Karlsruhe Institute of Technology

ENERGY LAB 2.0

Medium Voltage DC grids: an European perspective

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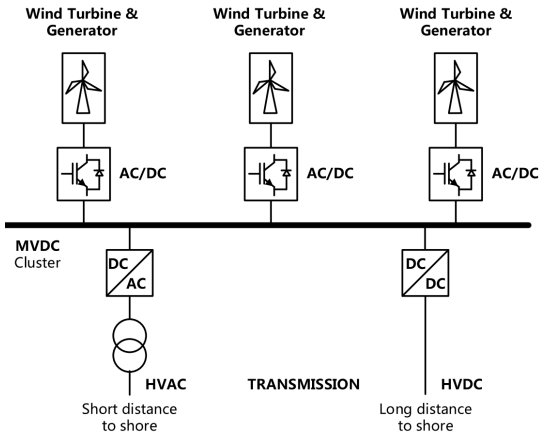
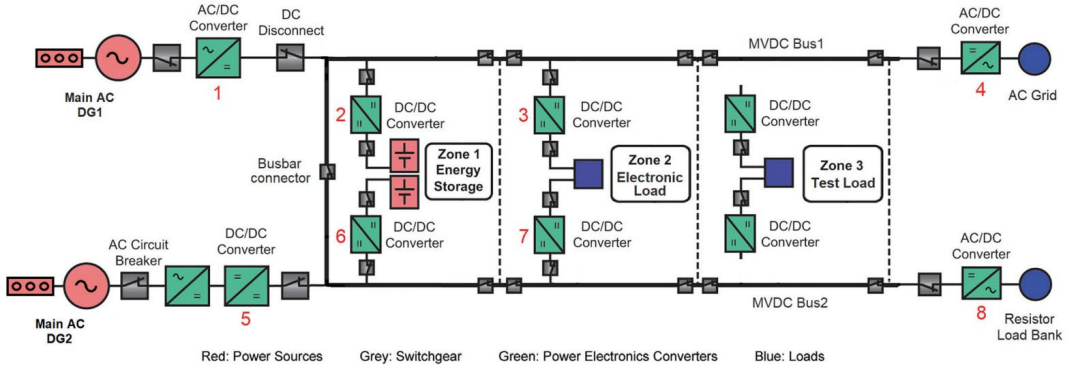
Applications for MVDC

Wind farm / PV connection



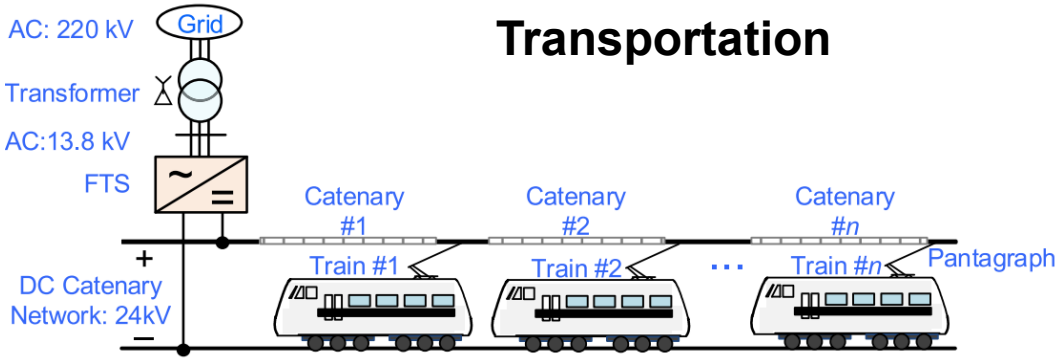
J. K. Steinke, P. Maibach, G. Ortiz, F. Canales, P. Steimer, “MVDC Applications and Technology”, PCIM 2019, Nuremberg

Ships’ on-board power network



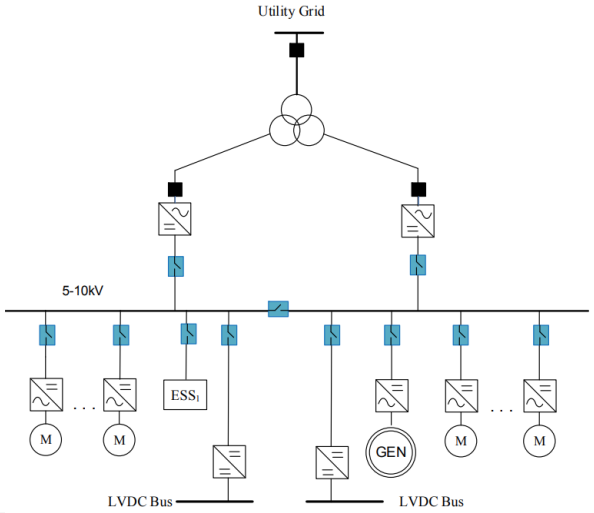
D. Bosich, et al., "High-Performance Megawatt-Scale MVDC Zonal Electrical Distribution System Based on Power Electronics Open System Interfaces," in *IEEE Transactions on Transportation Electrification*, vol. 9, no. 3, pp. 4541-4551, Sept. 2023

Transportation



X. Zhu, H. Hu, H. Tao, Z. He and R. M. Kennel, "Stability Prediction and Damping Enhancement for MVdc Railway Electrification System," in *IEEE Transactions on Industry Applications*, vol. 55, no. 6, pp. 7683-7698, Nov.-Dec. 2019

Industrial grids



L. Qi *et al.*, "DC power distribution: New opportunities and challenges," *2017 IEEE Second International Conference on DC Microgrids (ICDCM)*, Nuremburg, Germany, 2017, pp. 40-46, doi: 10.1109/ICDCM.2017.8001020.

