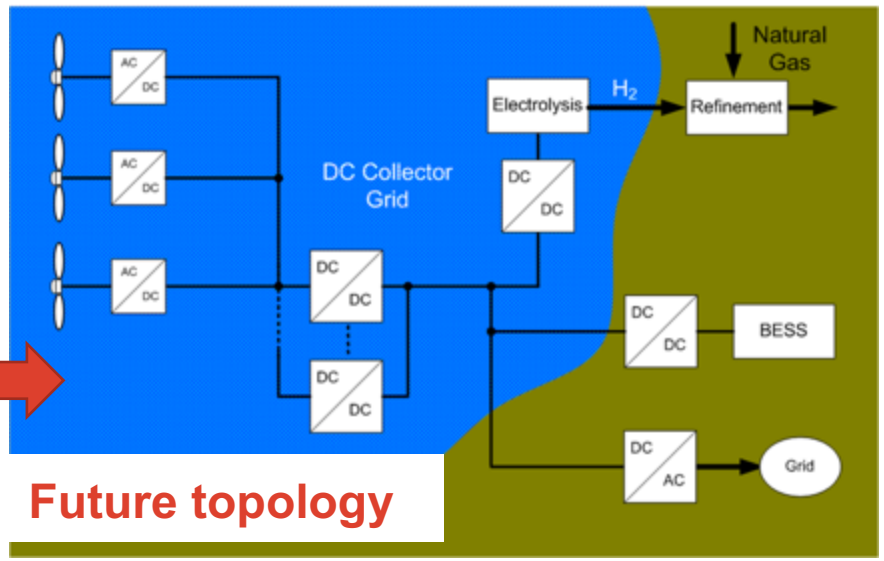




System Integration
MVDC Collector Grid for Offshore Wind Farms





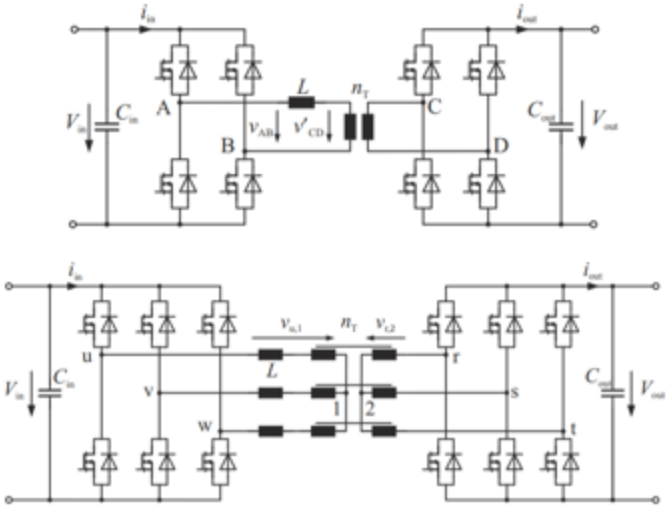
- Increased efficiency
  - 2% higher compared to AC systems
  - Simple more reliable wind turbines
- Smaller and lighter transformers
  - Weight reduced to 30 %

- Reduced costs
  - Smaller off-shore platforms
  - Reduced LCC
  - Reduced installation, transportation and investment cost
  - Improved reliability

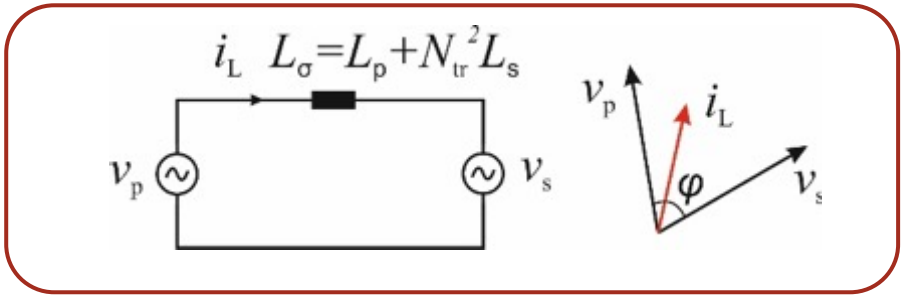
Key Enabling Component for DC Intelligent Substations
Dual Active Bridge DC-DC Converter

DC Solid-State Transformer Initially Invented for Space Station

- Bidirectional dc-dc conversion
- Galvanic isolation with medium-to-high frequency transformer
- High step-up/down ratio possible
- Buck and boost operation
- Inherent zero-voltage switching capability
- Simple control of power flow similar to a synchronous machine connected to ac grid
- So many variants
  - Single-phase
  - Three-phase
  - Multi-level
  - Multi-port
  - Resonant

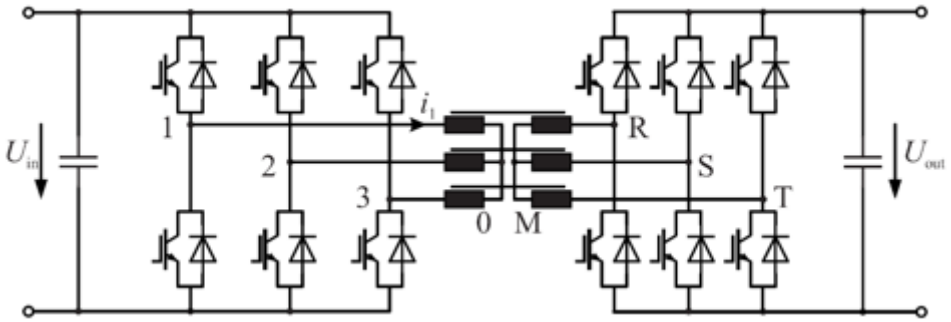


First-order harmonic model

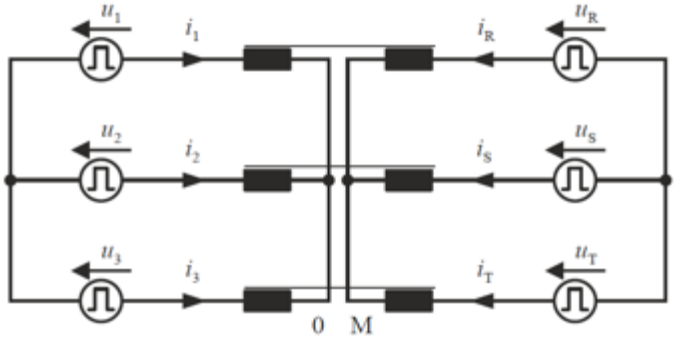


Three-Phase Dual-Active-Bridge Converter in Block-mode Operation

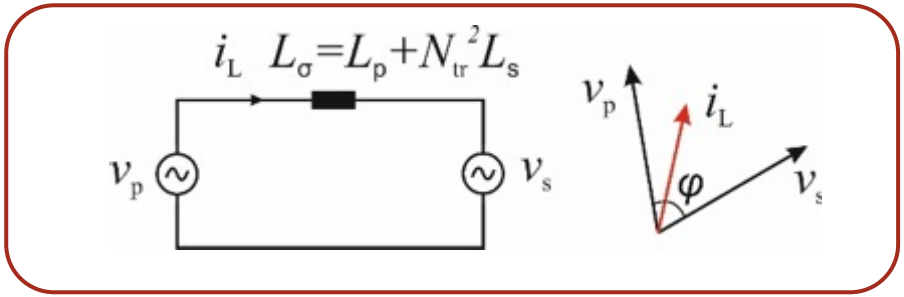
Dual-Active-Bridge-DC-DC-Converter with IGBTs



Equivalent circuit diagram with voltage sources



First-order harmonic model



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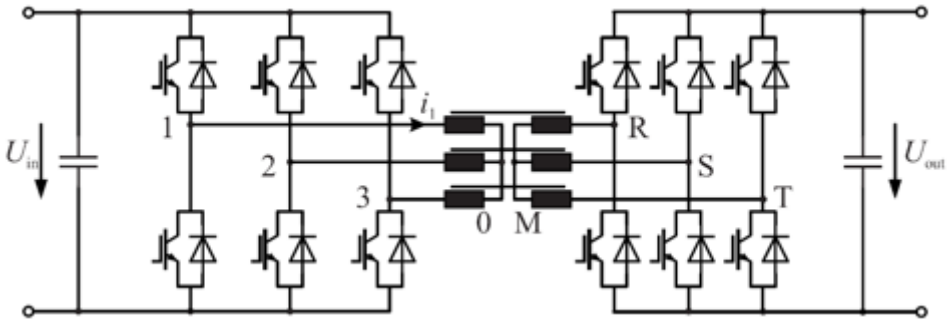
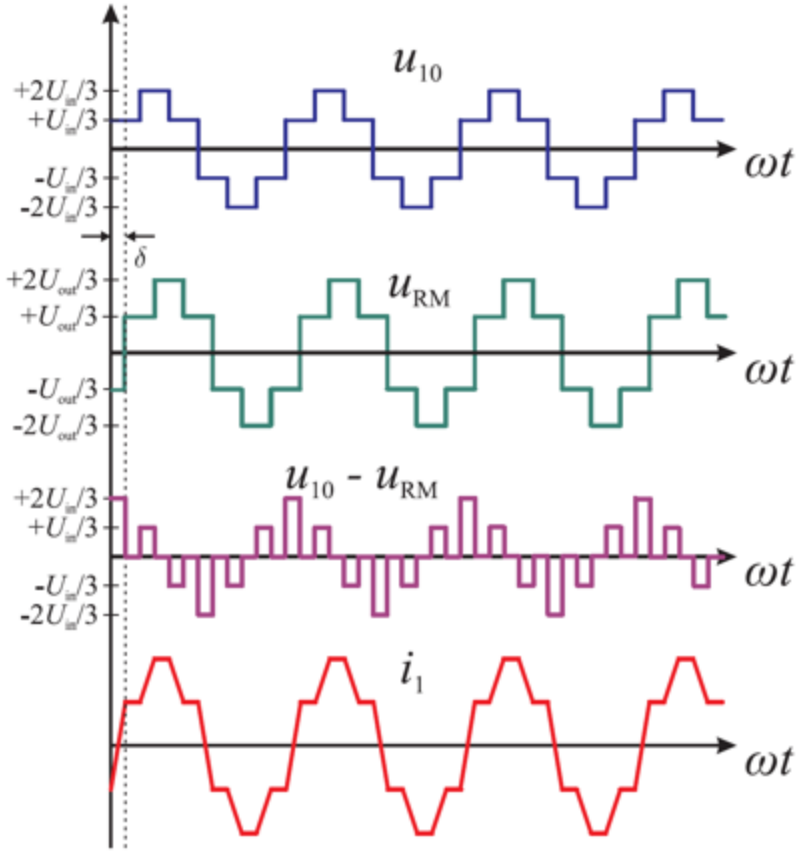
Three-Phase Dual-Active-Bridge Converter in Block-mode Operation

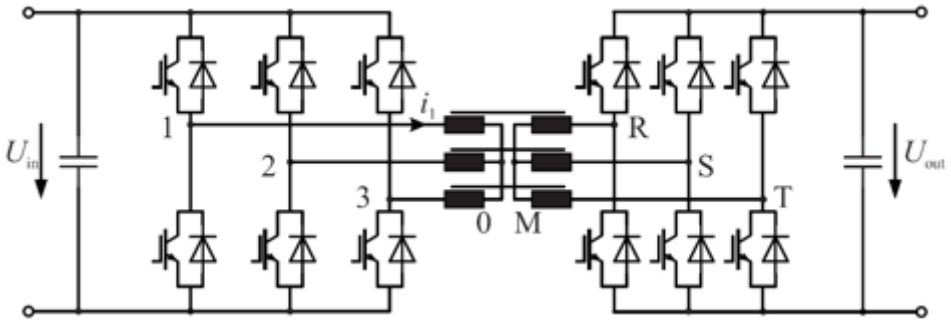


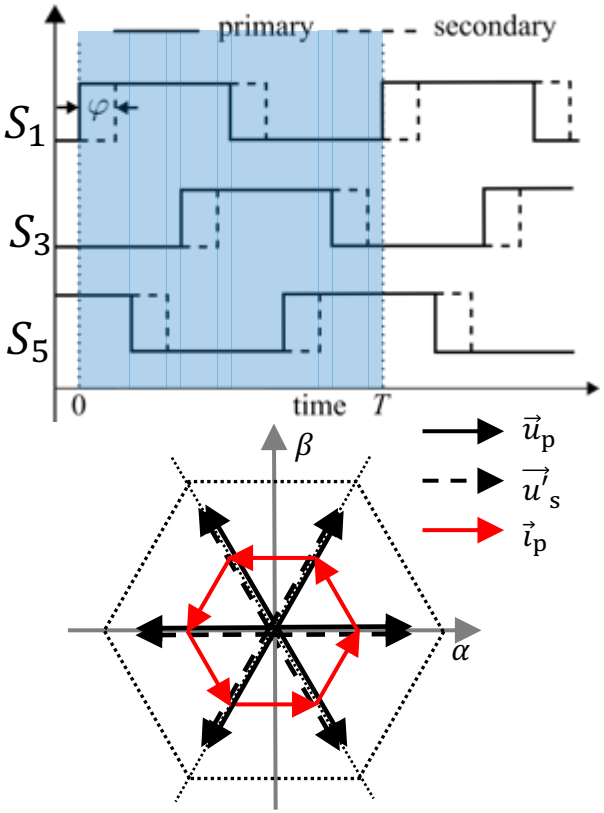
$$u = L \cdot \frac{\mathrm{d}i}{\mathrm{d}t} \Leftrightarrow i = \frac{1}{L} \int u \mathrm{d}t \quad \text{mit } L = L_{p\sigma} + L'_{s\sigma}$$



Waveforms of Dual Active Bridge

Three-Phase Dual-Active-Bridge Converter in Block-mode Operation





$$\vec{u}_\mathrm{p} = u_{\mathrm{p}\alpha} + \mathrm{j}u_{\mathrm{p}\beta}$$
$$\vec{u}'_\mathrm{s} = u_{\mathrm{s}\alpha} + \mathrm{j}u_{\mathrm{s}\beta}$$
$$\vec{i}_\mathrm{p} = i_{\mathrm{p}\alpha} + \mathrm{j}i_{\mathrm{p}\beta}$$

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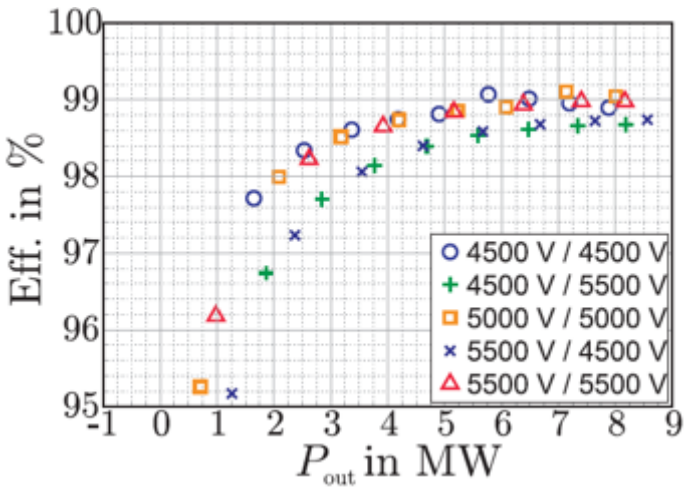
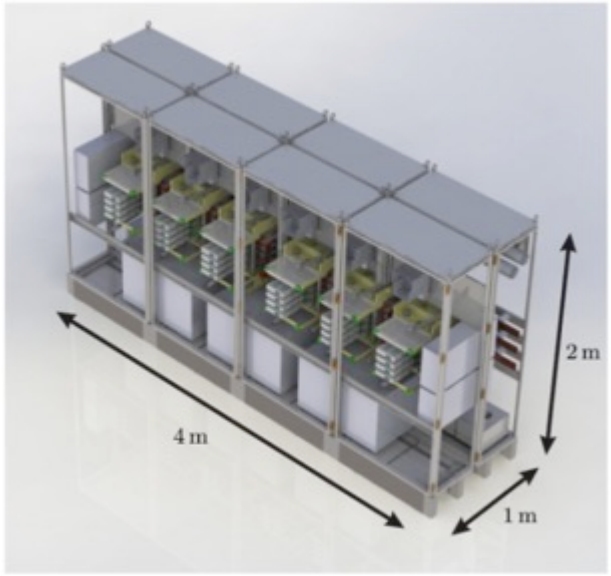
Demonstrator Development
E.ON gGmbH High Power DC-DC Converter

- P = 7 MW, VDC = 5 kV ±10 %
- Efficiency up to 99.2 %
- Calculation based on synthetic tests:
  - Measured losses of semiconductor switches
  - Measured transformer losses (300 kVA)
- Ultimately air-cooled devices are an option



R. Lenke, Doctoral Thesis, *A Contribution to the Design of Isolated DC-DC Converters for Utility Applications*, 2012, PGS

ABB



N. Soltau, H. Stagge, R. W. De Doncker and O. Apeldoorn, "Development and demonstration of a medium-voltage high-power DC-DC converter for DC distribution systems," *2014 IEEE 5th Int. Symposium on Power Electronics for Distributed Generation Systems (PEDG)*, Galway, 2014

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GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

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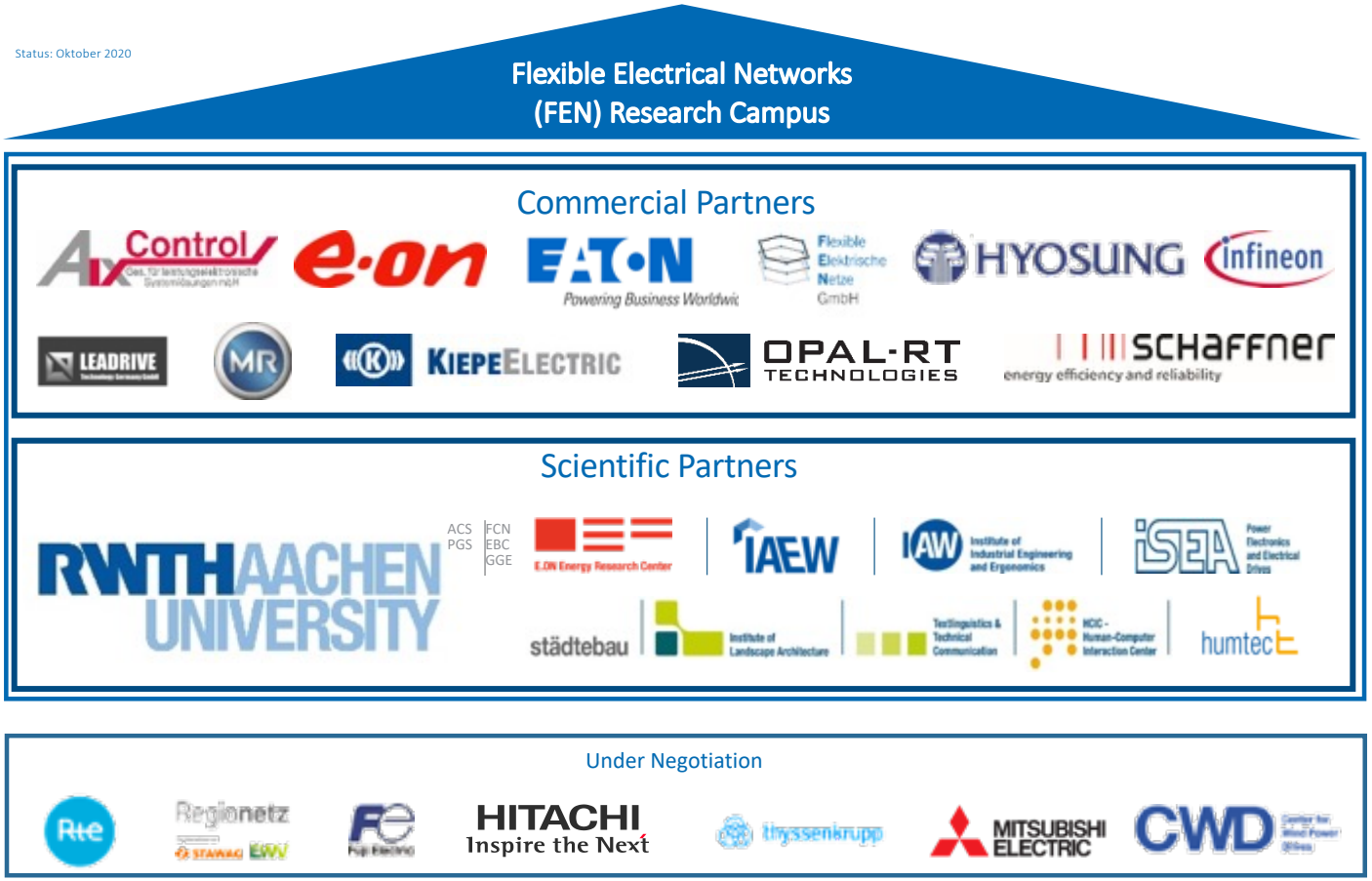
Forschungscampus
Flexible Elektrische Netze FEN

Partners of FEN Research Campus accelerate Innovation



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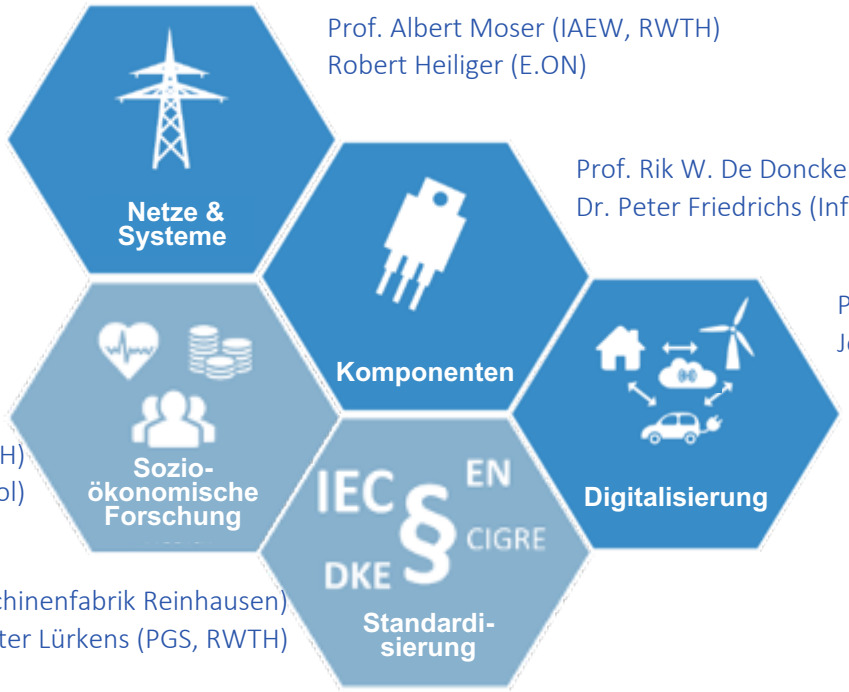
FEN Fachbereiche



Prof. Albert Moser (IAEW, RWTH)
Robert Heiliger (E.ON)

Prof. Rik W. De Doncker (PGS, RWTH)
Dr. Peter Friedrichs (Infineon)

Prof. Antonello Monti (ACS, RWTH)
Jörgen von Bodenhausen (Eaton)

Prof. Eva-Maria Jakobs (HCIC, RWTH)
Dr. Jochen von Bloh (AixControl)

Prof. Stephan Rupp (Maschinenfabrik Reinhausen)
Dr. Peter Lürkens (PGS, RWTH)

Technologieforschung

Sozio-ökonomische Forschung, Standardisierung

- Integrieren und koordinieren technische, soziale und ökonomische Perspektiven
- Sind paritätisch besetzt
- Die Leitungen der Fachbereiche bilden den FEN-Vorstand

FORSCHUNGSCAMPUS FLEXIBLE ELEKTRISCHE NETZE

Motivation

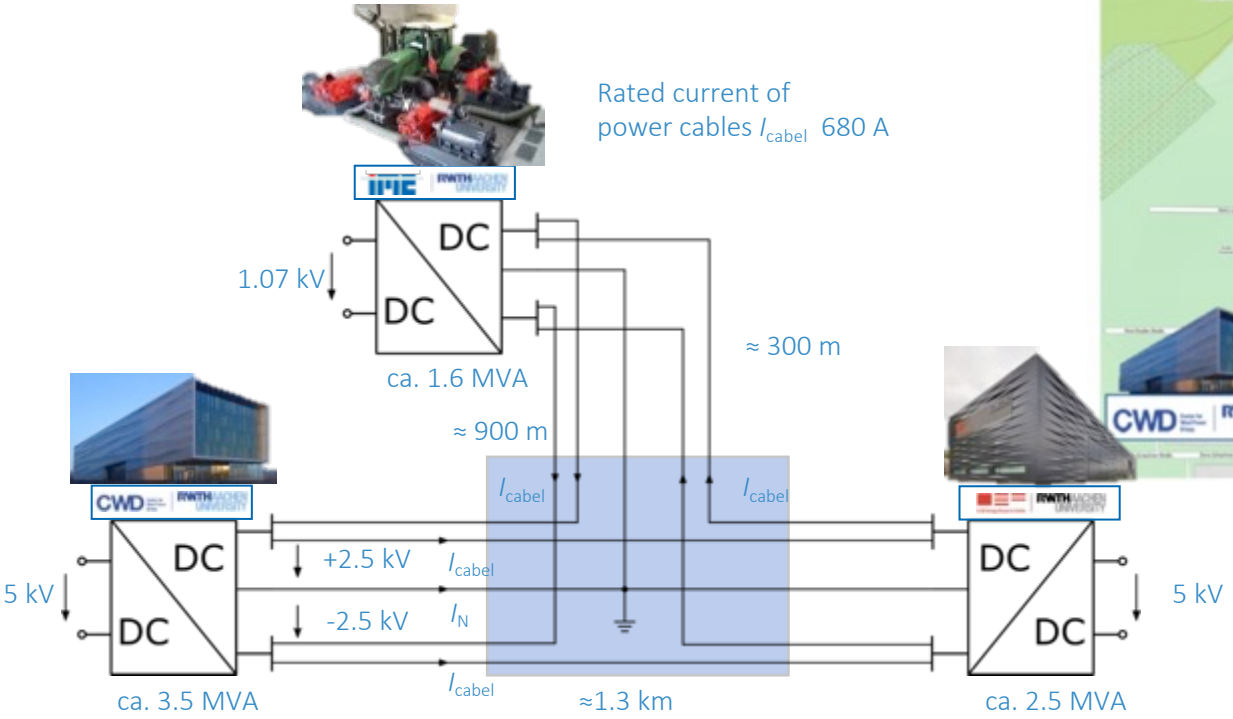
- **Verteilung der elektrischen Energie wird eine entscheidende Aufgabe.**

- Aktuell 40% regenerativer Anteil im deutschen Stromsektor*[1)]
- Bis 2024 weltweites Wachstum der erneuerbaren Energien um 50% *[2)]
- Verkehrswende durch e-Mobilität mit 1 Mio. Ladepunkten in Deutschland bis 2030*[3)]

Die Energiewende findet in den Verteilnetzen statt!

*[1)] EEG v. 01.04.2000 nach dem „Aachener Modell“; „Erneuerbare Energie in Zahlen“, BMU 23.10.2019
*[2)] International Energy Agency 2019
*[3)] Bundesregierung 05.11.2019

FEN Medium-voltage (5 kV) DC CAMPUS grid



M. Stieneker, J. Butz, S. Rabiee, H. Stagge and R. W. D. Doncker, "Medium-Voltage DC Research Grid Aachen," *International ETG Congress 2015; Die Energiewende - Blueprints for the new energy age; Proceedings of*, Bonn, Germany, 2015, pp. 1-7.

