Energy Hubs- solution for charging heavy duty vehicles

DC Systems, **E**nergy Conversion & **S**torage
Delft University of Technology, the Netherlands
Prof. dr. Pavol Bauer

DCE&S group people

- 1 Full professor


Pavol Bauer

- 8 Assistant/Associate professors


Laura Ramirez


Gautham Chandra Ram Mouli


Jianning Dong


Hani Vahedi


Sebastian Rivera


Zian Qin


Aditya Shekhar

- 5 Technical staff


Bart Roodenburg


Harrie Olsthoorn


Mladen Gagic


Joris Koeners

- 1 Secretary


Sharmila Rattansingh

- 2 Postdoctoral researchers
- 36 PhD students (1 upcoming, 4 external)
- ~ 40 MSc diploma students / AY
- Total: ~ 80 member

DCE&S
DC systems, Energy conversion & Storage

DC systems, Energy conversion and Storage

Components for integration of renewable energy sources and energy storage in DC systems and future HVDC transmission and distribution grid

Research themes

- Electric mobility
- DC microgrids and energy hubs
- Efficient energy conversion (power electronics)
- Power Electronics Reliability

Pavol Bauer

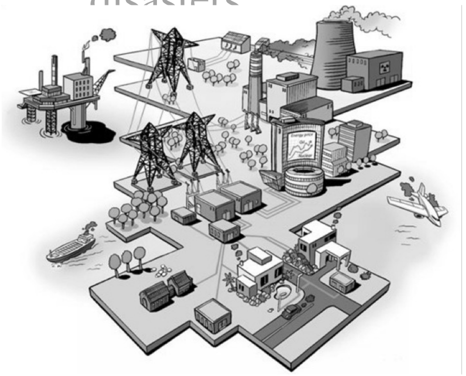
DCE&S

DC systems, Energy conversion & Storage

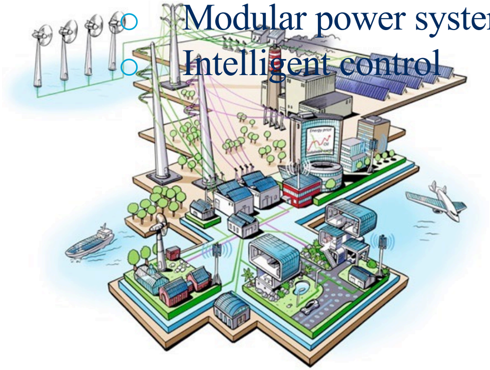
Introduction

Future energy system

- Analogue energy system:
  - Impact global warming
    - Renewable energy sources
    - Electrification of society
  - Relying on unstable supply
  - Highly susceptible to disasters



- Future energy framework:
  - Facilitate easy, fair, and efficient
    - Energy generation
    - Energy consumption
    - Energy storage
  - Decentralised flexible operation
    - Peer-to-peer energy trading
    - Modular power systems
    - Intelligent control



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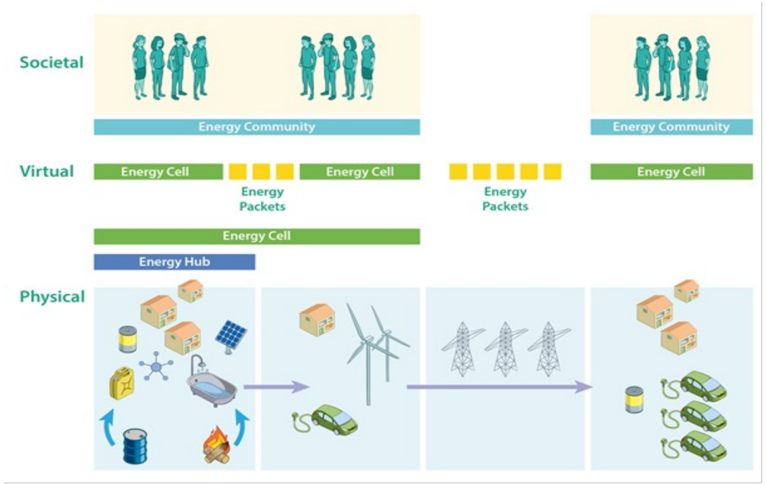
Research program

Research program

- Digital energy concept:
    - Energy cells
    - Energy conversion hubs
    - Energy packets
    - Virtualisation
    - Energy communities



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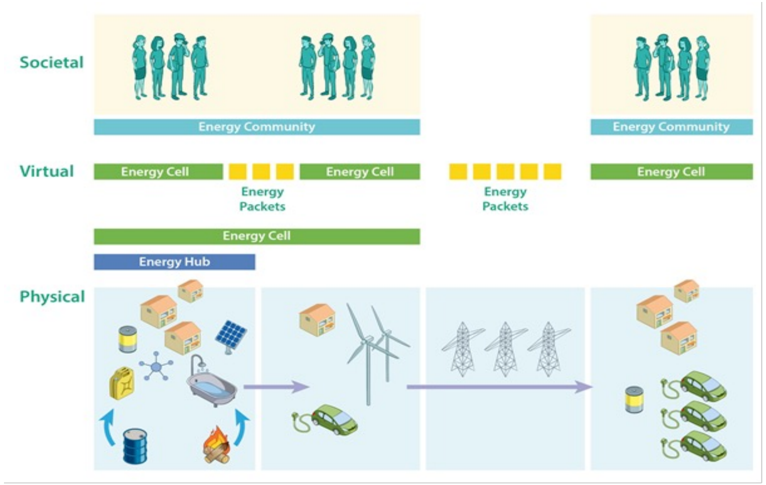

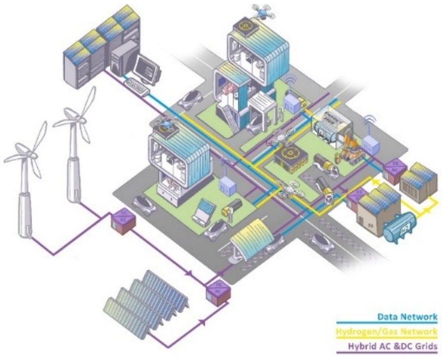

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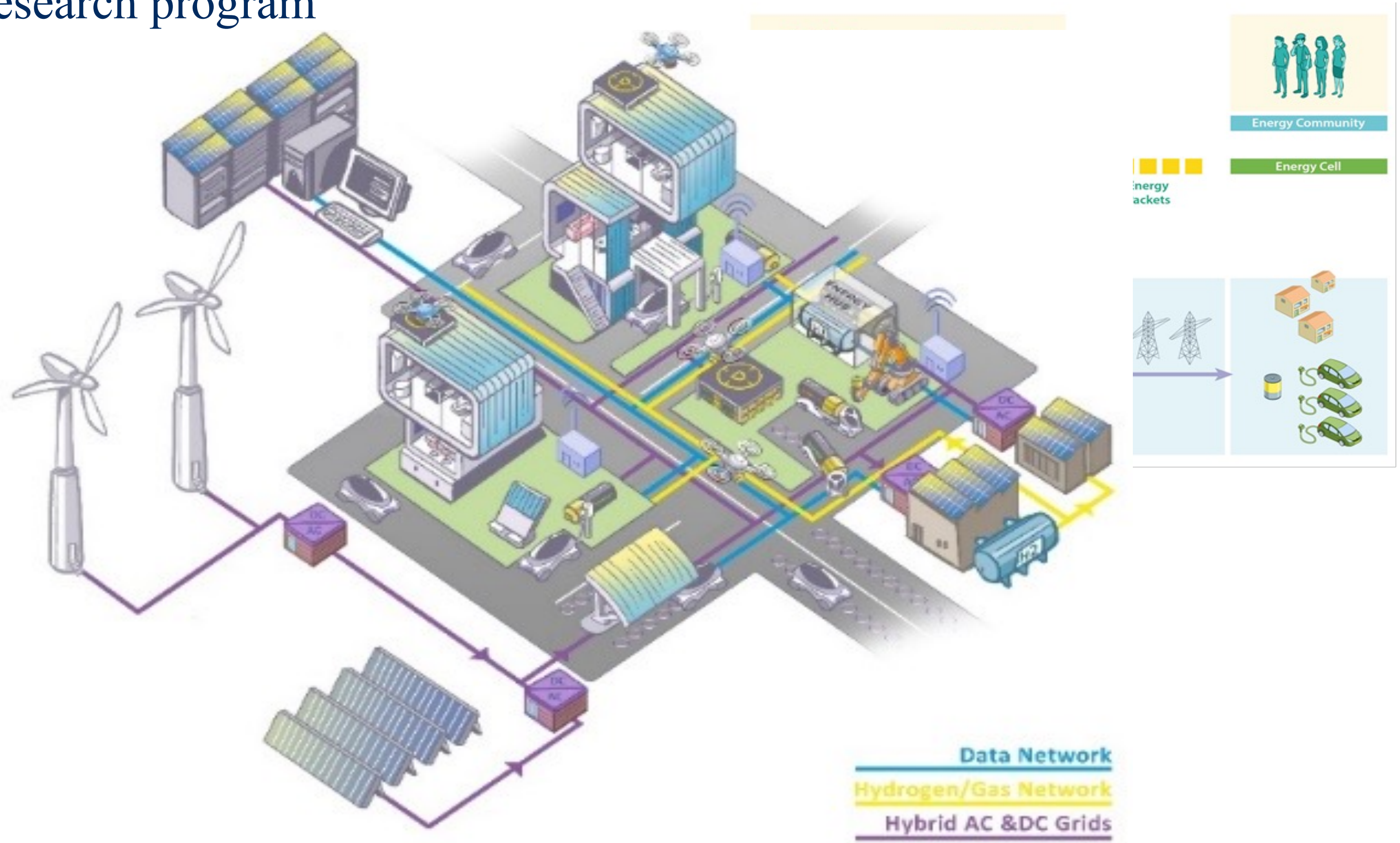

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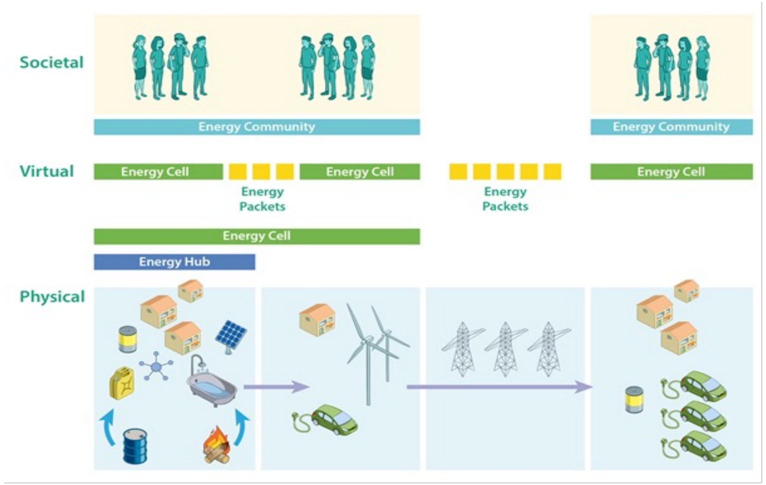