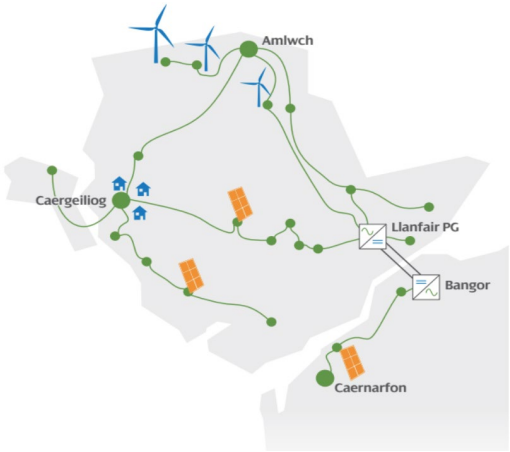
Technical Application Papers No. 24, Medium voltage direct current applications, ABB Library

Angle DC project - Scottland

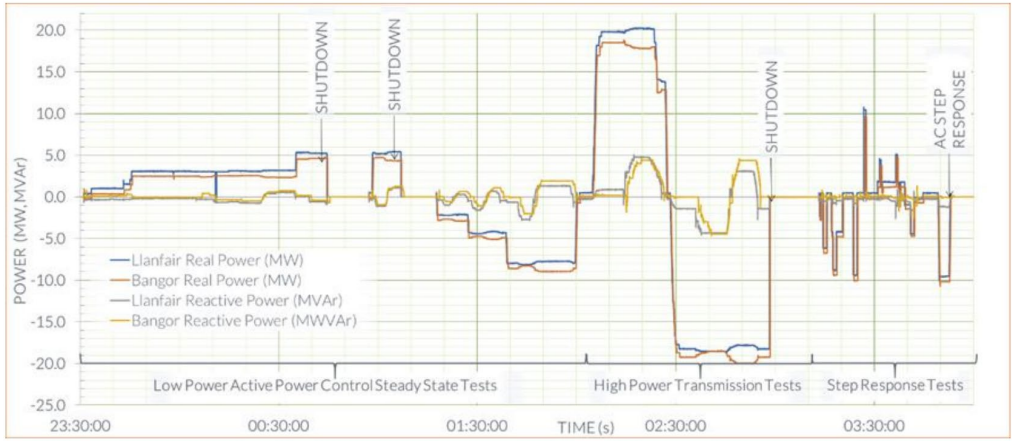
- The island of Anglesey is constrained by large wind power in-feed
- Refurbishing a 33kV AC line with a ±27kV DC System
- Project realized from 2016 to 2020 and current in operation
- In 2040 expected 110GWh losses saving with respect to the MVAC
- Potential for additional 40MW generation, equating to 350GWh per year.