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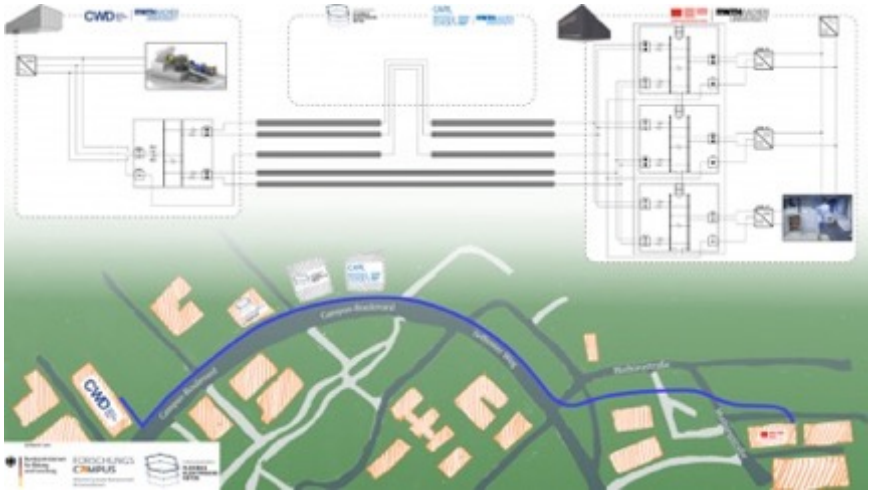
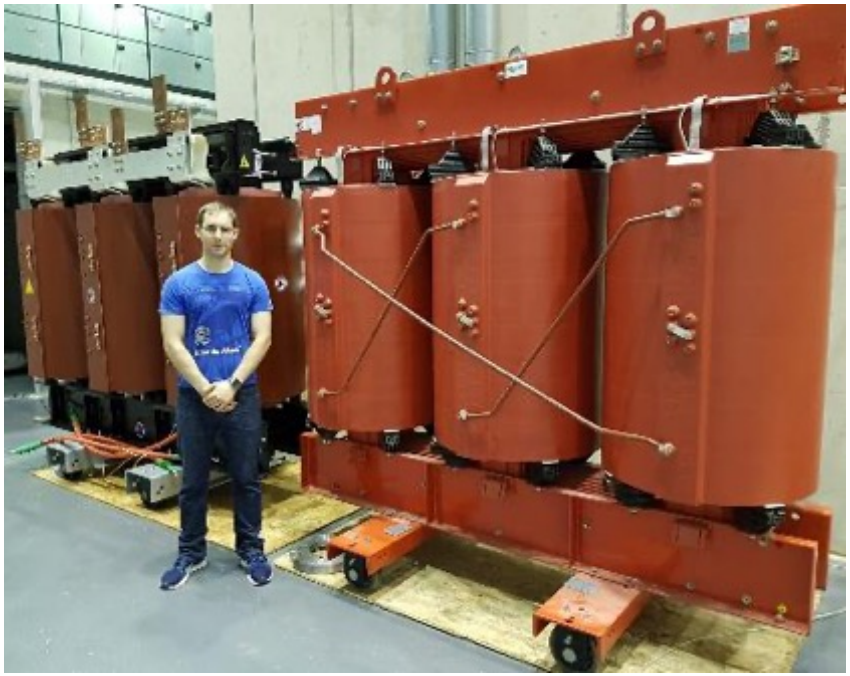
FEN-MVDC- Grid at RWTH Campus Melaten
Official start operation 5 kV MVDC-Grid 19.11.2019



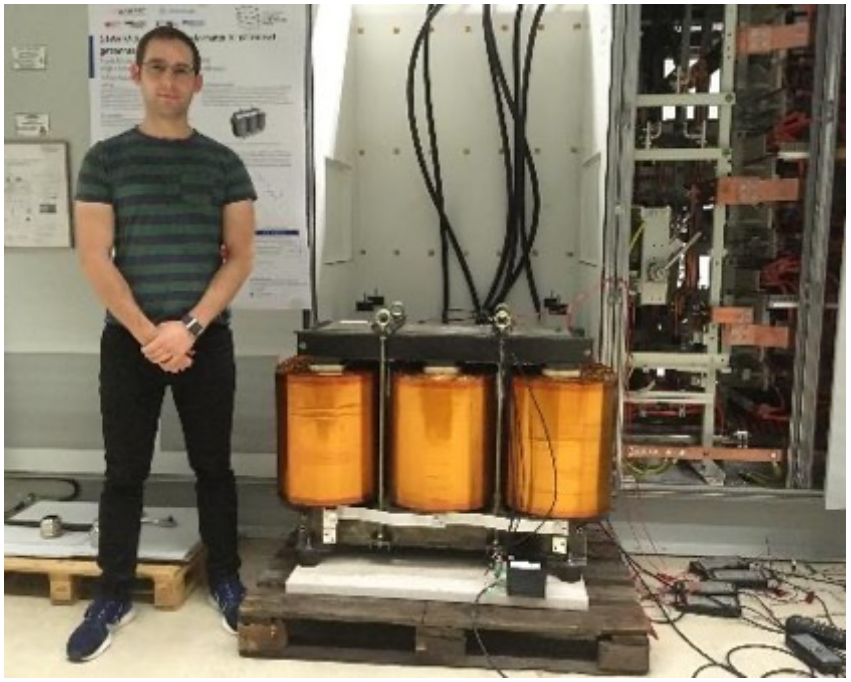
Stromrichtertechnik und Elektrische Antriebe
E.ON Energy Research Center
FLEXIBLE ELEKTRISCHE NETZE
RWTH AACHEN UNIVERSITY

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)



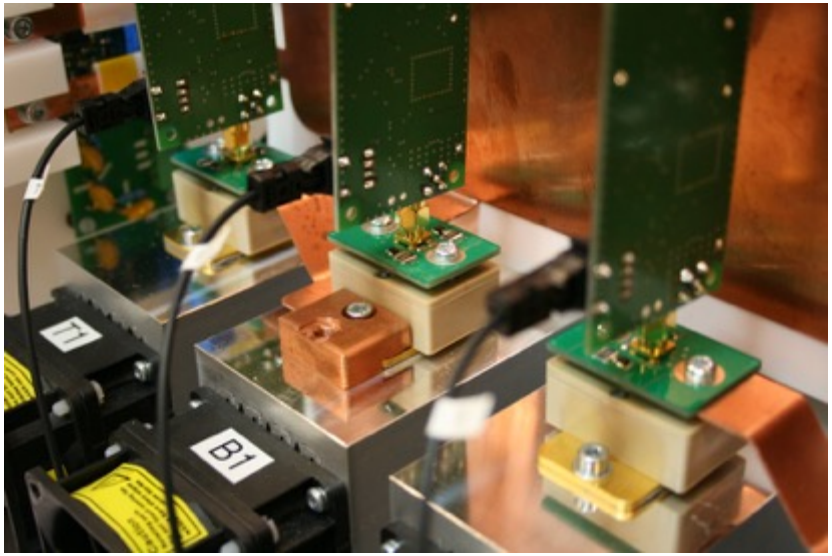
5,0 MVA, 1.000 Hz Transformator
675 kg (0,14 kg/kVA)

Solid State DC transformers reduce significantly our CO_2-foot print

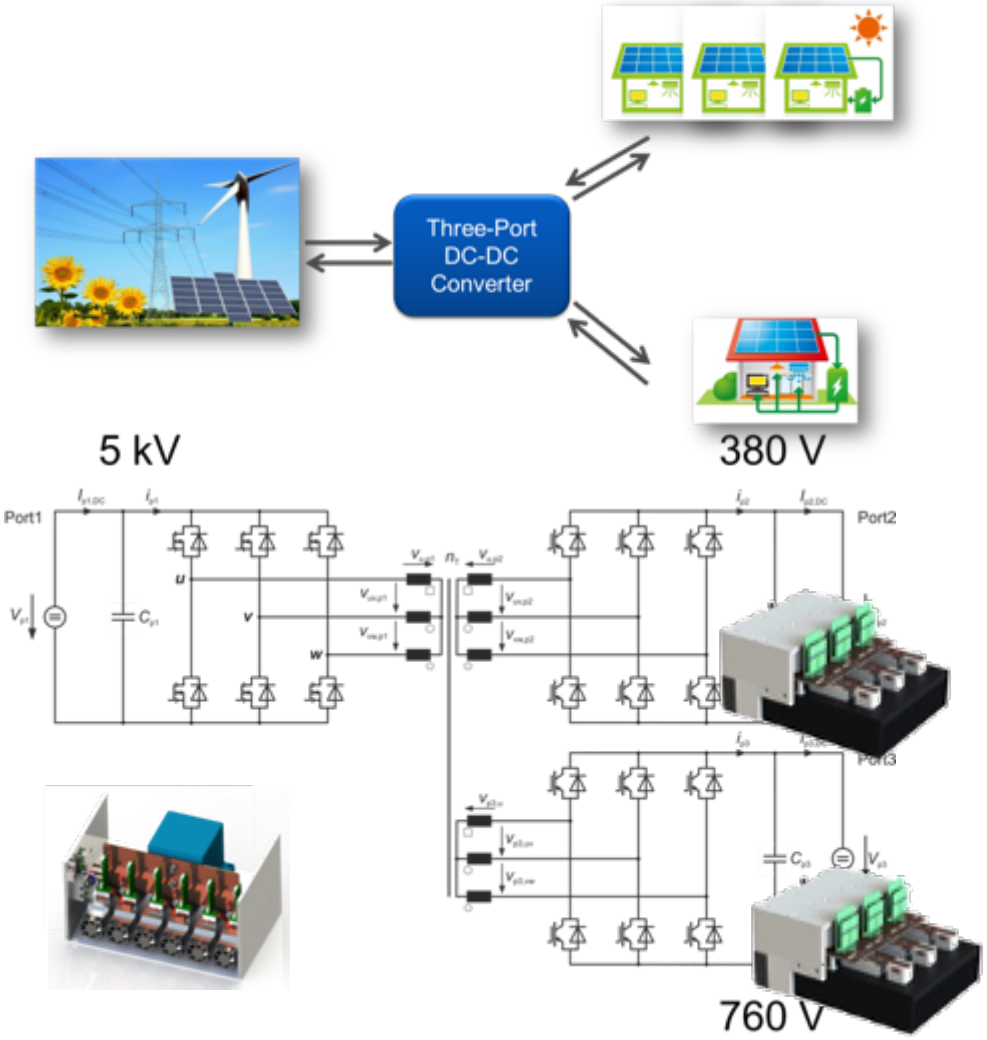
Estimated Transformer use; AC@50 Hz >25,000 ton/GVA, DC@1 kHz Grid < 1,500 ton/GW

150 kW Multiport DC/DC Converter

- Coupling of MV to LV DC grids
- 150 kW
- SiC MOSFETs
- Sophisticated dynamic control for stable operation



10 kV SiC MOSFETs and drivers of the medium-voltage port



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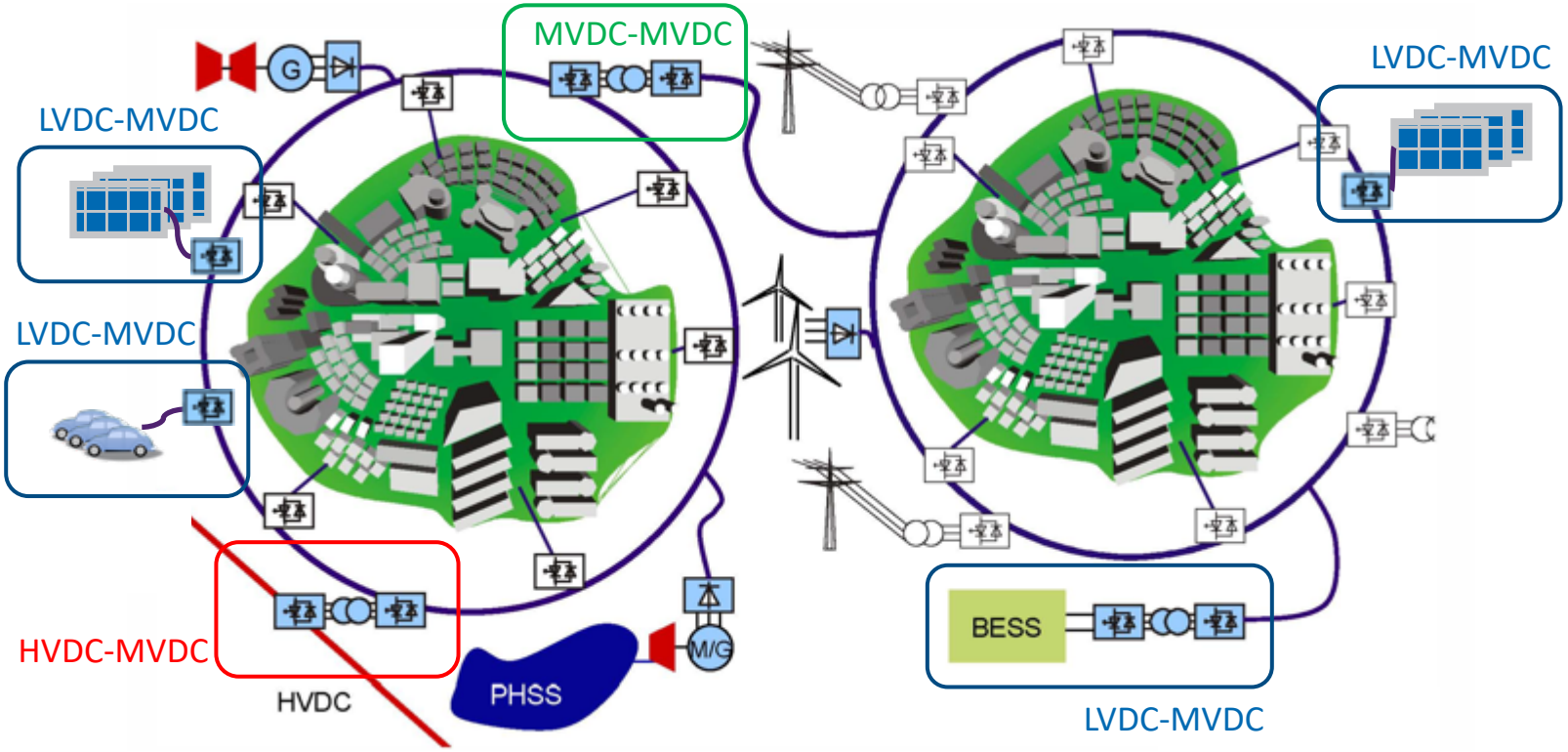
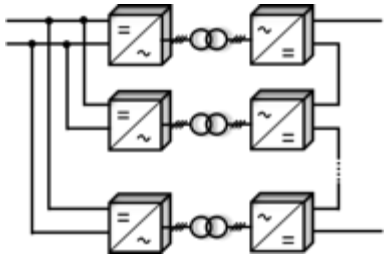
Flexible Grids for Decentralized Power Generation

Cellular Grid Topologies, Sector Coupling and DC Intelligent Substations

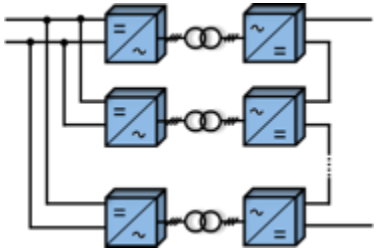


Technological Vision on DC Intelligent Substations

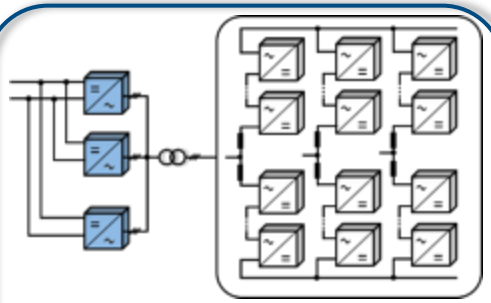
LVDC-MVDC | MVDC-MVDC | MVDC-HVDC



- IPOS DAB converter
- Modular, scalable
- IGBT, SiC Mosfet



- IPOS DAB converter
- Multi-level topology or device series connection
- IGBT, IGCT

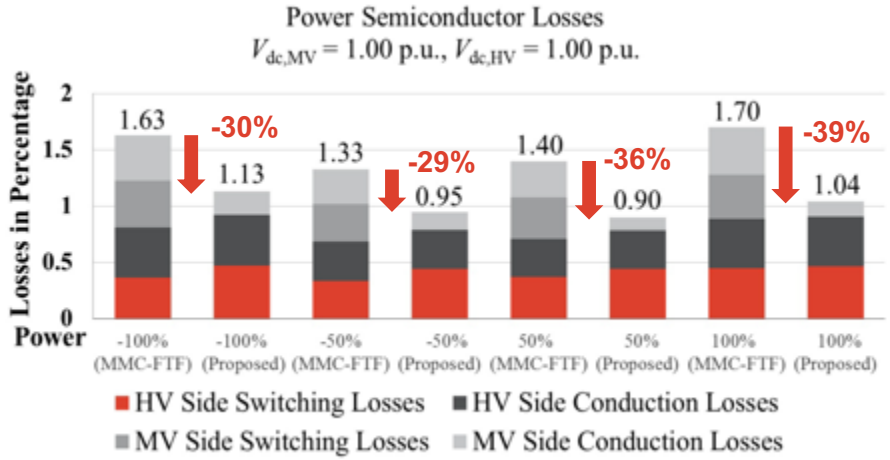


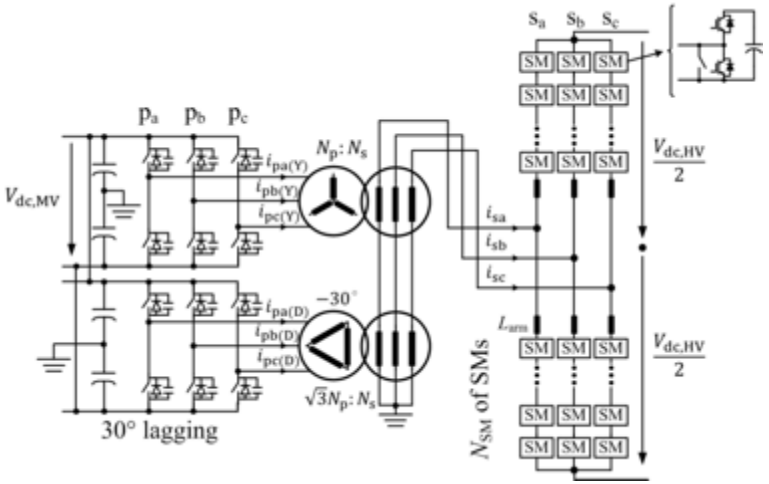
- MMC + DAB
- Insulation requirement for IPOS tranformer is too high
- Multi-level topology or device series connection on MV side
- IGBT, IGCT

29

MVDC-HVDC Converters – Combining MMC and DAB
Comparison with 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.)**





S. Cui, PhD thesis, “Modular multilevel DC-DC converters interconnecting high-voltage and medium-voltage DC grids”, Dissertation, RWTH Aachen University, 2019, DOI: 10.18154/RWTH-2019-05892

S. Cui, N. Soltau and R. W. De Doncker, "Dynamic performance and fault-tolerant capability of a TLC-MMC hybrid DC-DC converter for interconnection of MVDC and HVDC grids," *2017 IEEE Energy Conversion Congress and Exposition (ECCE)*, Cincinnati, OH, 2017, pp. 1622-1628, doi: 10.1109/ECCE.2017.8095986.

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Outline

- Introduction – RWTH Aachen University
  - E.ON ERC
  - ISEA and PGS
  - Research CAMPUS Flexible Electrical Networks
- Background – Energy Transition and Flexible Grids
  - Renewables and decentralized power generation impact grid structures
  - Flexible DC Distribution grids and sector coupling
  - eMobility impact on distribution grids
- Conclusions
  - Use cases where DC technology makes a lot of sense
  - DC technology never went away
  - Standardization
  - Urgency to drive the DC (r)evolution

Background
Energy market mechanisms that enabled more decentralized power production

Market changes that were introduced stepwise (EU):

1. **Market liberalization** allowed decentralized power generation, creating prosumers, typically small scale power generation (CHP) and REN sources (mostly volatile sources, such as PV and wind)

2. **CO_2** certificates, Emission Regulations

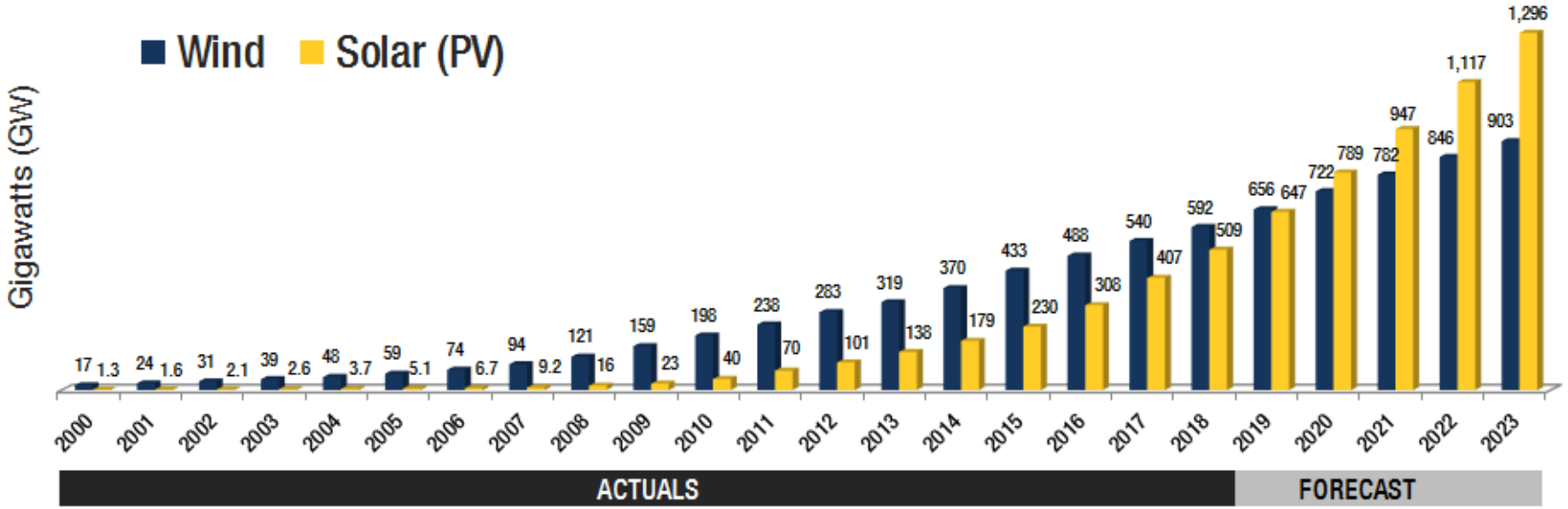
3. **Unbundling** of power generation and grid operation

4. **Unbundling** of TSO and DSO

Engineering challenges:

Need to find technical solutions that are socially and economically viable within these new markets and regulations

Global installed capacity of wind

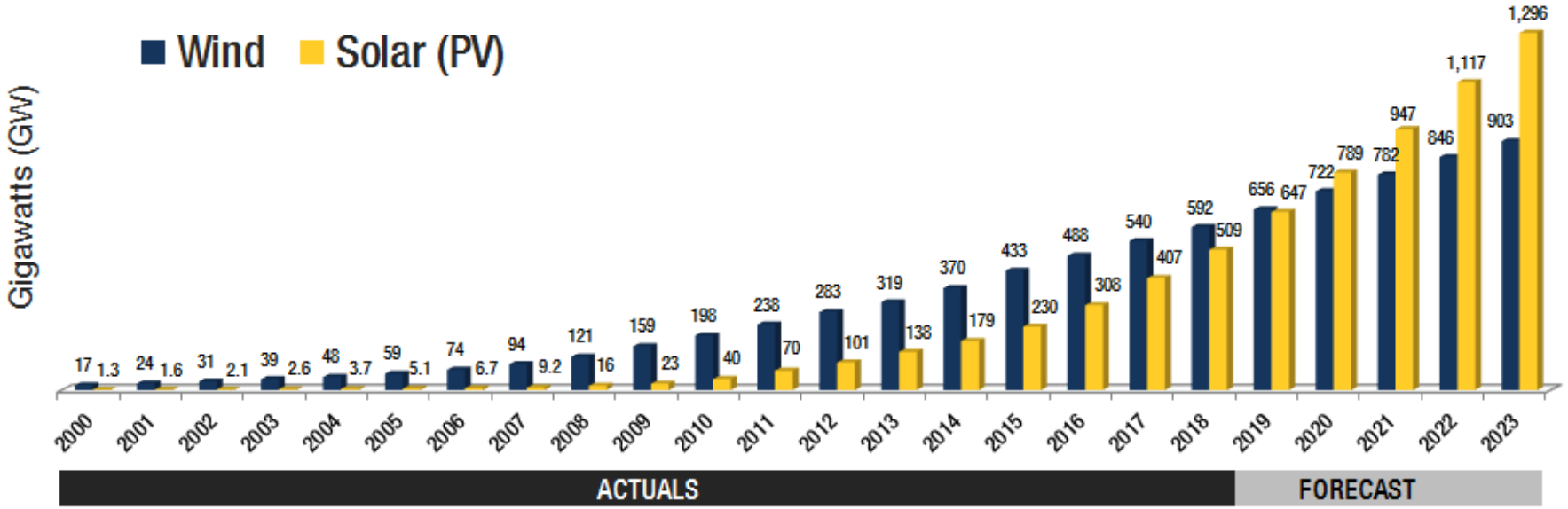


Source: PowerWeb

720 GW_{peak} installed capacity by the end of 2020 – assuming 50% DFG, this translates in approximately **1,080 GVA** of power electronic converters

Multi-megawatt power electronic converters are becoming a mass product. During the past 25 years a major cost reduction of voltage source inverters took place; from 500 €/kVA down to 20 €/kVA

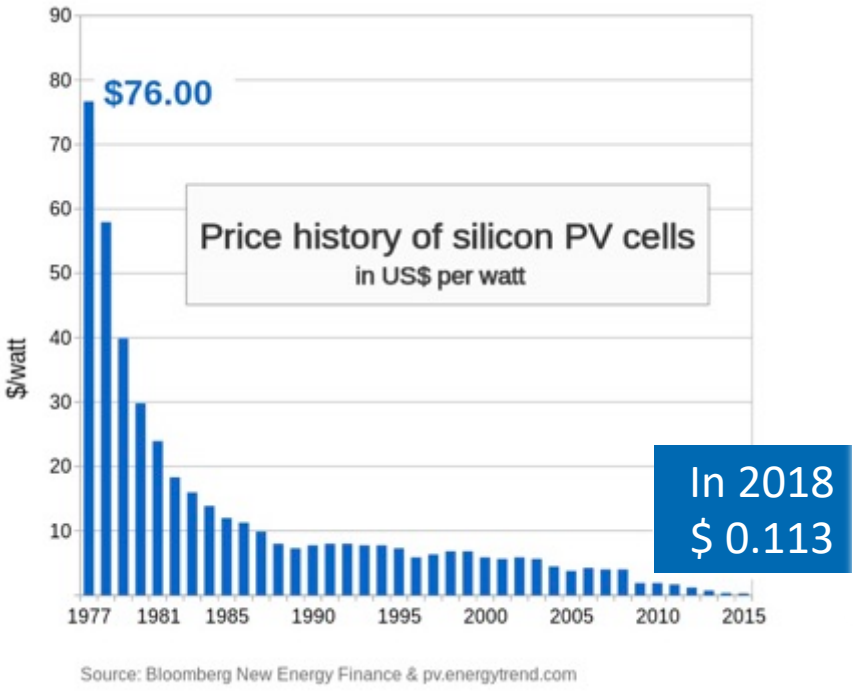
Global installed capacity of PV is accelerating

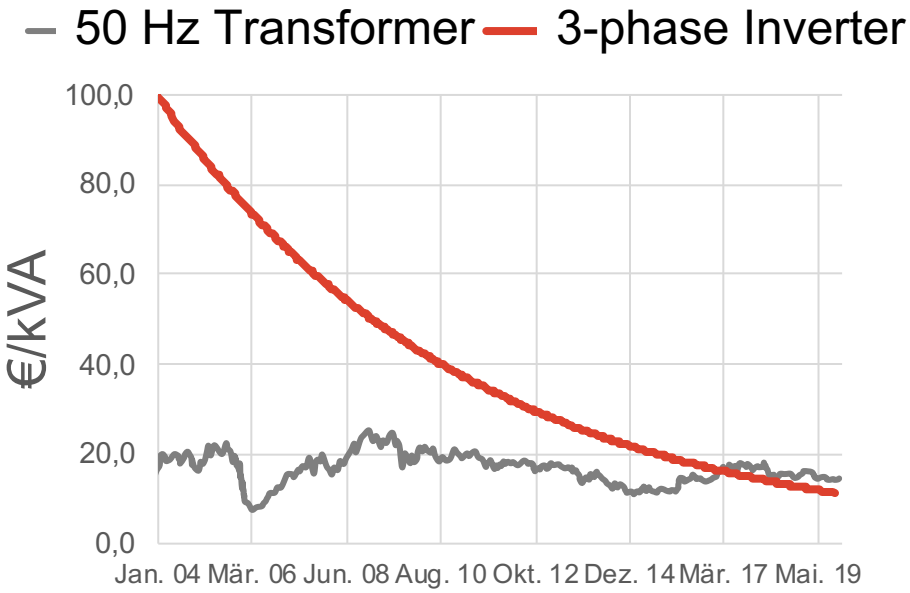


Source: PowerWeb

- 789 GW_{peak} of PV installed by 2020
- About 870 GVA of PV (string and central) inverters are installed by 2020
- LCE of PV in some countries is lower than that of wind or coal power plants

Price of silicon cells and power electronics inter-twined?