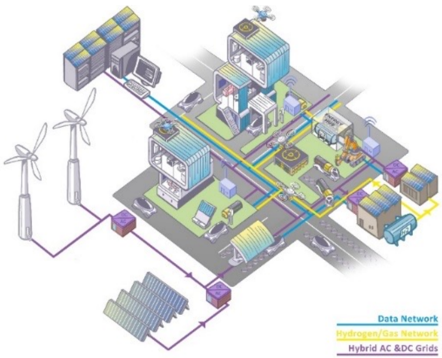

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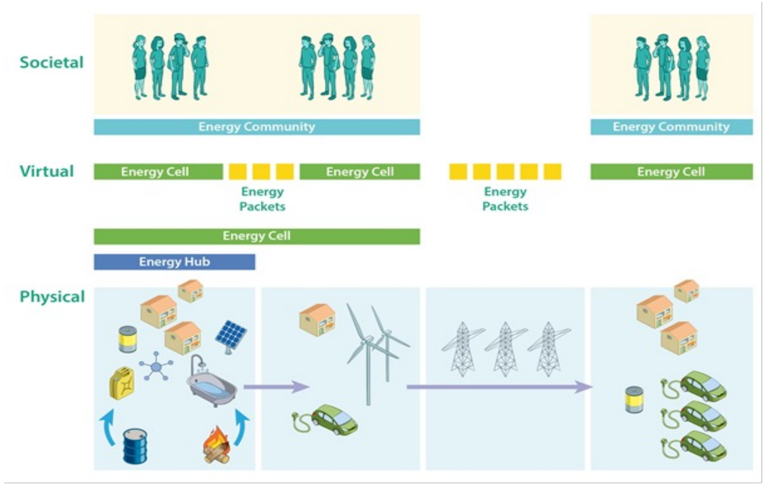

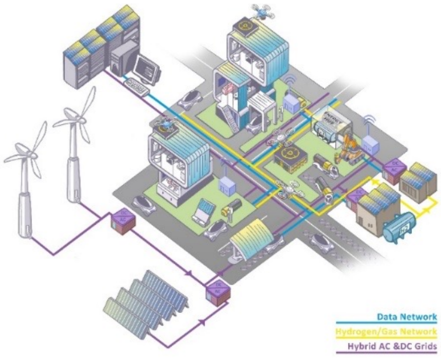

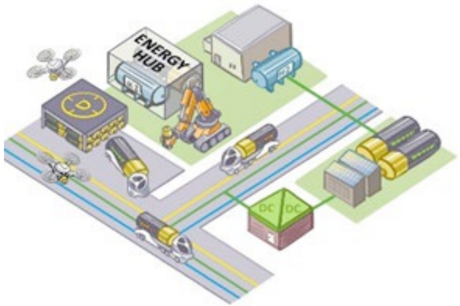

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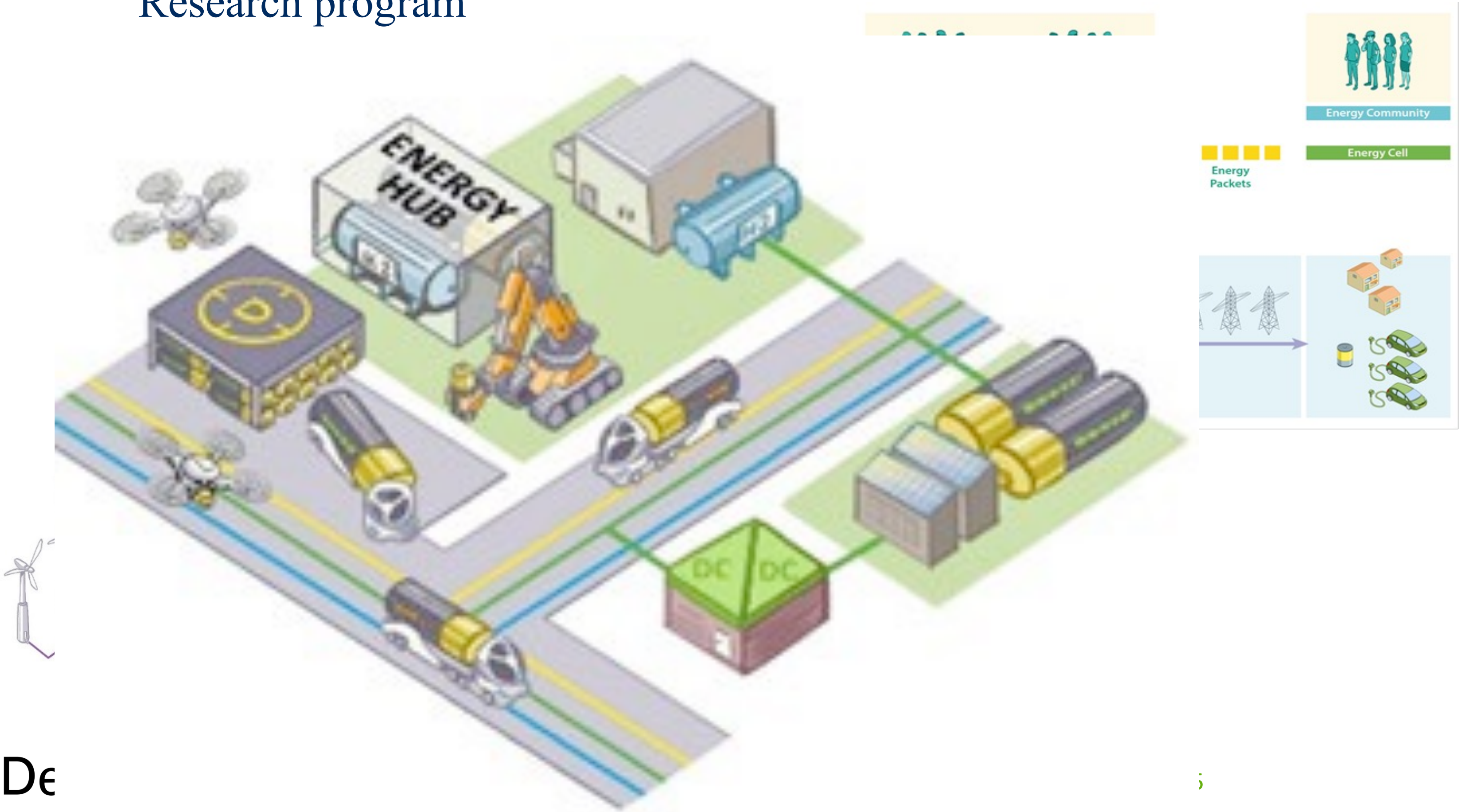

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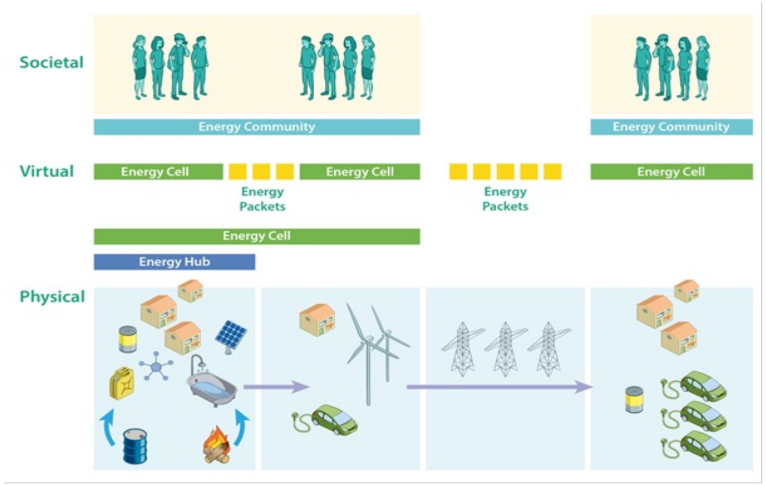

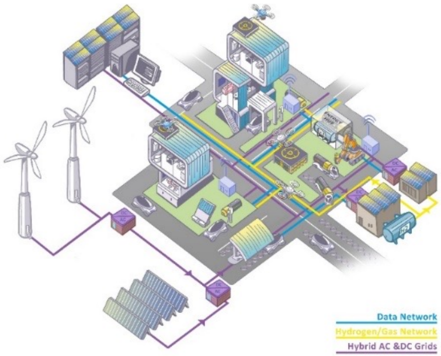

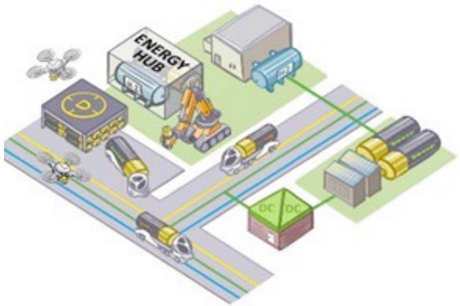

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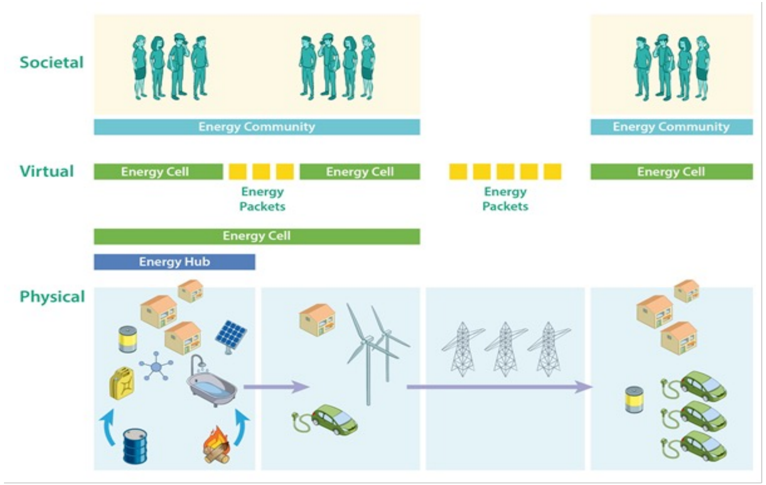