https://www.spenergynetworks.co.uk/pages/angle_dc.aspx

Location of Angle DC Project in Scottland

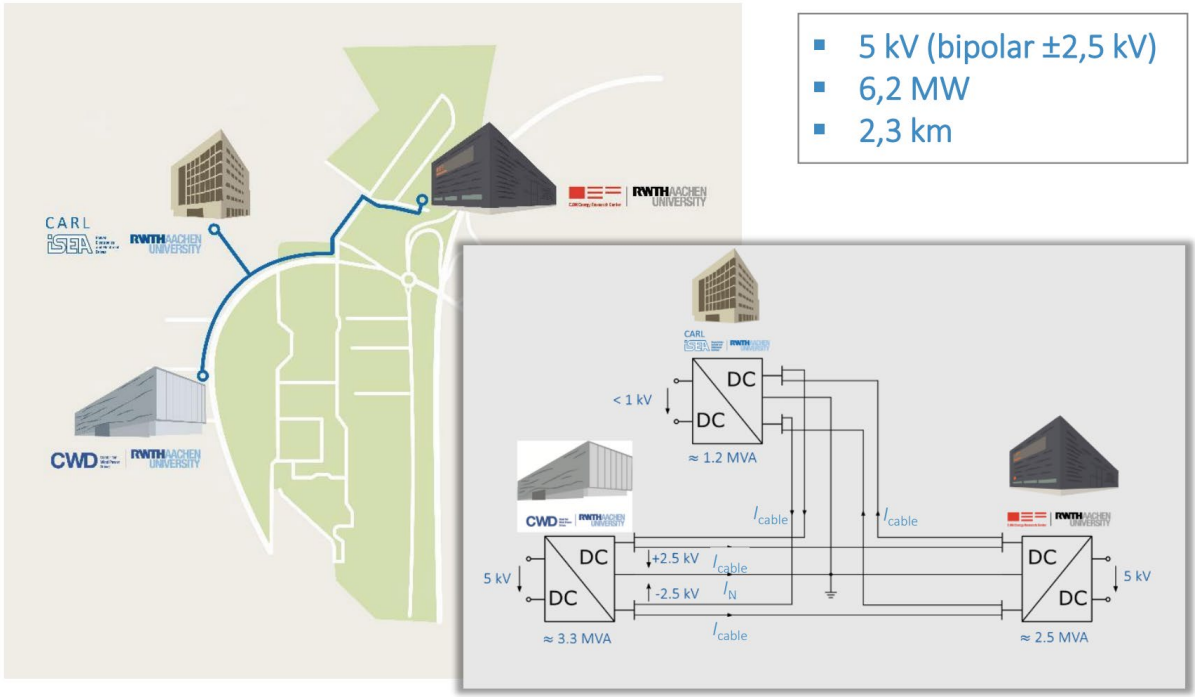


First power tests for the MVDC connection



Flexible Electrical Network - Germany

- Campus research facility with focus DC grids
- Interconnection with ±2.5kV DC network and three-phased DAB converters
- Focus on real time monitoring, protection and DC/DC conversion



https://www.fenaachen.net/vision

Advantages in developing MV DC

Technical Advantages

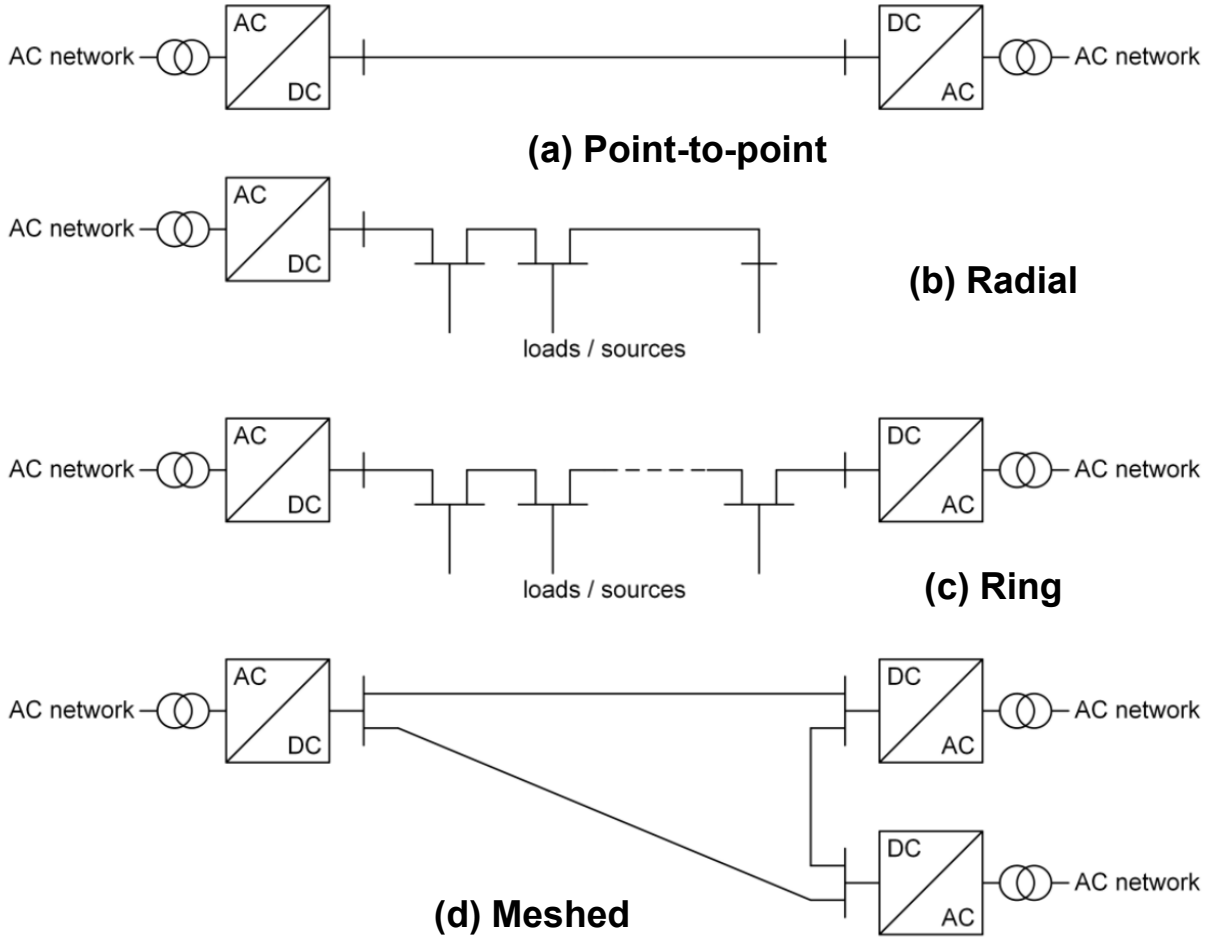
- Phase and frequency immunity
- Higher possible RMS voltage at the same peak field strength
- Zero reactive power
- Lower losses or higher power capacity
- Almost zero leakage losses
- Zero corona losses for overhead lines
- Zero steady-state induced sheath current and voltage and zero capacitive leakage (cables)