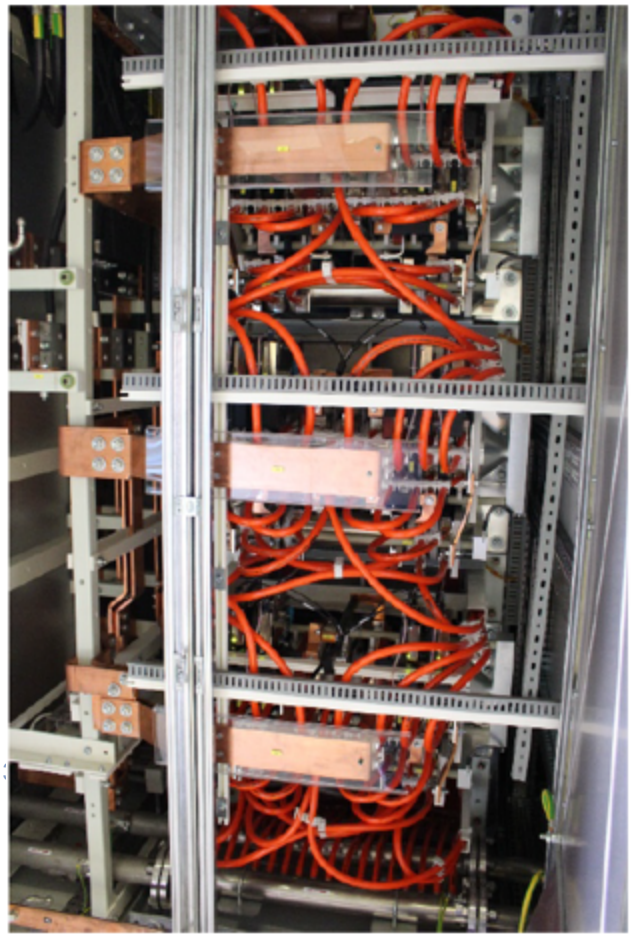


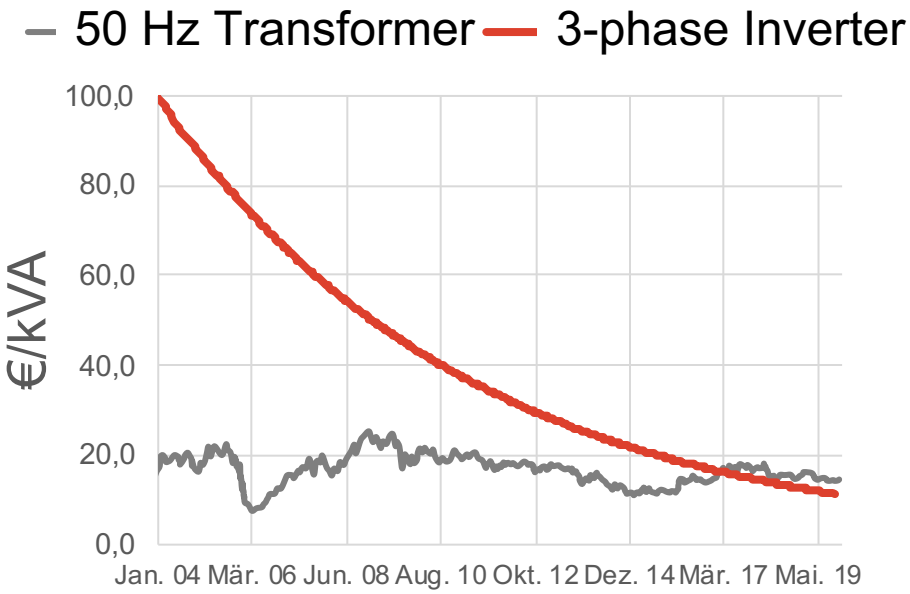


Silicon is made of SiO_2 (i.e. sand, an abundant material) and **energy**
Energy is produced by **PV**
PV energy is controlled and converted by **power electronics** made of **silicon**

Driving Factor

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



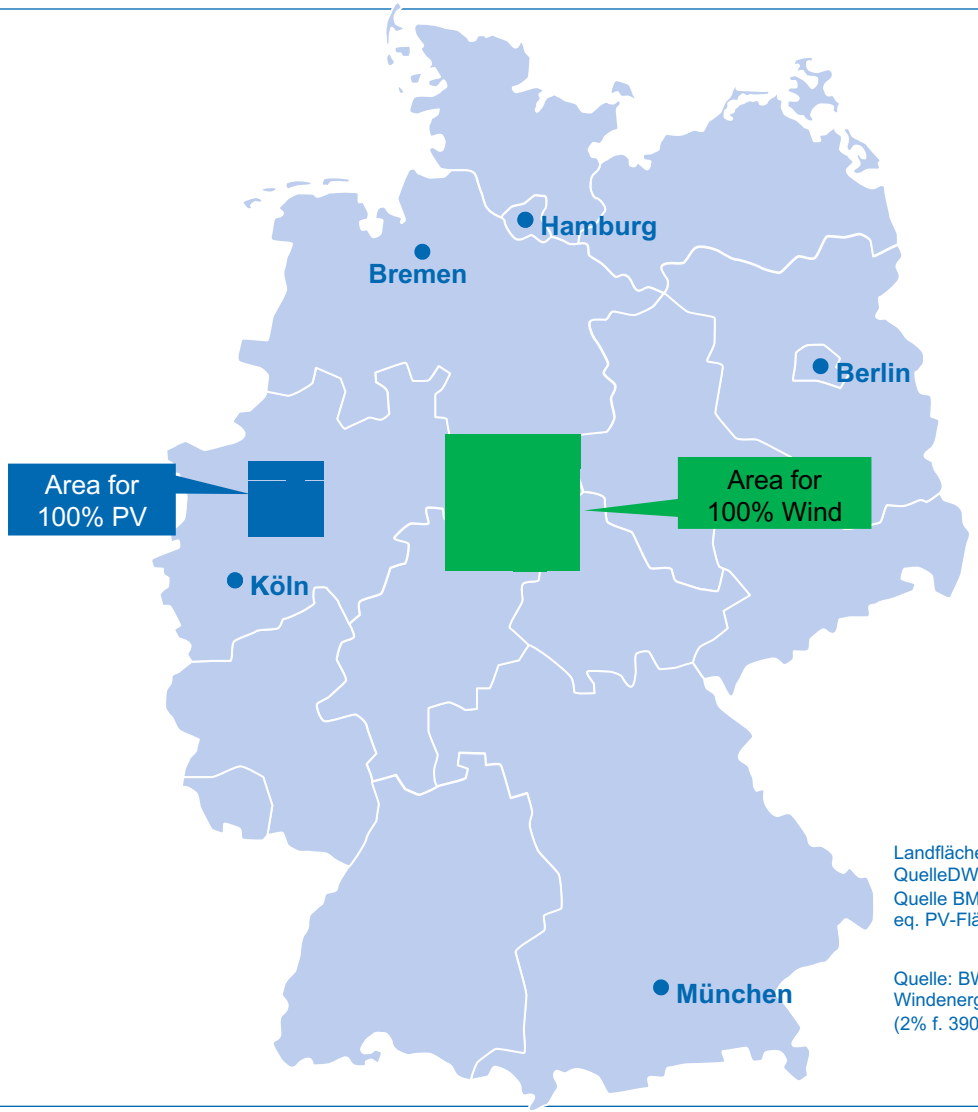


Estimated cost for 2020

Automotive inverter 3 €/kVA

DC Solid-State Transformer 9 €/kVA

Renewable Energy Supplies can Cover all Electricity Needs
(example Germany)



Landfläche BRD: 357.186 km^2
QuelleDWD: 1050 kWh/m^{2}a → 15% Wirkungsgrad →157 GWh/km^{2}a
Quelle BMWi: Bruttostromerzeugung 2015: 627,8 TWh,
eq. PV-Fläche 3993 km^2 (1,1%, ca, 63 km x 63 km)

Quelle: BWE Studie Potenzial
Windenergienutzung an Land (Kurzfassung)
(2% f. 390 TWh)

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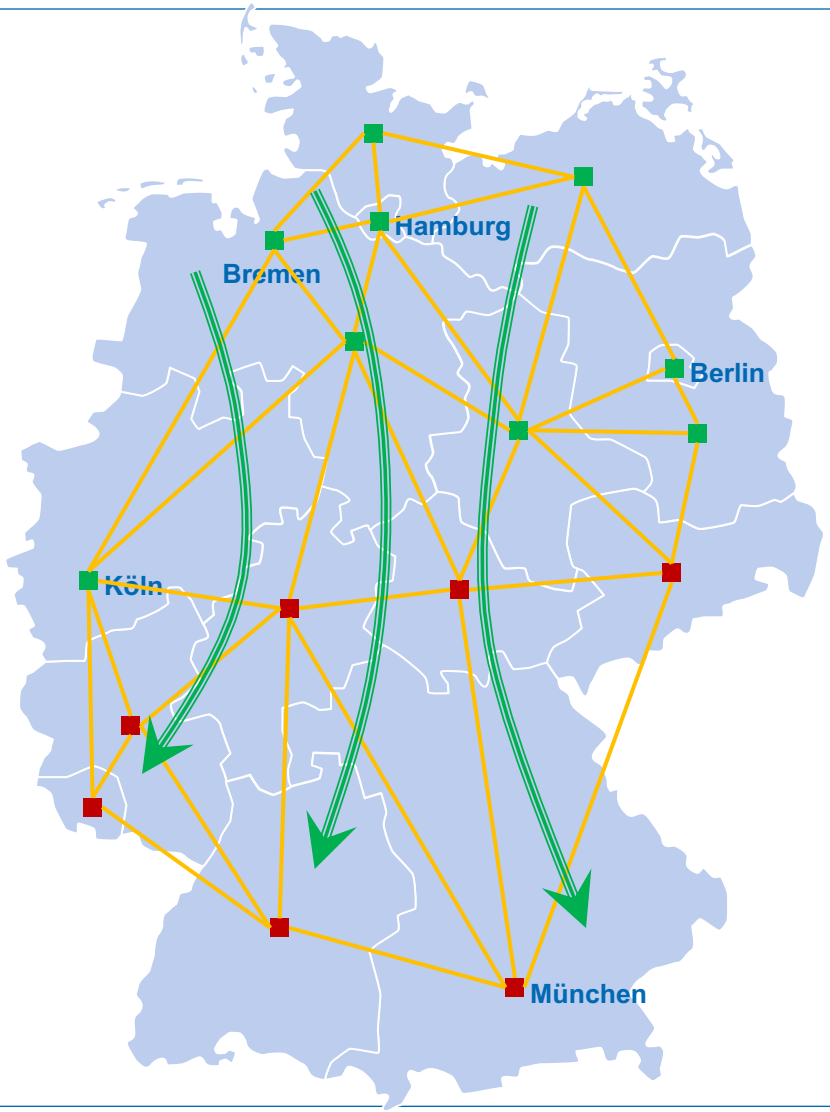
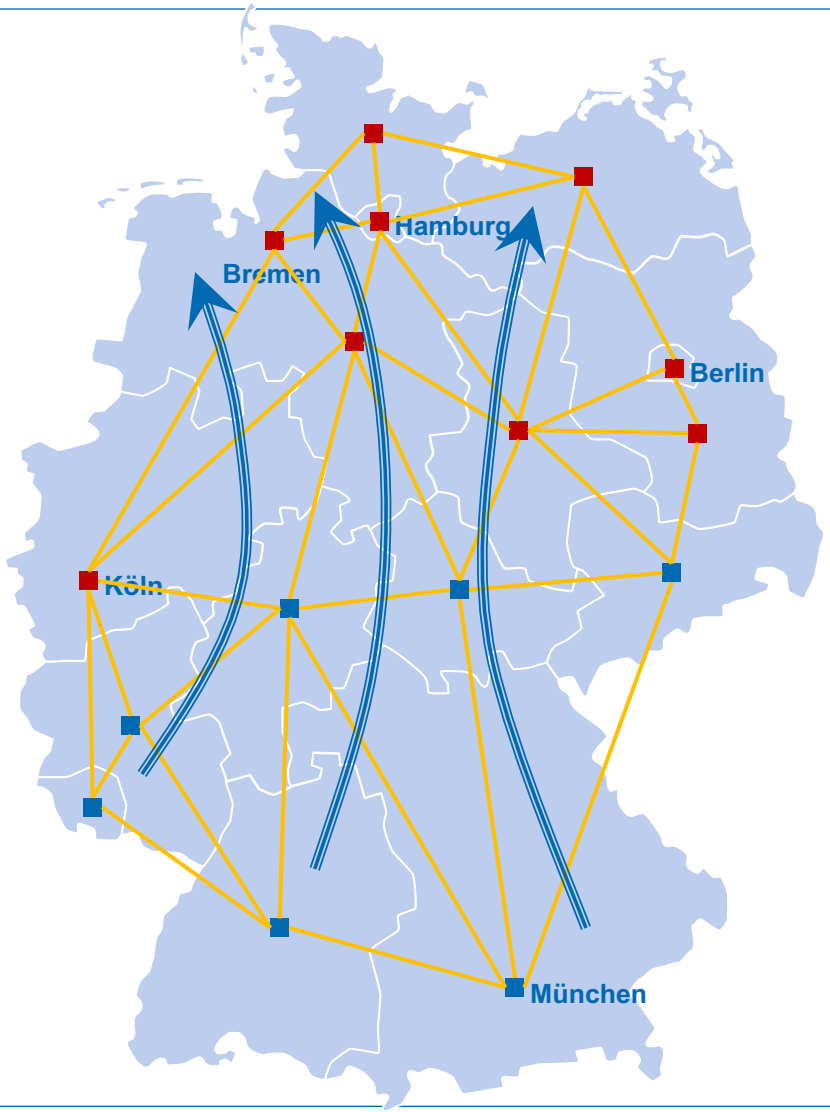
Fall and Winter – mostly Wind Energy

Massive Power transfer needed from South to North – Overlay HVDC



Spring and Summer – mostly PV

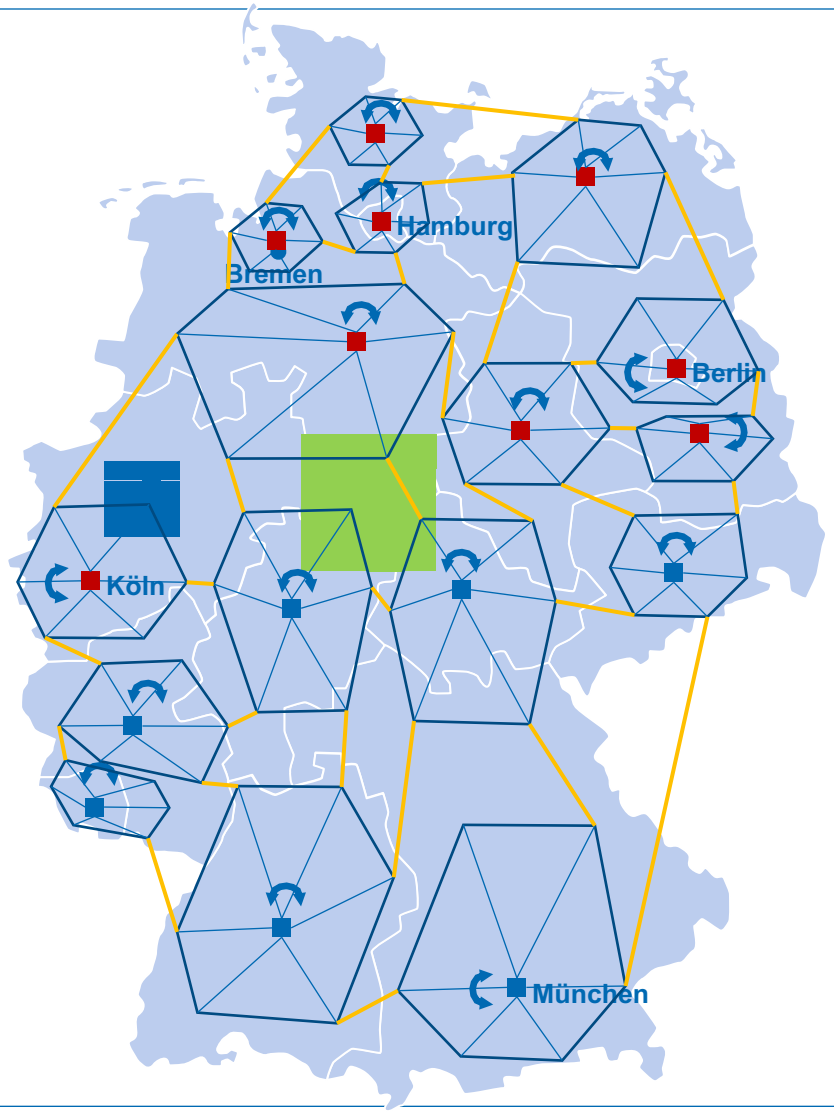
Massive Power transfer needed from South to North – Overlay HVDC



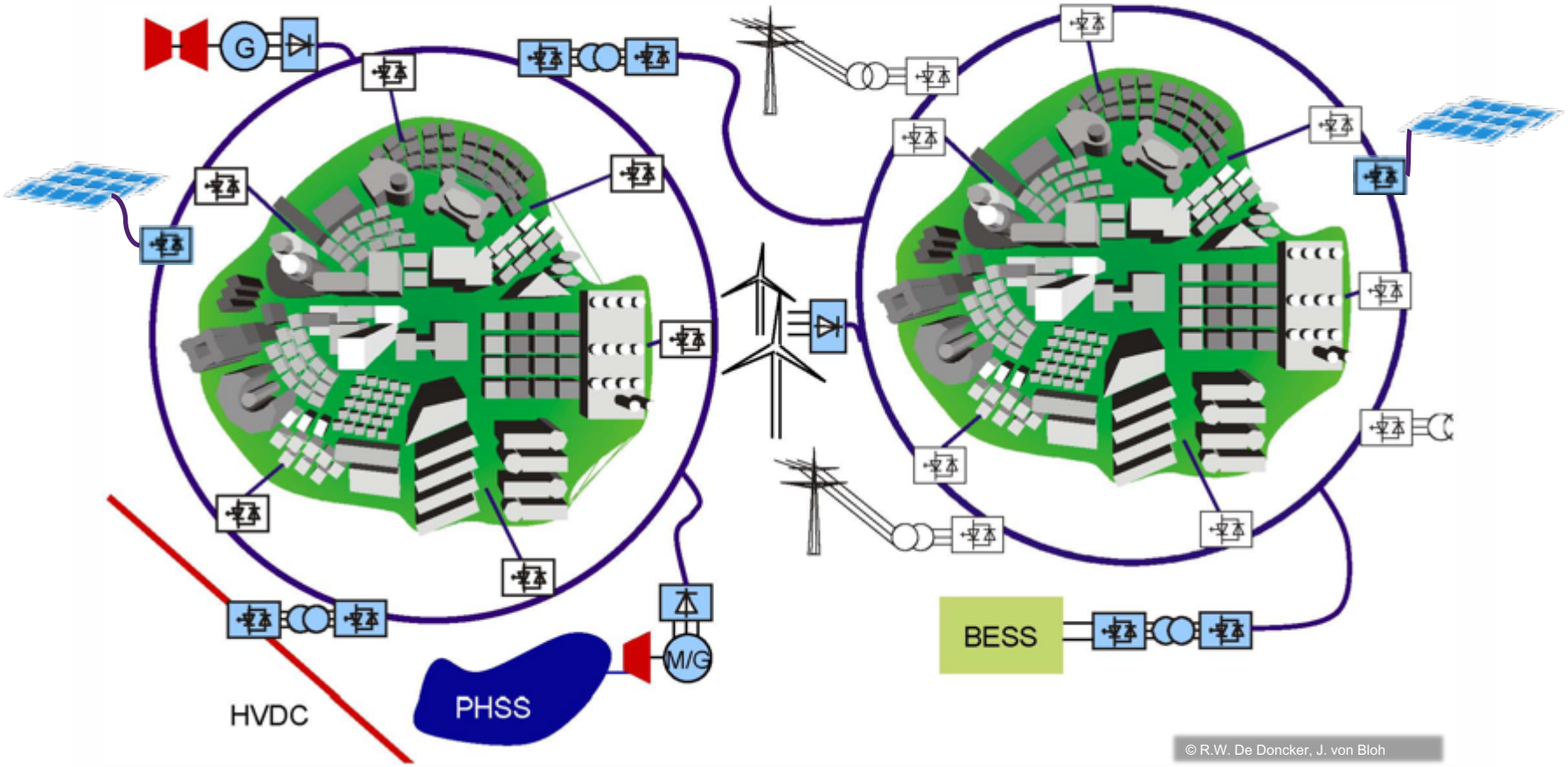
Distributed Installation of REN - Underlay Grid

Exchange of energy via cellular, interconnected medium-voltage distribution grid

Underlay distribution grid is an interesting business proposition from DSO perspective

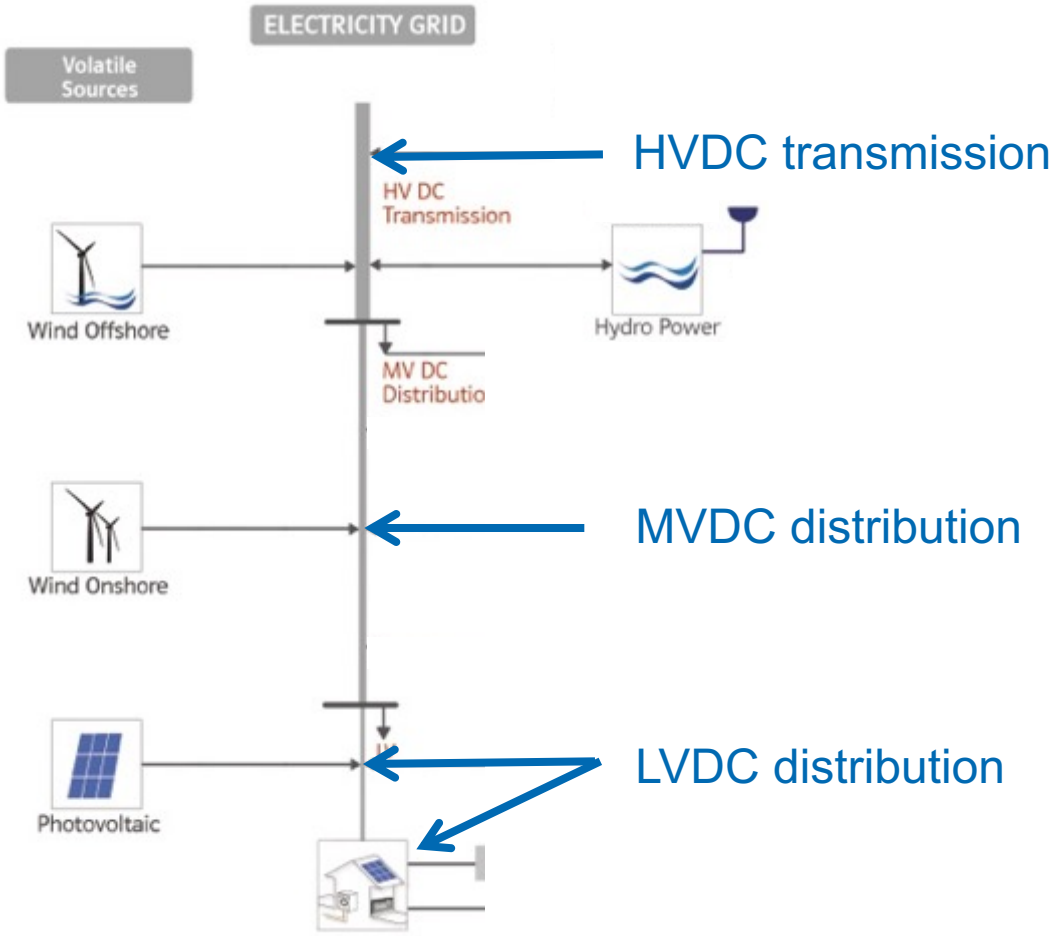


Urban Regional, Flexible, Multi-terminal MVDC Distribution Grid



Concepts for a CO_2-neutral Energy Supply System

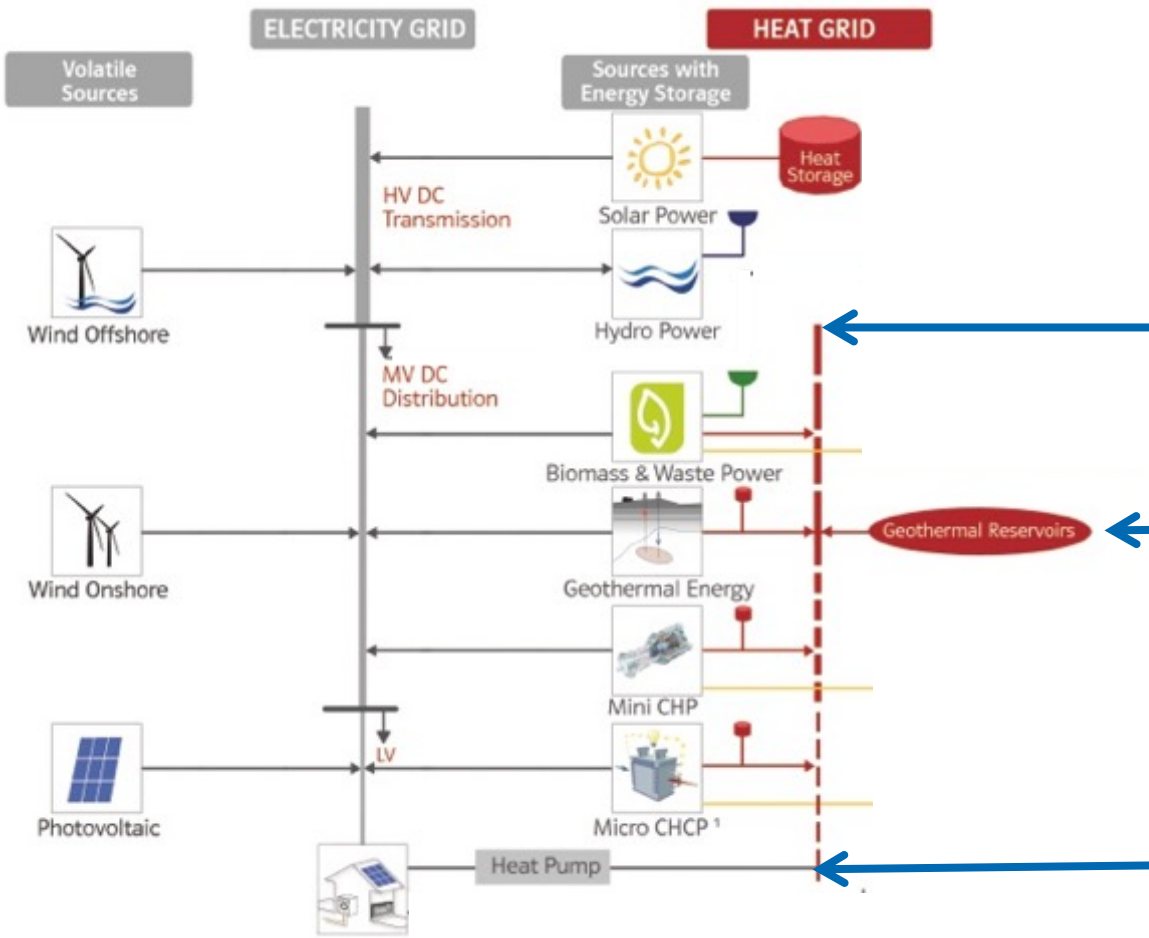
Digitalization and Electrification linking Sectors to make the transition economically viable



Large scale use of renewables, i.e. hydro, wind and PV as primary energy sources. Sources are far distance and local in buildings, city quarters.

