# MVDC
## *closing the voltage gap*
## *top-down or bottom-up?*

Johan Driesen, KU Leuven & EnergyVille

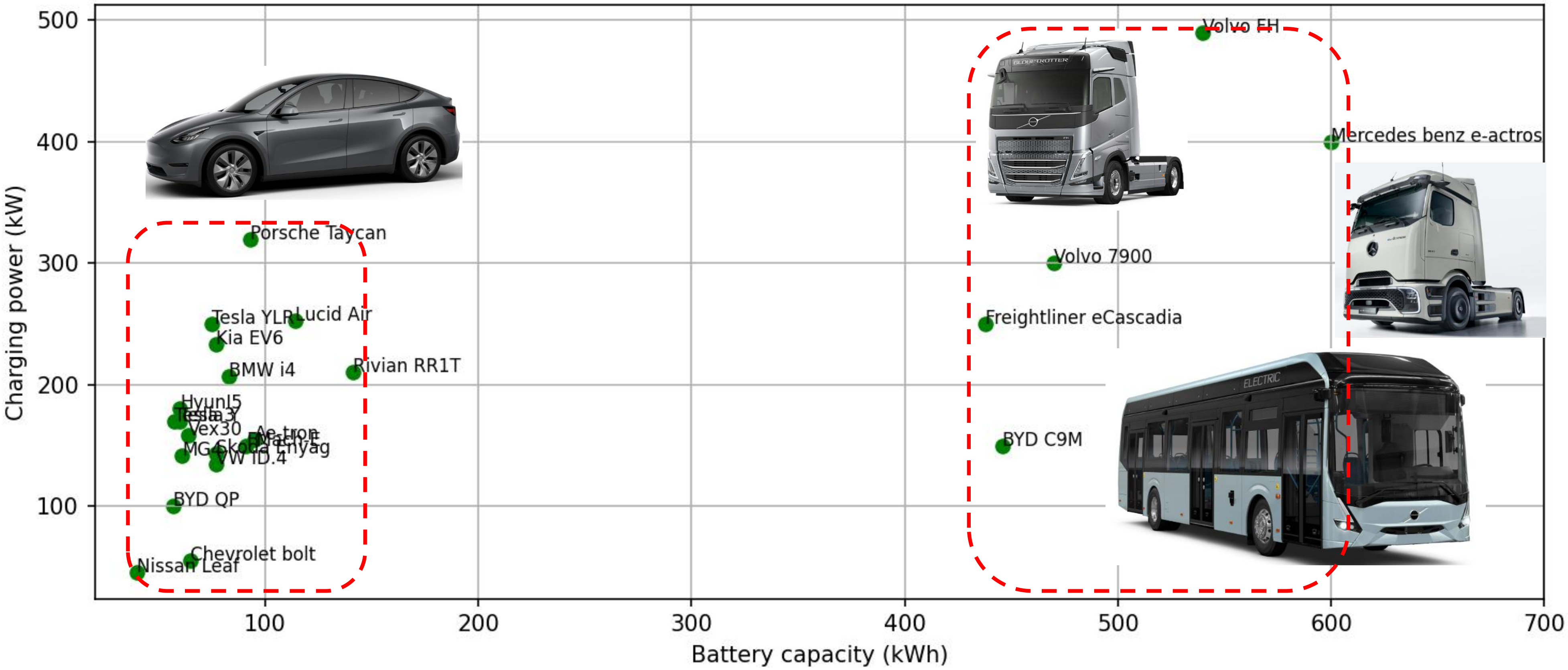
# Introduction

- All 3 main end-consumption sectors affected by **electrification**: cities, industry & mobility
- Technology shifts
  - Power systems: **AC → DC**, driven by power electronics
  - Storage: towards **modular batteries** offering multiple services
  - Mobility: electrification of cars → **electrification of heavy transport** (e-**trucks**)
  - New loads: **data centres**
- Converge to **MVDC microgrids**
  - LVDC: power limitations
  - HVDC: complexity

# Electrification challenge (heavy-duty) Mobility

# Charging power vs. battery capacity

## Charging power/energy trend




500 kW charger

# E-Truck charging challenge

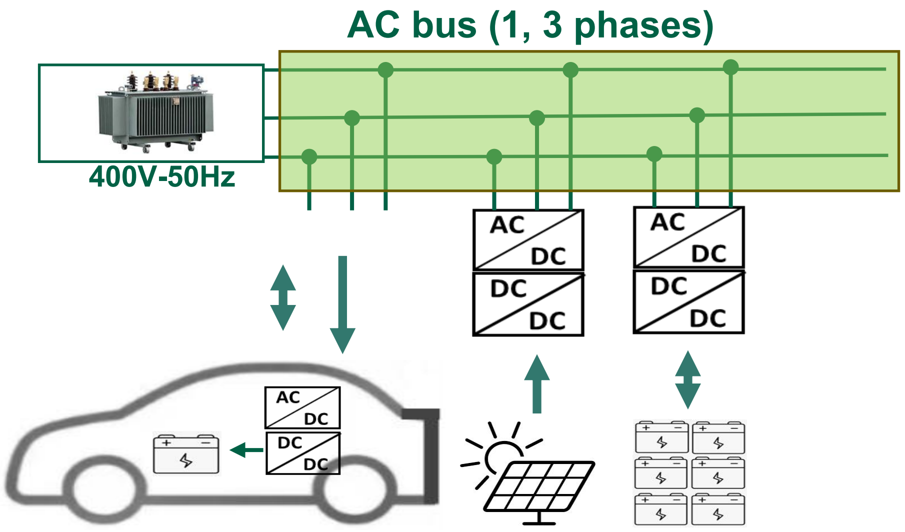
**Example Windrose**

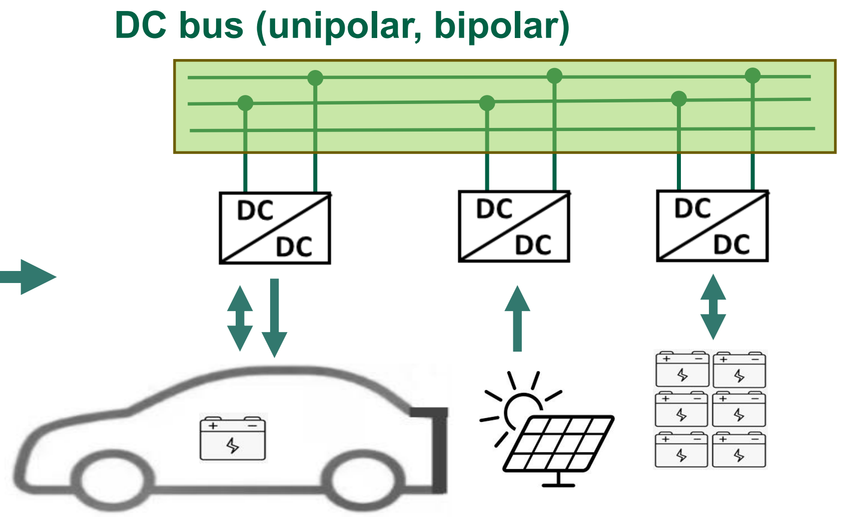
# Specific for (heavy) trucks: MCS

- Megawatt Charging System (MCS)
  - Max 1.250 V & 3.000 A (DC)
  - Power: 1 - 2 - 3,75 MW


# Electrical system architecture

*ICON HUME project VITO/KUL*




mature protection system
standardized technology

complex control
more conversions
power quality issues

simple control
less conversions
less power quality issues

**Better integration of PV/BESS**

complex protection system
non-standardized technology

## Operating Efficiency?

What is important for a CPO from an operation/business perspective?

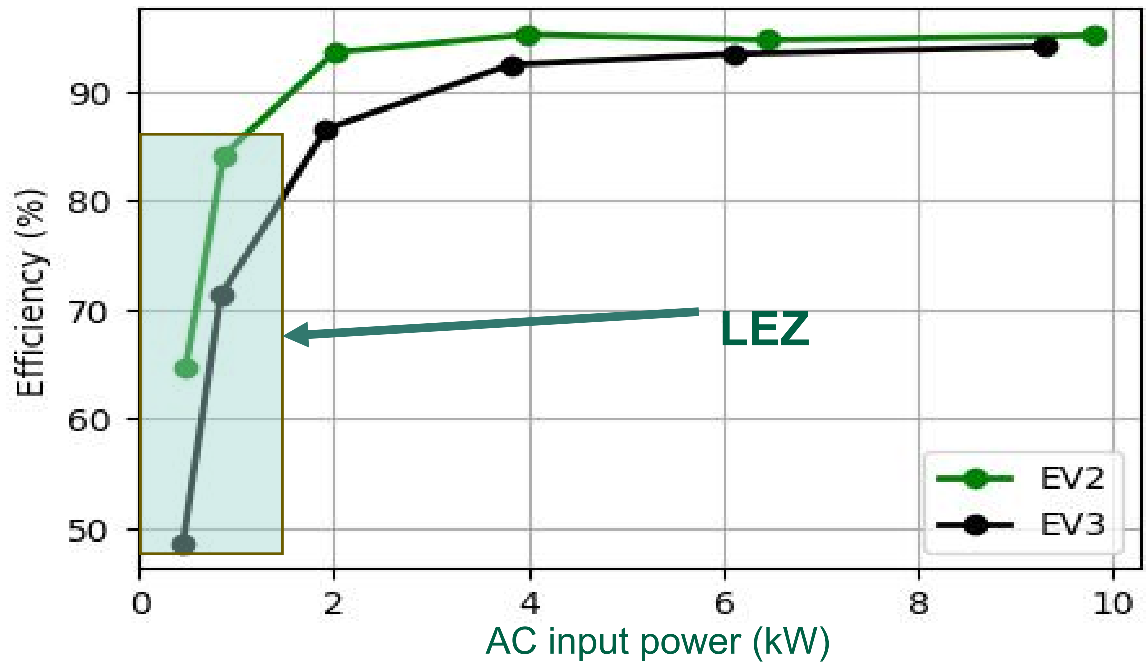
CPO: charging point operator
BESS: Battery Energy Storage Systems