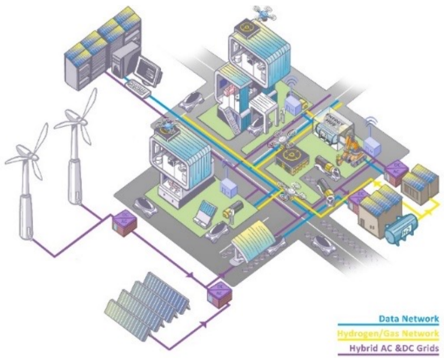

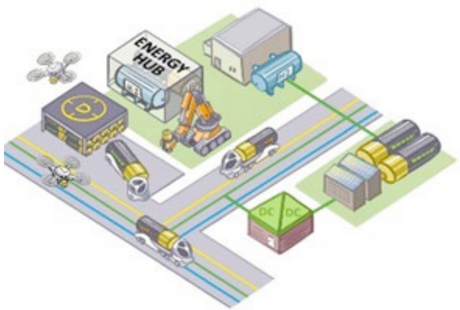

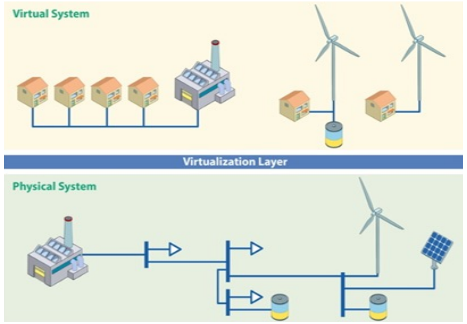

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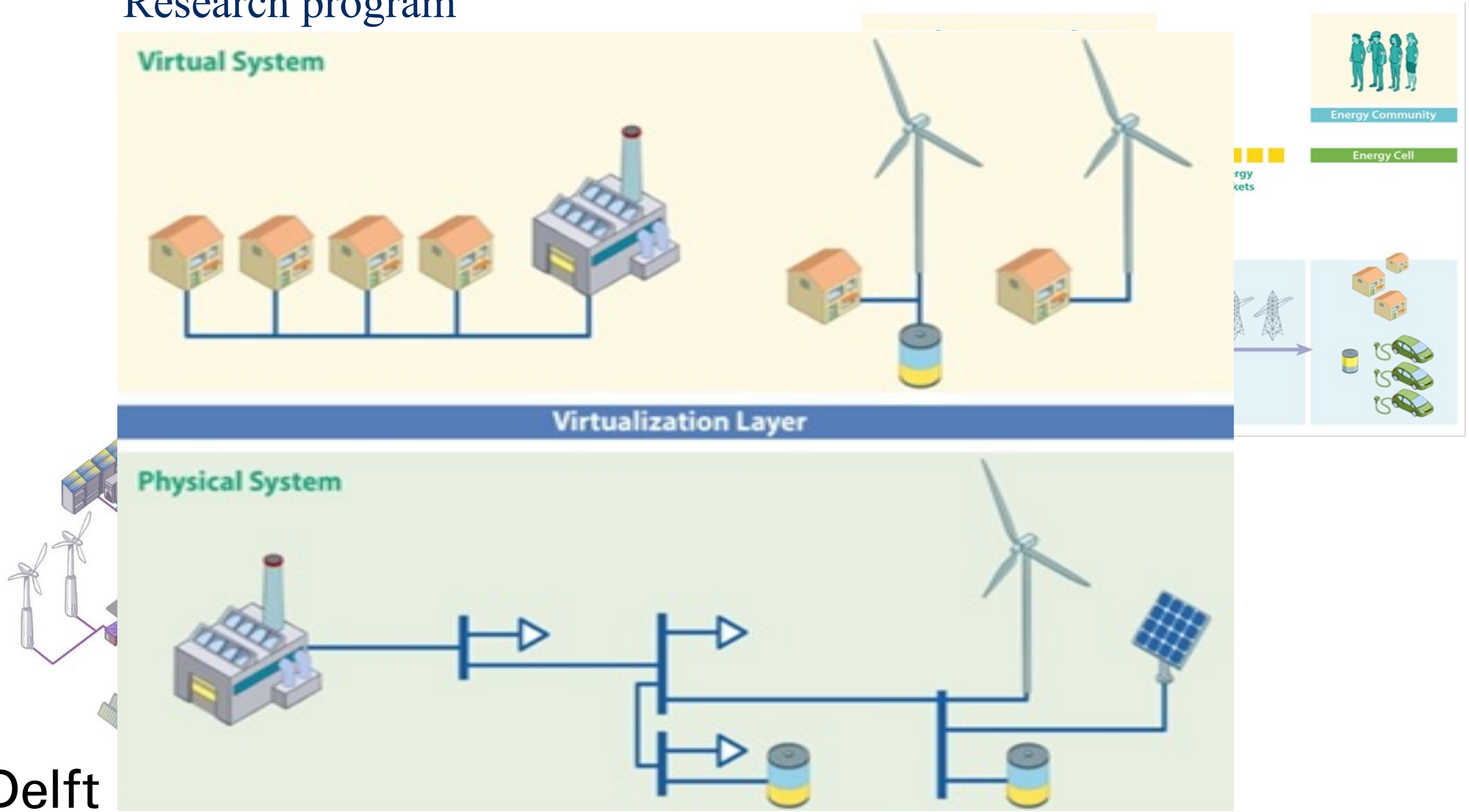
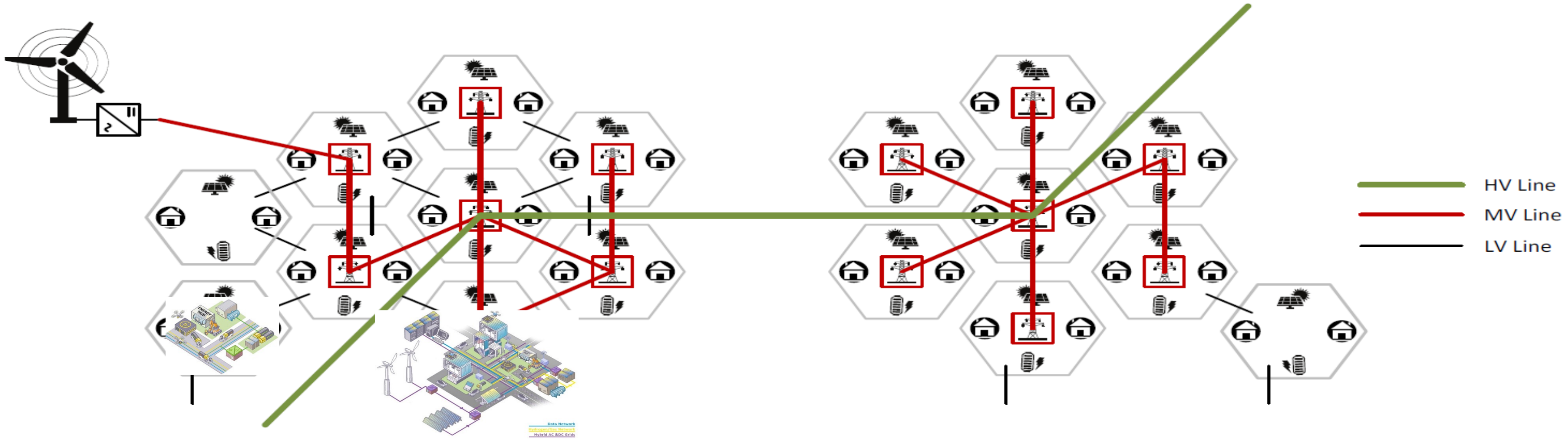


Interconnected energy cells

Research program



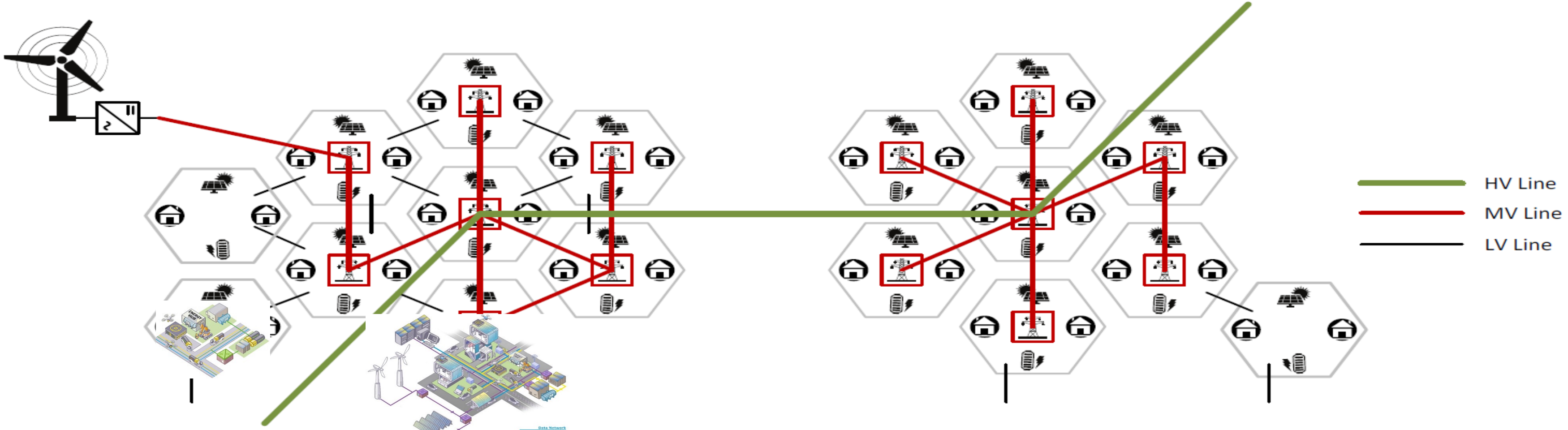
L. Mackay, N. H. van der Blij, L. M. Ramirez-Elizondo and P. Bauer, Toward the Universal DC Distribution System", Electric Power Components and Systems, vol. 45, no. 10, 2017

Energy Hubs - Basic building block for energy transition

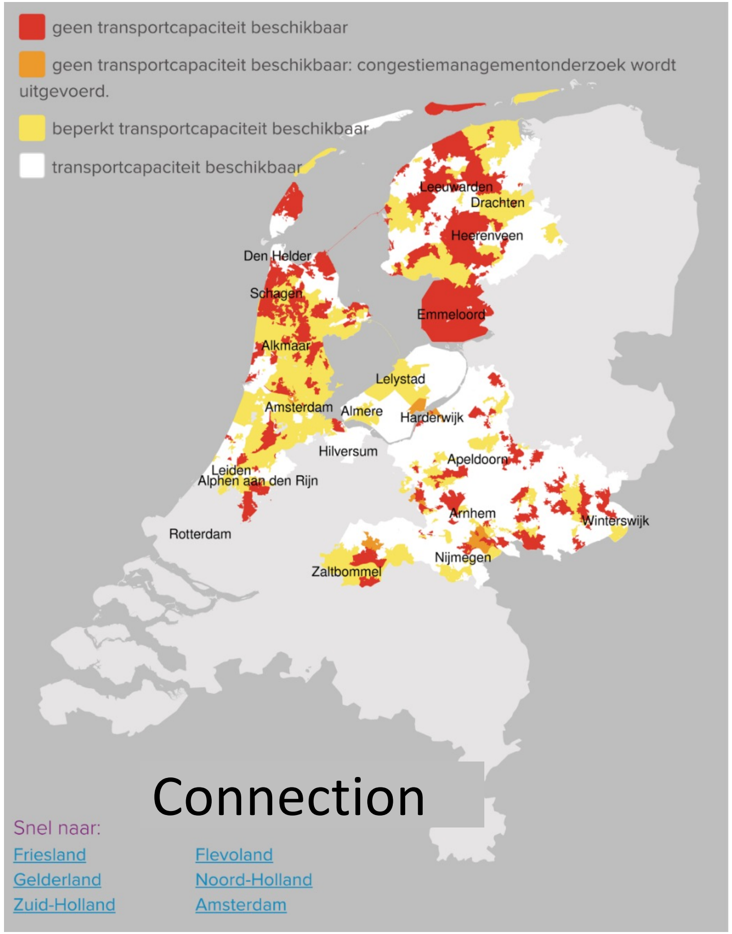
- Energy is exchanged between **multiple energy carriers**