Economical Advantages

- Enhanced power supply capacity and power flow management;
- Control of AC voltages and reactive power at the ends of the distribution circuit;
- Lower losses in the wider distribution network due to the improved voltage control;
- Rapid support to the system voltage during faults;
- Fault level decoupling between distribution systems;

MVDC connection possibilities

- Point to point transmission
  - Power flow control, connection between two feeders
- Radial network
  - Feeding a local grid, DC grid forming
- Ring network
  - Same as point-to-point, with integration of loads and sources
- Meshed grid
  - Power flow control between 3 and more terminals. High flexibility

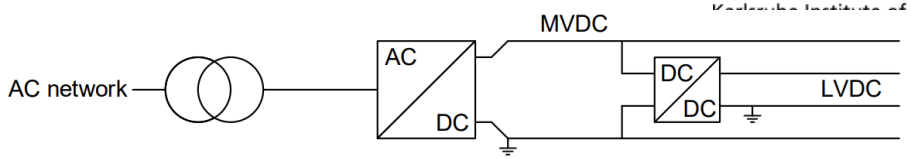


*TB 875 - Medium Voltage DC Distribution Systems

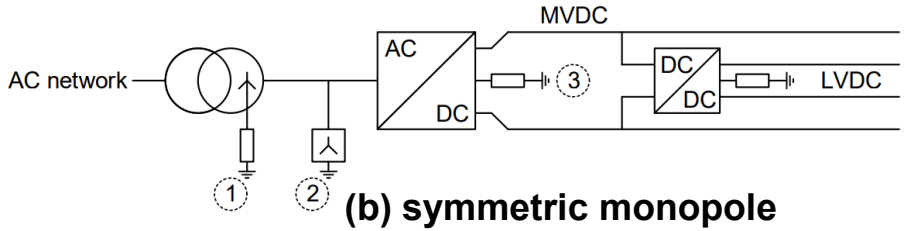
MVDC topologies

- Asymmetric monopole
- Symmetric monopole
- Bipole
- Hybrid - Bipolar, simmetric monopole
- Grounding with different possibilities
  - Transformer star connection
  - Star-connected reactor
  - DC grounded

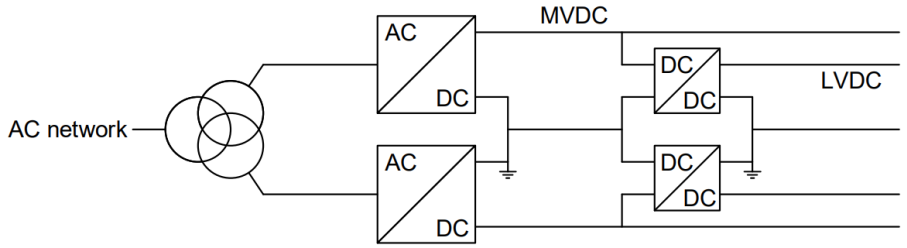
*TB 875 - Medium Voltage DC Distribution Systems



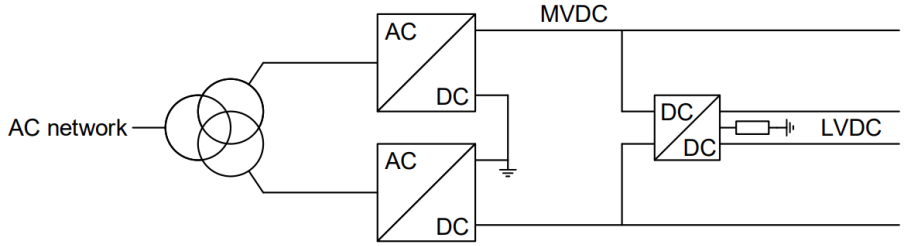
(a) asymmetric monopole



(b) symmetric monopole



(c) bipole



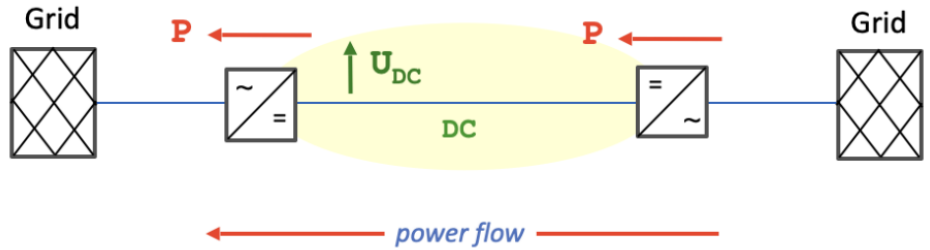
(d) Hybrid bipole - symmetric monopole

Control possibilities

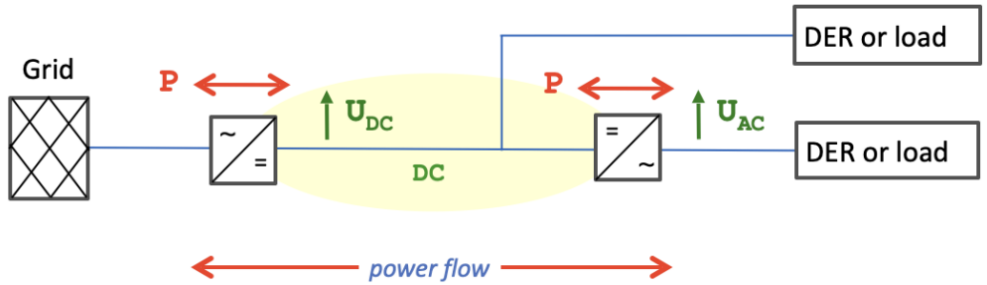
- Power flow management
  - Typical of point-to-point connections
- Voltage management
  - One terminal forms the AC network, regulating the DC power flow
  - Loads and generators connected in DC
- DC coupling
  - One terminal forms the DC grid
  - The second terminal may control the power flow or form the AC grid