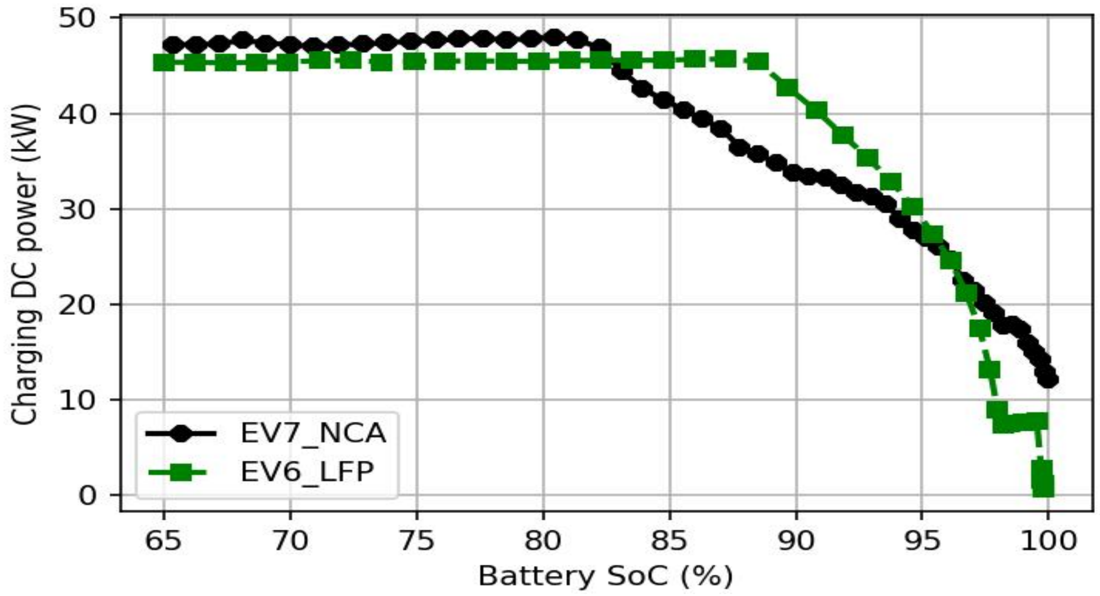
KU LEUVEN

# Do not forget: real-life charging efficiencies may yield problematic load balancing

*ICON HUME project VITO/KUL*

Operating efficiency at different charging power level

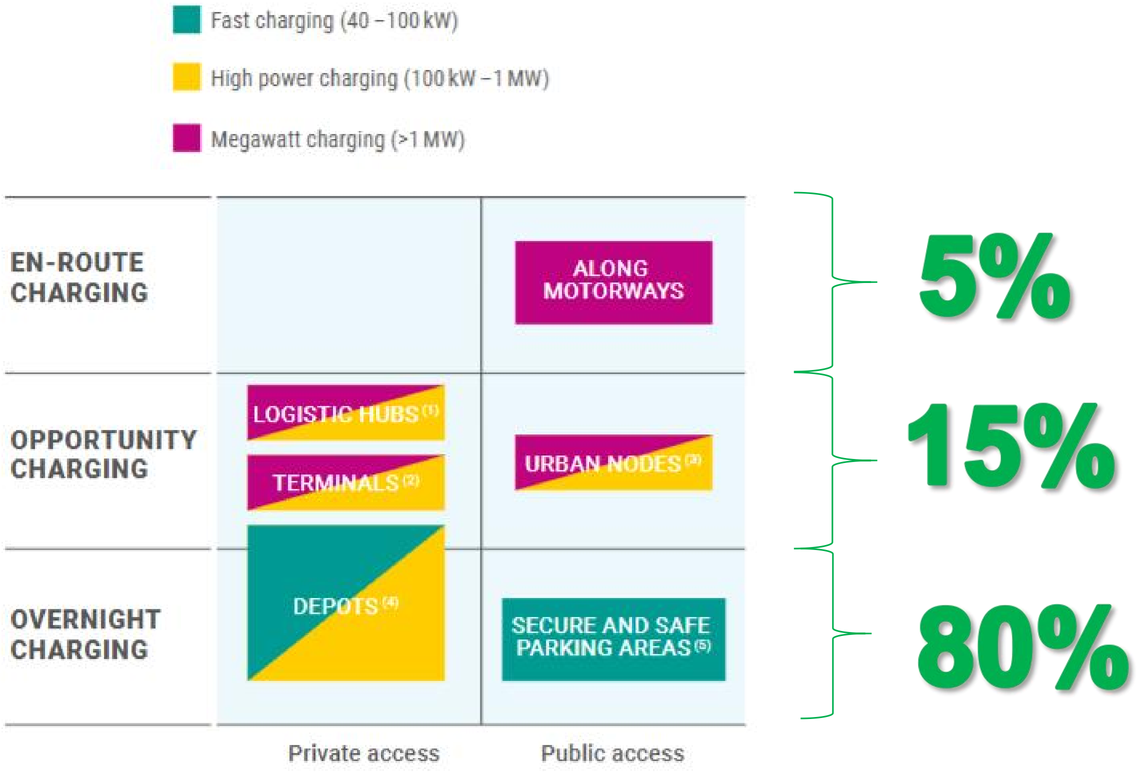



**10-15% charging power level means less than 85% efficiency**
**Note: double losses in case of V2X**

KU LEUVEN

# Energy requirement based on transportation demand

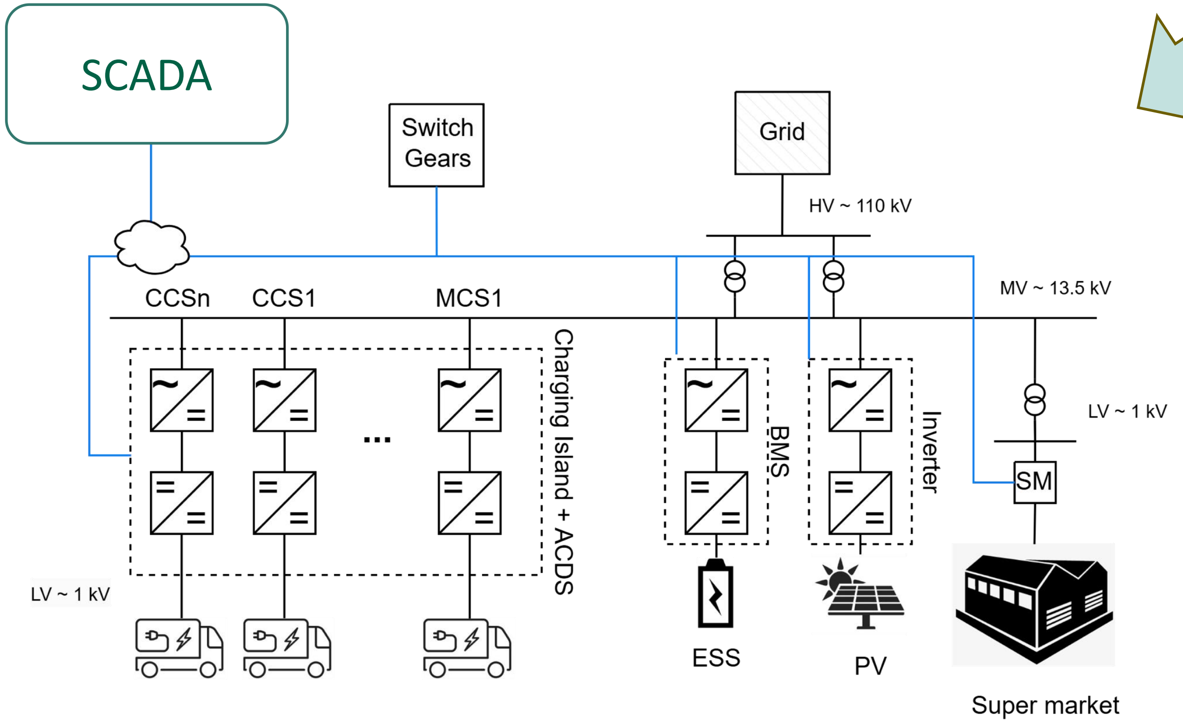



Total energy required

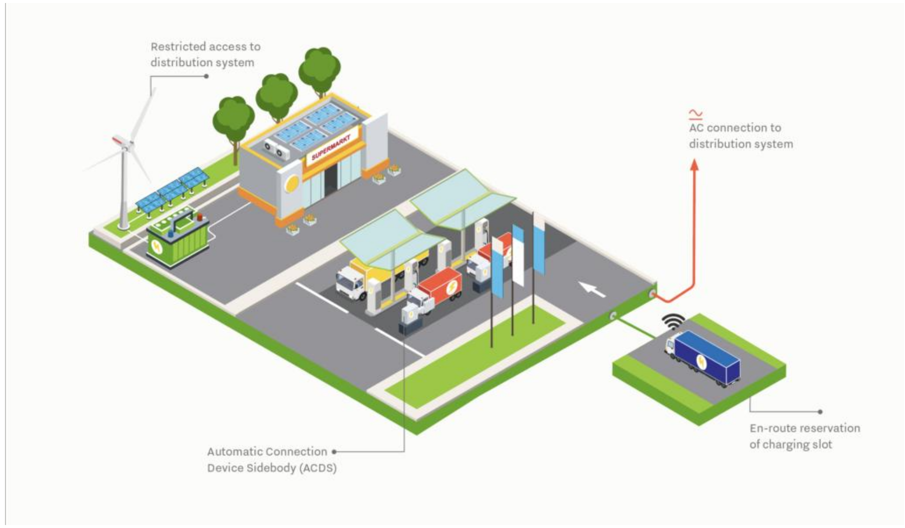
Total energy required

# Business Cases

## Trends in the market



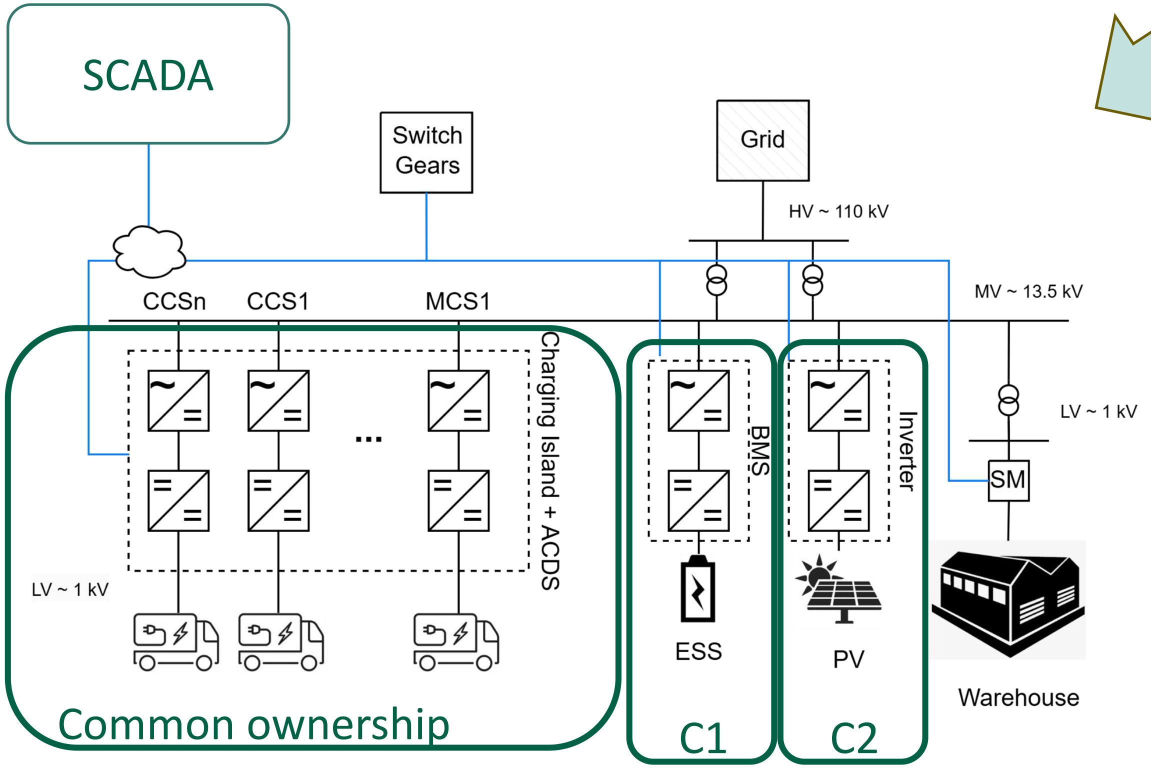

Adapted from [Charging Energy Hubs]



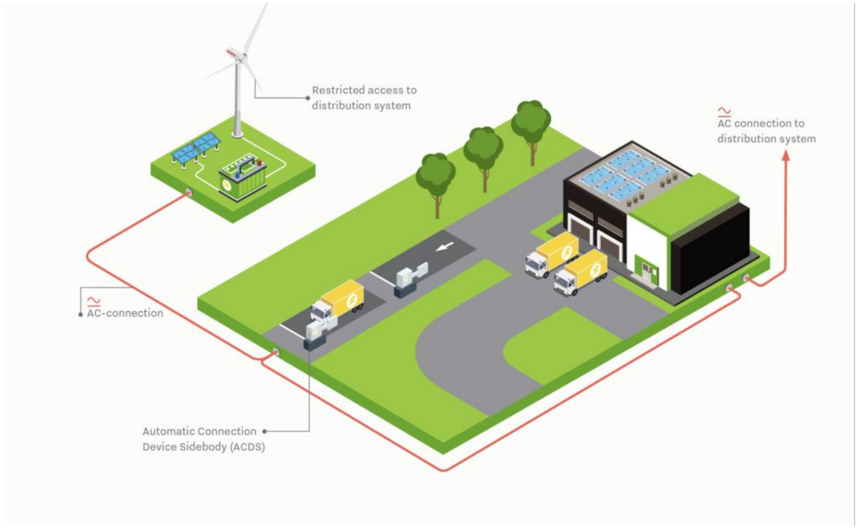

- **Charging Hubs (Public):**
  - Truck-oriented layout available
  - Option to book charging timeslots (Increased QoS)
  - PV/Wind integration potential near existing companies (supermarkets, ports, etc.)
  - Uniform and transparent tariff scheme (lower operation costs for LC)