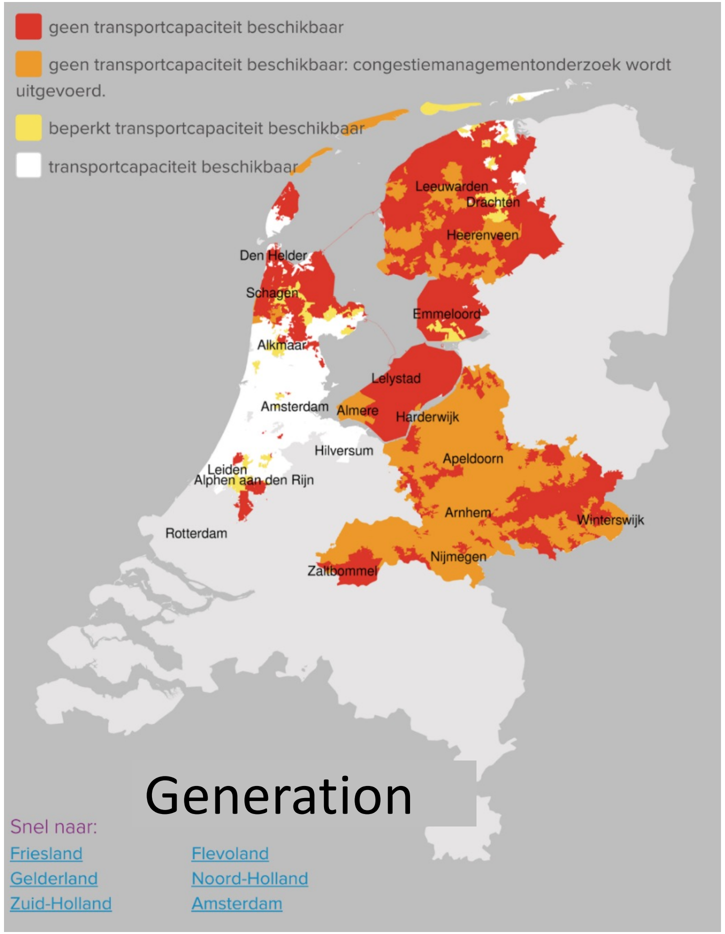
- Weak power connection, congested grid
- Large peak power - low average power
- Large energy demand
- Virtual hub and virtual wire

DC microgrids and energy hubs



Availability of network capacity





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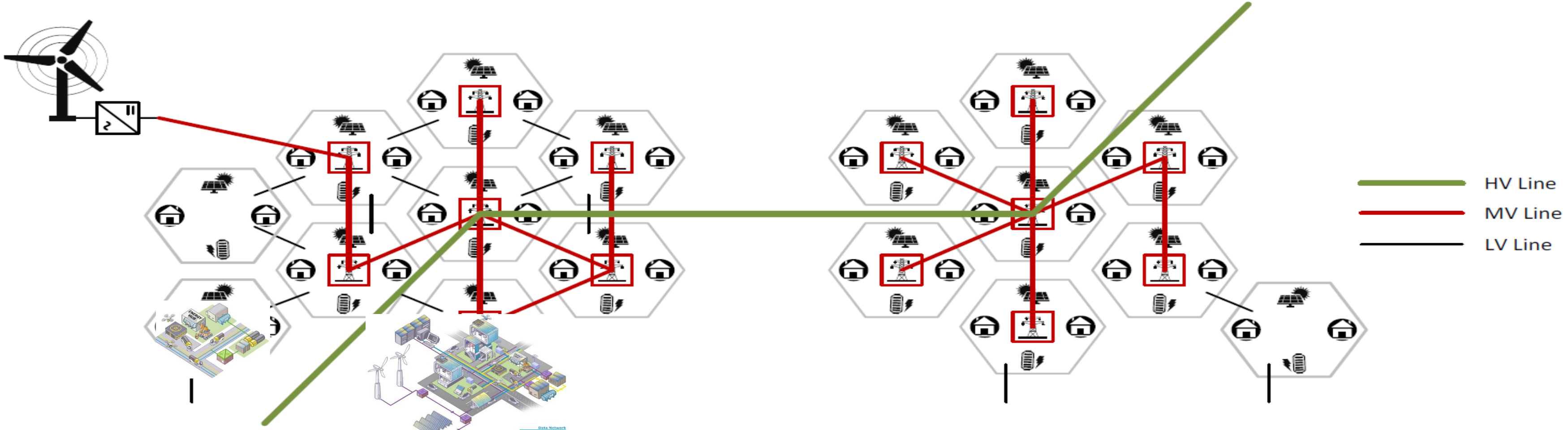


Energy Hubs - Basic building block for energy transition

Interdisciplinary challenges:

- Integration of Diverse Energy Sources
- Technological Complexity
- Regulatory and Policy Barriers
- Community Acceptance
- Cybersecurity Risks

DC microgrids and energy hubs

Different power, energy carriers, layout, topologies AC/DC, PE solutions, PQ; advanced energy storage, power and energy management

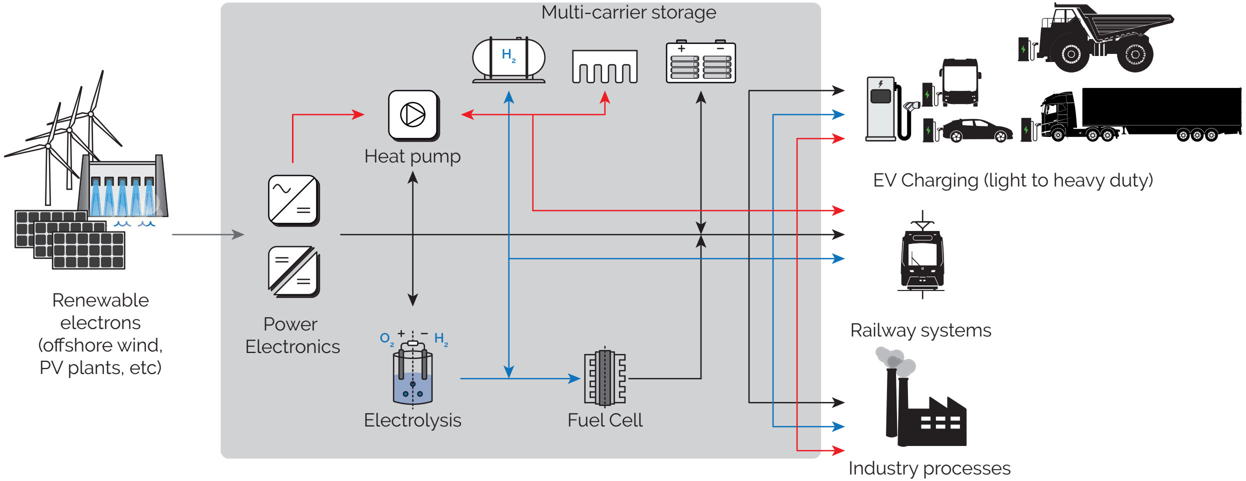
Research at DCE&S – Energy Hubs

TUDelft

Energy Hubs as the basic building block of Energy Transition

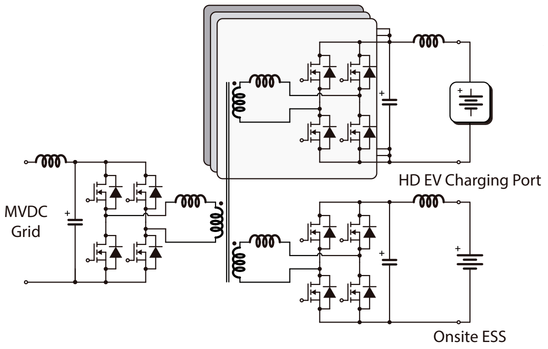
- Energy hubs create multiport pathways for different energy carriers to enable the modernization of the electric system and further electrification of industry processes as energy prosumers (bidirectionality).
- Power electronics is the enabling technology to manage the resources in a compact and efficient manner. Maximizes the future use of renewable electrons.
- By modularizing energy processing blocks, elegant and innovative solutions can benefit from economies of scale, future expansions, reconfigurability or redundant operation.

Sebastian Rivera



Energy Hub

Multiport power converter



Energy Hubs - Basic building block for energy transition

- Energy hub for offshore wind
- Energy hub for charging heavy duty vehicles
- Energy hub for railways
- Energy hub for airports
- Energy hub electrification of industry

DC microgrids and energy hubs

Different power, energy carriers, layout, topologies AC/DC, PE solutions, PQ; advanced energy storage, power and energy management

Energy hubs for Offshore Wind

TenneT Target grid (TG) developent for 2050

Offshore wind energy

9GW 2022 -> 20GW 2030 -> 50GW 2040 -> 72GW 2050

Renewable electricity generation

39 TWh 2022 -> 453 TWh 2050

Building blocks of Target Grid

AC-DC hybrid grid

Meshed HVDC grid with offshore & onshore hubs

Flexibility

Local H_2 conversion, market-driven battery storage

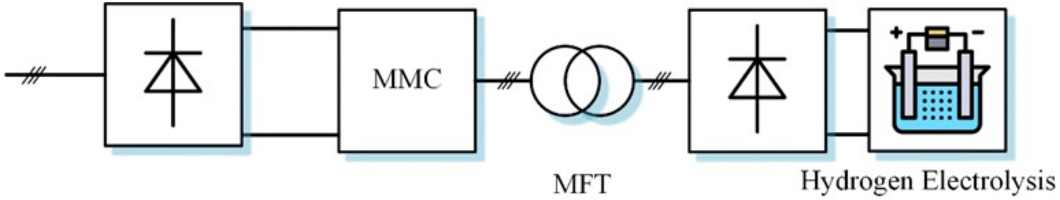
Power module design in solid state transformers

To break the bottlenecks and reduce the LCOH, the promising technology, solid state transformer (SST), can be applied to replace the line frequency transformer. The transformer's weight and volume are inversely proportional to its operation frequency, so there is still a huge potential to reduce the weight, volume, and requirement of magnetic material using SST. This research focuses on the power electronics converter design and modelling.