*TB 875 - Medium Voltage DC Distribution Systems

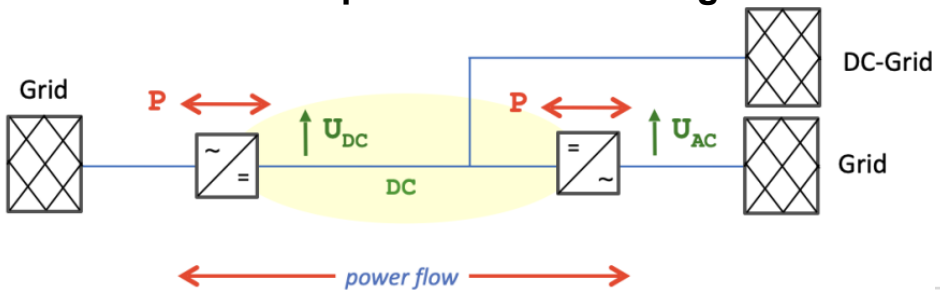
Power Flow Management



Voltage Management and AC forming



DC couplers and DC forming



Connection scenario for MV DC grids

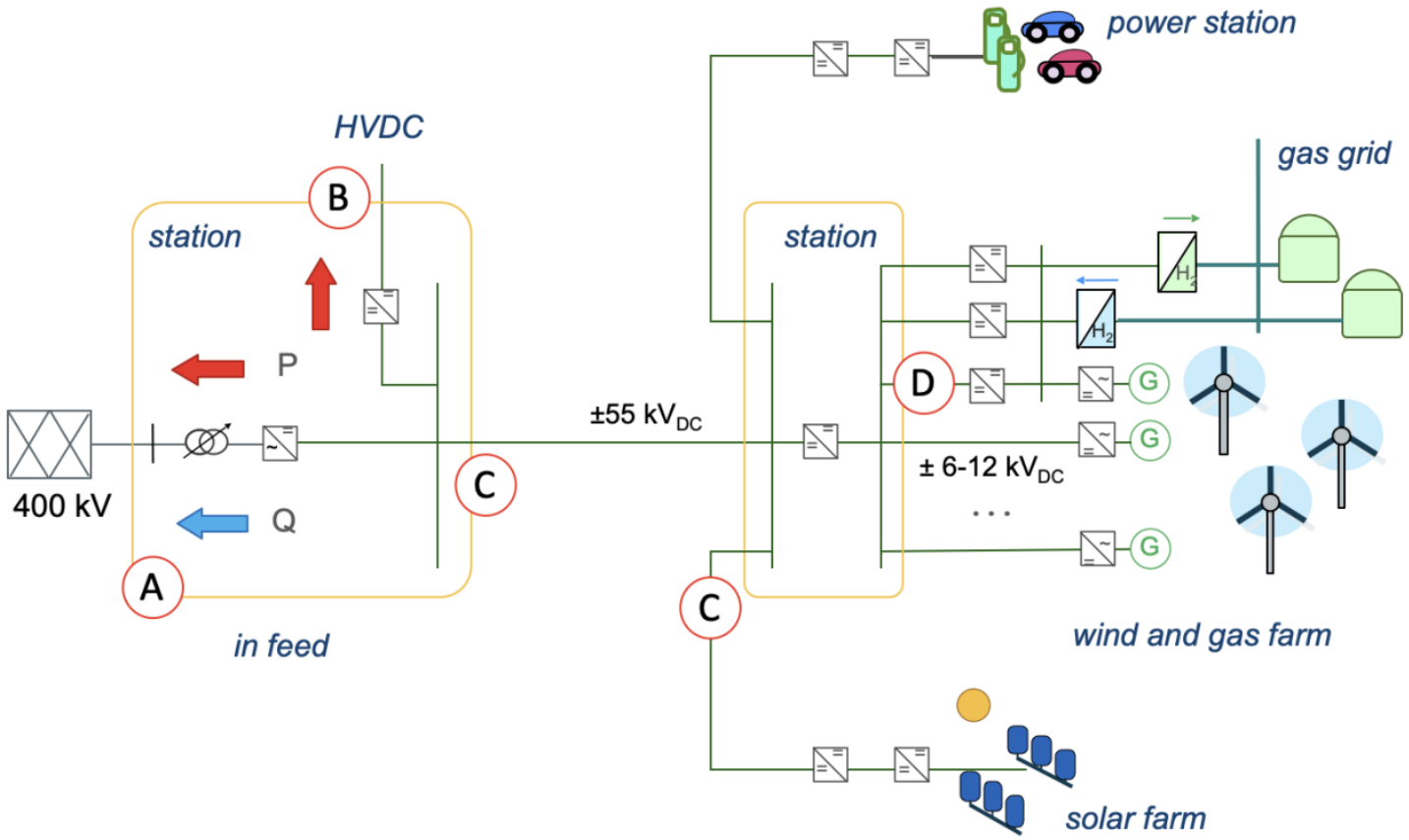
(**A**) Direct connection to HVAC network