Concepts for a CO_2-neutral Energy Supply System

Digitalization and Electrification linking Sectors to make the transition economically viable



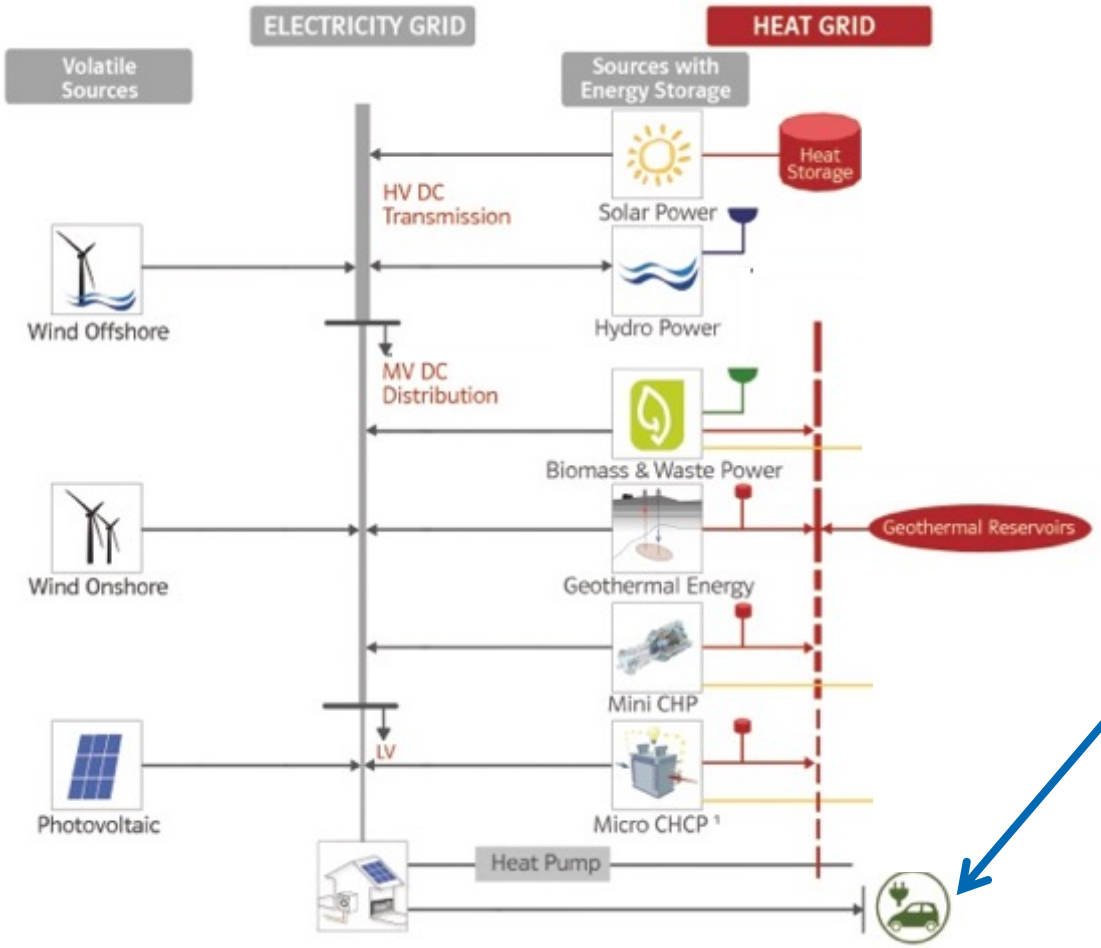
Linking e-grid to heat sector for short term and seasonal energy storage.

Small scale CHP power back-up sources.

Heat pumps for full electrification of HVAC of buildings.

Concepts for a CO_2-neutral Energy Supply System

Digitalization and Electrification linking Sectors to make the transition economically viable



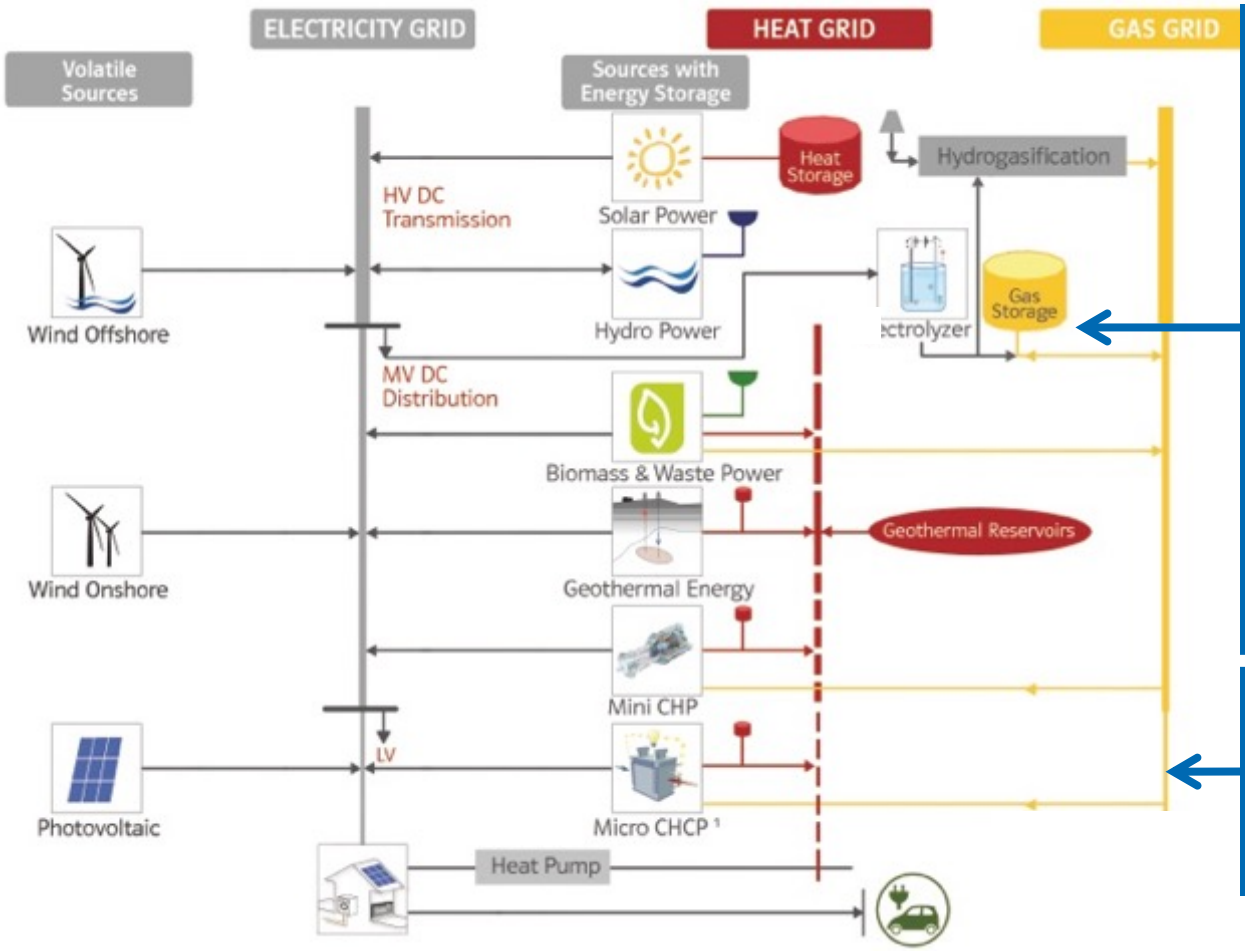
Linking e-grid to e-Mobility sector.

Providing DMS and short term grid stability.

Full electrification of mobility in the urban environment

Concepts for a CO_2-neutral Energy Supply System

Digitalization and Electrification linking Sectors to make the transition economically viable

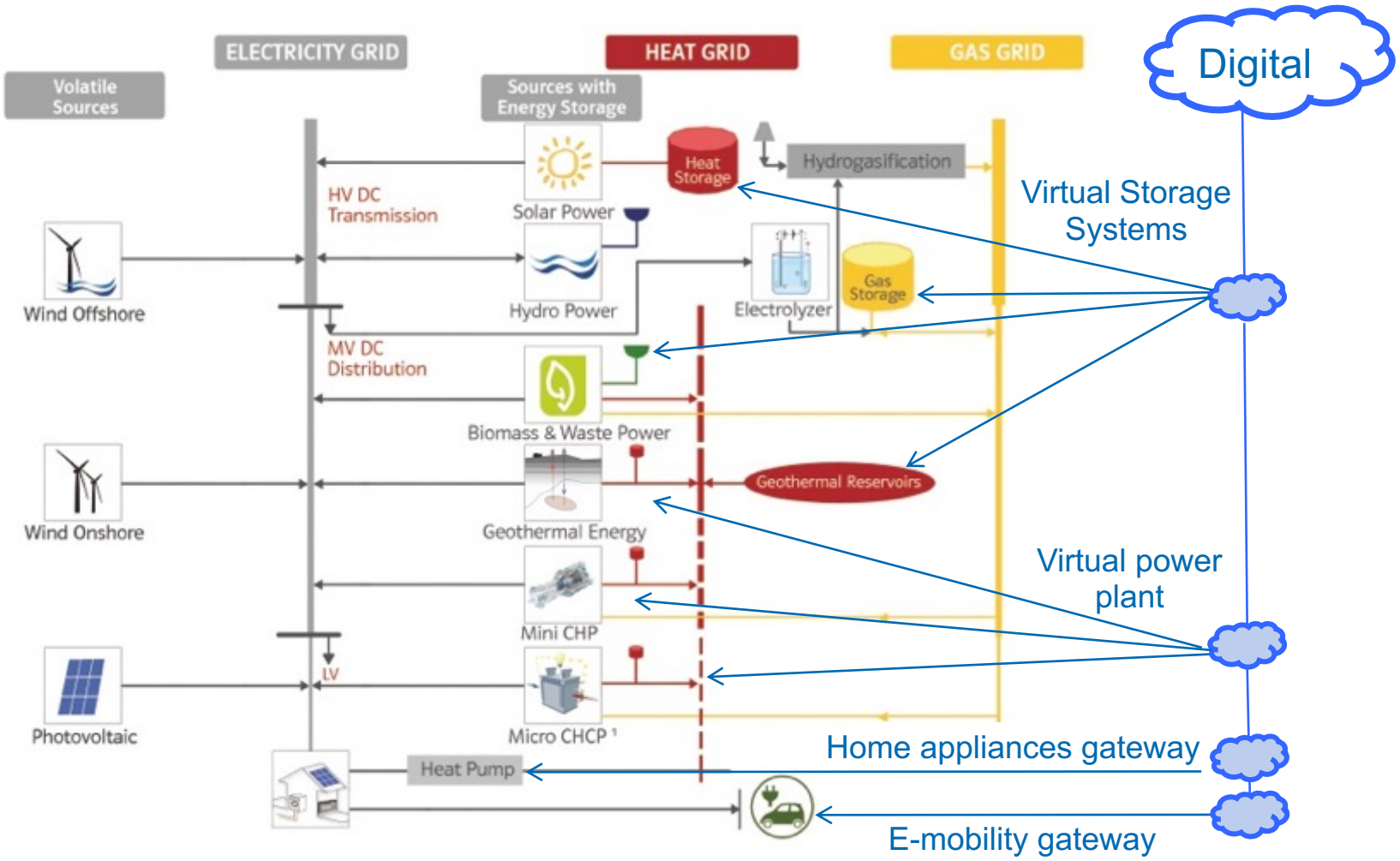


Linking e-grid and heat grid with electrolysers to gas and synthetic fuels sector for long term strategic energy storage.

Reuse of existing infrastructure

Concepts for a CO_2-neutral Energy Supply System

Digitalization and Electrification linking Sectors to make the transition economically viable



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Concepts for a CO_2-neutral Energy Supply System

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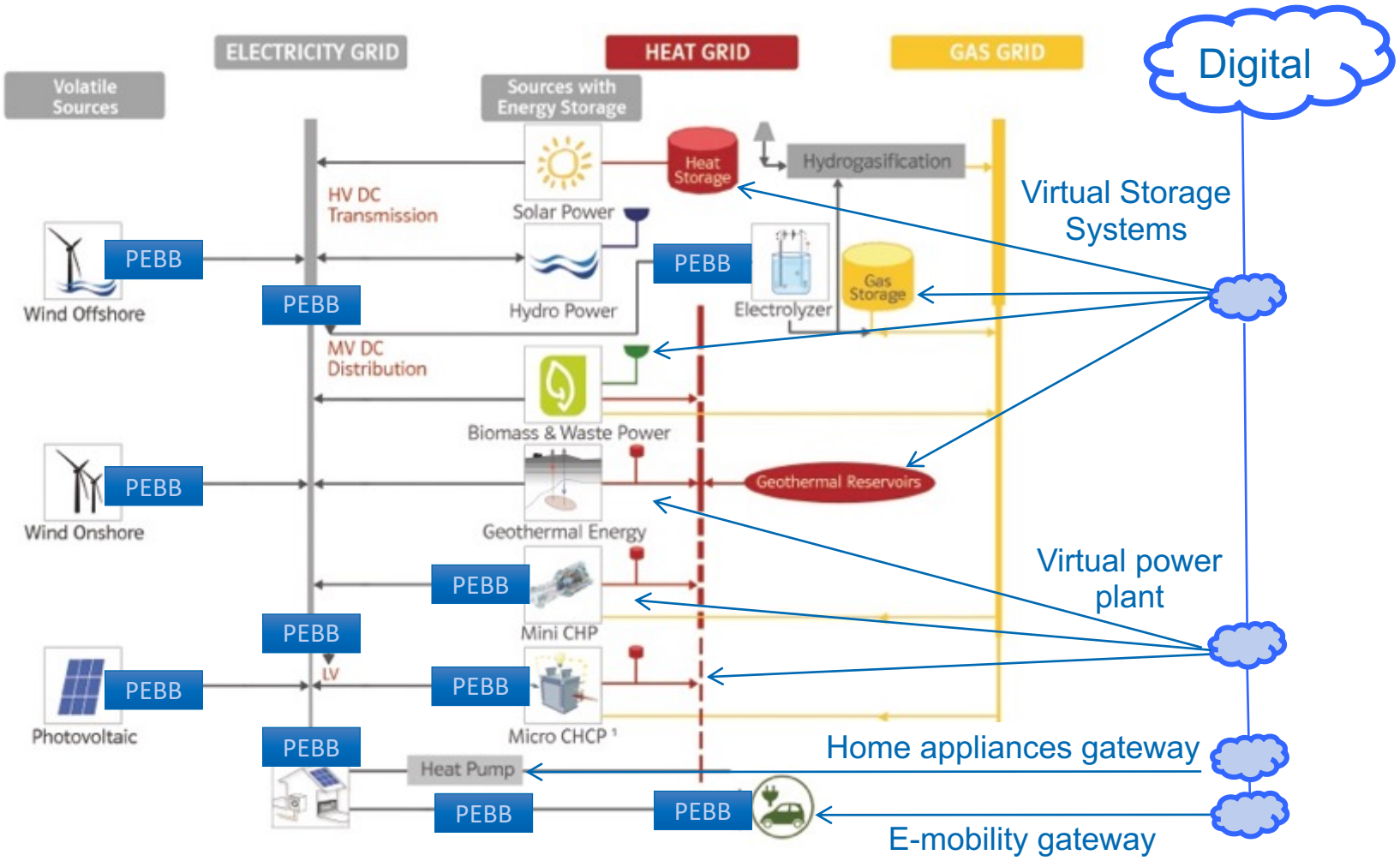

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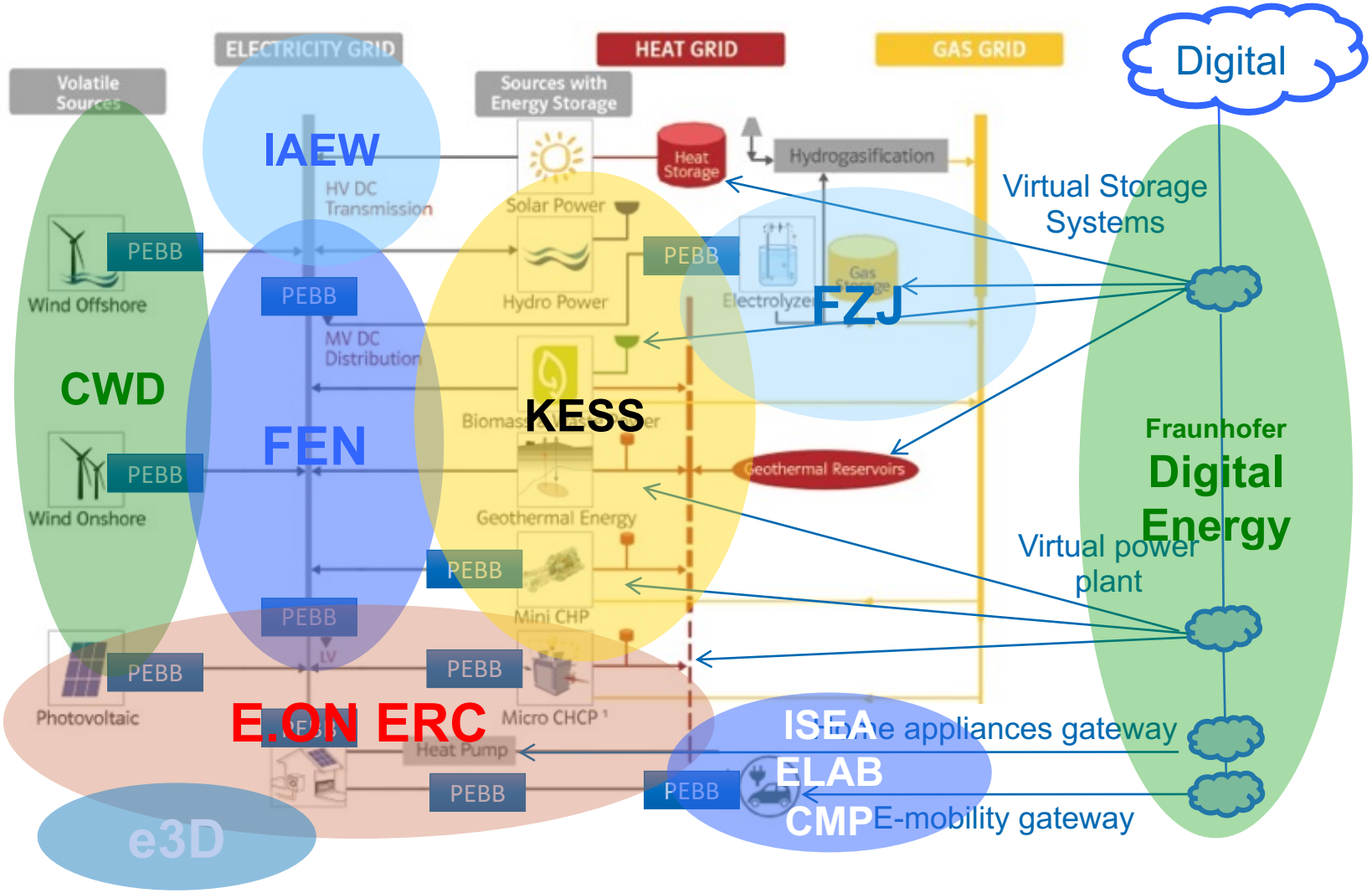
RWTH Centers, JARA Institutes with Fraunhofer have all expertise needed to build a sustainable energy system



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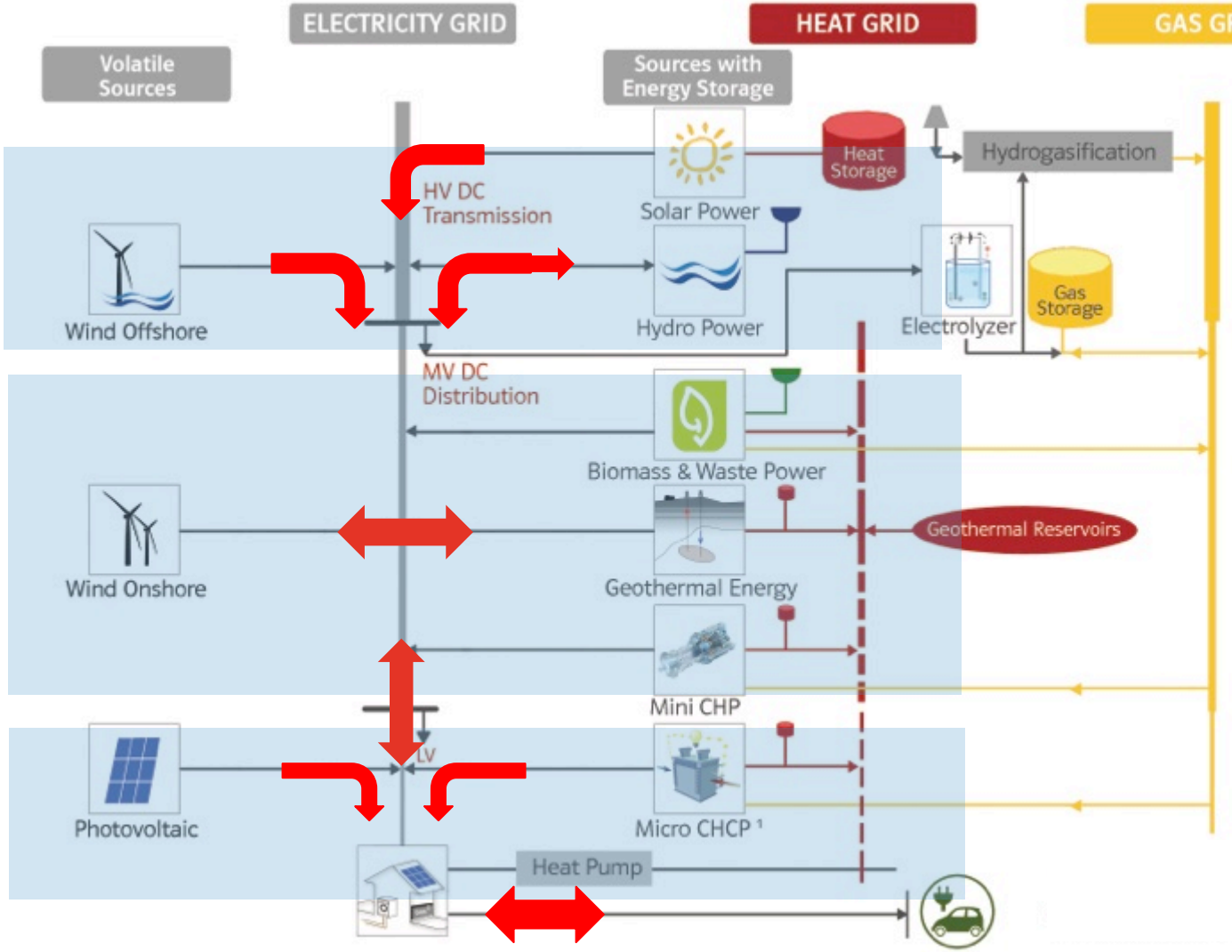
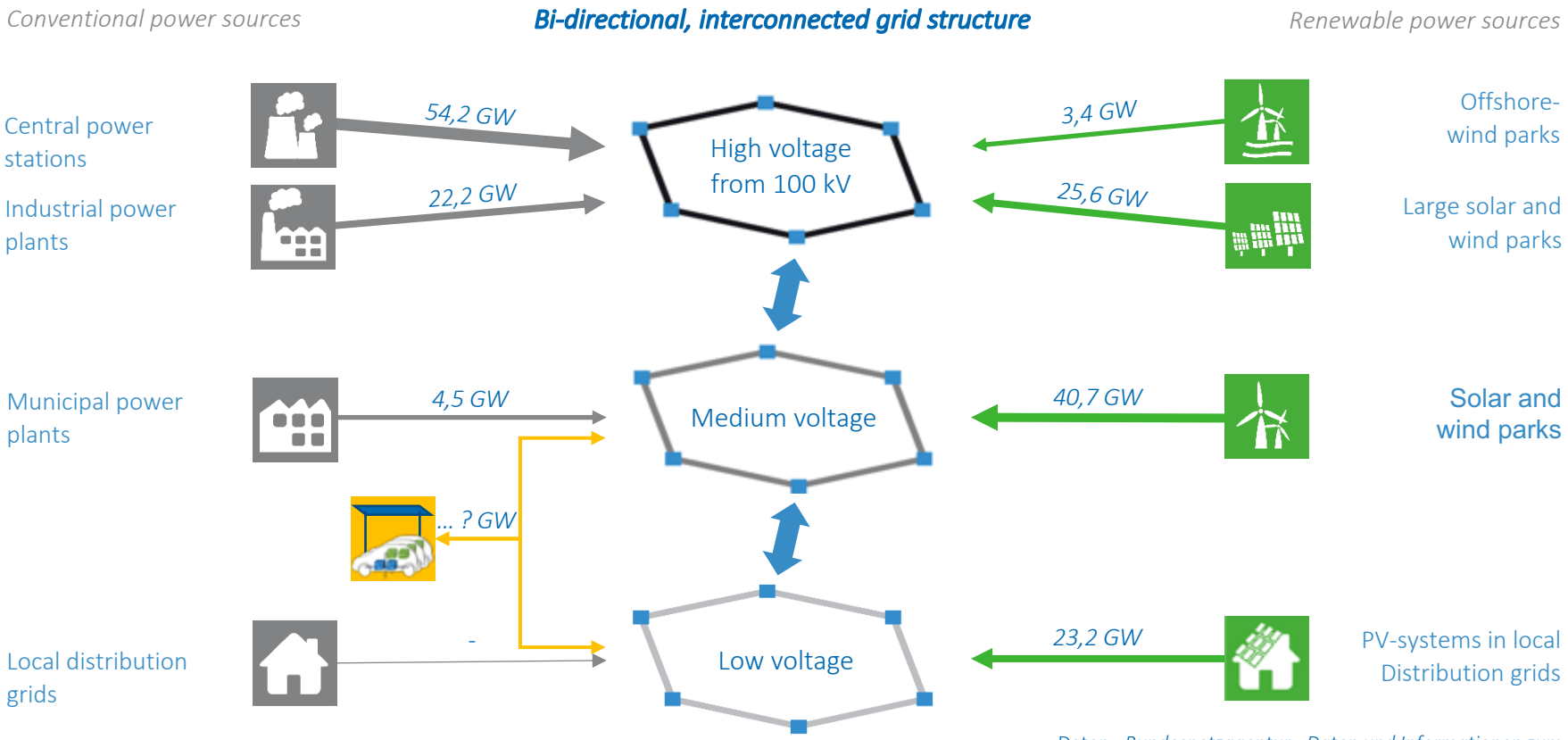
Electrical Grids for a CO2 Neutral Electrical Energy Supply System
About 1/3 in HV, 1/3 in MV, 1/3 in Low-Voltage Distribution Grid



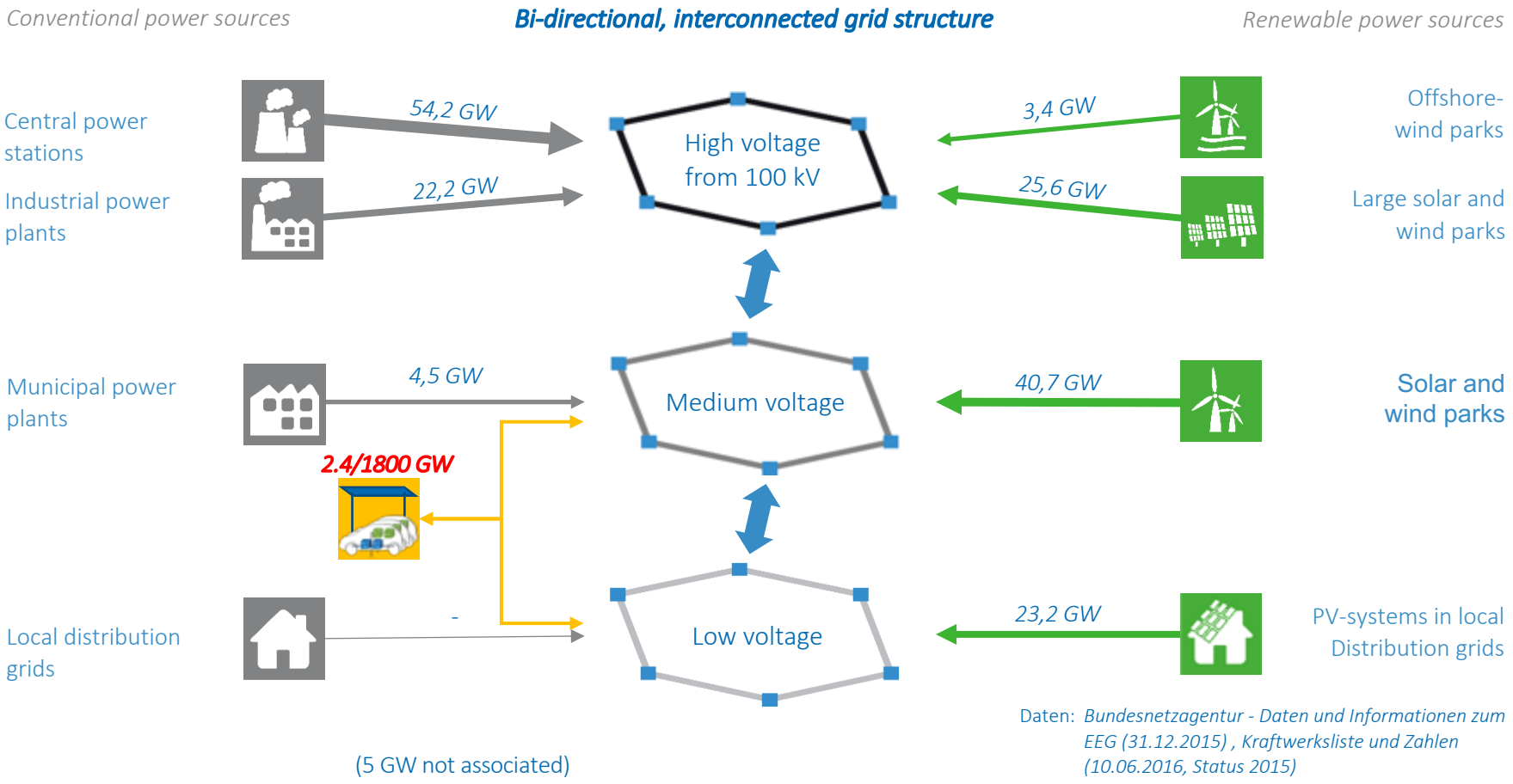
Interesting observation:
The transmission grid requires just minimal extension with HVDC.
ETG Task Force expects less cost for DC integration in infrastructure.
The MV distribution grid will become bottleneck.