PhD topic of Zhengzhao Li

The research goals associated with this PhD project are as follows:

- To choose the most suitable topology, power switch, and modulation strategy for the SST.
- To design the control strategies in normal conditions, abnormal conditions, optimal operation control of electrolyser, and local protection strategy.
- To analyse the stability issue of SST, considering numerous numbers of MMC modules, which increase complexity of impedance modelling.



Research at DCE&S - PE/E-Mobility, DC Grid, Storage

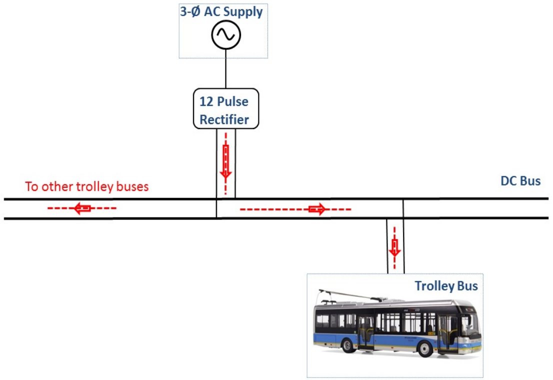
Trolleybus Grid as an Active DC grid

- Transforming the mono-functional trolley-grid into an active DC grid (storage, PV, EV charging)
- Developing a new modular DC/DC converter for PV (variable voltage), and a bidirectional converter for EV charging and battery storage
- Developing a smart Energy Management System for the newly designed active grid

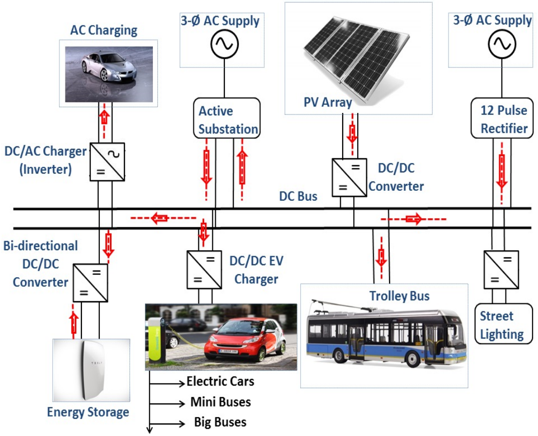
PhD of Ibrahim Diab

Trolleybus

The Conventional Trolleybus Grid



The Future



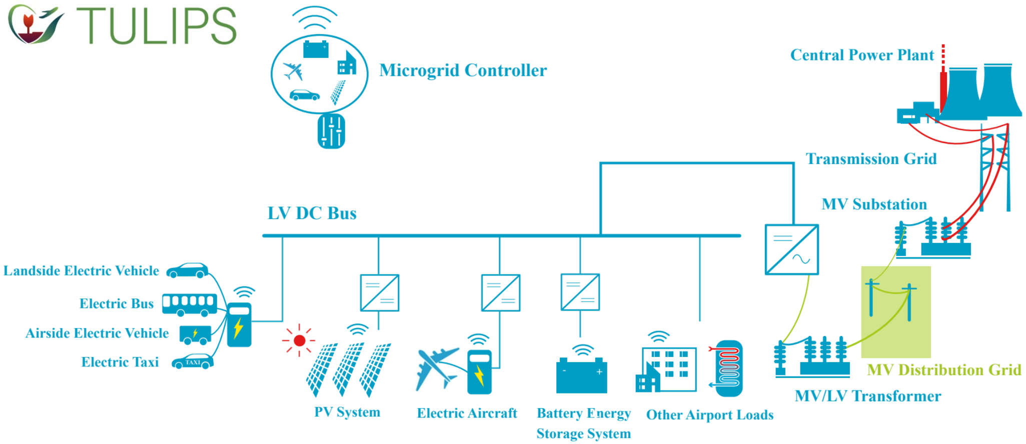
Energy hubs for Airports

Integrate and analyze electrified airside and landside mobility for green airports.

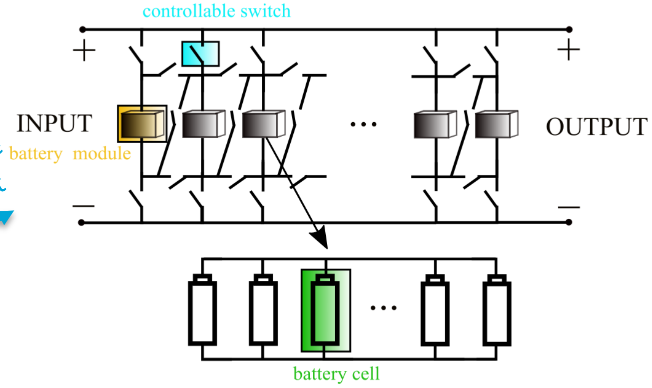
- Integrate electric vehicles (i.e., electric aircraft, airside electric vehicles, and landside electric vehicles) in a DC-based fast charging station with photovoltaics + battery storage system for which implements a smart charging strategy to mitigate the grid impact, reduce operating costs and increase the use of local renewables.

- Develop and demonstrate a reconfigurable modular large battery packs and charging system for electric aircrafts and analyse its effect on the battery lifetime and state of health.

PhD topic of Yawen Liang



Eviation Alice



A diagram of reconfigurable battery pack design

Energy hubs for Railways

Research at DCE&S - Energy Hubs

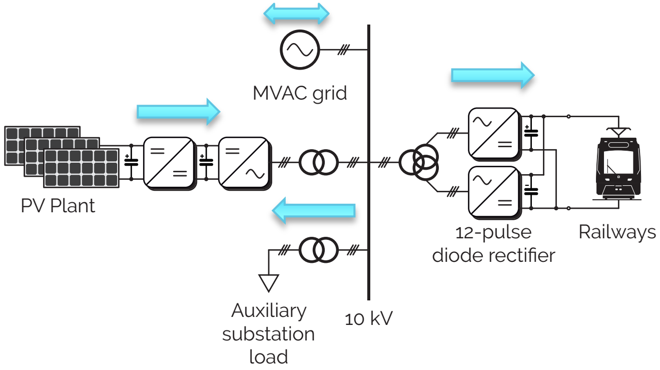
Energy Hubs for the Railway System

PhD Topic of Julian Rojas Villarroel

- DC powered railway infrastructure in the Netherlands can reach its full potential. More train lines can be added without compromising nor saturating the electric grid.
- Energy efficient power processing hubs will maximize energy from braking besides integrating energy systems based in different carriers.
  - Re-use the braking energy, Increase the use of RES for railways, decrease emissions, create new local balancing area with EV charging and define new potential places for RES connection. Expanding the leading position in the area of sustainable transport infrastructure in the Netherlands

New fast IC train Amsterdam - Rotterdam - Breda

Simplified topology of the railway network



Energy hubs for Charging Heavy Duty Vehicles

Plug-in project

- Funded by the Ministry of Economic Affairs and Climate

Elaadnl

HAN_

CONNECTR

Shell

Rijksdienst voor Ondernemend Nederland

KEMA Labs

Firan

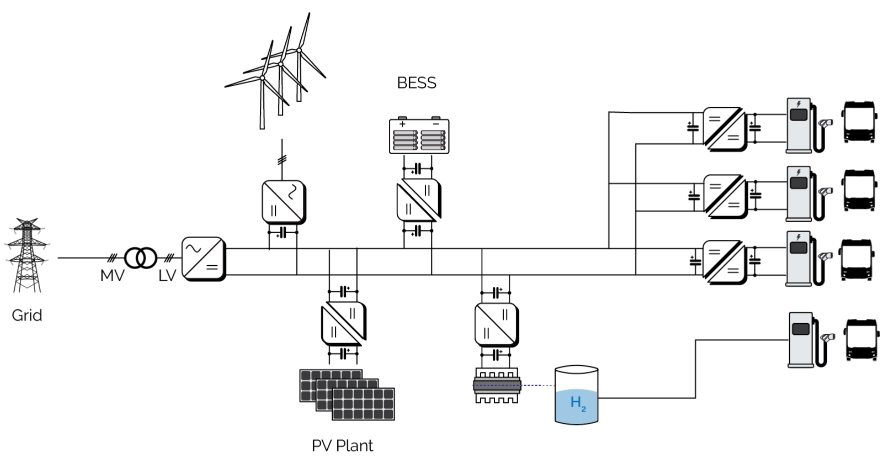
Research at DCE&S – Energy Hubs

Energy Hub sizing for Heavy Duty Electric Vehicles

PhD topic of
Manfredo Sartori

Goals:

- Assess and determine the power and energy specifications for a route charging of Heavy Duty electric vehicles.
- Develop a comprehensive concept for the system architecture and layout definition of an energy hub tailored for charging Heavy Duty Electric Vehicles
- Establish a multi-criteria optimization framework to determine the appropriate sizing of energy assets and charging infrastructures within the energy hub for vehicles.
- Identify the benefits of Energy Hub (EH) components in enhancing the charging process for electric vehicles and alleviating electrical grid congestion.



Funded by:

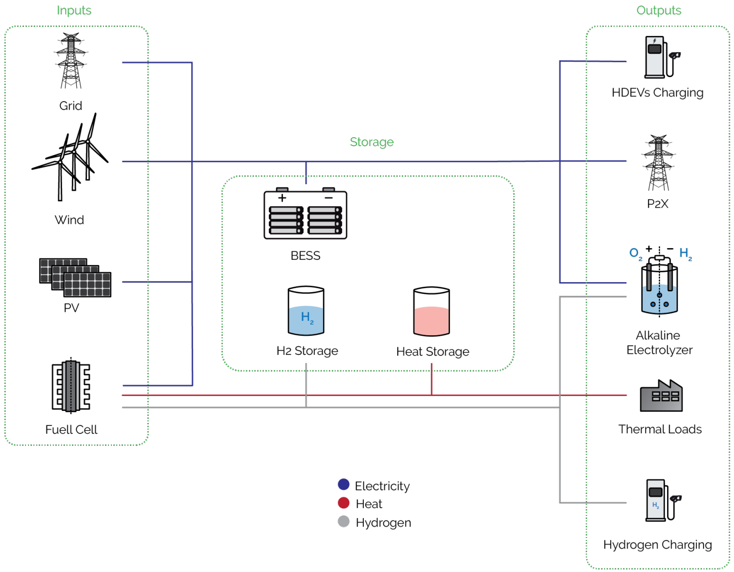
Ministry of Economic Affairs and Climate Policy, Netherlands

Goals

A scalable and robust concept of energy hub for charging heavy duty vehicles. Thumb rules for optimal system sizing to facilitate energy hub design.

