DC-INDUSTRIE
ENERGIEWENDE TRIFFT INDUSTRIE 4.0

DC-INDUSTRIE | April 2018

A concept for a DC grid in industrial production

Verbundvorhaben: DC-Industrie – Intelligentes offenes DC-Netz in der Industrie für hocheffiziente Systemlösungen mit elektrischen Antrieben

Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

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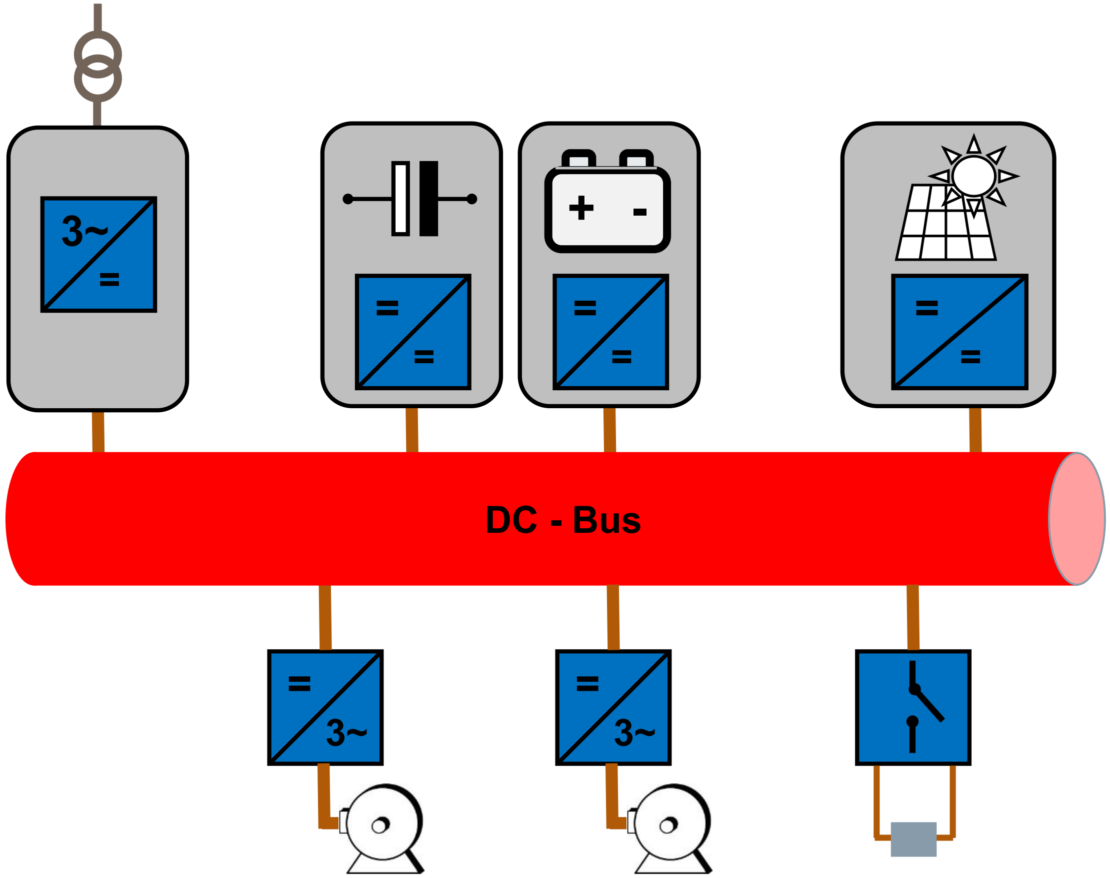
Customer expectations

Requirement	DC grid features
Reduced downtime	• Very fast disconnection from AC grid faults by semiconductor switch • Long ride through capability by storage devices and renewable energy sources
Improved energy efficiency	• regenerative braking via the DC link • Reduced conversion losses for storage and renewable energy

Typical devices in an industrial DC grid



- Variable speed drives
- Passive loads
- Infeed from the AC grid
- Storage devices (e.g. batteries, capacitors, flywheels)
- renewable energy sources (solar, wind)

Boundaries of an industrial DC grid

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- Industrial environment (no private homes)
- Spatial extension up to one production hall (e.g. 400m)
- Indoor (no overhead lines)