The “1/3 rule” already applies to the German installed capacities
What are requirements for massive charging and fast charging EVs?



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

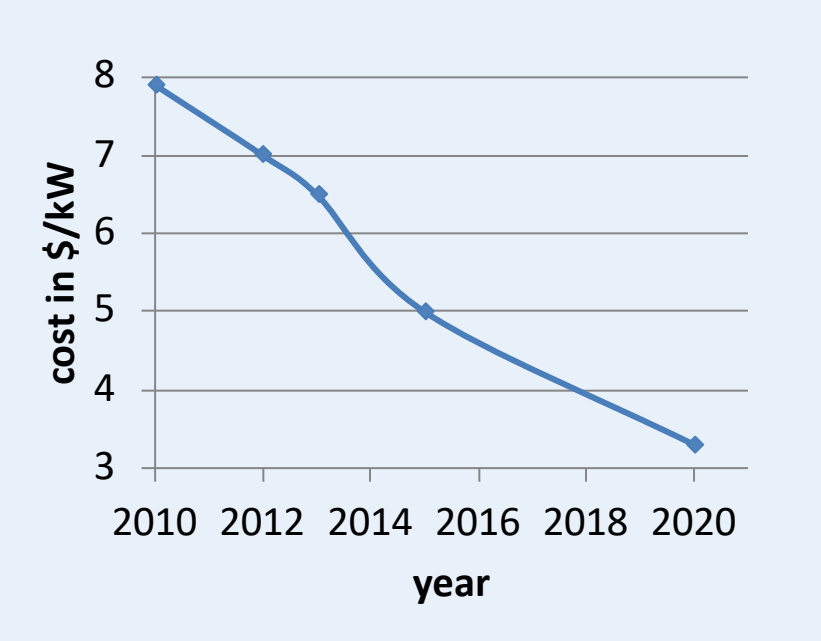
Additional installed capacity of 100% e-Mobility is huge

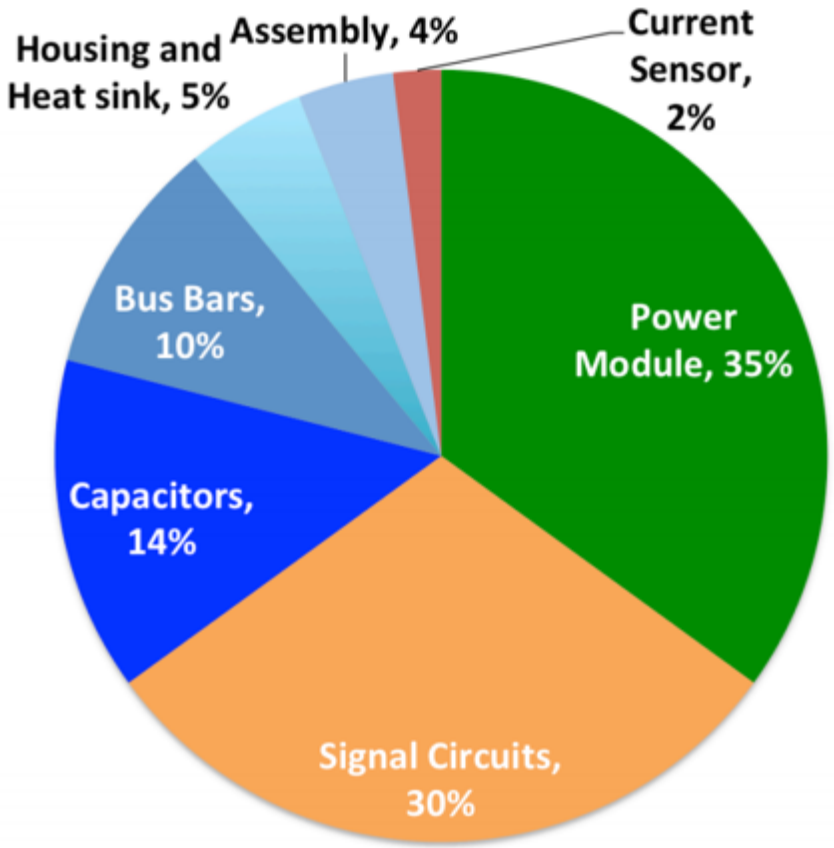


Future grids cannot ignore the energy feed-in in medium- and low-voltage distribution grids and e-Mobility and must become interconnected

Technology Drivers - Price Development of Power Electronics

- Specific cost for drive inverters
  - 1995: $50/kVA[1]
  - 2015: $5/kVA[2]
  - 2020 R&D target: $3.3/kVA

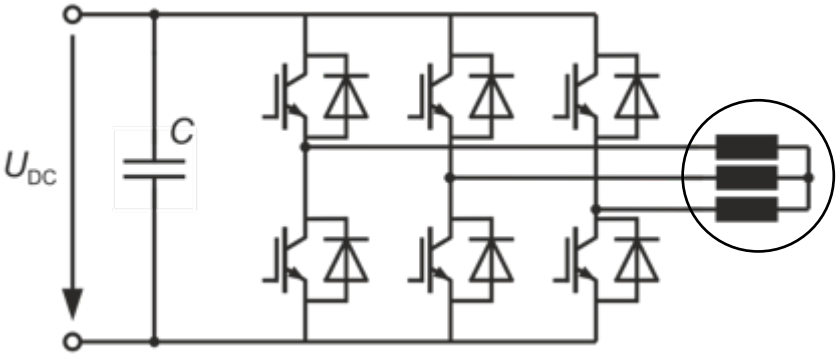




[1] Source: Data provided by R. De Doncker, based on DOE projects
[2] Source: U.S. Department of Energy, Vehicle Technologies Office

Modular drivetrain concepts
More integrated inverter & machine

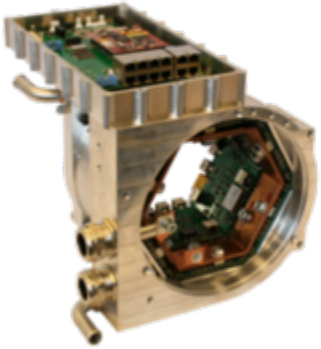
- Modular drive systems
- Competing drivetrain concept:
  - Optimization of individual components, i.e. Inverter and machine
  - Full integration of inverter in machine



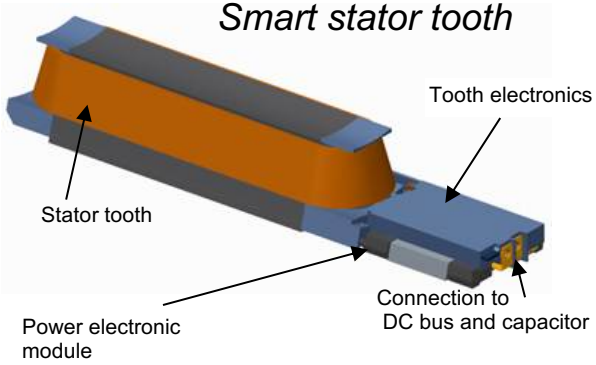
Level of integration

[ISEA, *e performance*, 2012]

[ISEA, *e performance*, 2012]



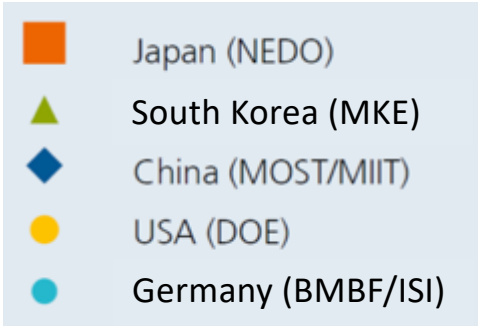
[ISEA, *eMoSys*, 2014]



[ISEA, *EMiLE*, 2016]

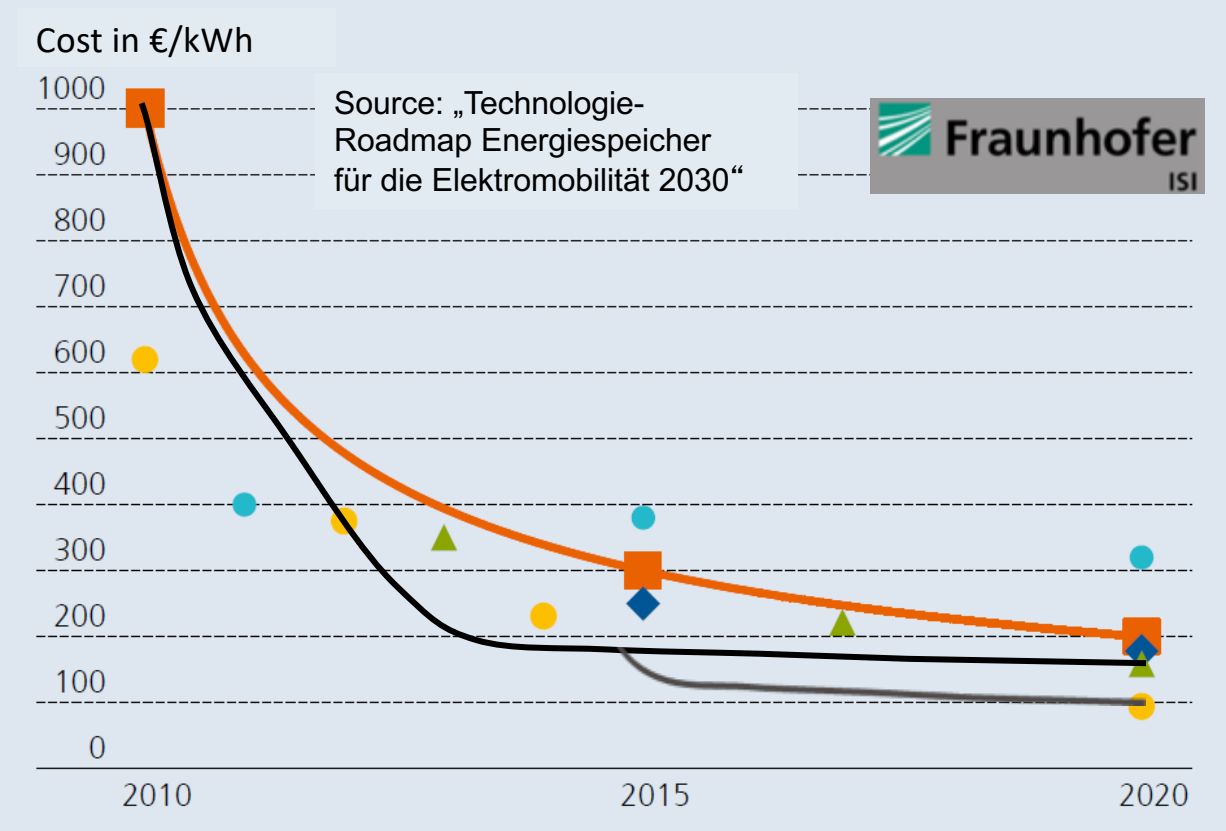
Technology Drivers - Price Development of Lithium-Ion Batteries (only cells)

- World-wide target for costs (€/kWh) for large-scale automotive LIB cells, published by the end of 2012



ISEA forecast (2010): Prices decreased faster than predicted by NEDO

Consumer cell are even cheaper (e.g. TESLA)



Example - eTron
Modular Electric Drive Train

AUDI AG

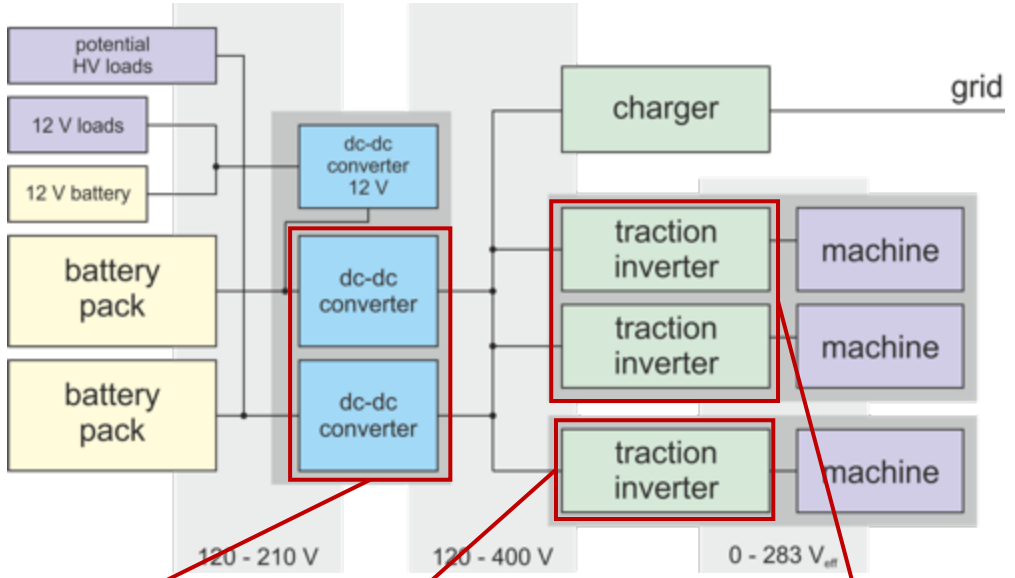
RWTH AACHEN UNIVERSITY

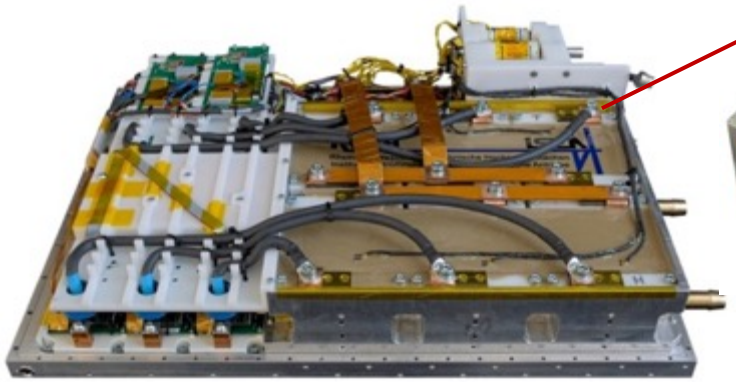
Audi Electronics Venture GmbH

GEFÖRDERT VOM Bundesministerium für Bildung und Forschung

Robert Bosch GmbH
Bosch Engineering GmbH

BOSCH Technik fürs Leben





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E-Mobility is coming
Demand for Ultra Fast Charging is coming with it, regardless if it is realistic!

e performance developed at RWTH/ISEA - predecessor of the Audi Q6 , production at AUDI Plant Brussels

- Demonstrator
  - 280 kW
  - 2x 115 kW ASM
  - 1x 50 kW PMSM
  - 2 Lilon batteries
  - 144 V and 216 V
  - 38,4 kWh

- Audi Q6 e-tron quattro
  - 370 kW (three motors)
  - Max. speed 210 km/h
  - 95 kWh Lilon, 500 km driving range
  - **DC charging with 150 kW**
  - **400 km in 30 min, 100 km in 8 min**

Definition of Fast Charging

- Definition from Elektromobilität NRW[1]
  - Fast charging: P > 22 kW
- Connectors are standardized in the EU

www.cleantechnica.com

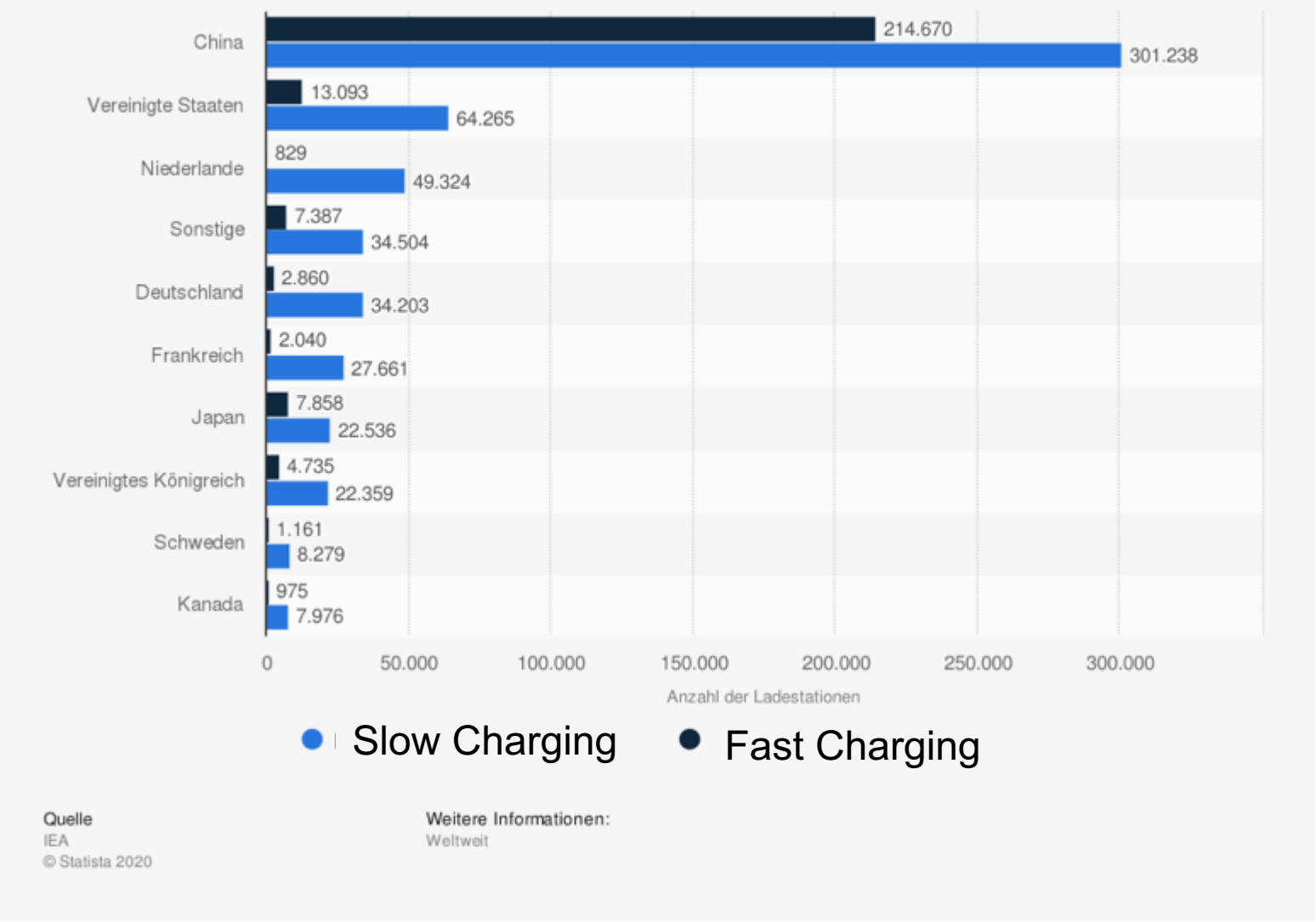
- Charging voltage up to 400 V_{ac} or 800 V_{dc}

	Household	Normal Charging	AC Fast-Charging	DC Fast-Charging
Installation	Plug socket	Wallbox/ Charge stick	Power stick	Power stick
Socket	SchuKo-socket	Typ-2-socket	Typ-2-socket	Combo-2-socket
Voltage	AC 230 V	AV 400 V	AC 400 V	DC < 800 V
Power	< 3.7 kW	< 22 kW	< 44 kW	< 170 kW
Charging Time (for 22 kWh battery)[2]	> 10 h	1-5 h	30 min.	< 30 min

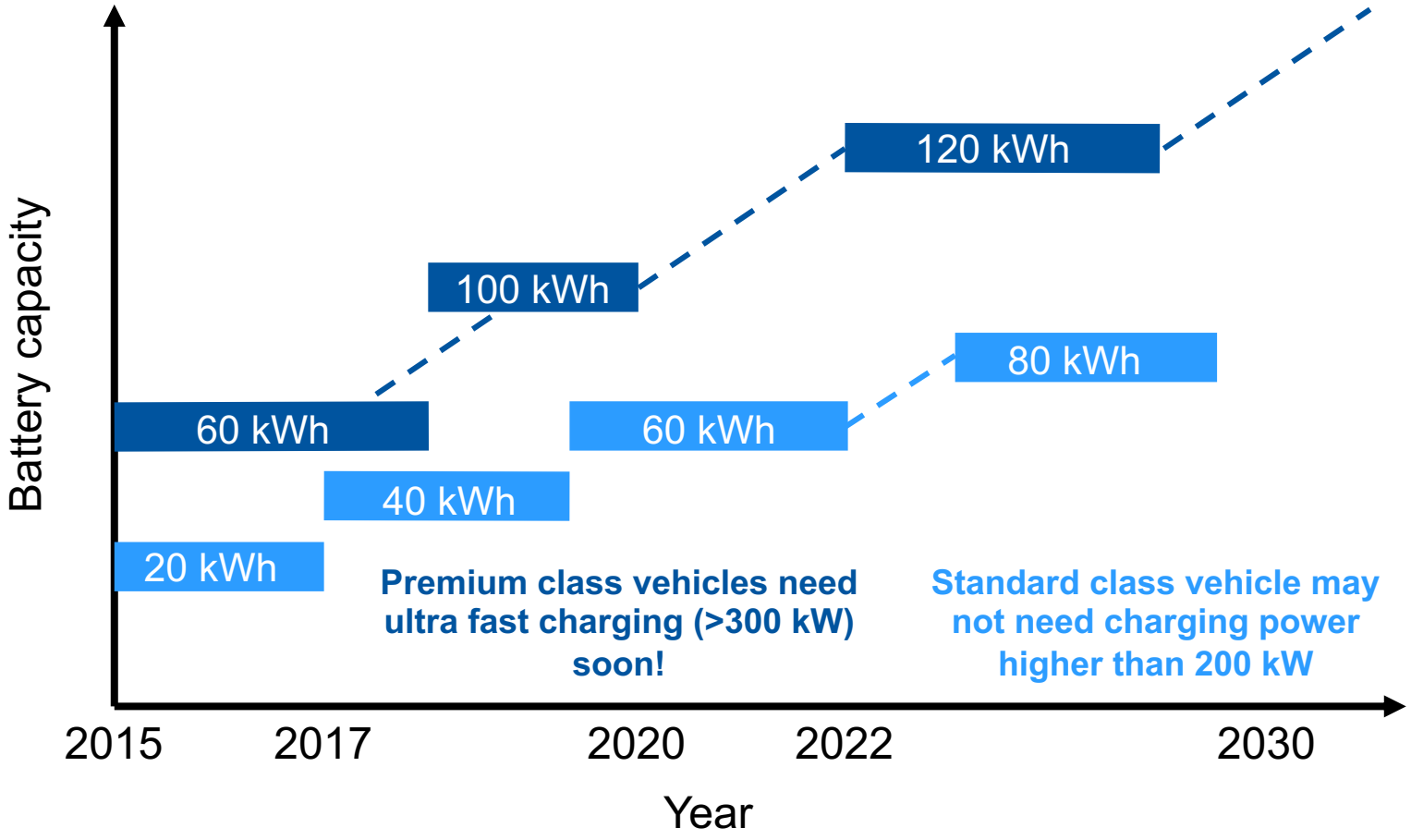
[2] Linear assumption. In reality a 22 kWh ist charged within 90 min. by a charging power of 22 kW due to chemical issues

[1]Source: www.elektromobilitaet.nrw.de

Number of public charging stations for electric vehicles in 2019

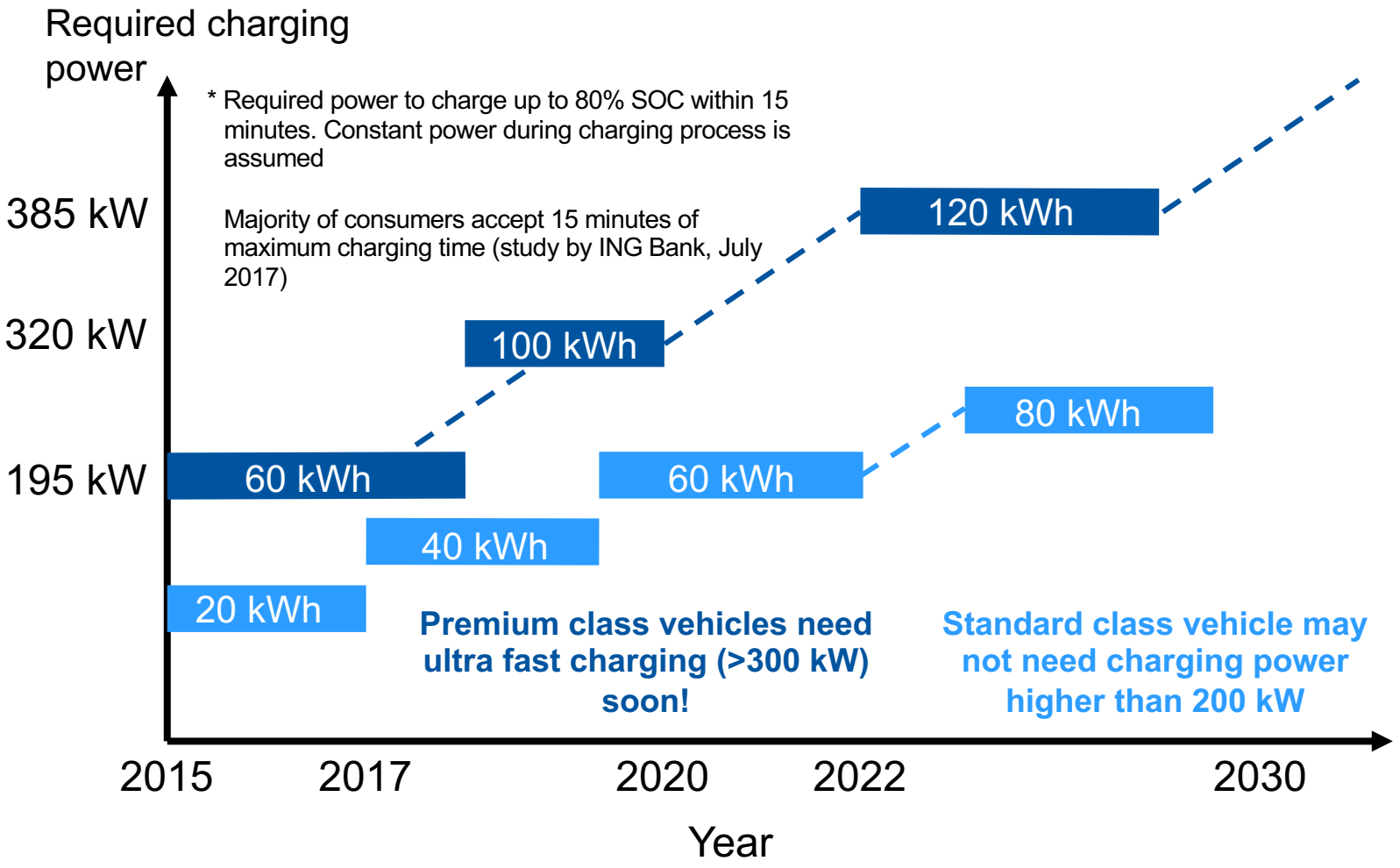


View of (French) OEMs and first Tier Suppliers
When is Ultra Fast Charging Infrastructure Required?