# Business Cases

## Trends in the market




Adapted from [Charging Energy Hubs]



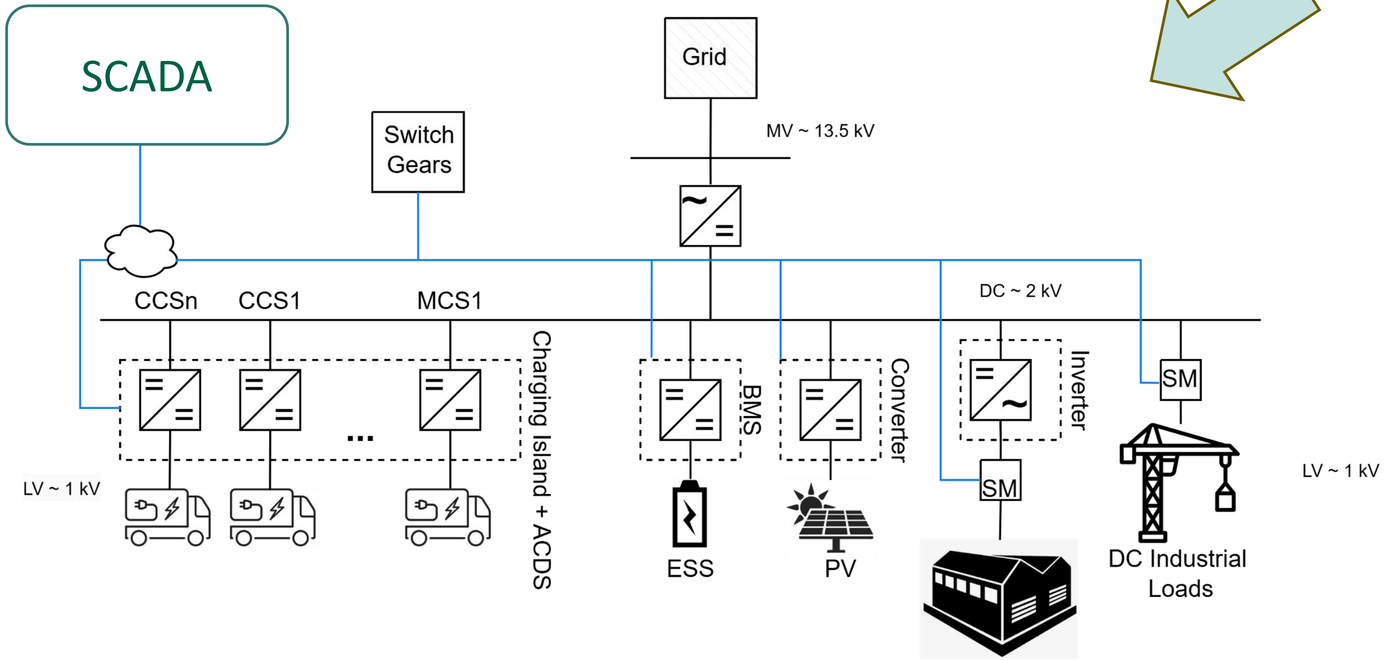

- **Collective Charging (Semipublic):**
  - One or more companies with operations in the same place. Suitable for "destination" or opportunity charging. **Common connection point.**
  - Cooperative strategies can be applied (PV generators, BESS owners, etc.)
  - Great opportunity for innovation and new charging schemes from CPO. Dynamic Operating Envelopes, Non-firm agreements.
  - Combination of MCS, CCS is ideal to support multiple operations.

KU LEUVEN

# Business Cases

## Trends in the market

Adapted from Charging Energy Hubs

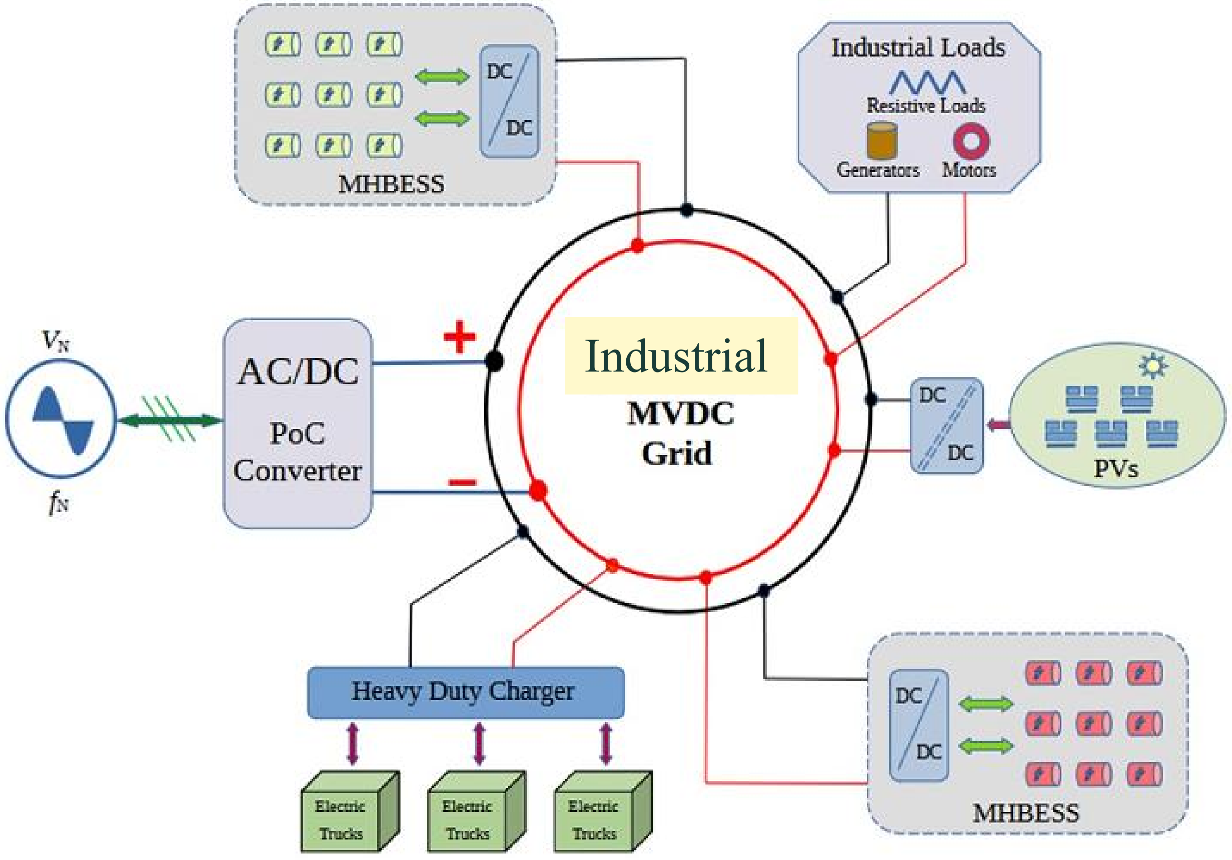




- **Private charging:**
  - More degrees of freedom possible: Greenfield.
  - DC topologies can be leveraged for improved control and efficiency.
  - Seamless integration with companies with heavy electrical drives (DC loads)
  - All gains from electricity produced from DER
  - Capital intensive for logistic companies