(**B**) Connection to HVDC network through „tapping“

(**C**) MVDC connection

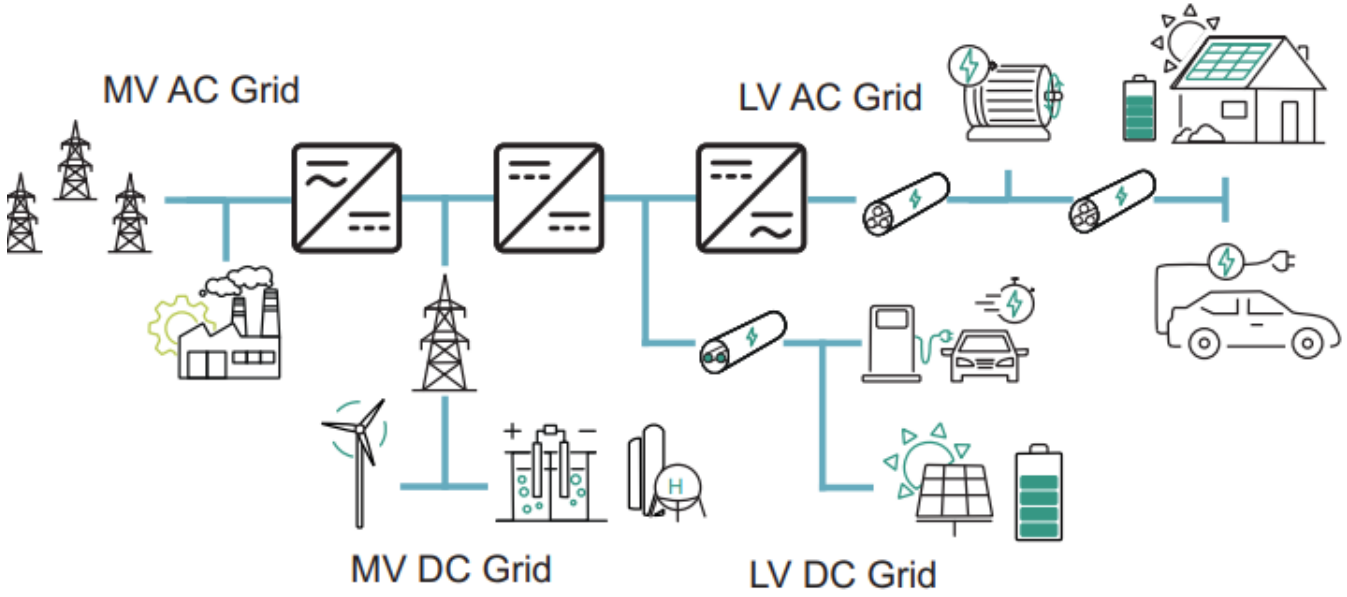
(**D**) Local MV- and LV-DC network

- Multiple- or single-load connection



Connection to LV grids – Solid State Transformer

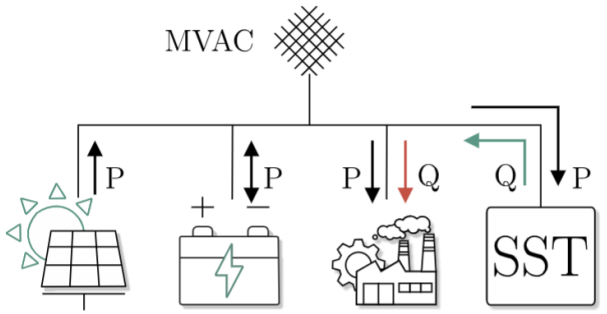
- Voltage transformation
- Galvanic insulation
- More topologies possible
  Let's focus on the 3-stage one
- Enabling possibilities to the grid
  - Dynamic voltage regulation
  - Higher power quality
  - Reactive power compensation
  - DC availability (MV & LV)



Connection to LV grids – Solid State Transformer

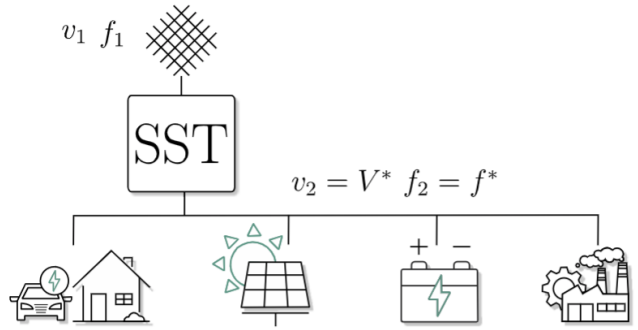
Voltage control

- ✓Voltage control at LV and MV level
- ✓Reactive power compensation
- ✓Harmonic compensation