Source: J.B. Moreau. „The EV charging market: present & future outlook“. APE Conference 2017. Paris

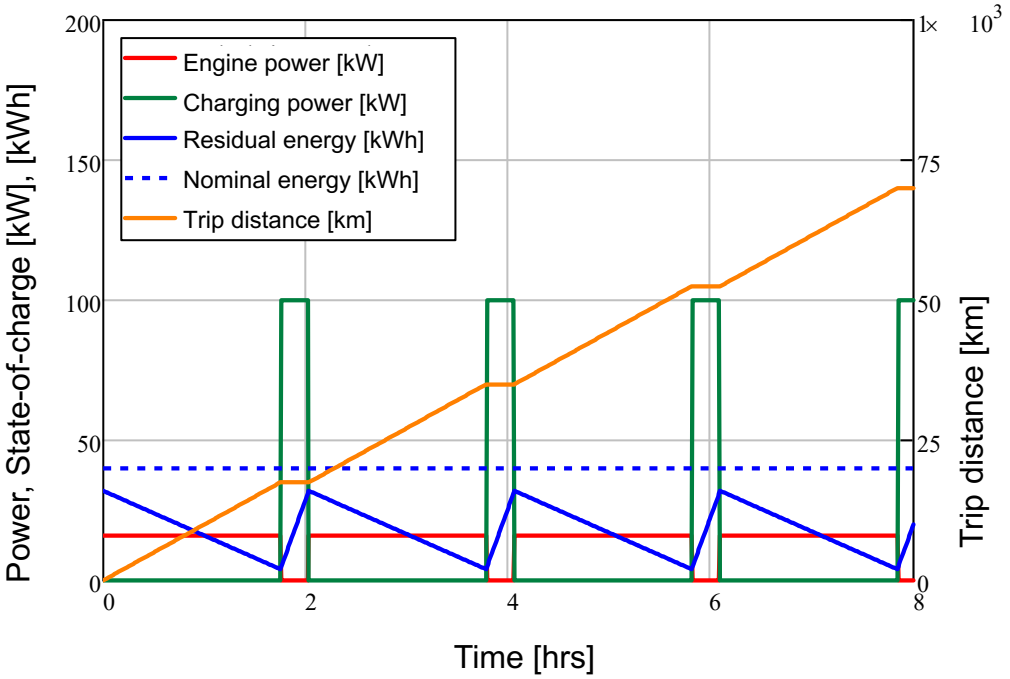
View of (French) OEMs and first Tier Suppliers
When is Ultra Fast Charging Infrastructure Required?



Source: J.B. Moreau. „The EV charging market: present & future outlook“. APE Conference 2017. Paris

Long-Distance driving using fast-charging with EV having 240 km range

- Assumptions
  - Minimum SOC 10%
  - After fast charge SOC 80%
  - Charging power 100 kW
  - Consumption
    - 16 kWh/ 100 km
    - At 100 km/h
- Result
  - Achieved distance after 8 hrs
    - **700 km**
  - 3 Recharge stops



A diesel car, with a 30 min break, can drive 750 km in 8 hours

It is all in our mind and ultra fast charging (>100 kW) seems unnecessary

100% E-Mobility is it a grid problem?
For example 100% E-Mobility in Germany

- Net electricity consumption DE 2016 [1]: 525 TWh
- Grid peak load 2016 [2]: 83.75 GW*)

- 44.6 Mio. registered cars, with 38 km/car and day
- Only 2% drive more than 100 km on a given day

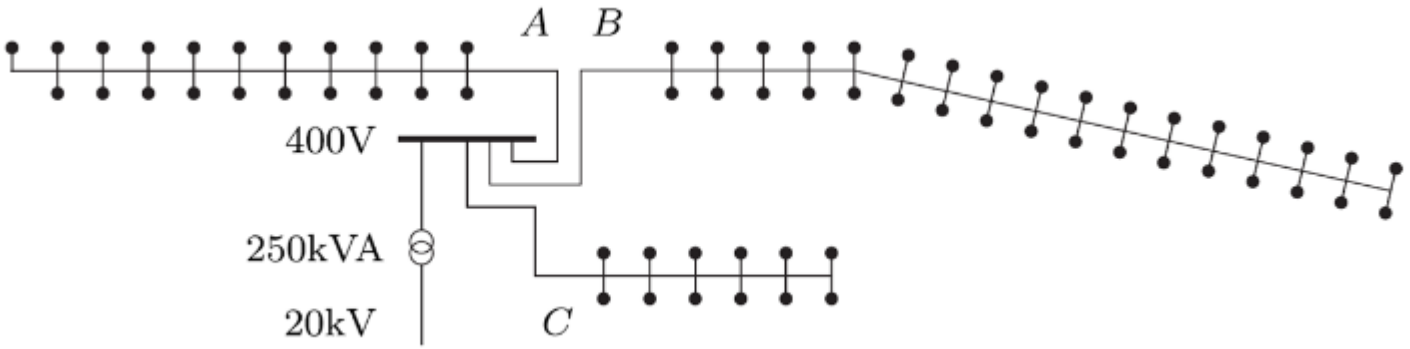
- 16 kWh/100 km (conservative driving Renault Zoe I)
  - Annual fleet energy consumption: 100 TWh, 19% of annual electrical energy
  - On-board storage 40 kWh/250 km: 1,78 TWh, 30 hrs of average grid load

- Installed Charging Power
  - 44.6 Mill. Cars, 4…40 kW on-board charger: 180-1800 GW, 2.1x … 21x grid peak load
  - Average fleet power (day, 24 hrs): 11 GW, 13% of grid peak load

[1] https://de.statista.com/statistik/daten/studie/164149/umfrage/netto-stromverbrauch-in-deutschland-seit-1999/
[2] https://www.agora-energiewende.de/de/themen/-agothem-/Produkt/produkt/76/Agorameter/
[3] http://www.kba.de/DE/Statistik/Kraftverkehr/VerkehrKilometer/verkehr_in_kilometern_node.html

On-board storage sufficient for primary reserve and possibly day-night balance.
The grid control power is distributed.

Distribution Grid
Typical Urban AC Grid Structure



Branch A
- 21 households, max. total power: 98 kW
- Length: 461 m

Branch B
- 34 households, max. total power : 129 kW
- Length : 715 m

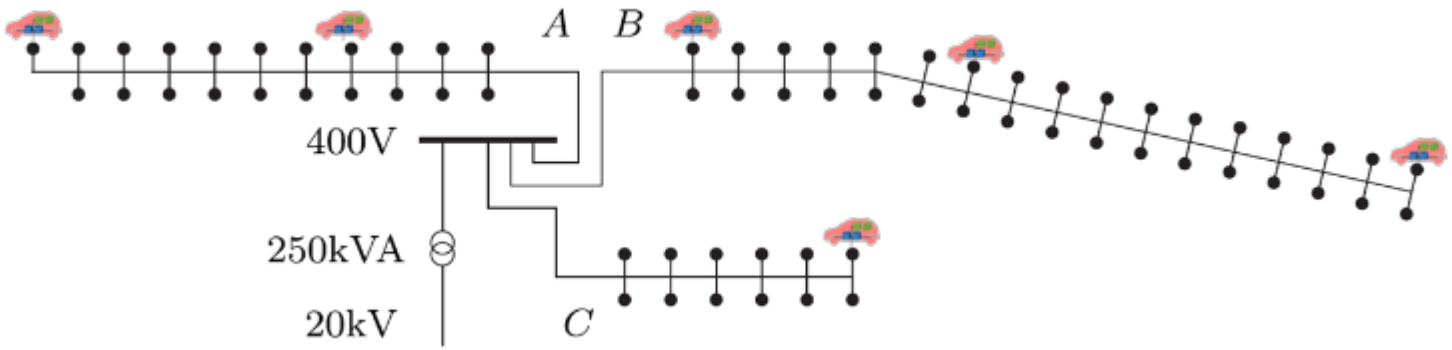
Branch C
- 10 households, max. total power : 68 kW
- Length : 185 m

Connection to transmission grid
- Max. total power : 250 kVA
- Average apparent power per household 3,85 kVA

M. Stieneker and R. W. De Doncker, "Medium-voltage DC distribution grids in urban areas," 2016 IEEE 7th International Symposium on Power Electronics for Distributed Generation Systems (PEDG), Vancouver, 2016

Distribution Grid – Challenge with 5 kW EV Chargers

Typical Urban Grid Structure with e-Mobility slow charging, 6 EVs



Branch A

- 21 households, max. total power: 98 kW → 108 kW (2 veh.)
- Length: 461 m

Branch B

- 34 households, max. total power : 129 kW → 144 kW (3 veh.)
- Length : 715 m

Branch C

- 10 households, max. total power : 68 kW → 73 kW (1 veh.)
- Length : 185 m

Connection to transmission grid

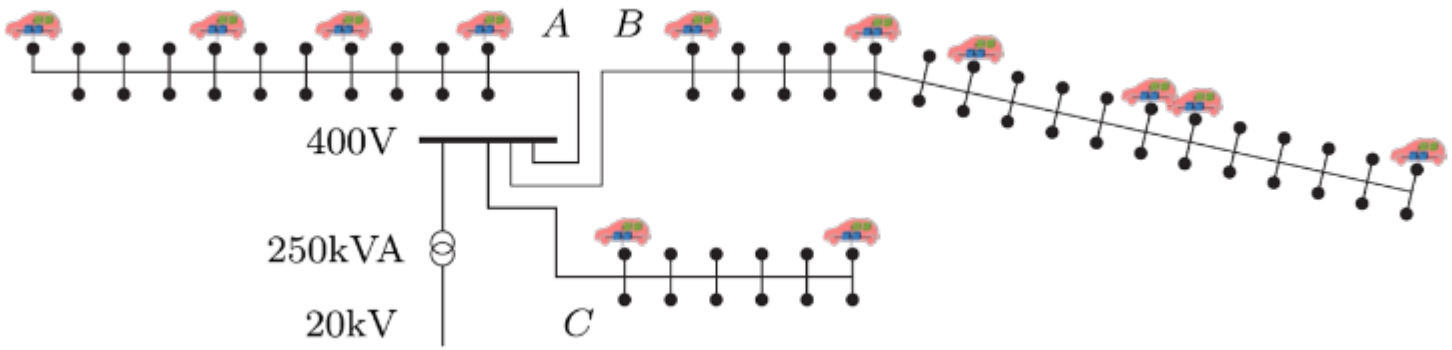
- Max. total power : 250 kVA → 325 kW (worst case)

M. Stieneker and R. W. De Doncker, "Medium-voltage DC distribution grids in urban areas," 2016 IEEE 7th International Symposium on Power Electronics for Distributed Generation Systems (PEDG), Vancouver, 2016

ISEA Stromrichtertechnik und Elektrische Antriebe | E.ON Energy Research Center | FLEXIBLE ELEKTRISCHE NETZE | RWTH AACHEN UNIVERSITY

Distribution Grid – Challenge with 5 kW EV Chargers

Typical Urban Grid Structure with e-Mobility slow charging, 12 EVs



Branch A

- 21 households, max. total power: 98 kW → 118 kW (4 veh.)
- Length: 461 m

Branch B

- 34 households, max. total power : 129 kW → 159 kW (6 veh.)
- Length : 715 m

Branch C

- 10 households, max. total power : 68 kW → 78 kW (2 veh.)
- Length : 185 m

Connection to transmission grid

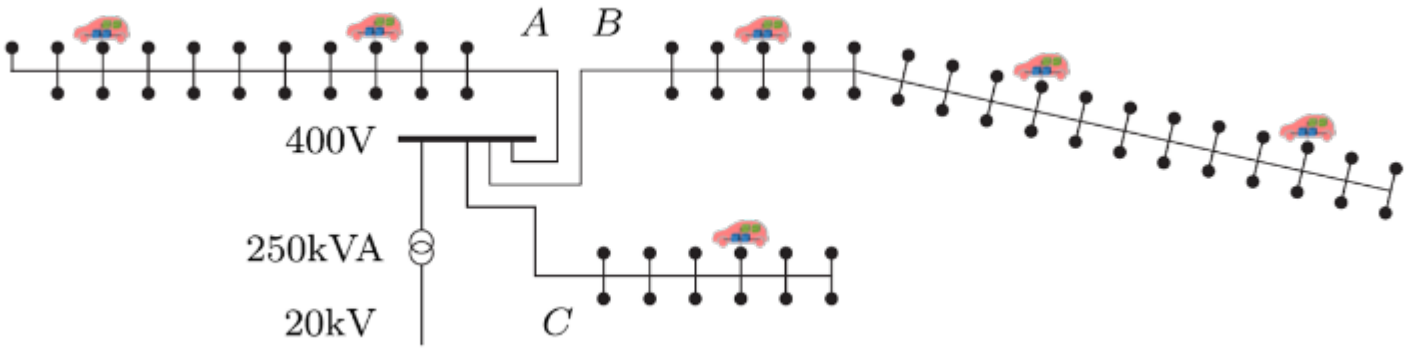
- Max. total power : 250 kVA → 355 kW (worst case)

M. Stieneker and R. W. De Doncker, "Medium-voltage DC distribution grids in urban areas," 2016 IEEE 7th International Symposium on Power Electronics for Distributed Generation Systems (PEDG), Vancouver, 2016

ISEA Stromrichtertechnik und Elektrische Antriebe | E.ON Energy Research Center | FLEXIBLE ELEKTRISCHE NETZE | RWTH AACHEN UNIVERSITY

Distribution Grid – Major Problem with 150 kW EV Charging

Typical Urban Grid Structure with e-Mobility fast charging, 6 EVs



Branch A

- 21 households, max. total power: 98 kW → 398 kW (2 veh.)
- Length: 461 m

Branch B

- 34 households, max. total power : 129 kW → 479 kW (3 veh.)
- Length : 715 m

Branch C

- 10 households, max. total power : 68 kW → 218 kW (1 veh.)
- Length : 185 m

Connection to transmission grid

- Max. total power : 250 kVA → 1.1 MW (worst case)

M. Stieneker and R. W. De Doncker, "Medium-voltage DC distribution grids in urban areas," 2016 IEEE 7th International Symposium on Power Electronics for Distributed Generation Systems (PEDG), Vancouver, 2016

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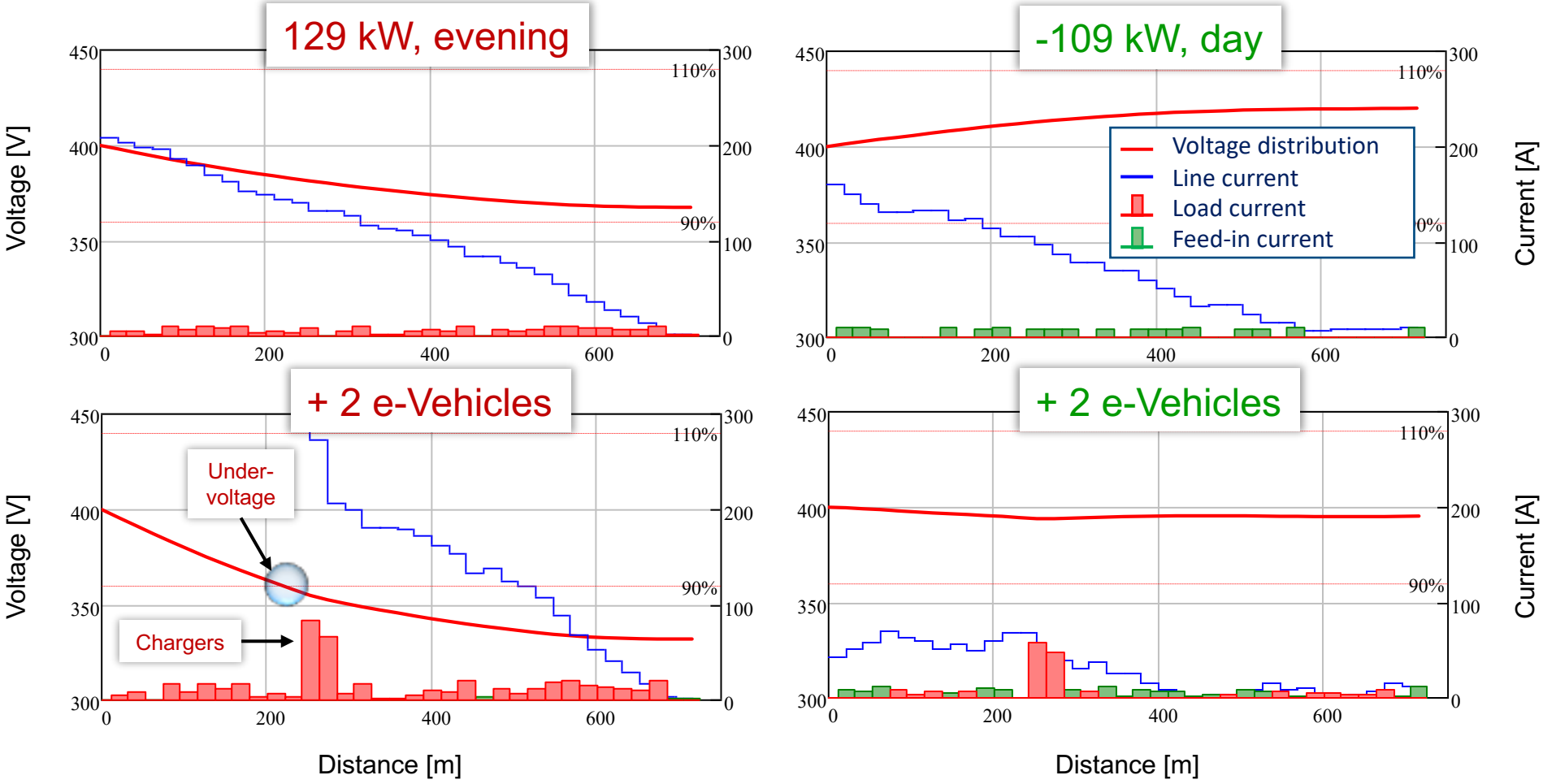
Low voltage distribution grid cannot reliably support e-Vehicles at higher power (40 kW, Segment “B”)



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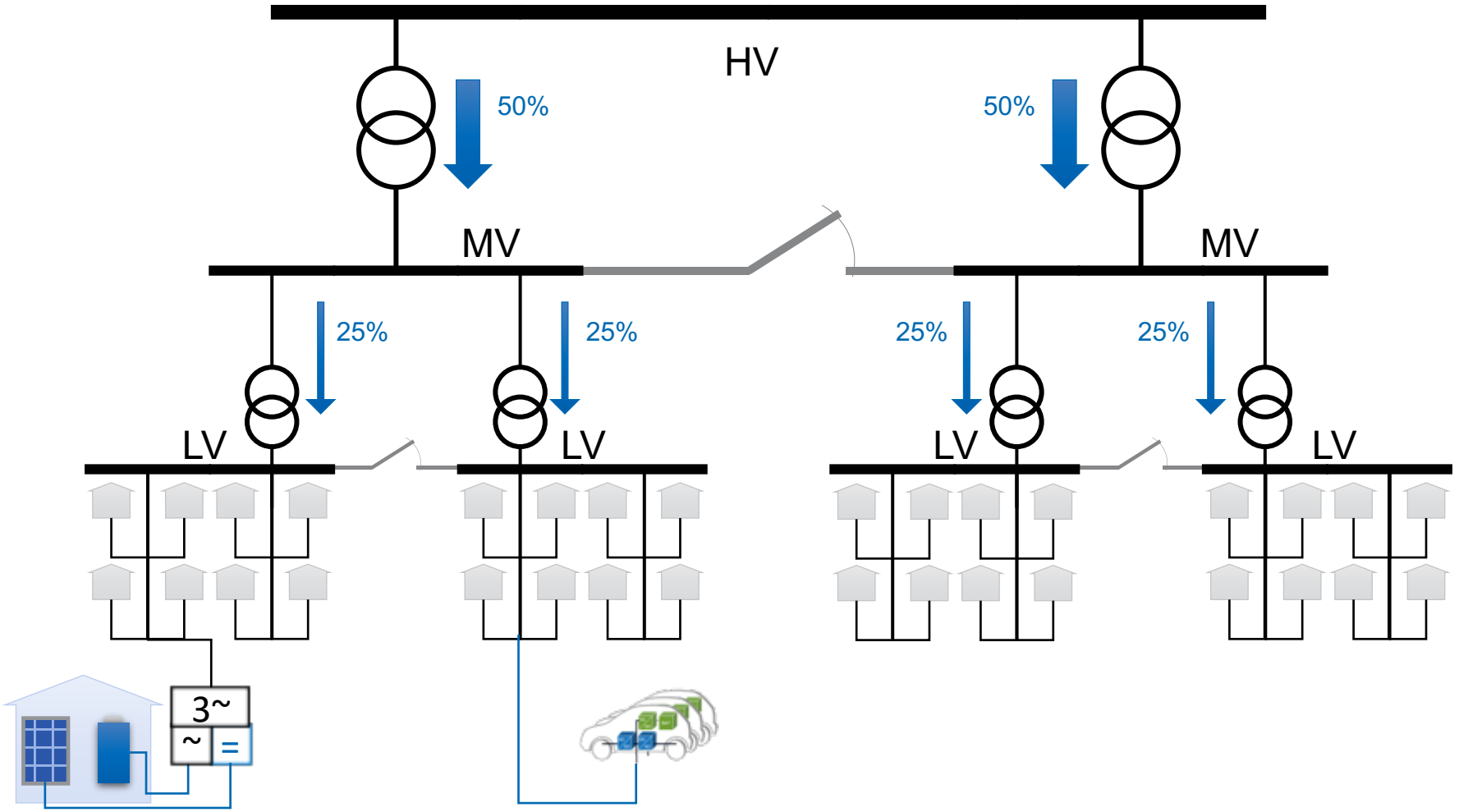
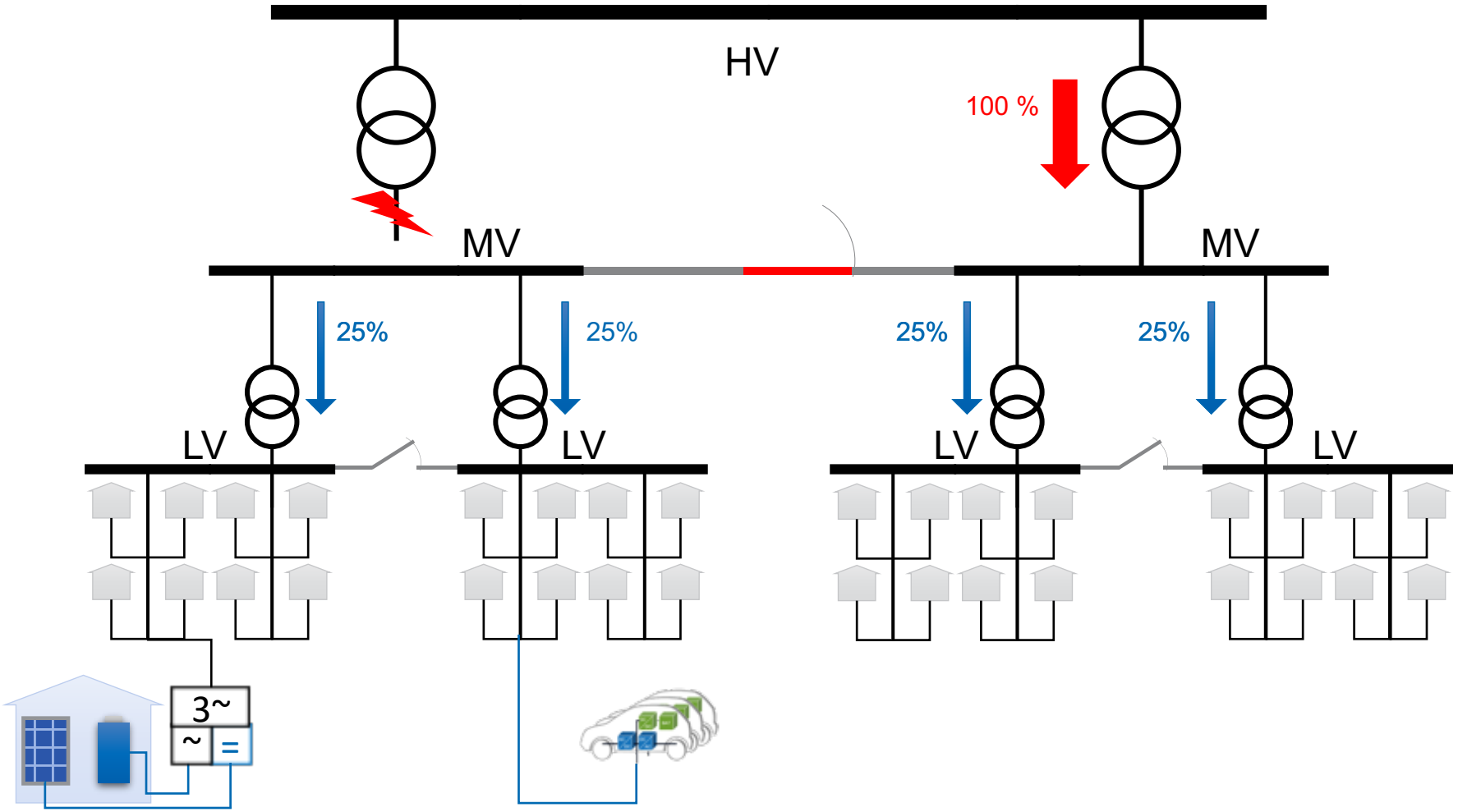
Classical Distribution Grids are radial

Integration of decentralized supplies. renewables, storage and e-Mobility is difficult