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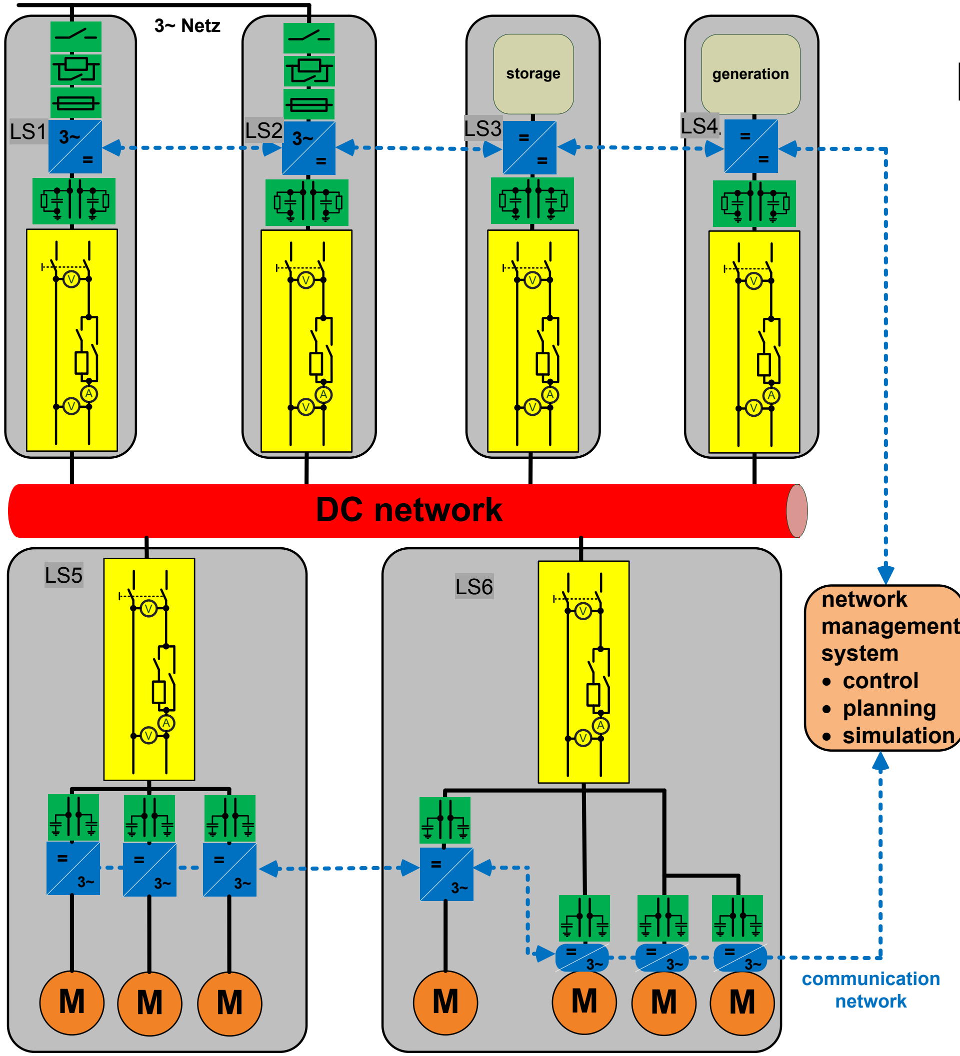
Overview of the DC grid

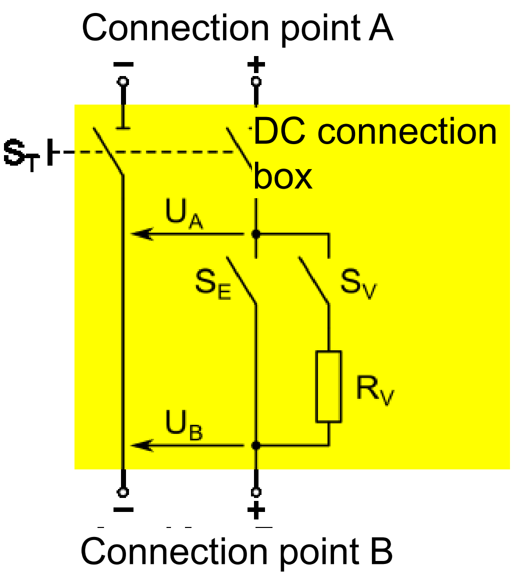


Load sectors…

- … form a common logical unit
- … contain components with strong functional interconnections
- … contain sufficient capacitance to keep transient events inside themselves
- … are connected to the DC grid via a DC connection box