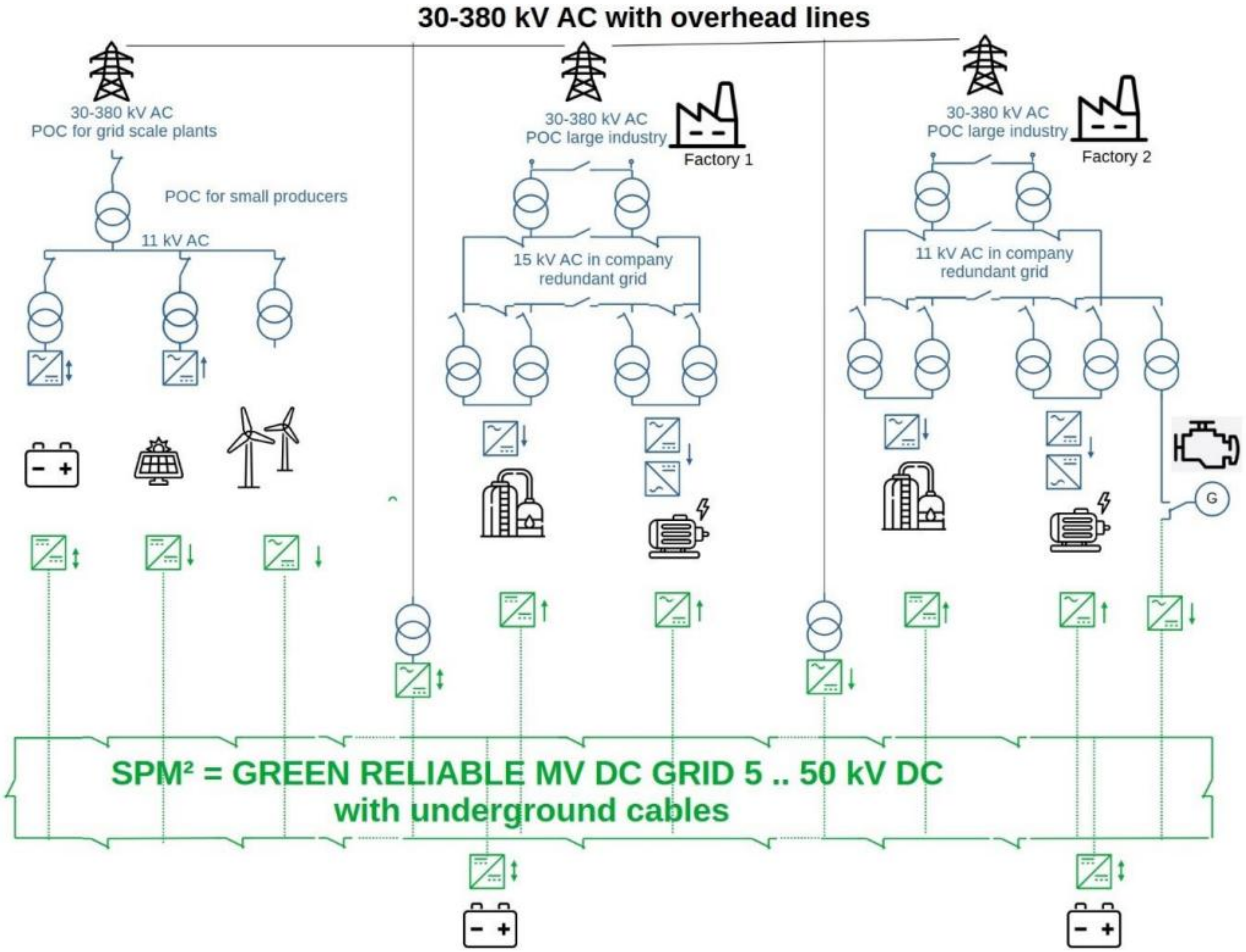
# Industrial systems: conversion architecture

# MVDC in industry

*Avoid Grid Reinforcements*
*for Industrial Transient peak-power and Electrification*