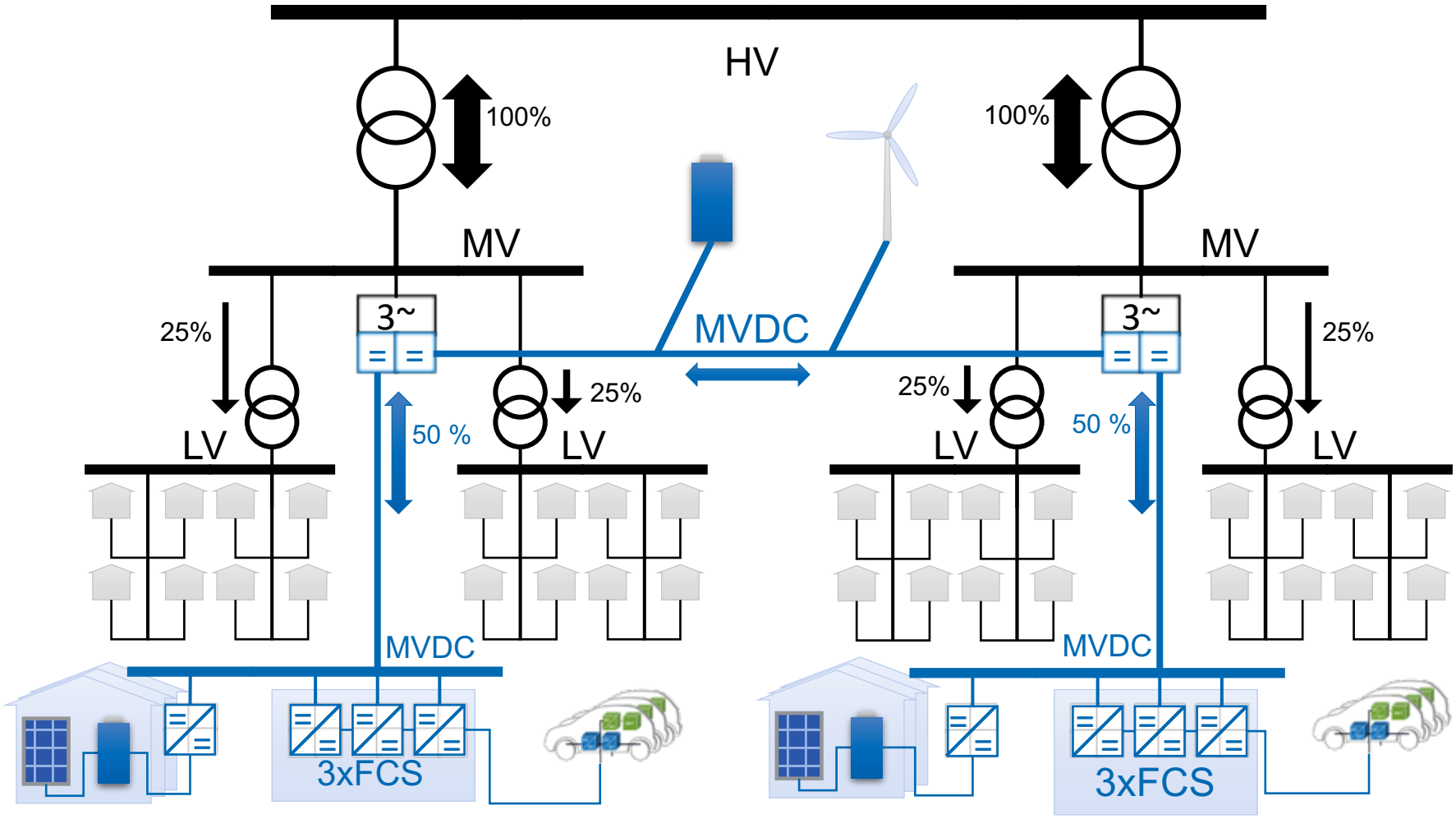


Classical Distribution Grids are radial and massively oversized

Integration of decentralized supplies. renewables, storage and e-Mobility is difficult



Hybrid Approach to Maximize Capacity of Distribution Grids
Integration of e-Mobility, PV, Wind, Storage … by MVDC-Backbone



iSEA Stromrichtertechnik und Elektrische Antriebe
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FLEXIBLE ELEKTRISCHE NETZE
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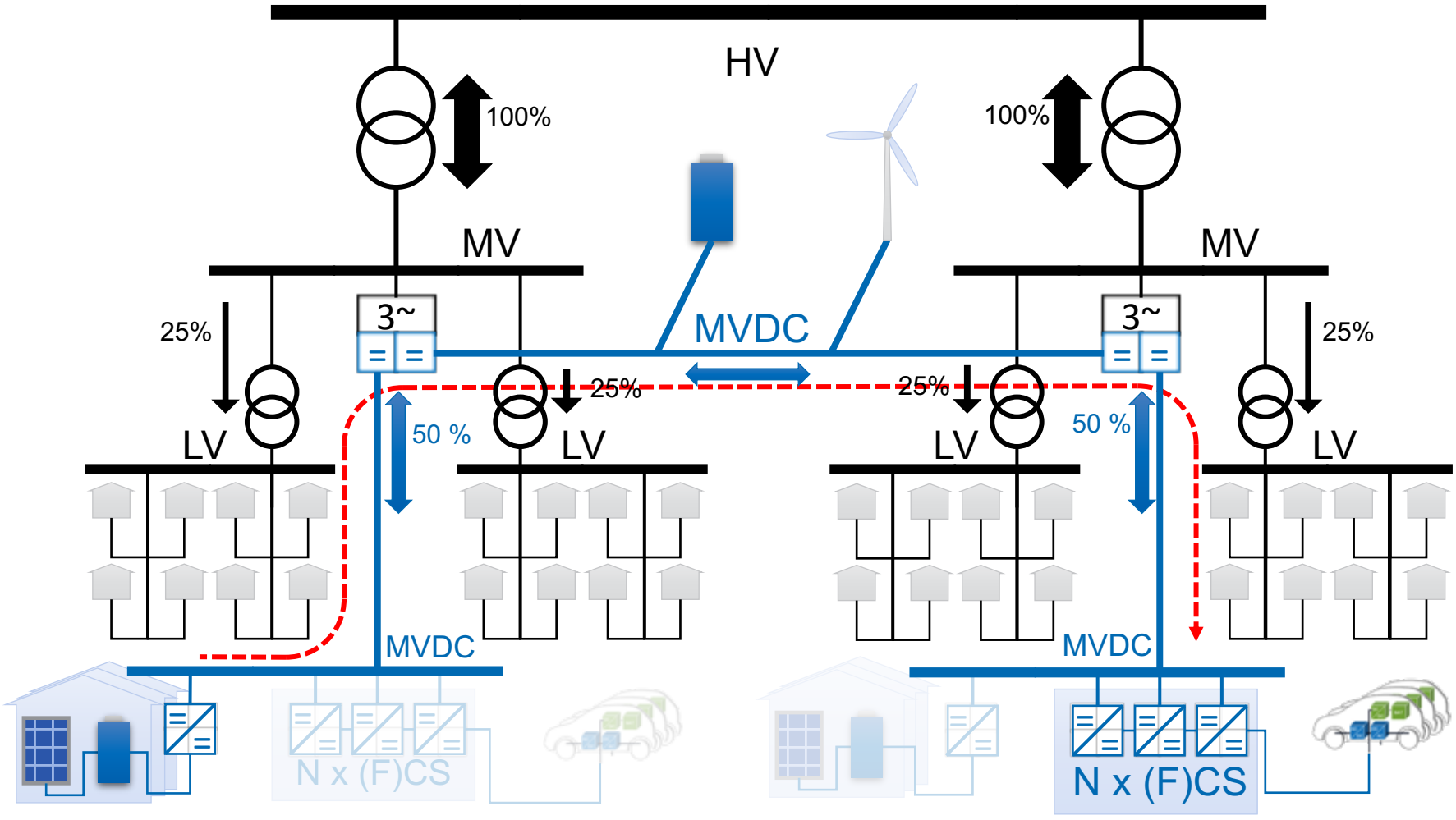
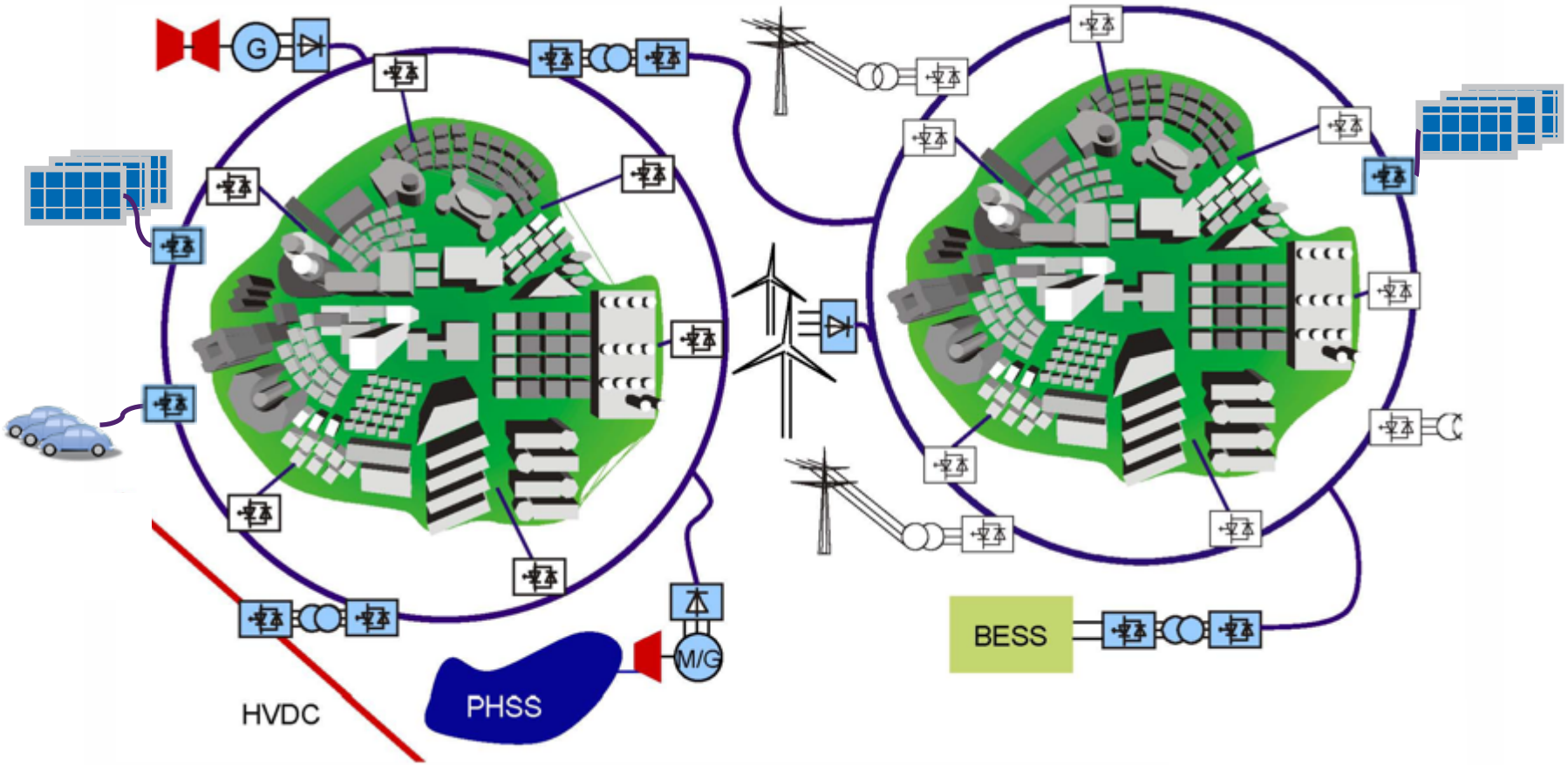
Hybrid Approach to Maximize Capacity of Distribution Grids
Integration of e-Mobility, PV, Wind, Storage … by MVDC-Backbone



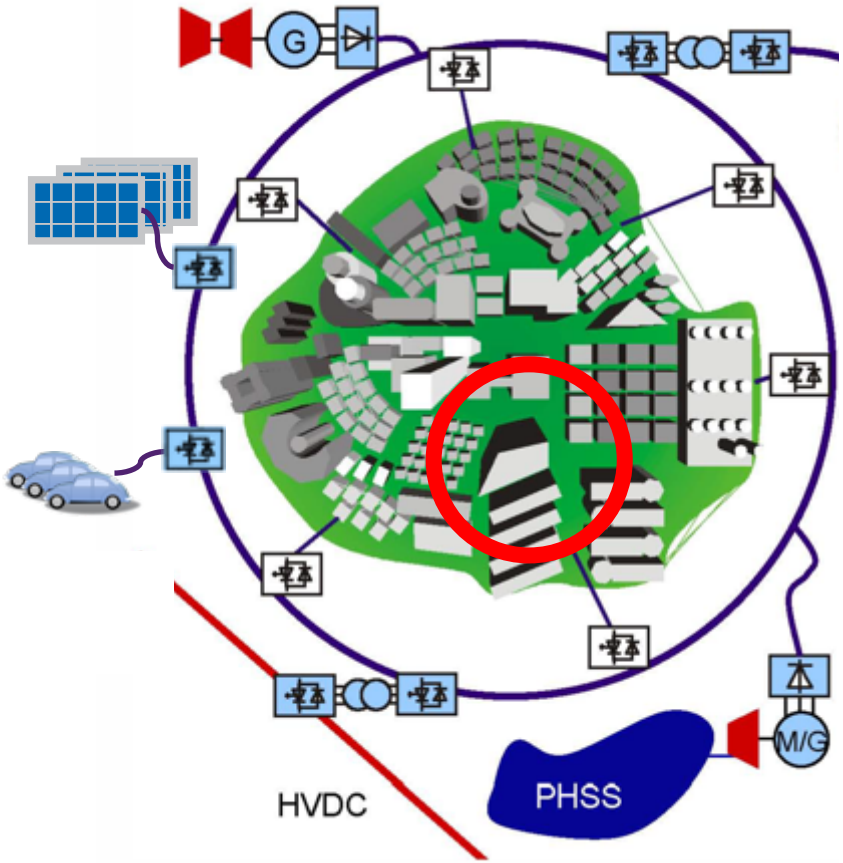
Outline

- Introduction – RWTH Aachen University
  - E.ON ERC
  - ISEA and PGS
  - Research CAMPUS Flexible Electrical Networks
- Background – Energy Transition and Flexible Grids
  - Renewables and decentralized power generation impact grid structures
  - Flexible DC Distribution grids and sector coupling
  - eMobility impact on distribution grids
- Conclusions
  - Use cases where DC technology makes a lot of sense
  - DC technology never went away
  - Standardization
  - Urgency to drive the DC (r)evolution

FEN Innovation
Zellulare Netzstruktur und Sektorenkopplung

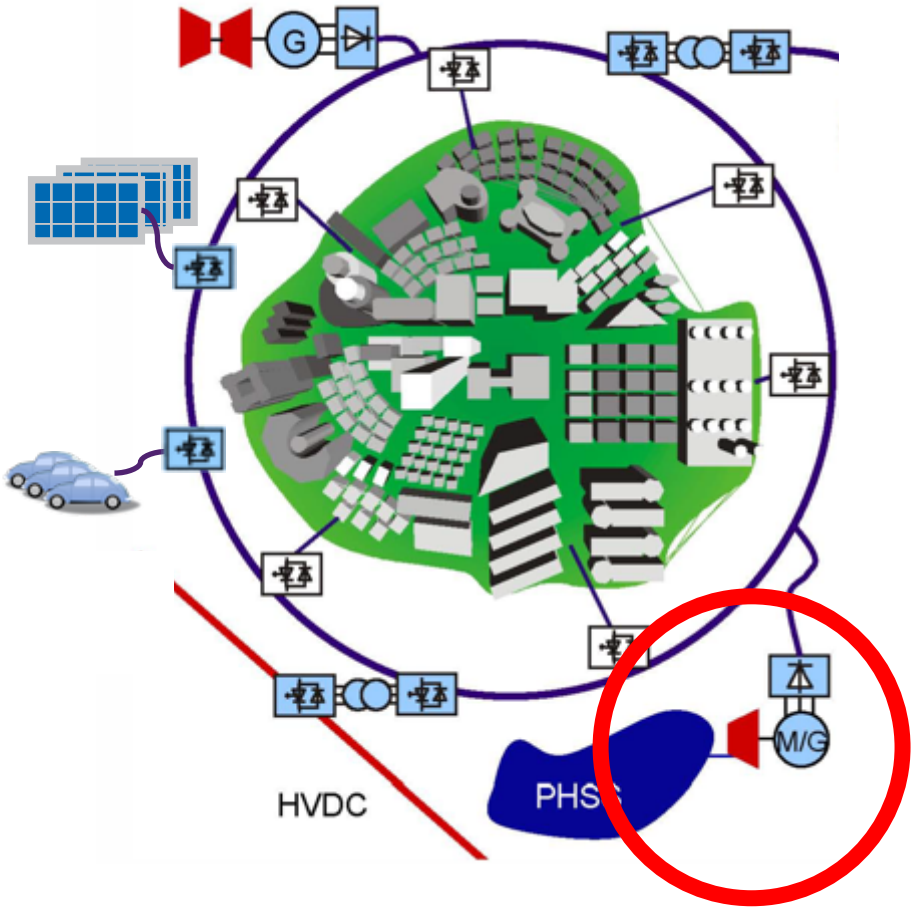


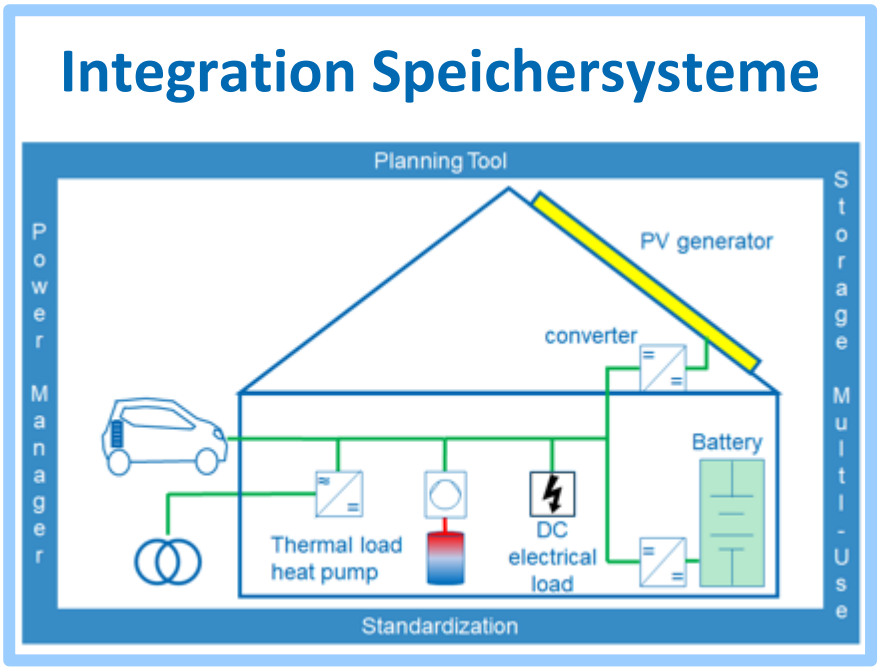
Aus der Nische mittelfristig realistische Anwendungsszenarien



Kommerzielle Gebäude

Aus der Nische mittelfristig realistische Anwendungsszenarien





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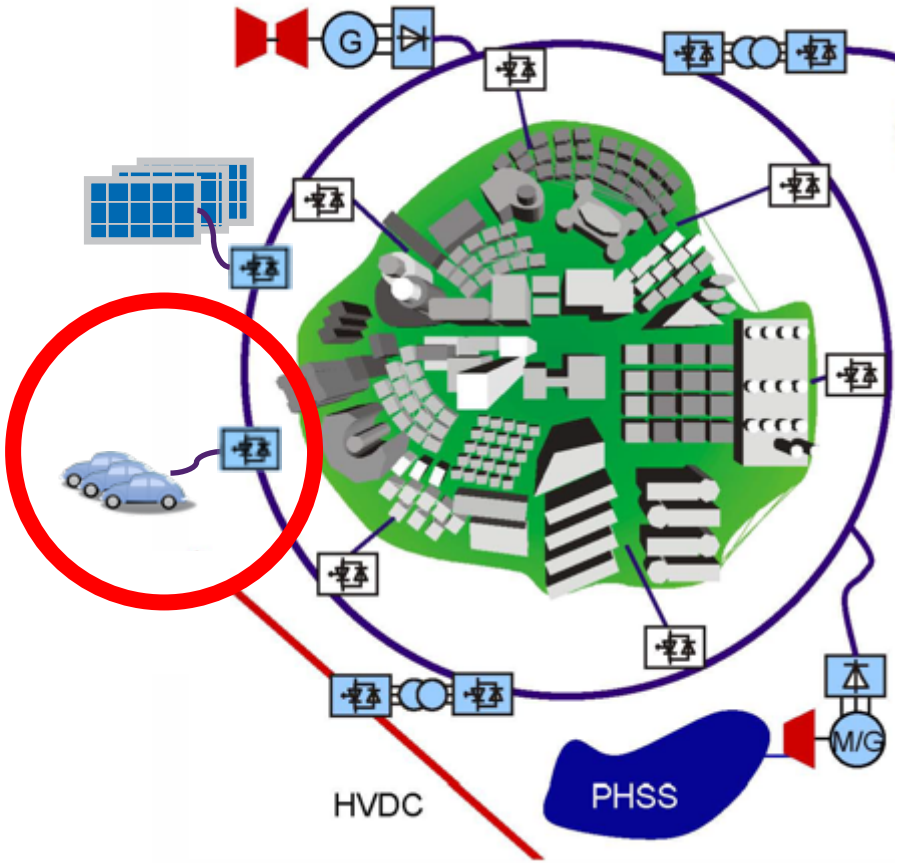

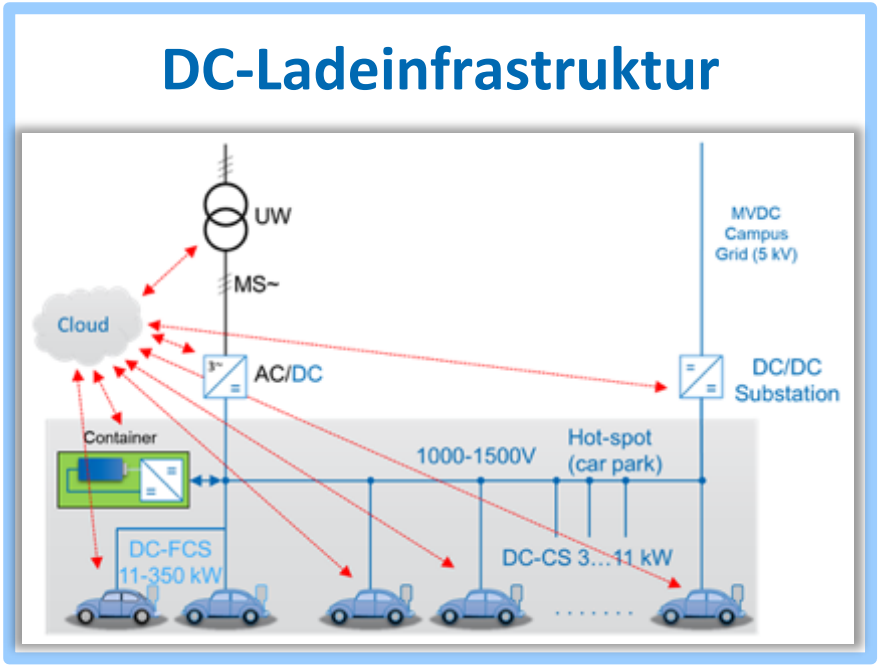

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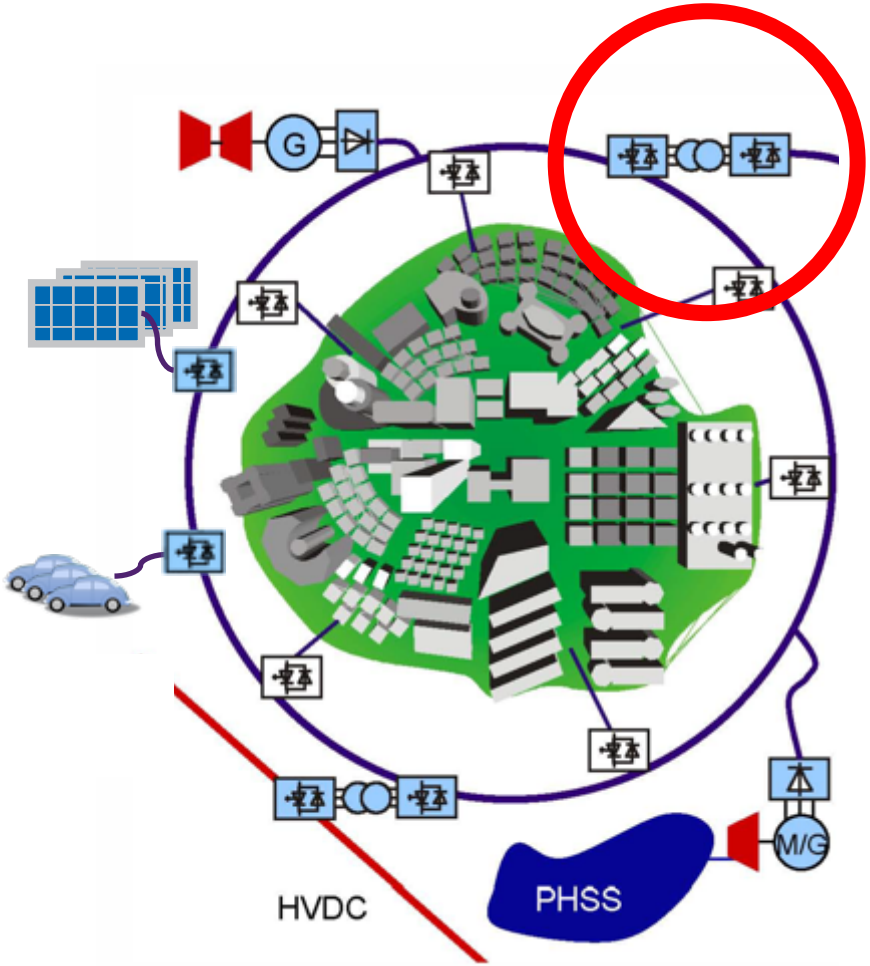
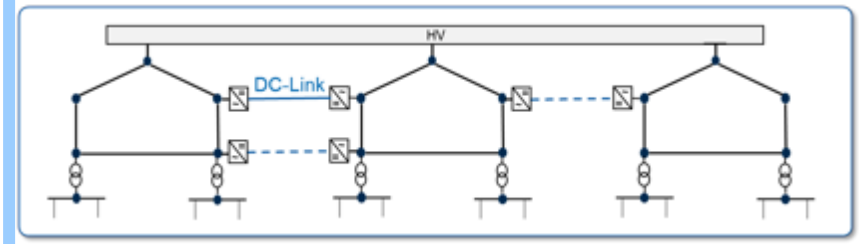
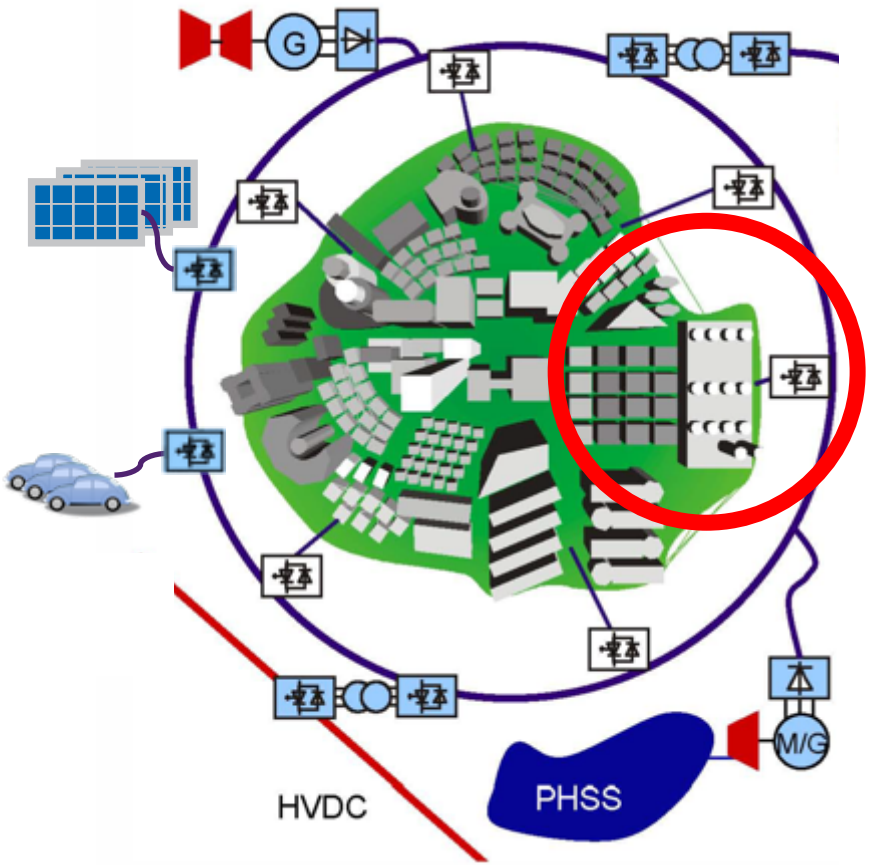