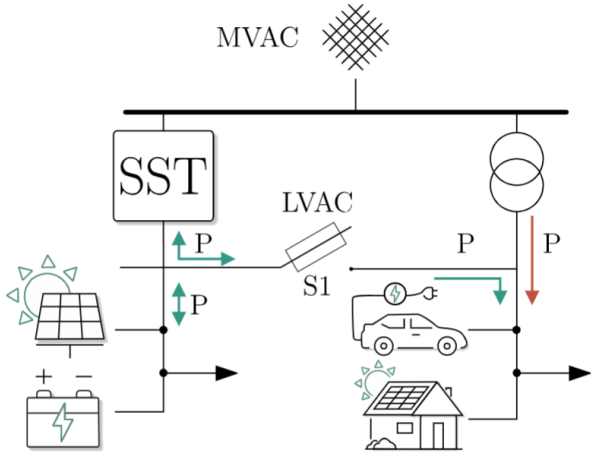
Variable V/f

- ✓Exploiting load V/f dependency to shape power consumption
- ✓No communication required



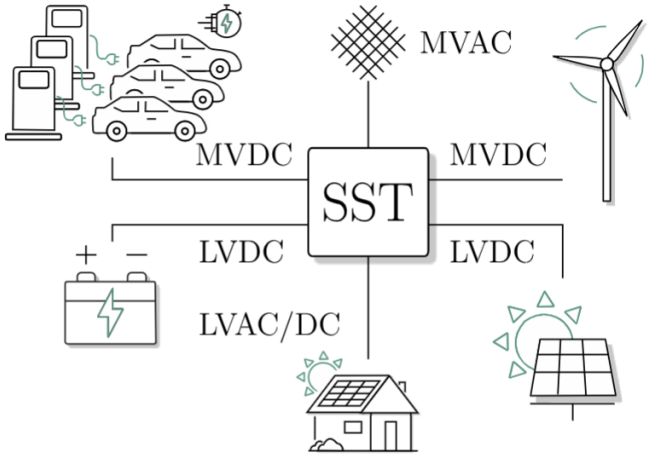
Power redispatch

- ✓Optimal power flow
- ✓Congestion management



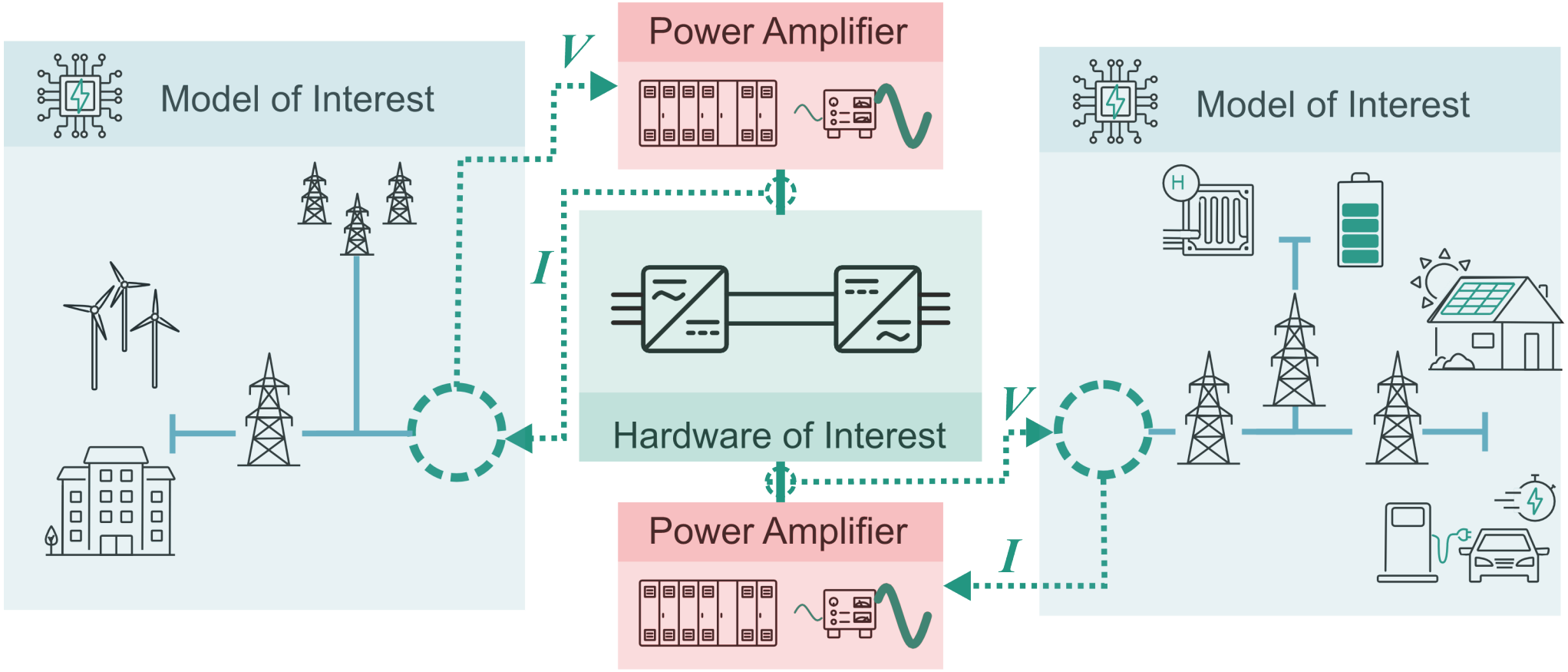
DC Hub

- ✓MV and LV connection
- ✓Focus on new loads / generators
- ✓Hybrid AC/DC networks