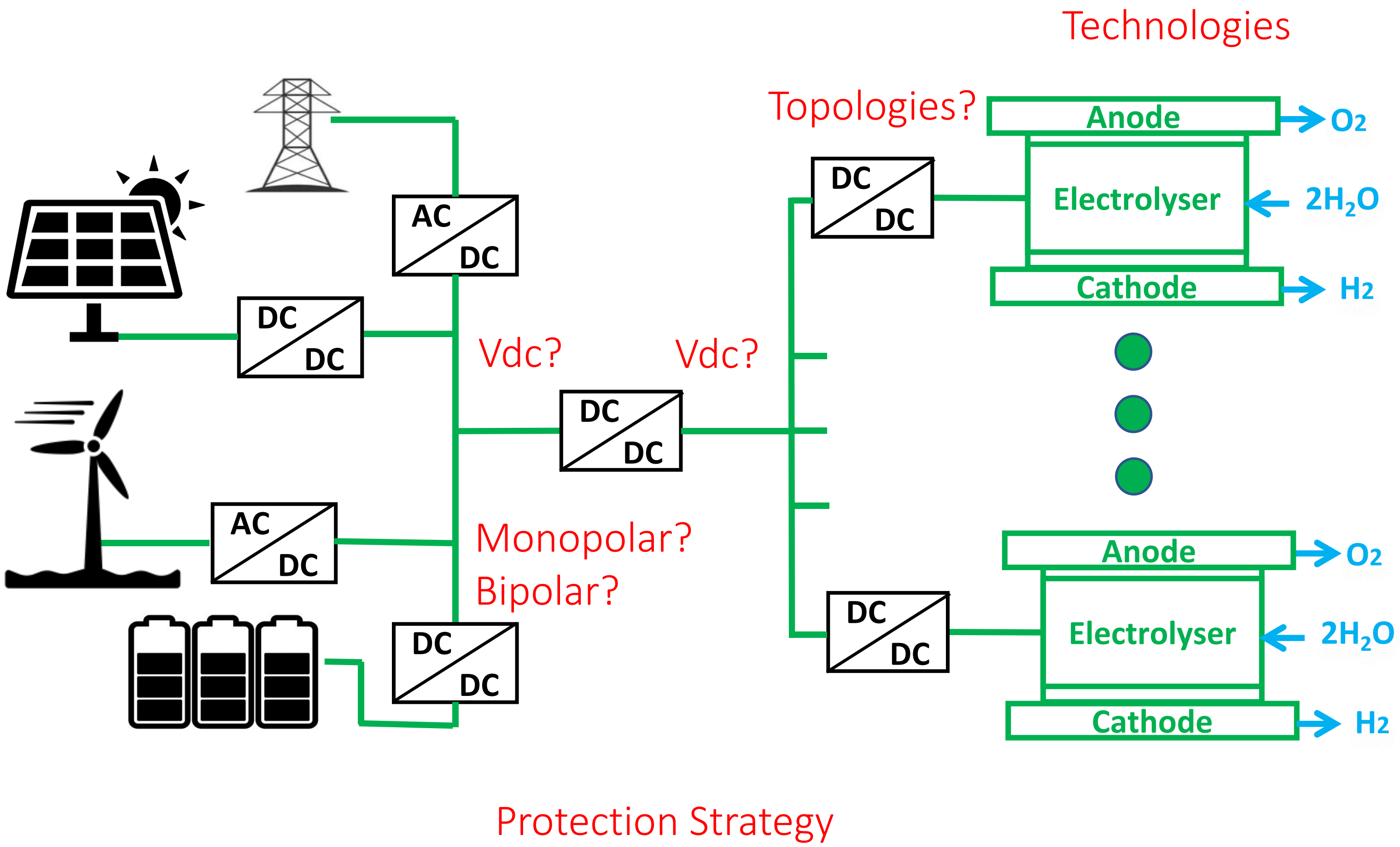


# Power conversion architectures for heavy industry



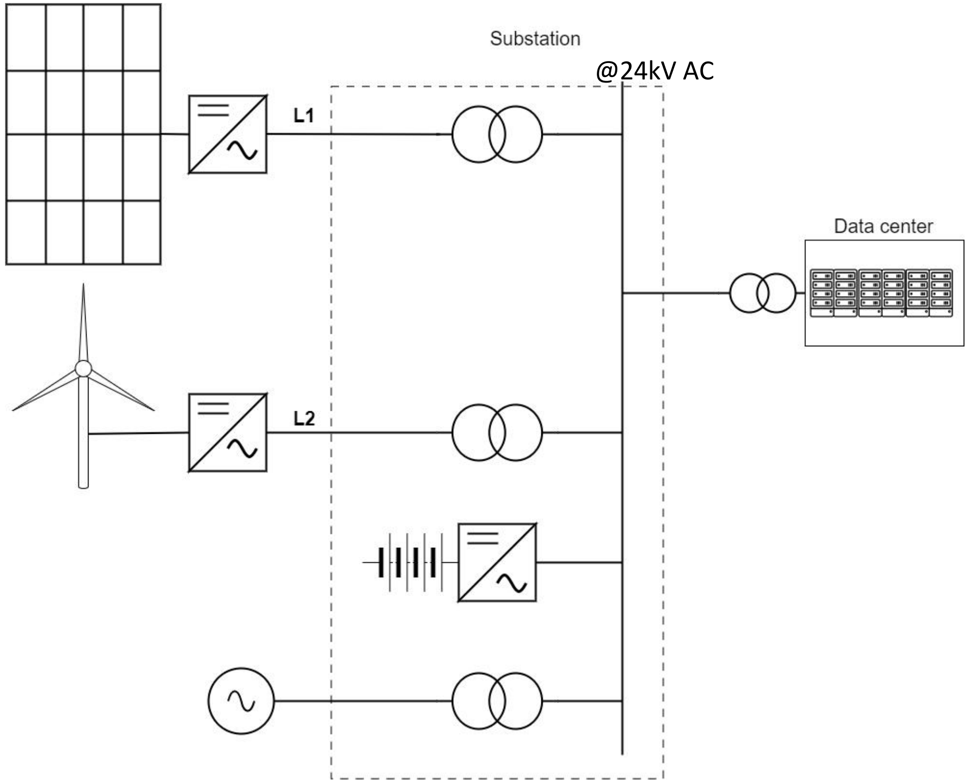

*Conceptual overview of a green and reliable MVDC grid, as compared to a state-of-practice MVAC distribution with redundant conduction paths.*

# Use case: Challenges for $H_2$ production



# Data centre power conversion architectures

# AC Benchmark



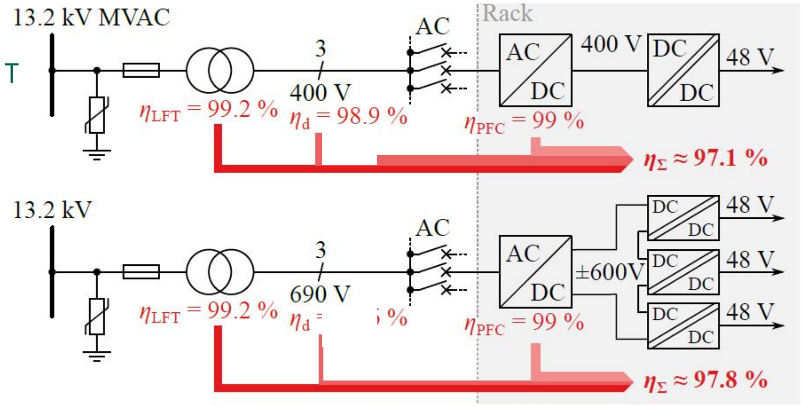

## AC distribution system + AC data centre

- Standard case
- Mature equipment
- Lowest CAPEX of the four scenarios
- Lots of industry experience

## Needed equipment

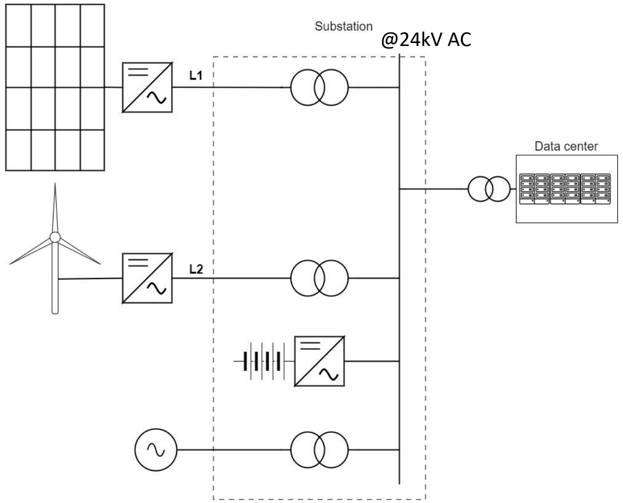
- Step-up transformers (PV and wind)
- Step-down transformer (data centre)
- PV and wind inverters
- Battery inverter

From substation bus to IT equipment:




J. Huber, P. Wallmeier, R. Pieper, F. Schafmeister, and J. W. Kolar, "Comparative Evaluation of MVAC-LVDC SST and Hybrid Transformer Concepts for Future Datacenters."

# AC Benchmark




## TRL levels

- Step-up transformers (PV and wind) – **TRL 9**
- Step-down transformer (data centre) – **TRL 9**
- PV and wind inverters – **TRL 9**
- Battery inverter – **TRL 9**

(https://www.atesspower.com/news/atess-releases-new-1mw-battery-inverter)
(https://www.chintpowersystems.com/string-pcs-station/)

Skid battery inverter example

## Pros and cons

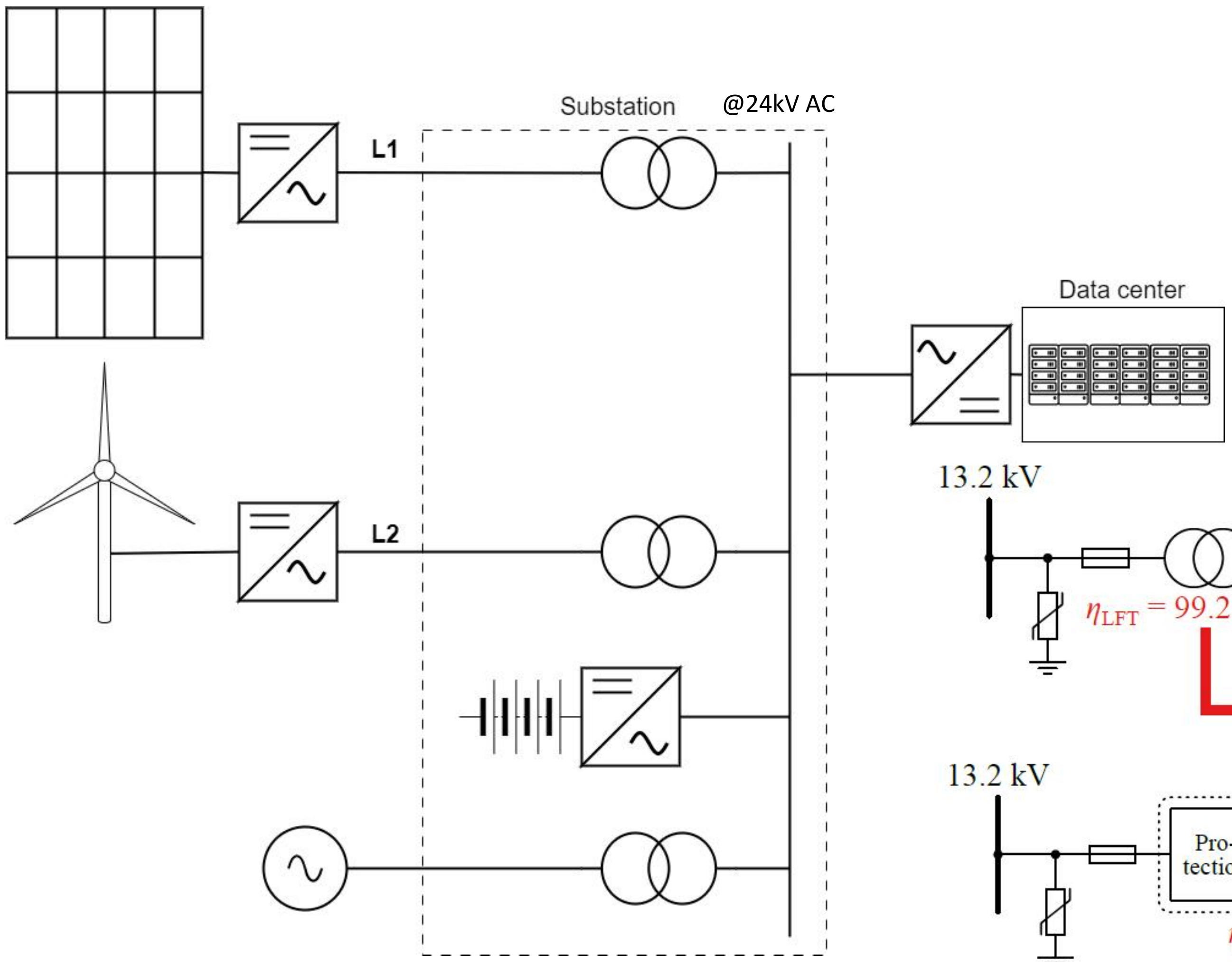
+ Commercial off-the-shelf components
+ Transformers are highly reliable and efficient (>98%)
+ Lots of industry experience
+ Application of standard designs
- Losses associated with AC power distribution
- Battery DC – AC – DC datacentre: lossy conversion steps