Punkt-zu-Punkt

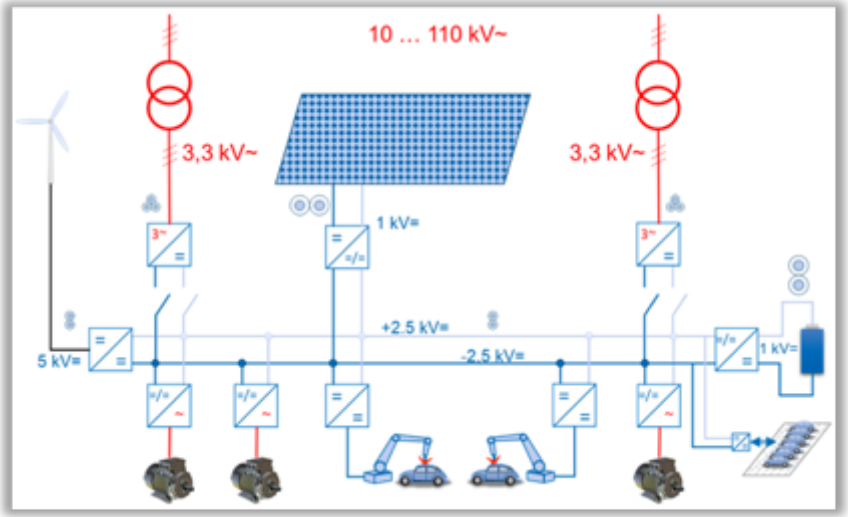


Aus der Nische mittelfristig realistische Anwendungsszenarien



Punkt-zu-Punkt

Industrielle DC-Netze



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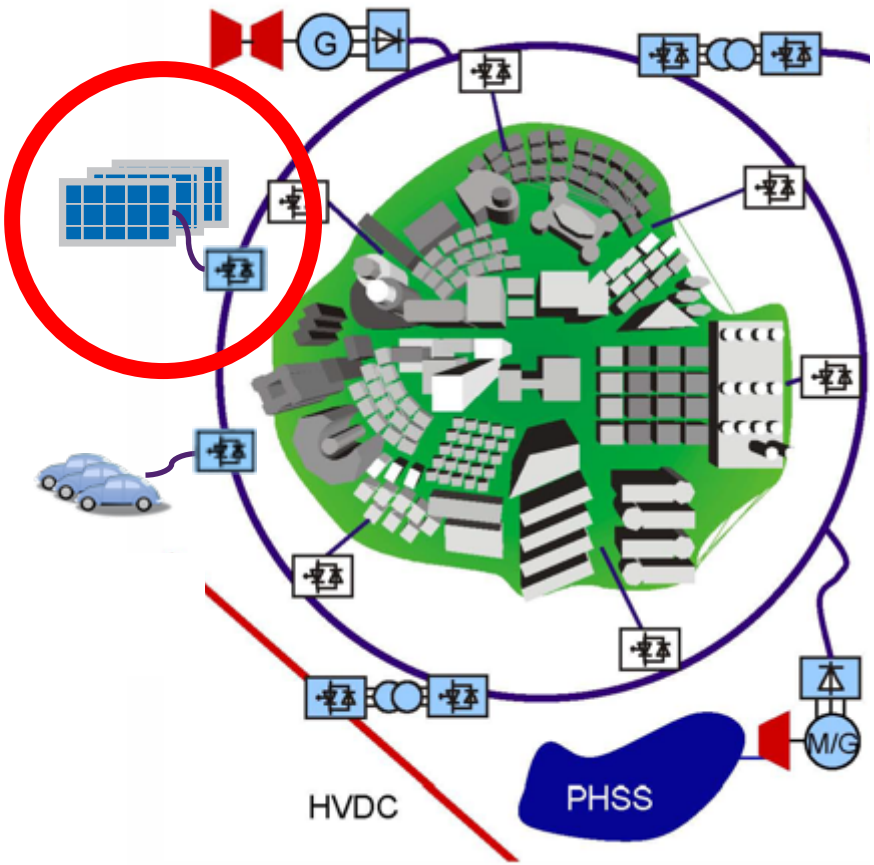
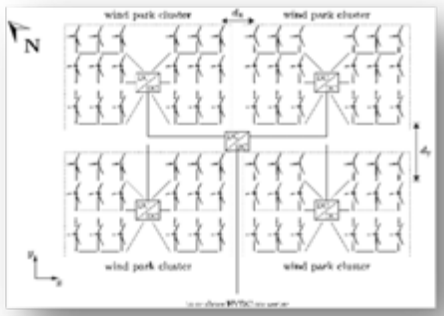
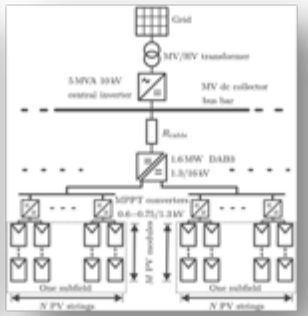


Punkt-zu-Punkt

Industrielle DC-Netze

Sammelnetze für PV & Windkraftanlagen





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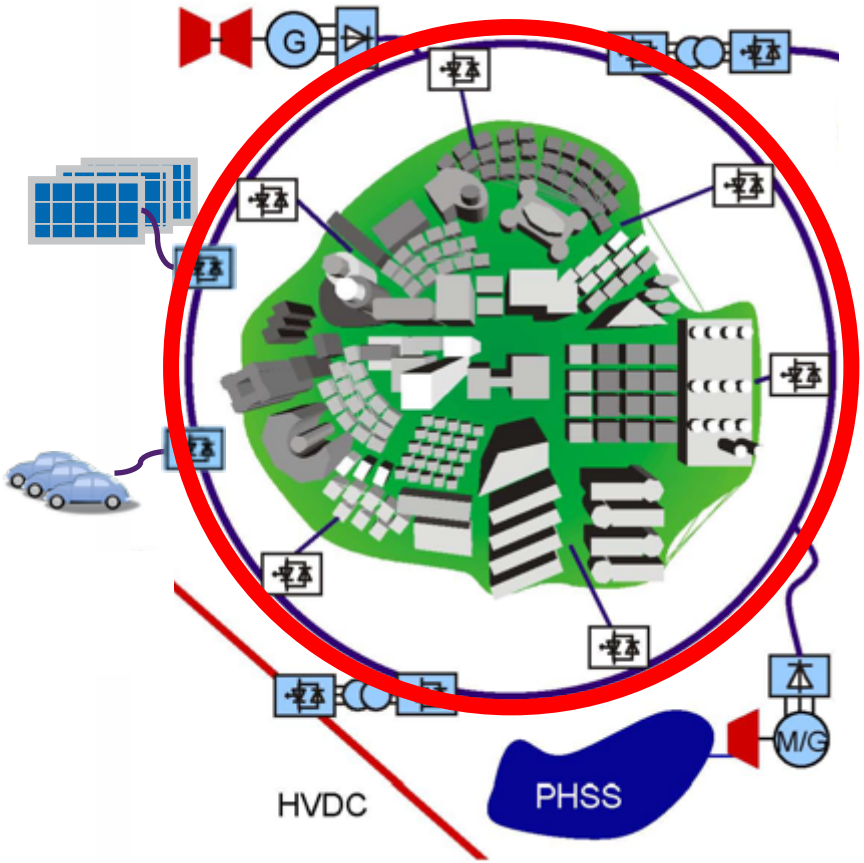
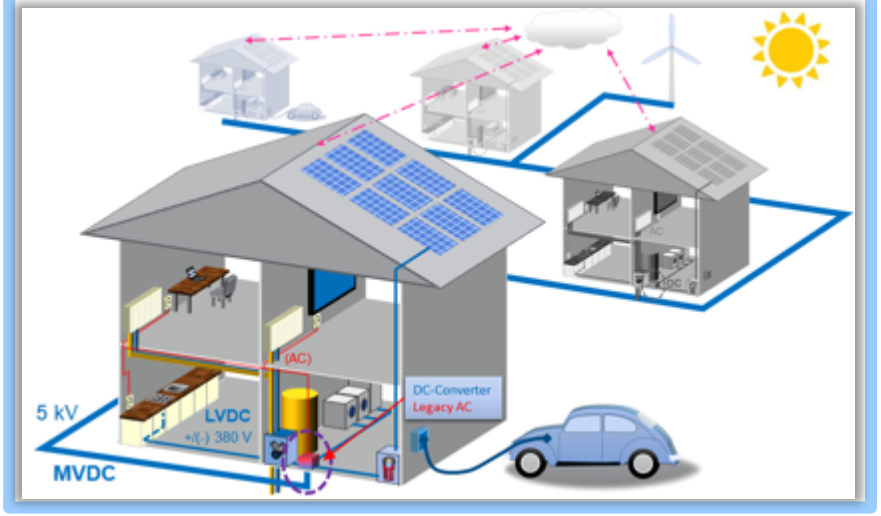
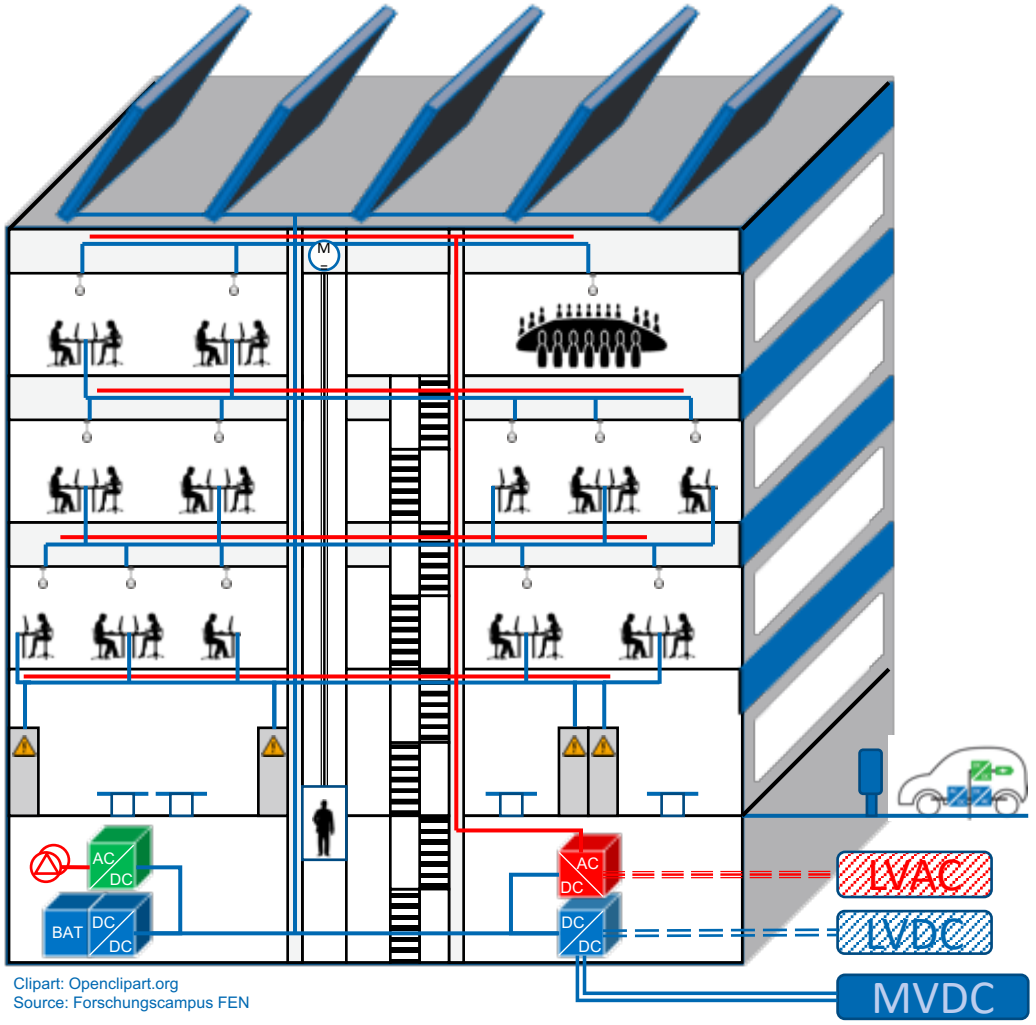


DC-Stadtviertel
und
Regionale Netze



Commercial DC Building and Factories

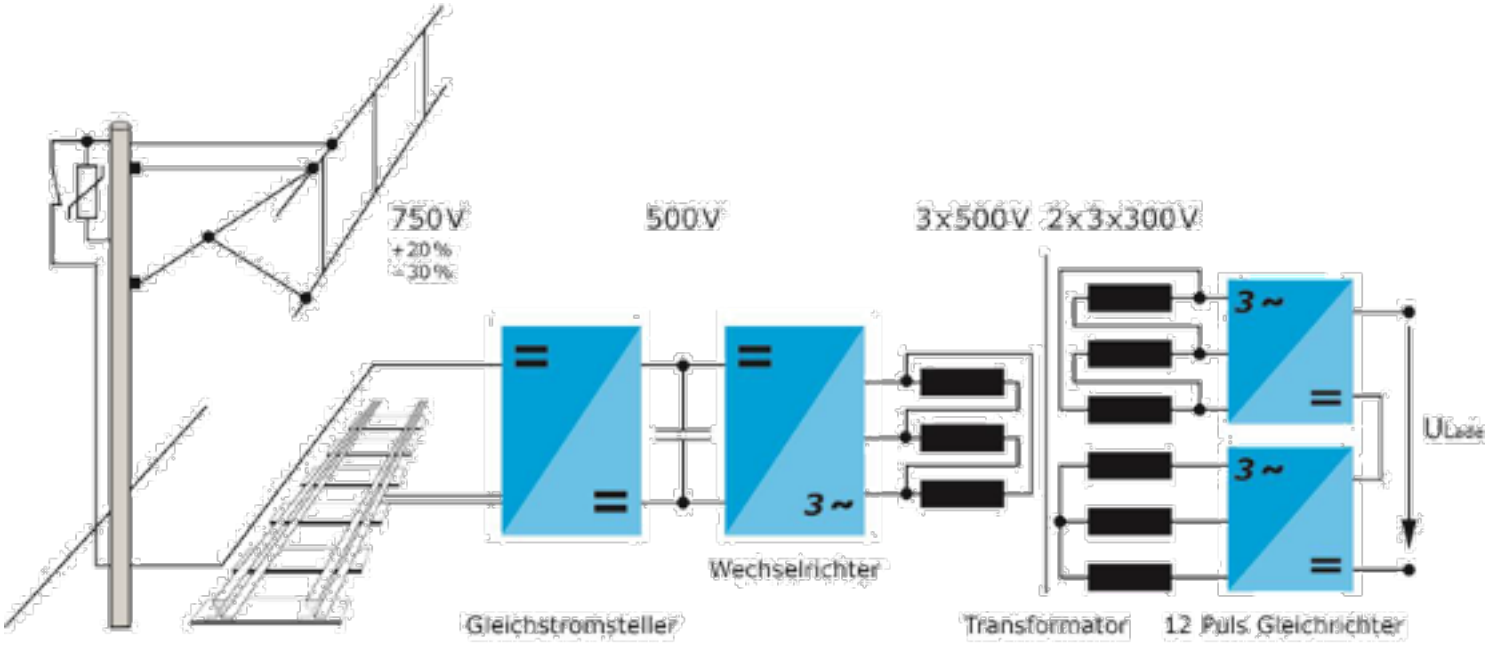
- Building infrastructure with DC
  - HVAC with heat pumps
  - Heat/cold storage
  - Lighting
  - ICT
  - Elevators/escalators
  - E-mobility parking lots (dual use of
  - Local generation and storage
- AC-branch for legacy devices
- Local hybrid AC/DC substation



Clipart: Openclipart.org
Source: Forschungscampus FEN

Fast-Charging Infrastructure
Dual Use of Railway and Light Rail Infrastructure

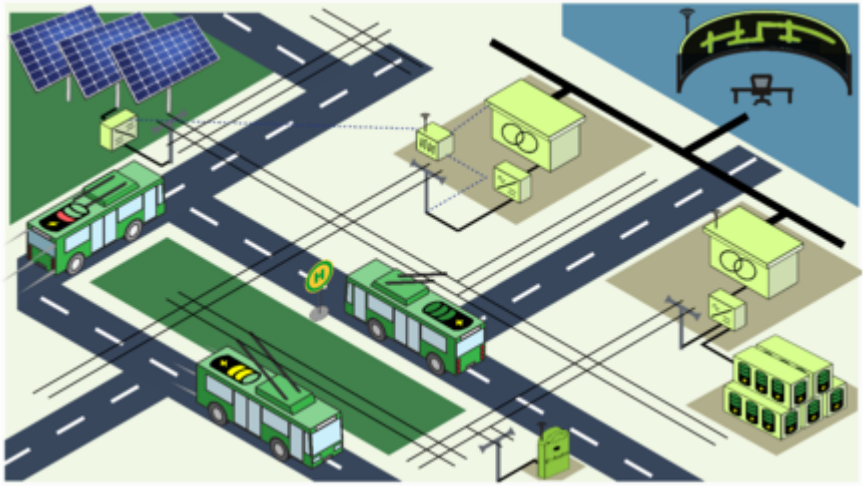
- Low utilization of large capacity railway infrastructure (12%)
- Existing capacities can be used for fast charging (85 GWh per day in Germany)
- Railway and light-rail grids are available in cities
  - Light rail typically 750 V_{dc}
  - Belgium, Spain, Italy, Russia use 3000 V_{dc}
  - France, NL use 1500 V_{dc}



Source: Müller-Hellmann

Fast-Charging Infrastructure linked to light-rail

- Research project „BOB“ (Solingen)
  - Double use of Trolley bus infrastructure
  - Catenary power used for charging of on-board batteries during operation
  - Possible electrification of lines without catenary
  - Integration of renewable energies
  - Services for feeding ac grid



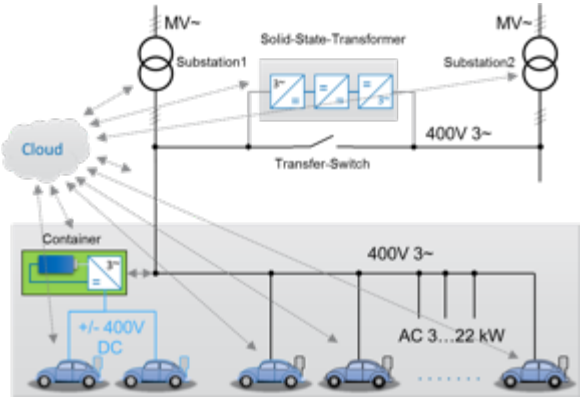
Source: Uni Wuppertal

- 4 GW (750 V_{dc}) installed capacity in German cities alone (VDV)
  - Average use is 12%
  - Each day about 85 GWh is available to charge EV
    - 1.4 million EVs with 60 kWh battery
    - 420 million km range (@20 kWh/100 km)

Newly Approved Research Project – ALigN
Project Overview

ALigN

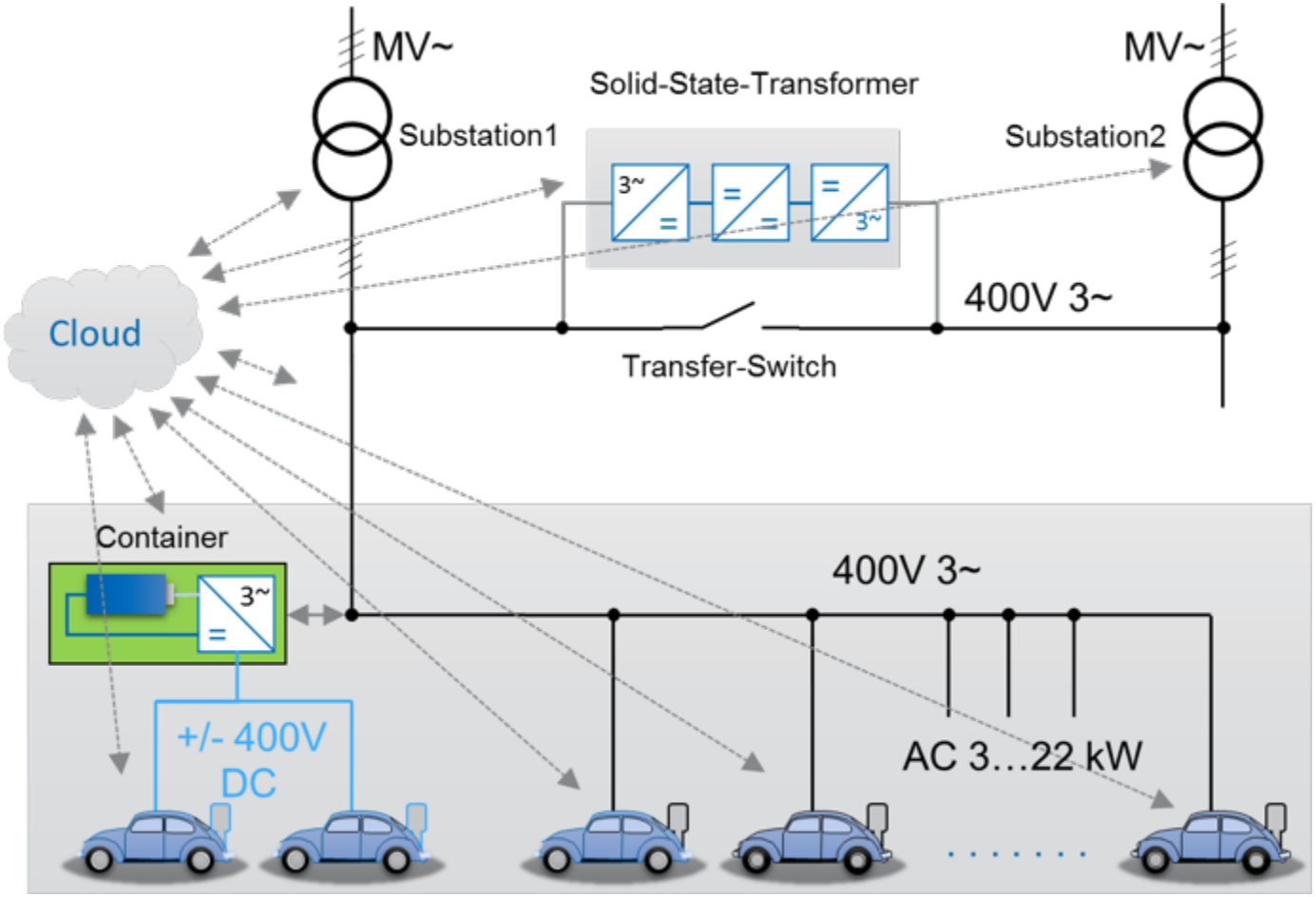
- High NO_x emissions in the city of Aachen (49 µg/m³) and the surrounding area
  - Commercial vehicles cause 53,9 % (438 t) of the overall NO_x emissions in Aachen (AC)
  - → Electrification of fleets (and commuters) offers great potential to reduce NO_x emissions
- Main challenges of electrification
  - Grid stability and expansion of the grid
  - Hesitant user acceptance
- Goals of ALigN
  - Implementation of 500 - 1000 charging points in AC
  - Implementation of intelligent fleet management, local monitoring and load management concepts
  - Development of demand-oriented charging concepts and business models
  - Optimization of stakeholder-specific communication and decision paths
  - Reducing grid constraints / enabling the grid
    - Development of intelligent load-management algorithms
    - Implementation of Solid-State-Transformers (dc underlay grid)
    - Implementation of energy storage elements



generalization of concepts by real-time simulation

Newly Approved Research Project – ALigN
Concept Overview

ALigN



Forschungscampus FEN in Standardisierung

- VDE/DKE
  - Gleichspannung in der elektrischen Energieverteilung (2015-2019)
    - R.W. De Doncker, M. Stieneker (FEN-PGS-RWTH)
    - A. Moser, J. Priebe (FEN-IAEW-RWTH)
  - Normungsroadmap Gleichstrom im Niederspannungsbereich (2015-2019)
    - C. Loef/FEN-ISEA-RWTH
- CIGRÉ
  - Working Group C6 SC 6.31
    - Medium voltage direct current (MVDC) grid feasibility study (2015-2019)
    - Technical Brochure TB793 (M. Stieneker/FEN-PGS-RWTH, P. Lürkens/FEN-PGS-RWTH)
  - Joint Working Group C6/B4.37 Medium Voltage DC Distribution Systems (since 2018)
    - In Arbeit (S. Rupp/MR, P. Luerkens/FEN-PGS-RWTH)
  - Working group B4.89
    - Condition Health Monitoring and predictive maintenance of HVDC Converter Stations
    - In Arbeit (P. Joebges/FEN-PGS-RWTH)
- IEC/DKE
  - TS 8B-61
    - Guideline for the planning and design of the decentralized direct current distribution systems
    - C. Loef (FEN-ISEA-RWTH)
    - In Vorbereitung

Normative Aspekte beim Übergang zum Gleichspannungsnetz

- Ziel der Normung
  - Bereitstellung von Regeln zur interoperablen Funktion der Netzkomponenten
  - Sicherstellung der einwandfreien Funktion des Gleichstromnetzes
  - Sicherstellung des Personenschutzes

- Historisches : Normung Wechselspannungsnetz

  - Erste WS-Generatoren ca. 1890
    - f = 62,5 Hz, 198 kW, 2 kV, Bad Reichenhall)
  - Standardisierung der Netzfrequenz in DE 50 Hz ca. 1930, in Summe ca. 40 Jahre !
    - 1930 Erste 220kV-Übertragungsleitung vom Montafon/AT zum Ruhrgebiet zur Stabilisierung der der 50 Hz-Dampfkraftwerke mit Wasserkraft aus Speichersee (Vermuntwerk)
  - In USA 60 Hz
  - Heutige Situation : Teilweise Übernahme/Anpassung der WS-Normen für GS-Netze

https://de.wikipedia.org/wiki/Elektricit%C3%A4ts-Werke_Reichenhall

Normative Aspekte beim Übergang zum Gleichspannungsnetz

Normierungs/Validierungsbedarfe

- Schutz vor Überlast
  - Selektivität der Schutzorgane
  - Kurzschlussbehandlung
- Netzform
  - Verwendbarkeit von Netzformen
  - Potentialausgleich, Ausgleichs/Ableitströme
- Personenschutz
  - Art der anwendbaren Schutzmaßnahmen
  - Netzform
- Spannungsqualität
  - Spannungsbereiche, Nennspannungen
  - Spannungswelligkeiten, Spannungsspitzen
  - Störspannungen
    Emissionen (EMV), Immisionsfestigkeit (EMI)

Interaktion mit dem WS-Netz

- Schittstellendefinition
  - Galvanische Trennung
  - Schutz/Erdungsmaßnahmen

Netzführung

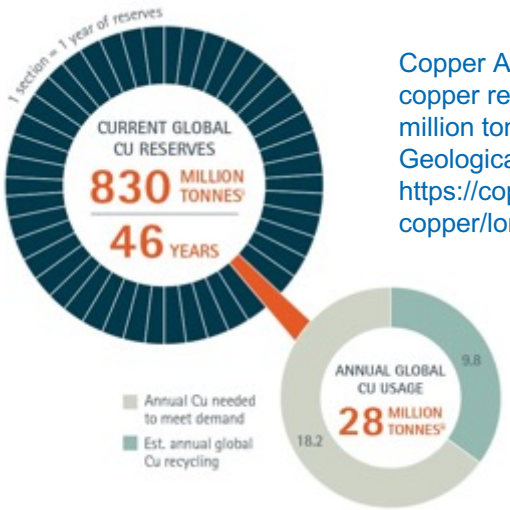
- Spannungsregelung DC-Netz
- Kurzschlußmanagement

Vorgehensweise

- Identifikation der Normen im Ac-Netz
- Validierung bzgl. Anwendung im DC-Netz
- Identifikation von Normen, welche im DC-Netz obsolet sind
- Harmonisierung der Normungsvorschläge auf internationaler Ebene (IEC)

Urgency to develop/demonstrate DC Intelligent Substations

- Saving material resources using power electronics 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 an “Electrical Silk Route” of more than +/- 1 MV.

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Thank you for your attention.

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