Features of the DC connection box

- Protection of other load sectors and lines
- Disconnection of the load sector
- Pre-charging of the load sector
- Optionally: Measurement functions



Challenges

- Switching of DC current
- Fast current rise
- All load sectors feed into a short circuit → Selectivity

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Grounding concept: principles and solutions

Principles:

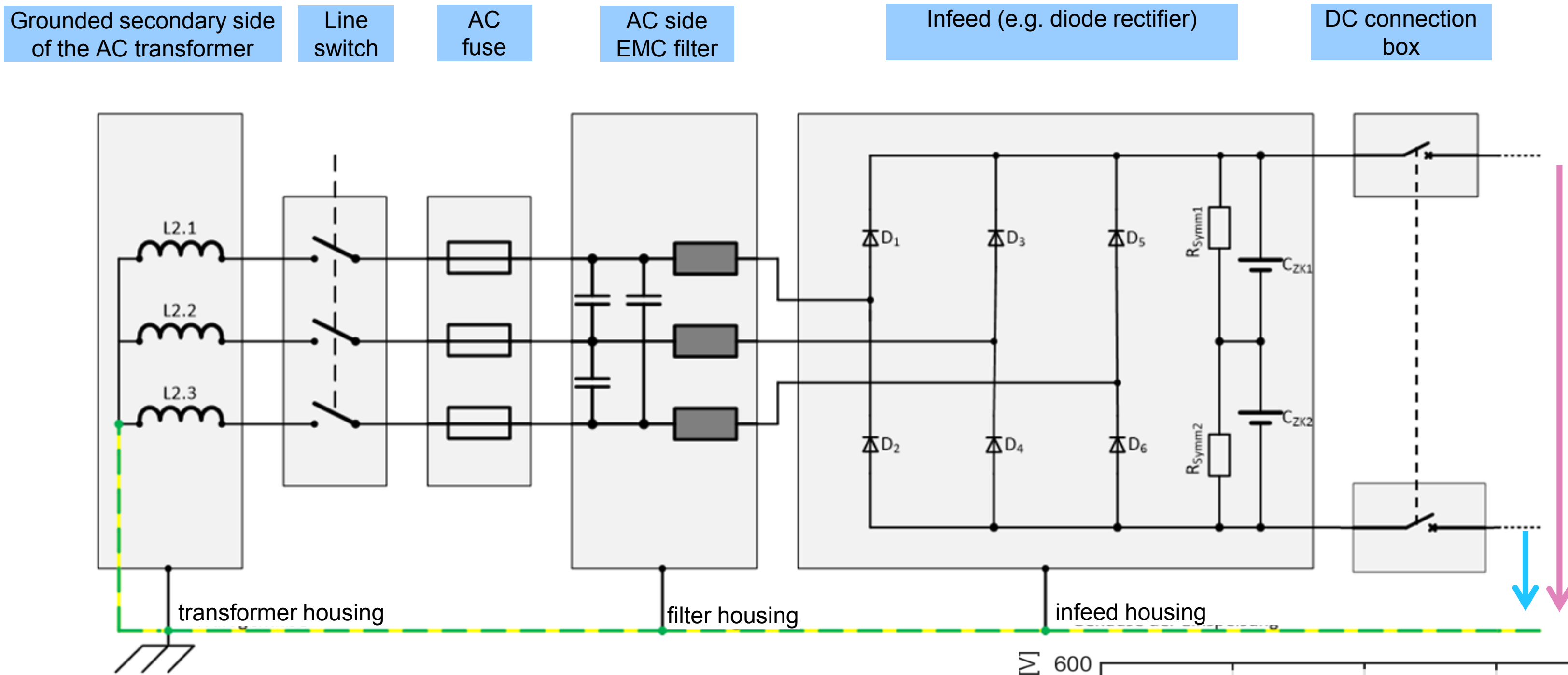
- Simple solutions (diode rectifier infeed) shall be possible
- Fast transients of the DC grid against ground should be prohibited for EMC reasons
- All grounding concepts shall require the same creepage and clearance distances inside the equipment