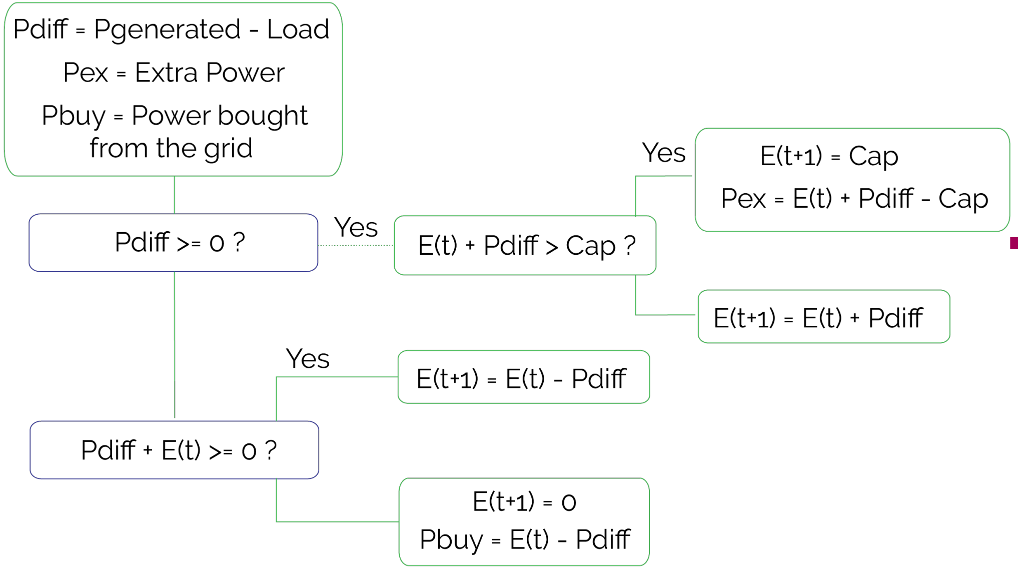
<u>**Goals:**</u>

- To investigate the HDEVs charging needs.
- To select and size the energy sources and storage systems.
- To analyze the advantages and disadvantages of different architectures and system layouts.
- To identify and study the advantages of EH for EV charging and in reducing grid congestion.

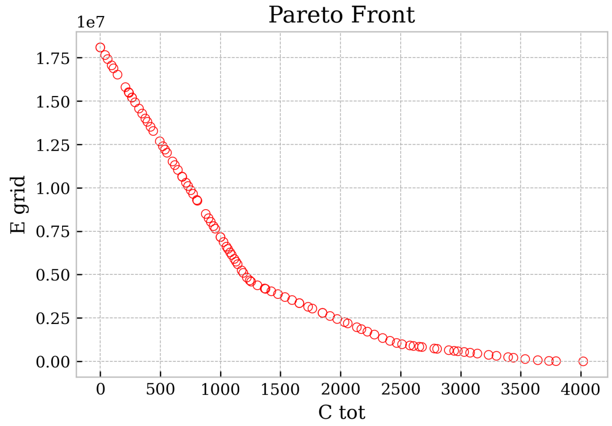


Energy Hub - Multi objective optimization

CONTRAINTS: Based on an Energy Management System



RESULTS:



Extra Constraints:

- SOC limits: 0.2 <= SOC (t) <= 0.9
- C rate: Pch(t), Pdch(t) <= Crate max * Cbattery

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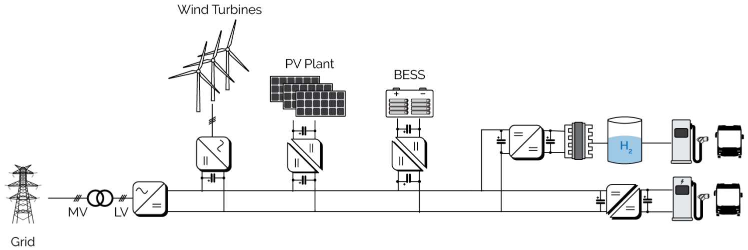
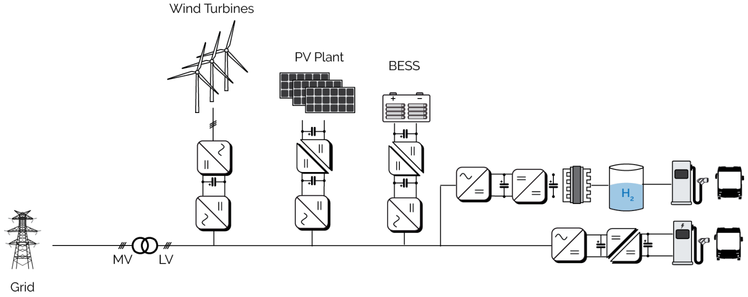
Fast charging station/energy hub architectures

Literature review of fast charging stations architectures and layout.

- Advantages/Disadvantages of DC vs AC systems.





AC :

1. More conversion stages – higher cost, lower efficiency
2. More complicated control techniques

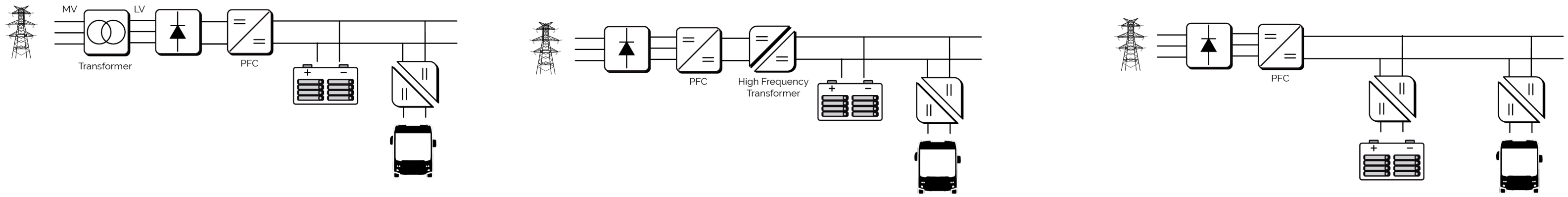
DC:

1. No established standards for protection coordination in the dc connected for high voltage
2. No established standards for metering

Fast charging station/energy hub architectures

Literature review of DC fast charging stations architectures and layout.

- Comparison between different layout based on energy sources selected and specific use case.
- No one for all solution



Example of possible alternatives considering Battery energy storage system

Future steps

1. Include optimal sizing of charging station features (number of chargers, power per chargers).
2. Investigate grid impact on real MV models and include it in the optimization.
3. Extensive review of archtectures, power conversion units, control system… for Energy hub layout.

Research at DCE&S - Energy Hubs

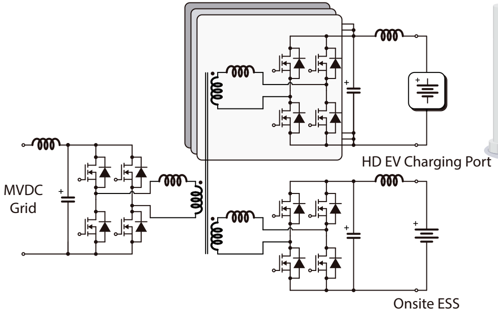
Energy Hubs for Heavy Duty EV Charging

PhD Topic of Felipe Calderon Rivera

- To design, develop and demonstrate versatile multiport PEEBs for interfacing HD chargers (above 1 MW).
- To coordinate and control several energy sources, storage and loads.
- Alleviate the impacts of high-power EV charging on the grid.
- Extend the functionality of charging stations to strengthen the power-electronic dominated grid.
  - Conception, development and assessment of a highly modular and versatile concept of multiport circuits for DC distribution at different levels.
  - Design and construction of hardware demonstrator. Experimental validation in relevant scenarios.
  - Flexible interface for different energy carriers.

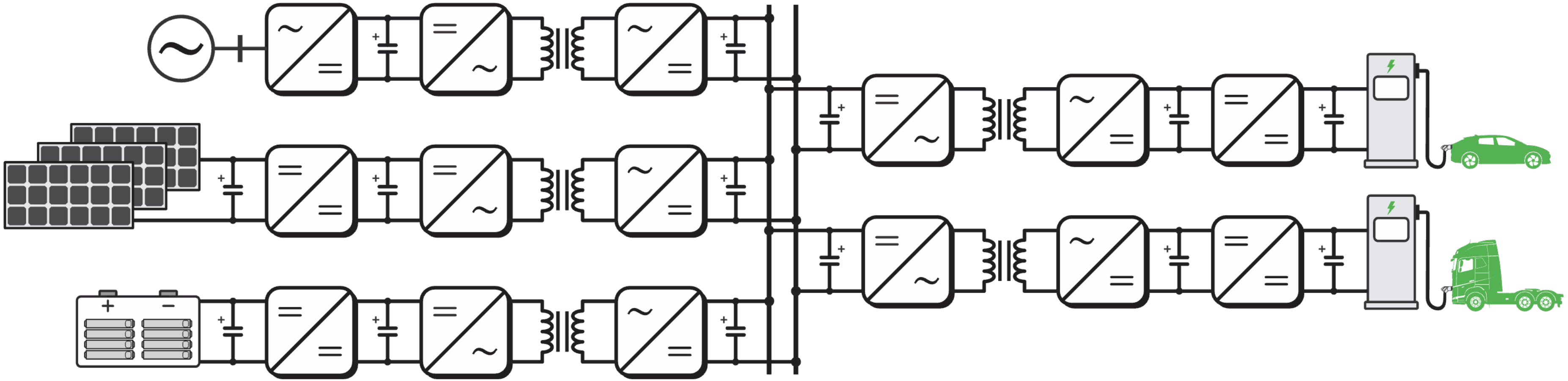
Aimed for Megawatt Charging System (MCS) Standard

Modular concept for versatile and tailored solutions



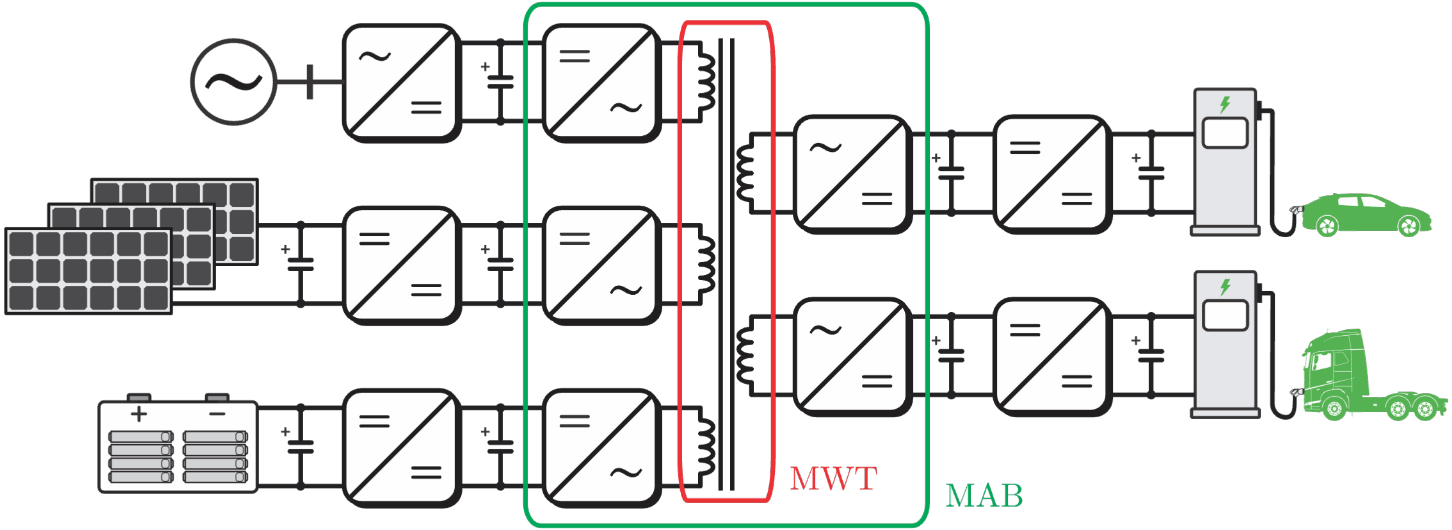
Component Design, Development, and Demonstration of a Medium Voltage DC Multiport Power Electronics Energy Hub