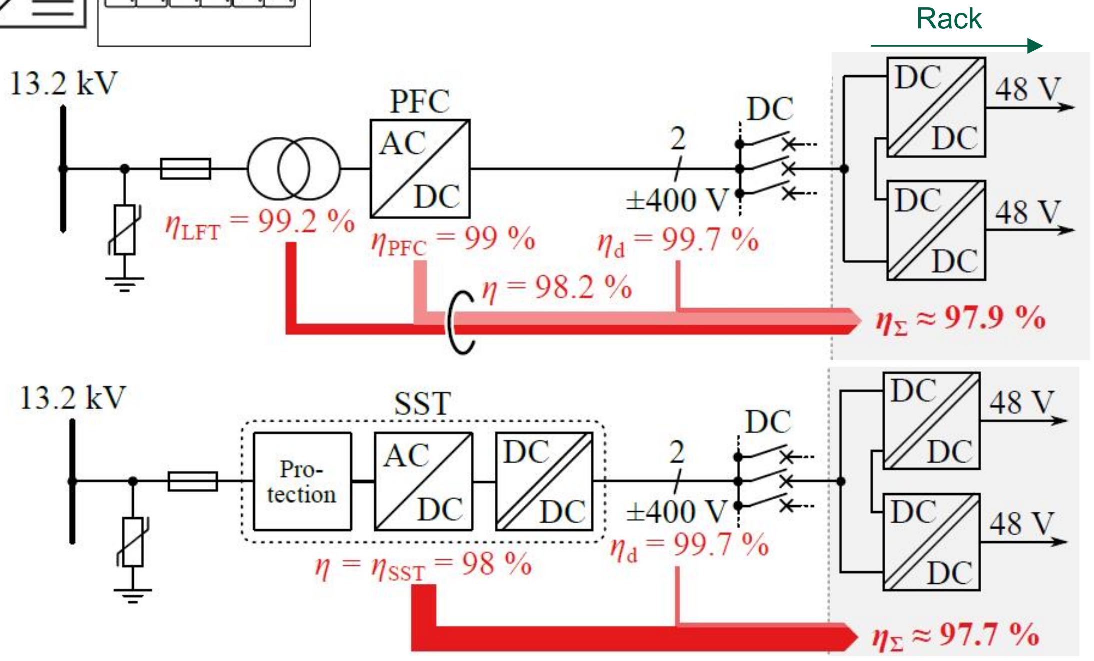
# AC distribution, DC data centre

- Power collection and distribution in AC
- DC power enters the data centre

## Needed equipment

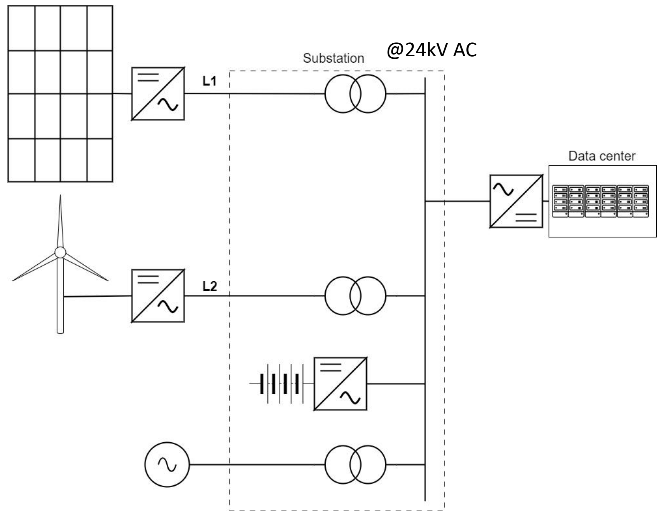
- Step-up transformers (PV and wind)
- MW-scale rectifier (data centre)
- PV and wind inverters
- Battery inverter




J. Huber, P. Wallmeier, R. Pieper, F. Schafmeister, and J. W. Kolar, "Comparative Evaluation of MVAC-LVDC SST and Hybrid Transformer Concepts for Future Datacenters."

# AC distribution, DC data centre




**Pros and cons**

+ MW-scale rectifiers for DC distribution are more efficient than kW-scale devices. However, the efficiency gain may be limited to the order of one percent [1].

  (Nonetheless, each % efficiency matters a lot because electricity usually accounts for 40-80% of the lifetime OPEX of a data centre [2])

+ DC distribution at the building level also raises reliability [1]

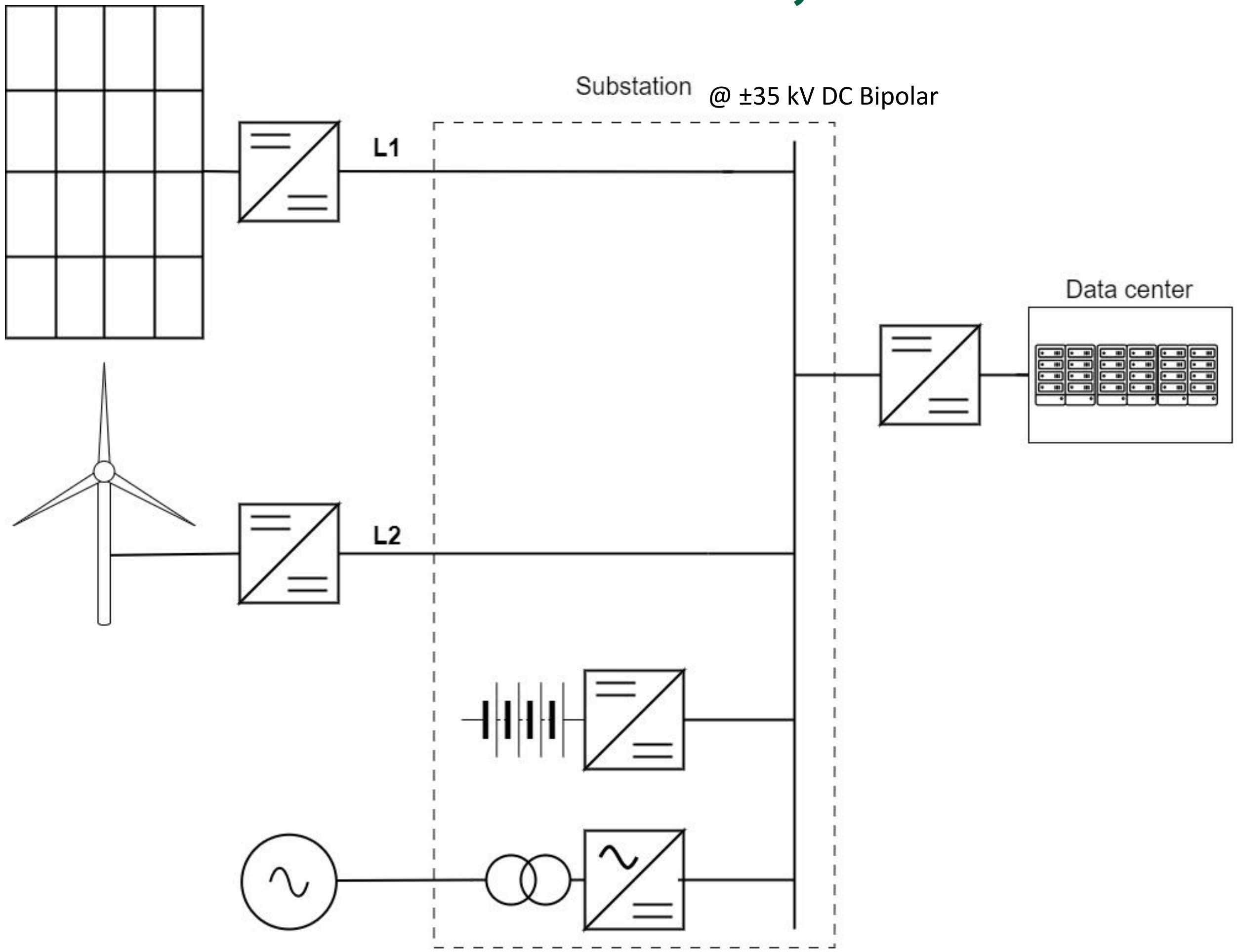
- DC power supply for the data centre may require changing the configuration of the Internal Power Conditioning System (IPCS)

- Grid-side rectifier to supply data centre is not standard equipment and will likely be a tailor-made converter (and therefore be expensive).

- DC power supply for data centre raises protection cost and complexity


[1] Y. Chen, K. Shi, M. Chen, and D. Xu, "Data Center Power Supply Systems: From Grid Edge to Point-of-Load," *IEEE J Emerg Sel Top Power Electron*, vol. 11, no. 3, pp. 2441–2456, Jun. 2023, doi: 10.1109/JESTPE.2022.3229063.
[2] P. T. Krein, "Data Center Challenges and Their Power Electronics," CPSS Transactions on Power Electronics and Applications, vol. 2, no. 1, pp. 39–46, Apr. 2017, doi: 10.24295/CPSSTPEA.2017.00005.

# DC distribution, DC data centre

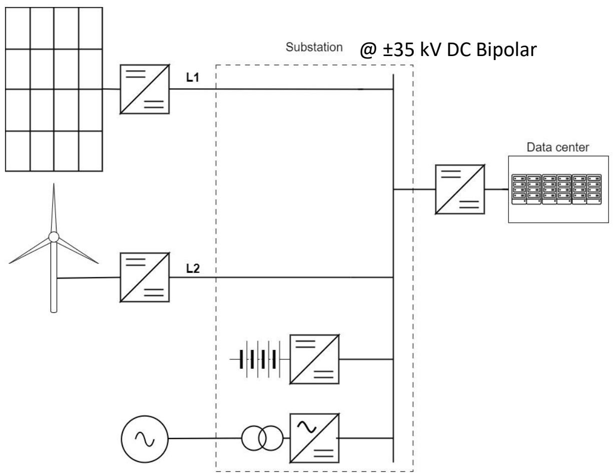



- Power collection and distribution in DC
- DC power enters the data centre
- DC voltage is stepped down before entering the data centre

## Needed equipment

- Step-up DC/DC converters (PV and wind)
- MW-scale step-down DC/DC converter (data centre)
- Battery DC/DC converter

# DC distribution, DC data centre




**Pros and cons**

+ Higher efficiency (less conversion steps)
+ Better reliability (less conversion steps)
+ Efficiency benefits of DC power distribution
+ Less power quality management issues

- Equipment is not readily available
- Installation is not exactly the same as for AC, which may require reskilling of workers.
- Avoidance of losses (lower OPEX) may not justify increased investment for converters (higher CAPEX)
- DC power supply for data centre raises protection cost and complexity
  (e.g. short circuit faults are much more severe for an MVDC system)