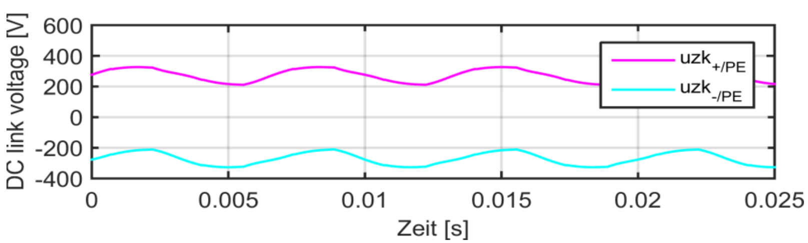
Two dedicated solutions:

a) Low impedance grounding of the star point of the AC grid

b) Capacitive grounding of the DC midpoint

Low impedance grounding of the AC grid star point





- Infeed will usually be an uncontrolled rectifier
- DC voltage to ground is impressed, both DC lines require a protective device.

Capacitive grounding of the DC midpoint

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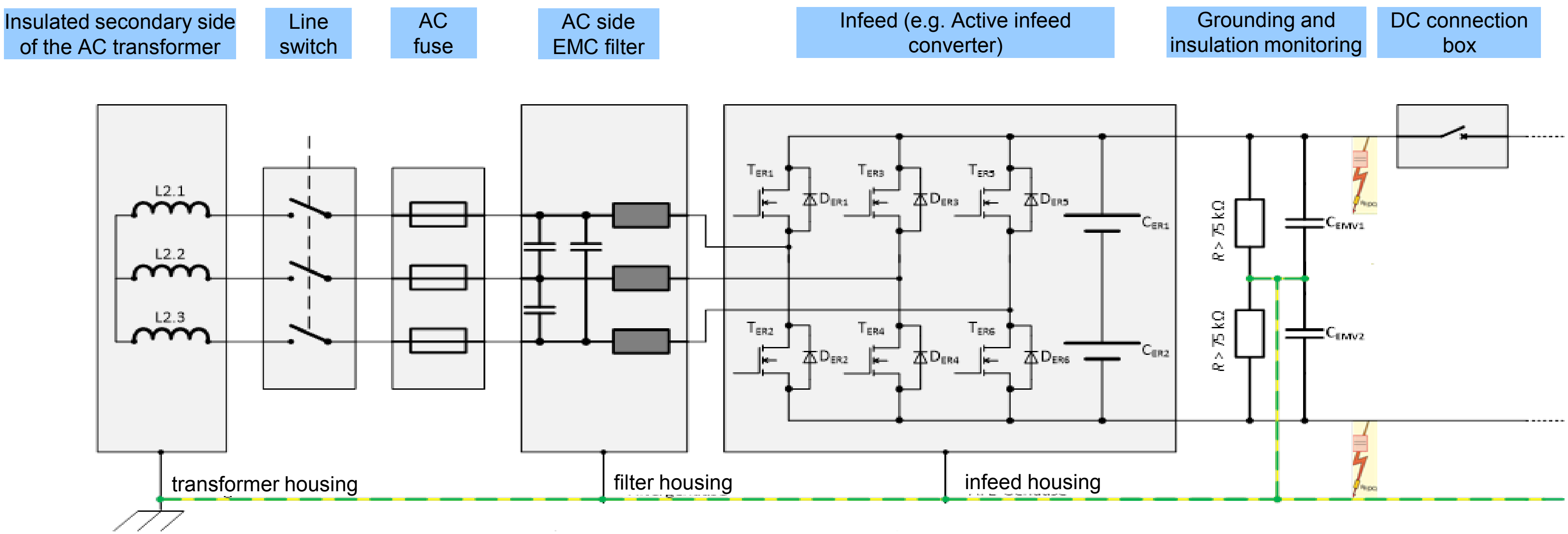
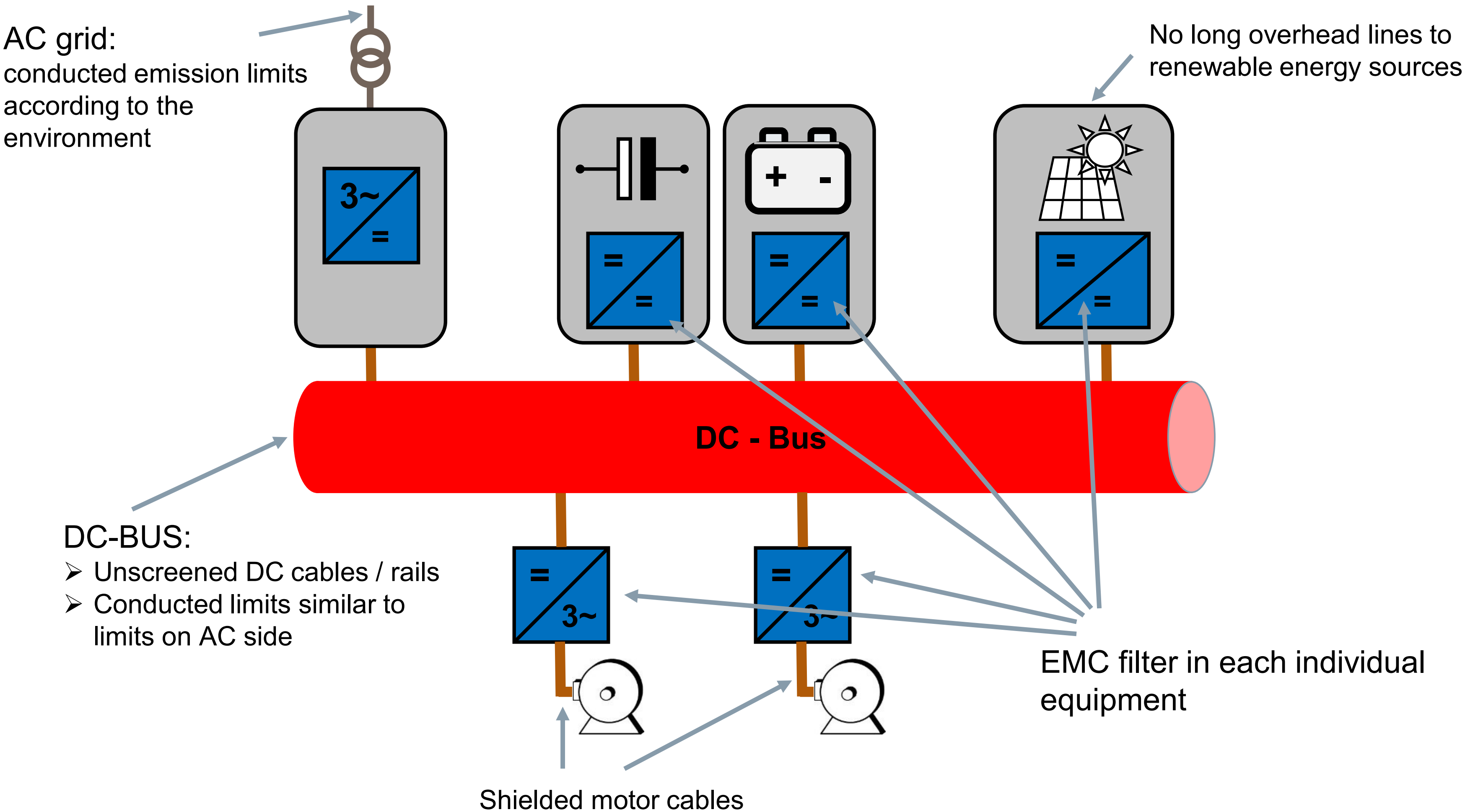