State-of-the-art topology for heavy-duty charging stations



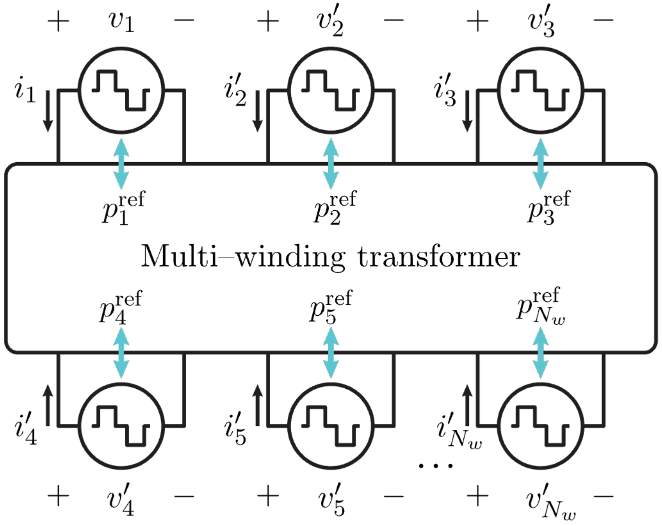
Component Design, Development, and Demonstration of a Medium Voltage DC Multiport Power Electronics Energy Hub

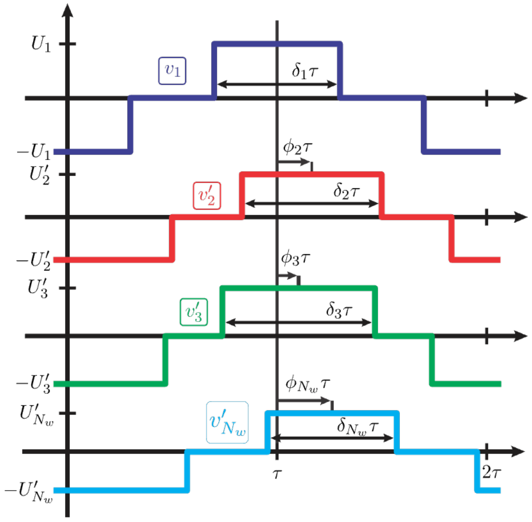
Proposed topology for heavy-duty charging stations



Component Design, Development, and Demonstration of a Medium Voltage DC Multiport Power Electronics Energy Hub

Multi-active-bridge converters





$$\min_{\boldsymbol{u} \in \mathcal{U}} \ \langle \boldsymbol{i}^\top(t)\boldsymbol{i}(t) \rangle,$$

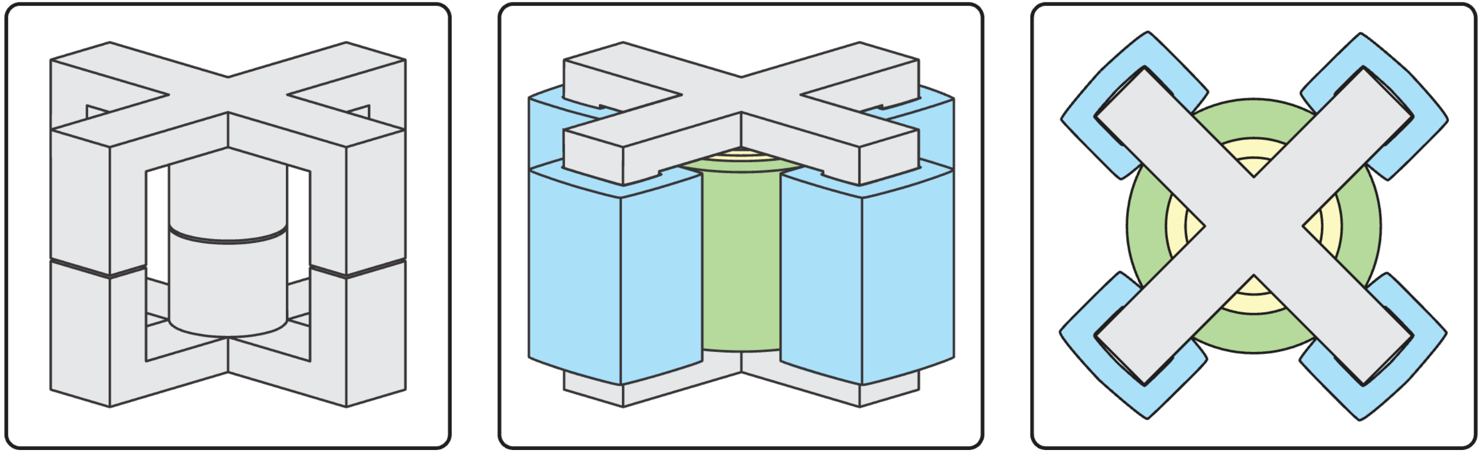
$$\text{s.t.} \quad \dot{\boldsymbol{i}}(t) = f\left(\boldsymbol{v}(\boldsymbol{u}, t)\right), \qquad t \in \mathcal{T}$$

$$p_k^{\text{ref}} = \langle i'_k(t)\, v'_k(t) \rangle, \quad k \in \mathcal{K}_w$$

$$\text{where, } \langle v \rangle = \frac{1}{T}\int_0^T v(t)dt.$$

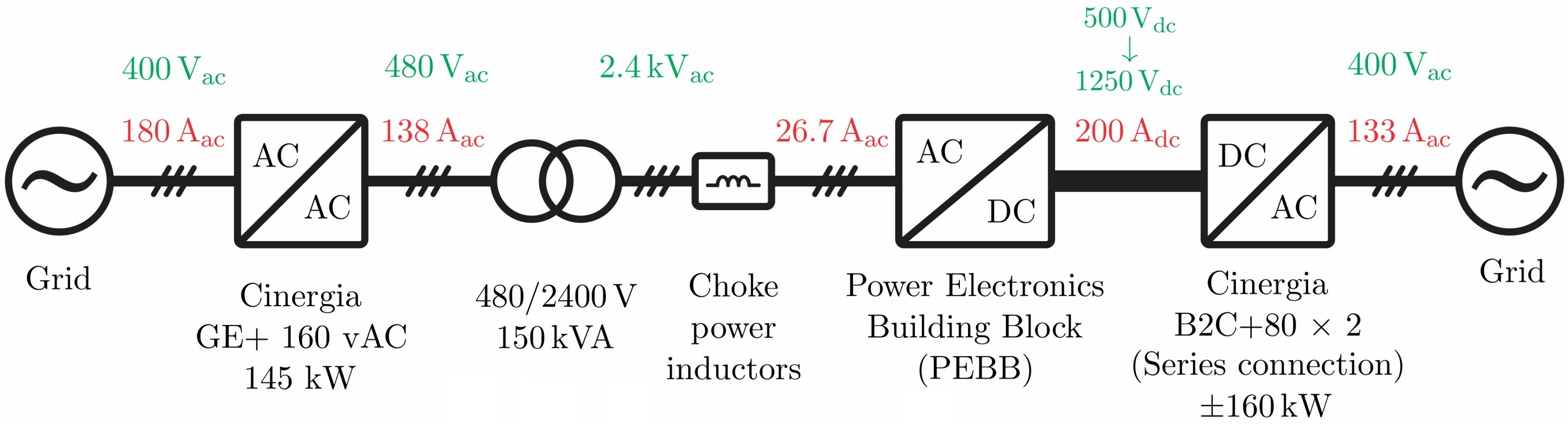
Component Design, Development, and Demonstration of a Medium Voltage DC Multiport Power Electronics Energy Hub

High-frequency multi-winding transformers



Component Design, Development, and Demonstration of a Medium Voltage DC Multiport Power Electronics Energy Hub

Preliminary 100-kW experimental setup

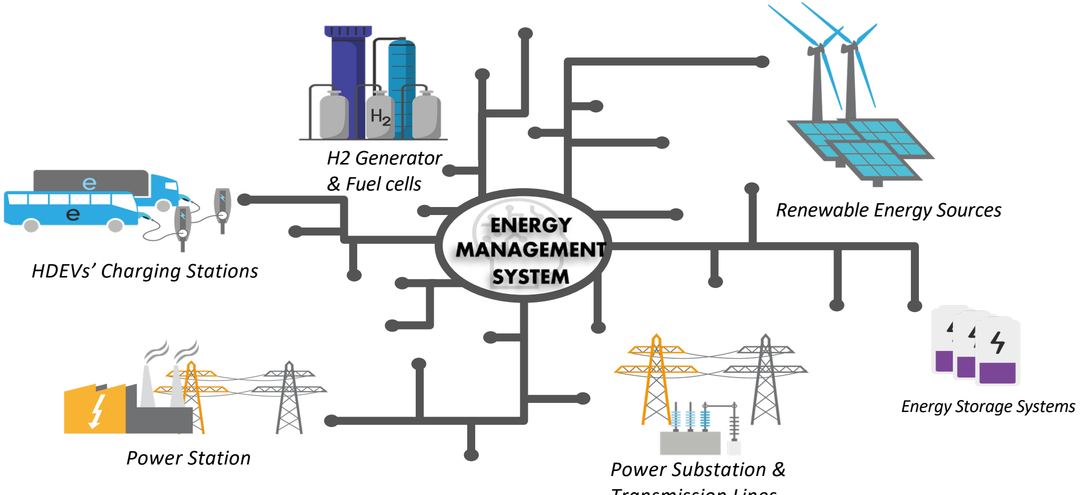


AI-based Energy Management System for Energy Hubs with Charging Stations for Heavy Duty Electric Vehicles

PhD topic of
Leila Shams

Goals:

- Heuristic or mathematical programming used in EMS for charging stations are limited in performance and time-consuming due to non-linearity of the energy hub's subsystems.
- In Plug-in project, the objective is examine the application of AI for energy management in an energy hub with charging stations for long haul heavy duty electric vehicles.
- An in-depth assessment of the energy hub while using the defined EMS in terms of congestion management, increased use of renewables, providing ancillary services at the lowest possible operating cost, etc.
- Evaluation of the defined algorithm in a PHIL setup and possibly at one of the project partners' test sites.