# Efficiency comparison

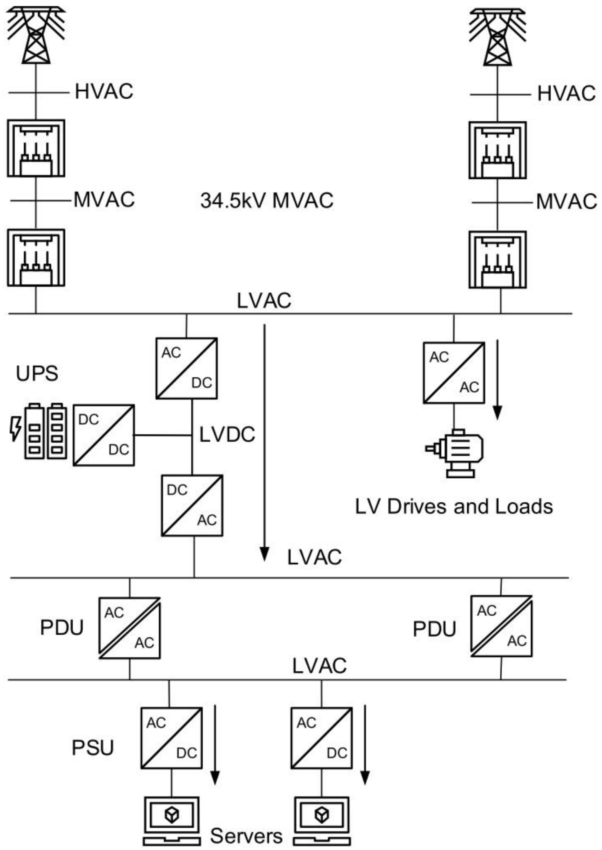



**Fig. 5** AC topology.

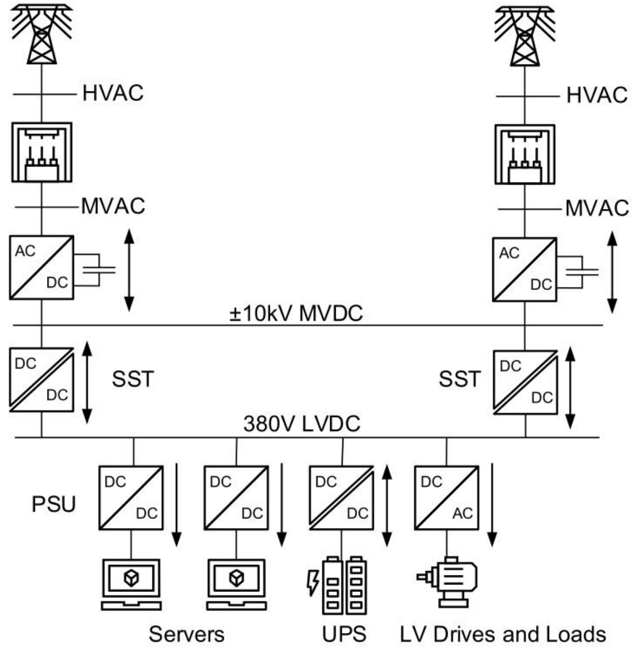


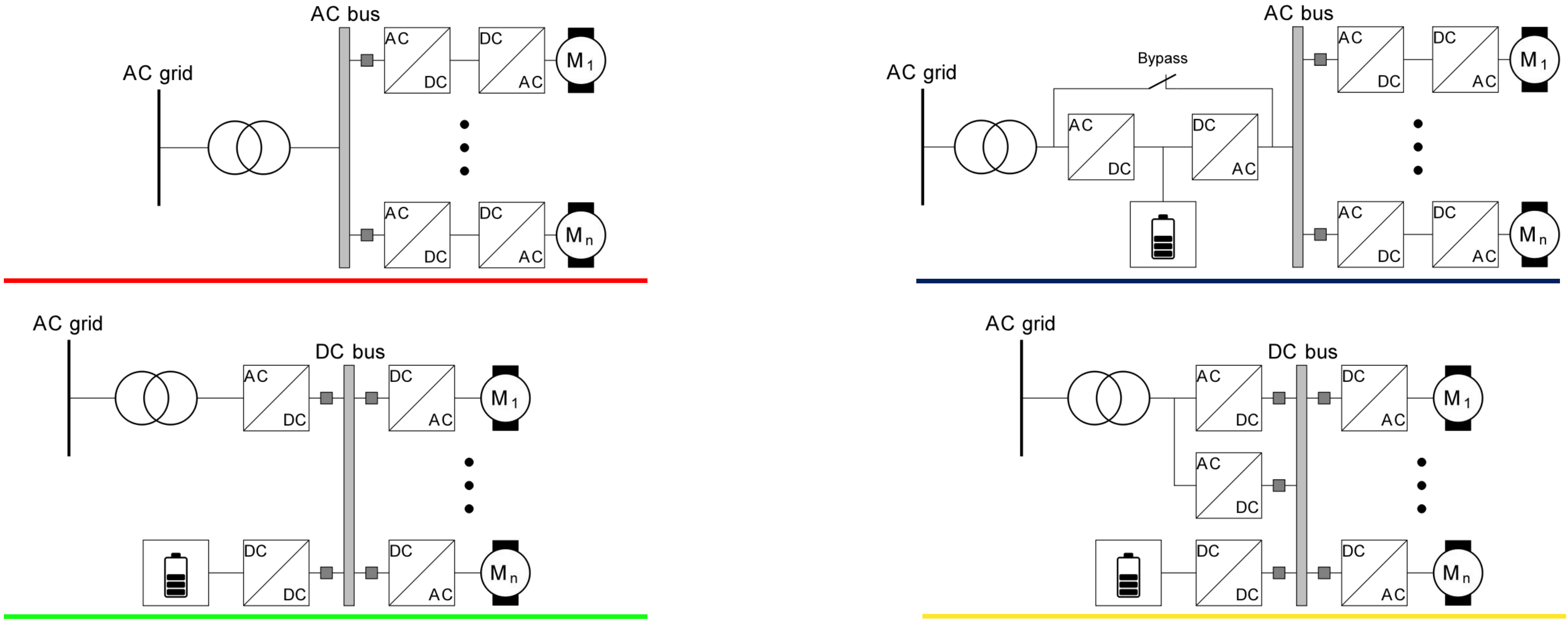

**Fig. 6** DC topology.

| Efficiency – IT (%) | | | |
|---|---|---|---|
| AC distribution | | DC distribution | |
| HV-MV transformer | 99.53 % | HV-MV transformer | 99.53 % |
| MV AC cables | 99.00 % | MV DC cables | 99.00 % |
| | | Power Converter | 99.00 % |
| MV-LV Transformer | 99.53 % | SST ±10 $kV_{DC}$-380 $V_{DC}$ | 98.70 % |
| UPS | 96.30 % | UPS | 99.85 % |
| PDU | 99.14 % | | |
| PSU | 93.20 % | PSU | 95.60 % |
| **Efficiency** | **87.26%** | **Efficiency** | **91.91%** |

**Source:** D. Siemaszko, S. Heinig, C. Yuan, J. Iglesias, and M. Mogorovic, "MVDC Distribution Concept for Green Data Centers: Achieving the Sustainability Roadmap with Highest Efficiency," in *PCIM Europe Conference Proceedings*, Mesago PCIM GmbH, 2023, pp. 301–309. doi: 10.30420/566091040.

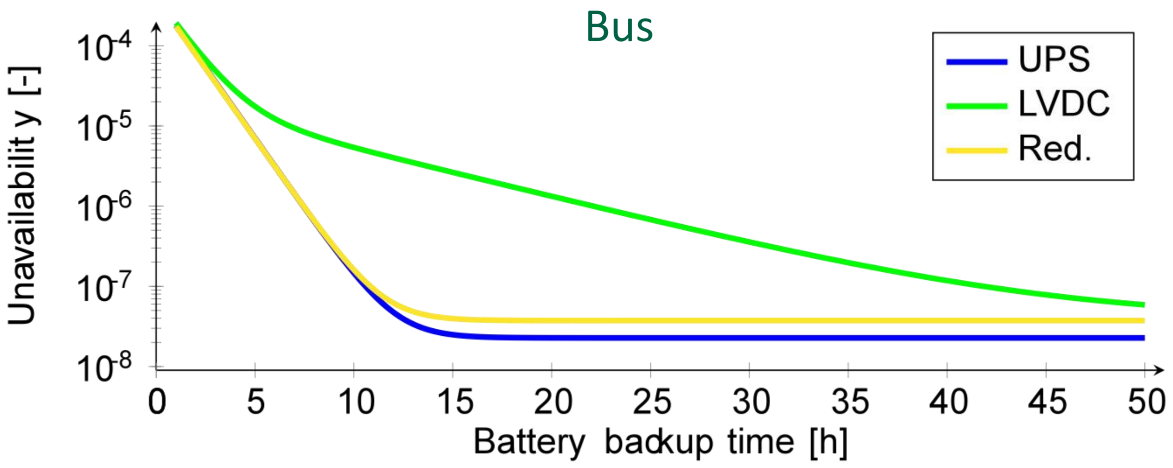
# Industrial systems: reliability

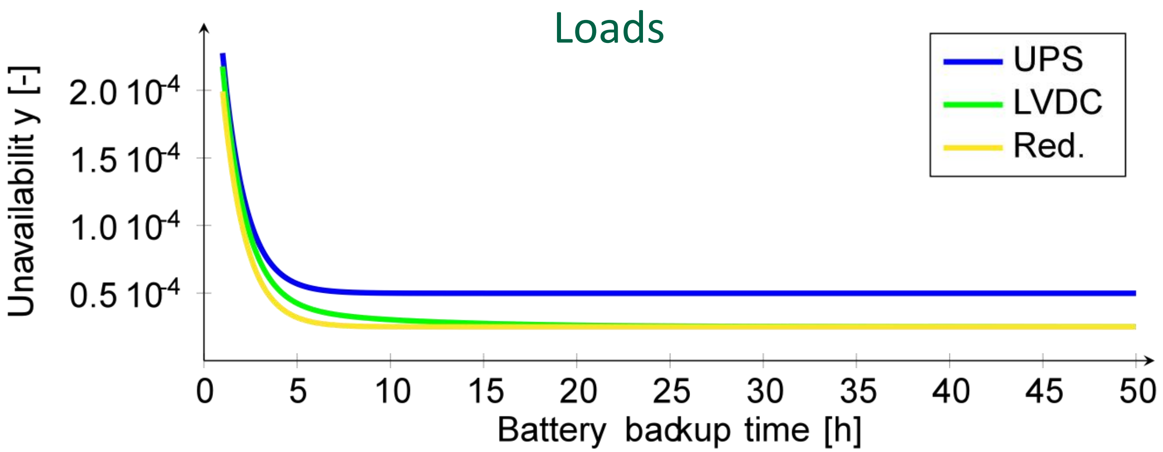
# Comparison of industrial distribution topologies