- The DC grid is de facto operated without connection to ground („quasi-IT“), there is only a high ohmic resistive (>75kΩ for the complete installation) and capacitive grounding
- Stable potential of the DC lines to ground due to EMC capacitors
- The AC grid is insulated from ground (insulating transformer)
- Only one DC line requires a fast protection device
- Operation may continue in case of one DC fault to ground

Overview of EMC ports



EMC concept - requirements

Two basic requirements:

1) All pieces of equipment in the industrial production site must not disturb each other
2) Radiated emissions must not disturb radio services

Standard requirements for motor cables and AC grid ports are identical to equipment used in today‘s AC grids

EMC concept - solutions

Particular issues for a DC grid:

1) High frequency common mode transients (DC → ground) may radiate
   → grounding concept avoids those

2) High frequency DC current may radiate
   → minimize area between DC rails
   keep high frequency currents inside a load sector (e.g. use shielded cabinet)
   shielding of DC rails is unwanted by customers

First artificial test results are positive

Final validation on test sites

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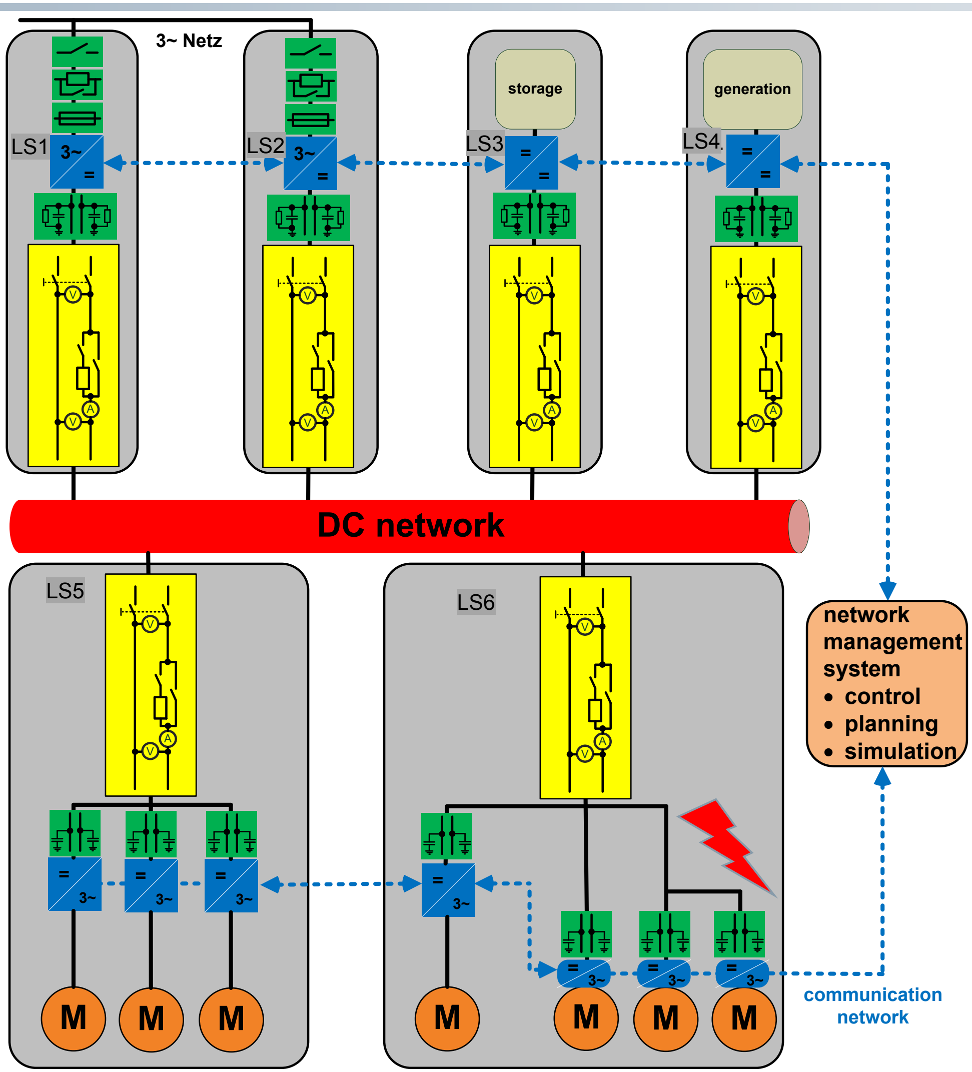
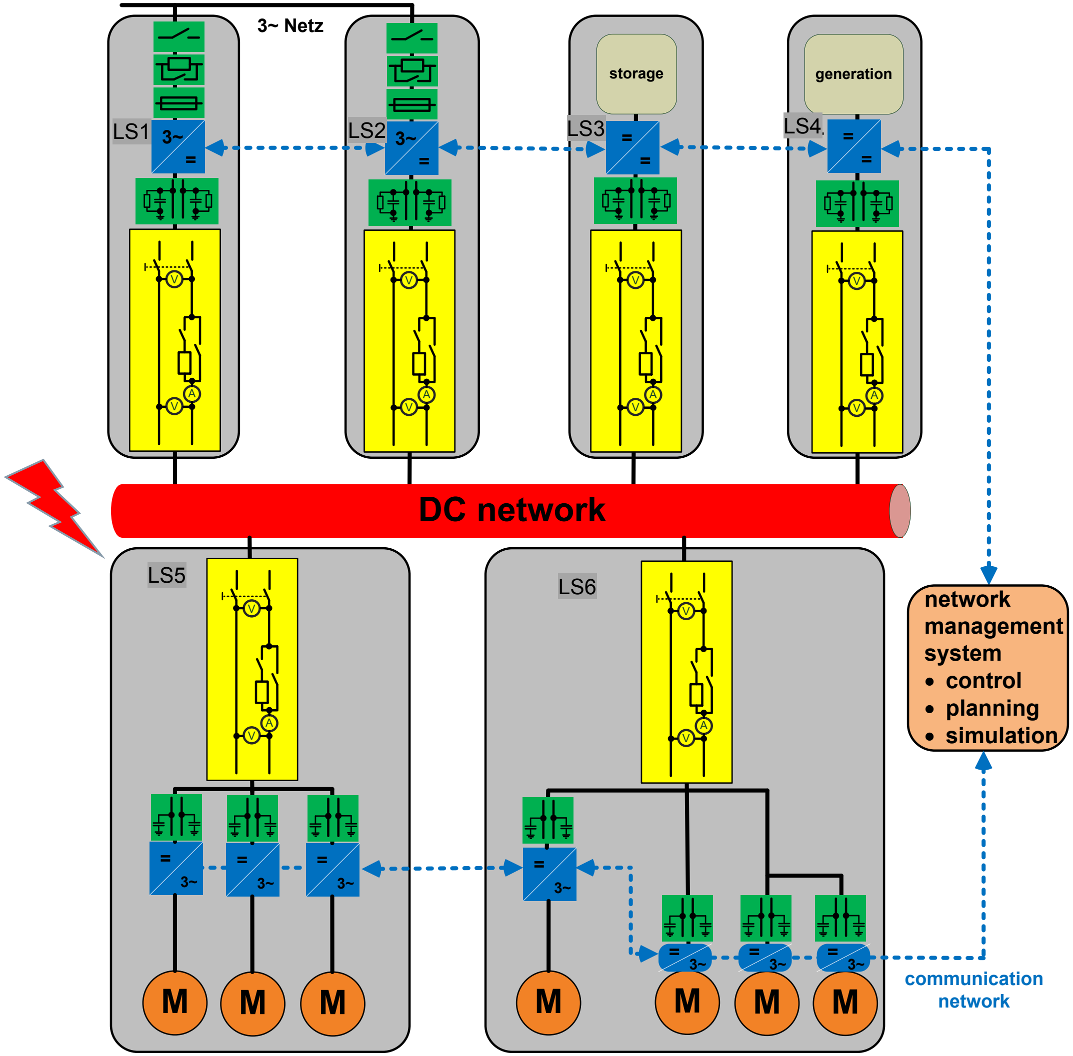
Scenario 1: Fault inside a load sector