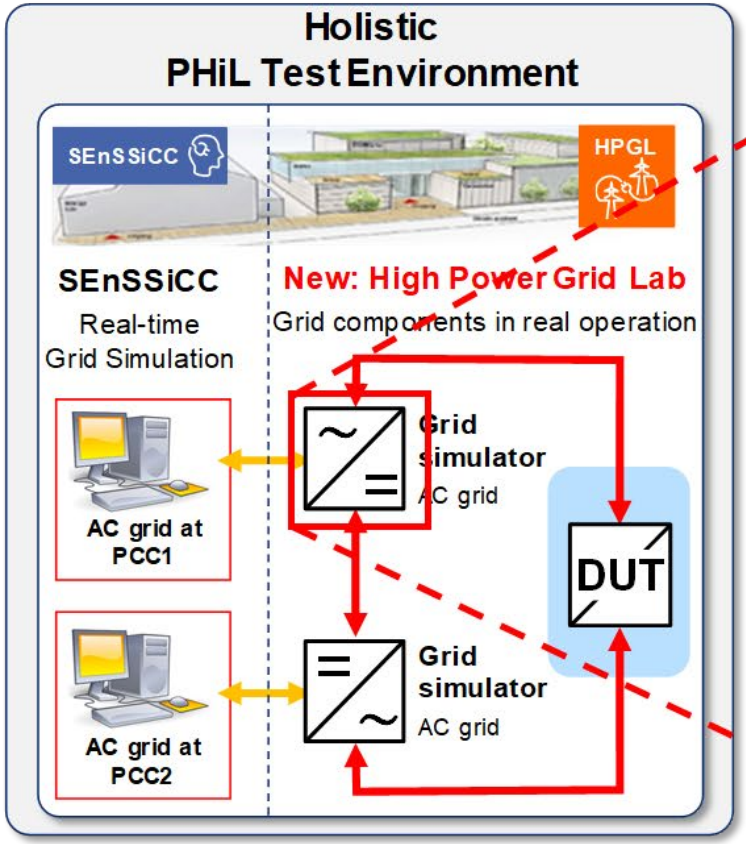
Power Hardware In the Loop

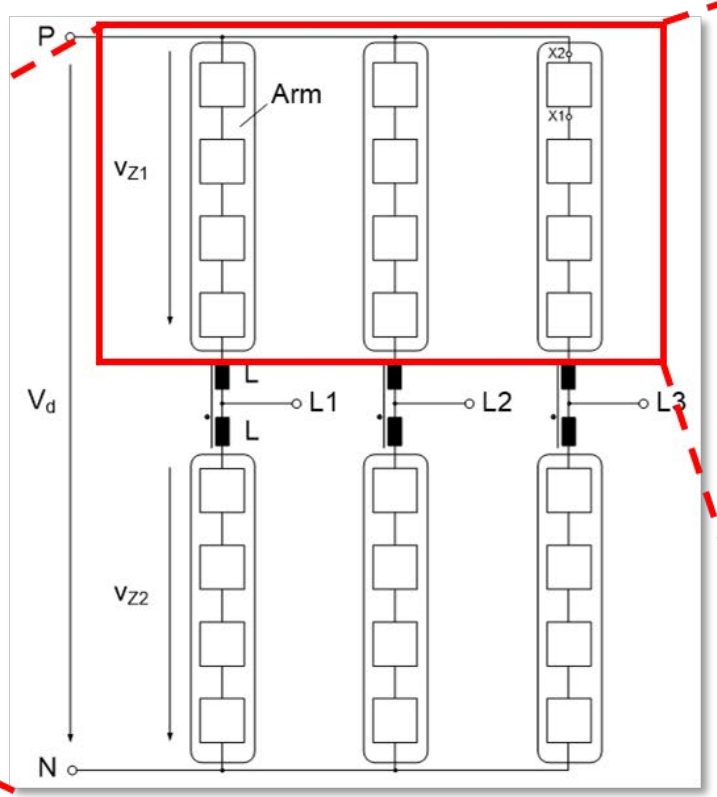
Testing MVDC in realistic conditions



High Power Grid Lab @ KIT

- **HPGL** as part of the **Energy Lab** will be a key research infrastructure in the program **ESD in PoF V**





Concluding our talk on MVDC

- In Europe we see a large potential for MVDC to solve network congestion and regulate voltage
- MVDC offers flexibility in the topology and in the control
- Potential connection with LV and HV grids, to enable a fully integratedand meshed grid
  - SST is a potential solution for an efficient integration
- **Challenges**
  - Business cases exists, but we need to demonstrate them!
  - We need to define clearer rules and standards for the operations
  - Need for testing infrastructures → PHIL can enable realistic testing, but it needs expertise

THANK YOU
Questions?

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