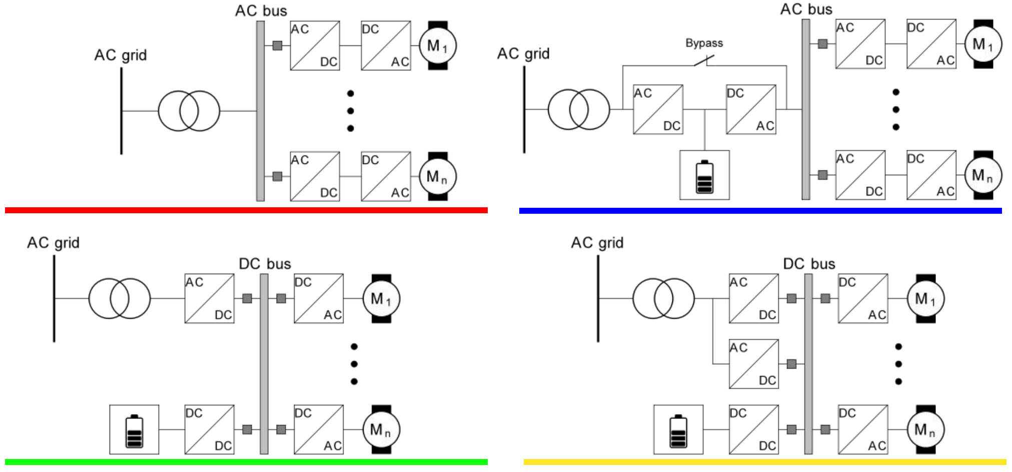



G. Emmers, J. Driesen, "Comparison of System-Level Availability in Industrial Grids", in 24th European Conference on Power Electronics and Applications (EPE'22 ECCE Europe), IEEE, Hannover, 2022.

# Unavailability analysis I



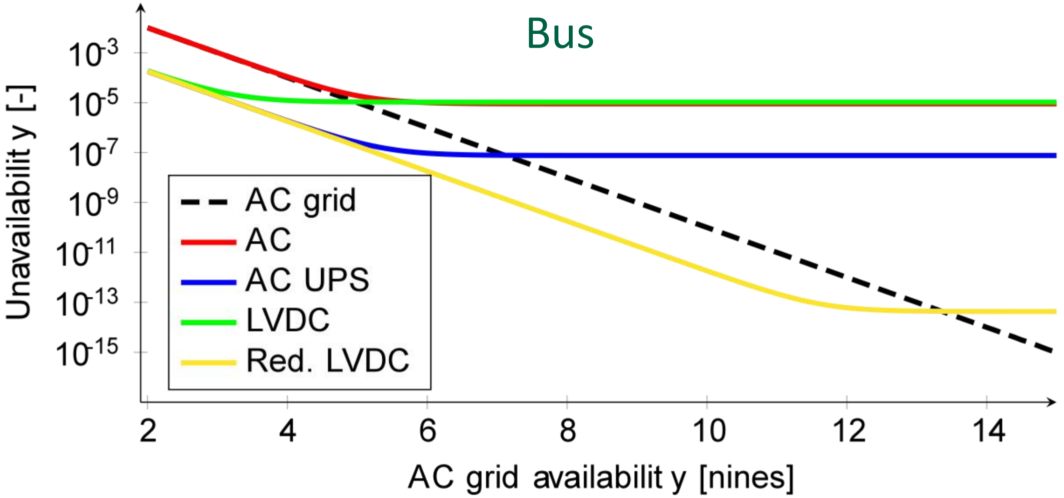



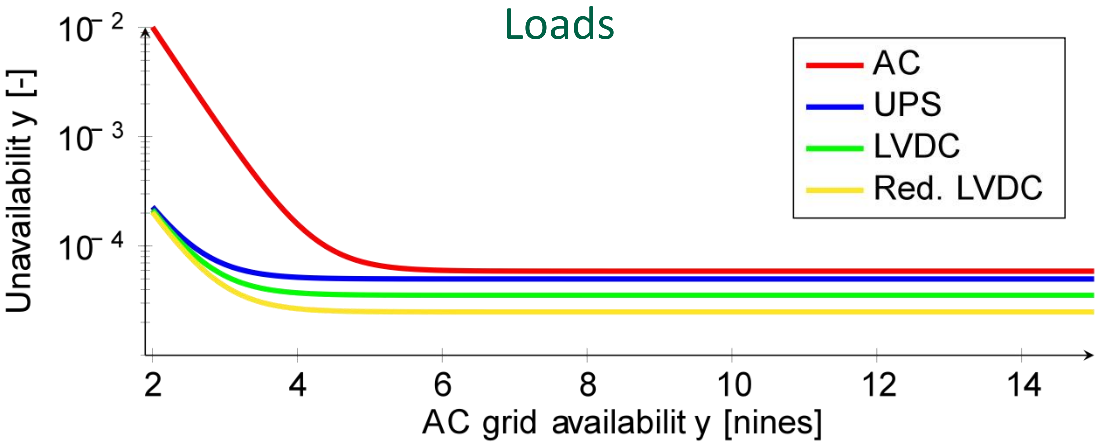



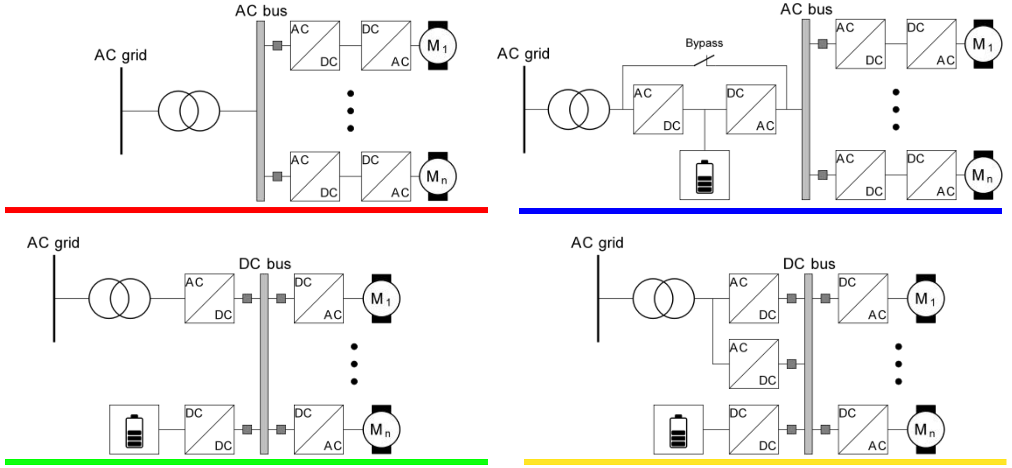

*Increasing battery size has limited impact*

G. Emmers, J. Driesen, "Comparison of System-Level Availability in Industrial Grids", in 24th European Conference on Power Electronics and Applications (EPE'22 ECCE Europe), IEEE, Hannover, 2022.

# Unavailability analysis II




*Bottlenecks: redundant converter is detrimental for AC systems*


G. Emmers, J. Driesen, "Comparison of System-Level Availability in Industrial Grids", in 24th European Conference on Power Electronics and Applications (EPE'22 ECCE Europe), IEEE, Hannover, 2022.

# Other use cases

# Construction sites

- Driver: low emission / low noise in cities
- Electrification requires extreme flexibility
  - Highly variable loads
  - Local grid connections: relatively weak – combine with local electricity production + storage
- High-power: need go to MVDC?

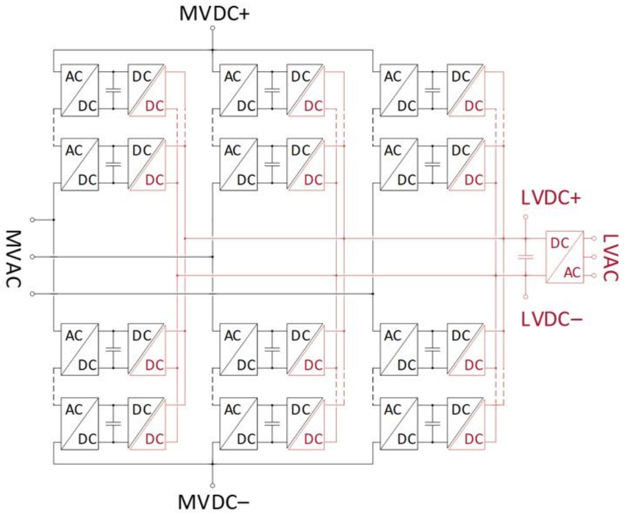
# Public power distribution

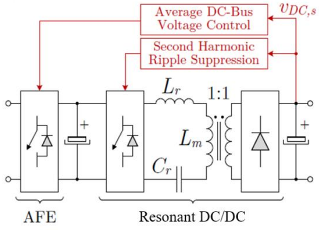
- Public distribution in MVDC?
  - Mainly cost-driven
  - May be relevant to upgrade capacity with existing cables

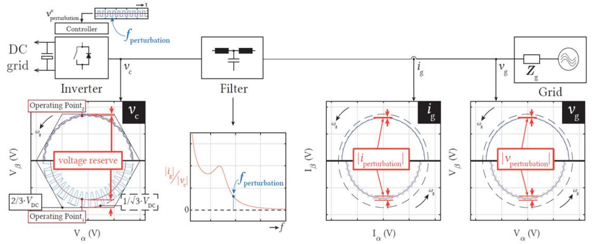
# Final Thoughts

# Closing the voltage gap

- Power converters
  - top-down evolution: consider MMC architectures?
  - Isolation required?
- Protection: bottom-up
  - Use SSCBs
  - Isolation required?
- Control: use best of both worlds
- Improved reliability possible using DC
- Unlock flexibility



Energy
Ville

ENERGY IN
TRANSITION