- All equipment in LS 6 is down
- Equipment inside LS 6 must protect itself
- DC connection box of LS 6 must open quickly
- LS 1 to 5 continue operation without interruption
- After clearing the fault, the DC connection box of LS 6 closes and pre-charges LS6. Equipment in LS 6 starts operation again.

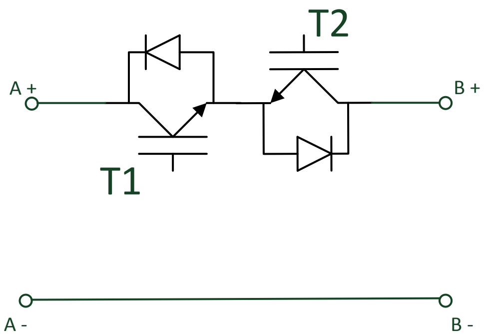
Scenario 2: Fault on the DC bus



- All load sectors feed into the fault
- All DC connection boxes open
- All equipment is down
- No equipment is damaged
- After clearing the fault, the DC grid is powered up again.

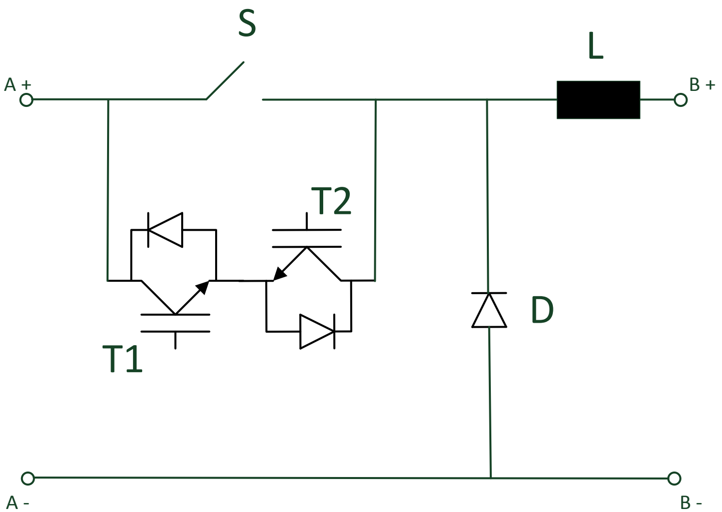
Today‘s ideas for fast protection switches

a) Fully electronic



- Very fast reaction time (few µs)
- High on-state losses

b) Hybrid:



- Low on-state losses
- Slower reaction time (few hundred µs)
- Choke required (careful design of resonances)

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Voltage ranges

Two possible rated voltages for the DC grid

- 540V: Suitable for 400V passive infeed
- 650V: Suitable for 400V active infeed and 480V passive infeed

Rated operating range:

- Operation of equipment without restrictions

Range of stationary over / under voltage:

- Equipment may be permanently operated in this range
- Functionality of equipment may be reduced (e.g. reduced power capability)
- Active equipment tries to compensate the voltage deviation

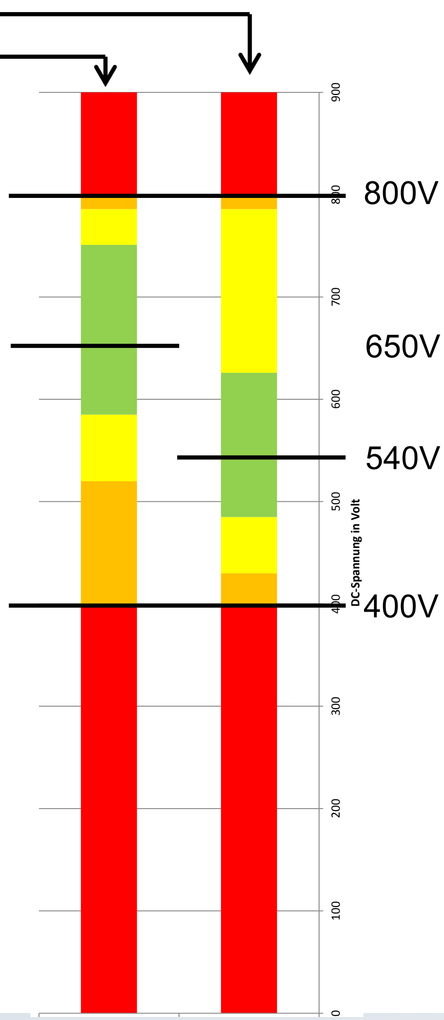
Range of transient over / under voltage

- Equipment may lose its function, but has to start operation again without any additional measures when the voltage comes back into the specified range
- Voltage may stay in this range for a limited time only

Protection limits: 400V / 800V

- Equipment switches off permanently

Manufacturers may define different power ratings for equipment when operated at different rated voltage



Voltage regulation algorithms

a) Uncontrolled operation (basic solution):

- No active control of the DC voltage (diode rectifier)

b) Droop control (decentralized voltage control):

- All active infeeds control their power according to the DC voltage
- Non-linear control characteristic
- No communication required

c) Extended decentralized voltage control:

- Control characteristic is adapted during operation by a central control unit
- Slow communication required

d) Central voltage control:

- Central control unit calculates setpoint values for the power of the infeeds
- Fast communication required

The support of one or more algorithms is a feature of the equipment and not defined by the concept

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Conclusions

- The DC grid consists of several independent load sectors
- Energy exchange between different loads and sources is very easy
- Grounding concepts are fixed and allow to use existing equipment with regard to creepage and clearance distances
- Main challenge is the development of fast and low loss protection devices
- Voltage ranges are fixed
- The DC grid may be operated with or without a higher-ranking management system for energy control

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