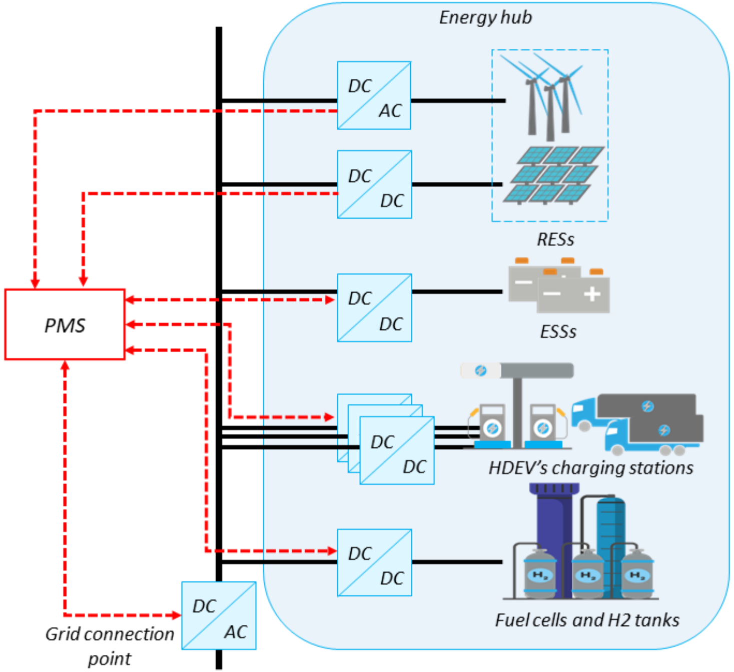
Elaadnl

Funded by:

Ministry of Economic Affairs and Climate Policy, Netherlands

Goal

- **Developing an AI-based algorithm for power and energy management in energy hubs with HDEV chargers.**



Scientific gaps

- EMS for HDEV charging stations and EHs
- Hybrid and physics-aware AI approaches in the field of EMS at an EH with HDEV charging stations
- Providing services to the system or the electrical grid using the hydrogen fuel cells (H2P mode)
- Coordination of different EHs in an area or even sharing some assets

Research questions

- What are the charging demand and control strategies for medium- and long-haul HDEVs?

- What is the efficient strategy in terms of computational power, accuracy and precision, scalability, and robustness for developing the PMS under consideration?

- To what degree may the collaboration of several PMSs lessen the overall grid impact?

- How to replicate the impact of control operations on the aging of the stationary ESS, whether new or second-life, and the vehicle's battery?

Energy hubs for urban energy

Research at DCE&S – Energy Hubs

TU Delft

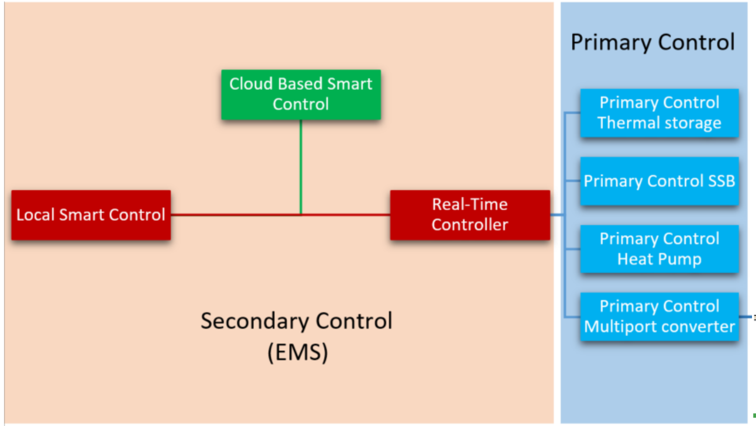
Control & Energy management in multicarrier systems

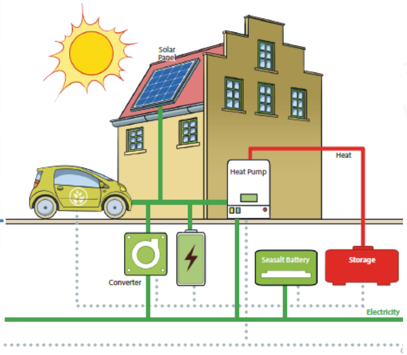
Goal: Perform the energy management of a multicarrier integrated system including PV generation, heating, energy storage and EVs for a residential building.

Challenges:

- Provide a multi-layer hierarchical controller capable of smart operation and real-time operation simultaneously
- Compensate for uncertainties and failures while keeping the normal operation


Dario Sleifstain and Joel Alpizar Castillo

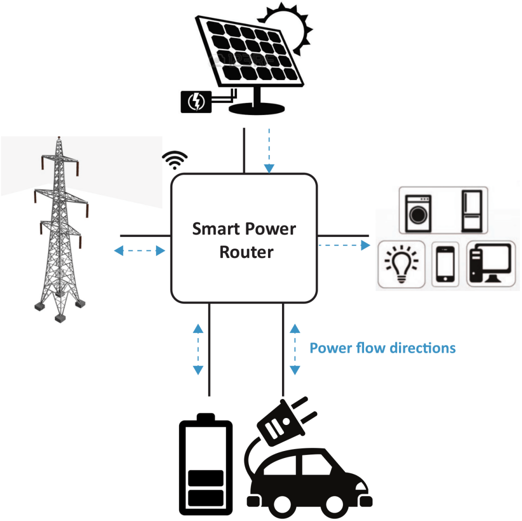




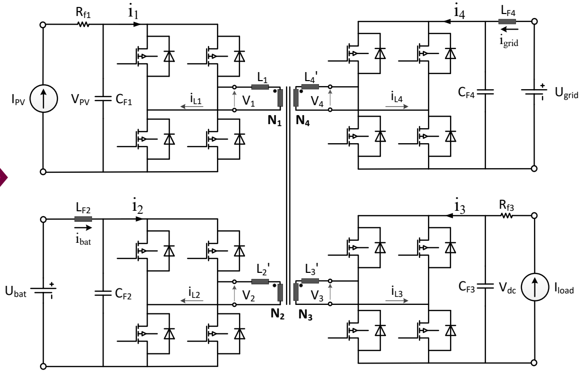
Design, Topology and Optimization of Smart Residential DC Grids

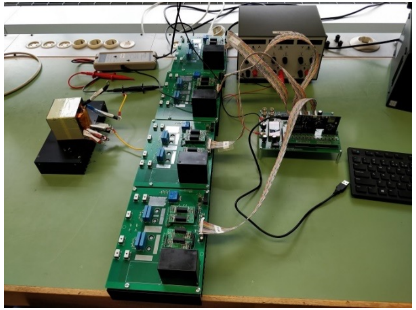
PhD Topic of Soumya Bandyopadhyay

- To Develop safe, robust and intelligent residential dc grids suitable for future smart grid integration with V2H / V2G capability



Quad-Active Bridge Converter





Protection DC

Protection of Low Voltage DC Systems

System is **safe** for devices and individuals interacting with the grid

The detection methods are **sensitive** to the different types of faults

The protection devices are **secure** and do not trip unnecessarily

The protection scheme is **selective** and isolates the faulted section

The fault is cleared **fast**, so that blackout and damage is prevented

The protection of the system is **cost-effective**

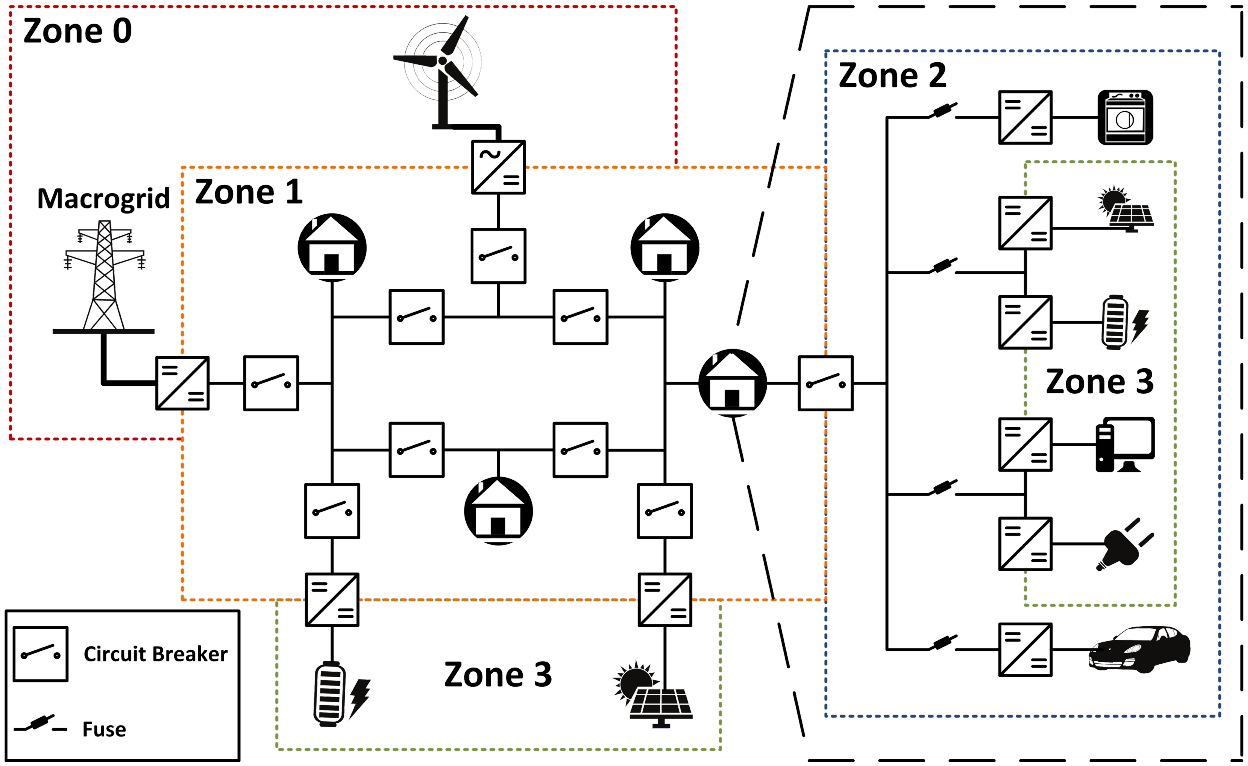
Protection of Low Voltage DC Systems

Lack of a zero crossing

Fast interruption is required: low inertia, component design

Selectivity: meshed systems, fast interruption, challenging selectivity

Protection Zones



N. H. van der Blij, P. Purgat, T. B. Soeiro, L. M. Ramirez-Elizondo, M. T. J. Spaan and P. Bauer, Decentralized Plug-and-Play Protection Scheme for Low Voltage DC Grids", Energies 2020

Protection Zones

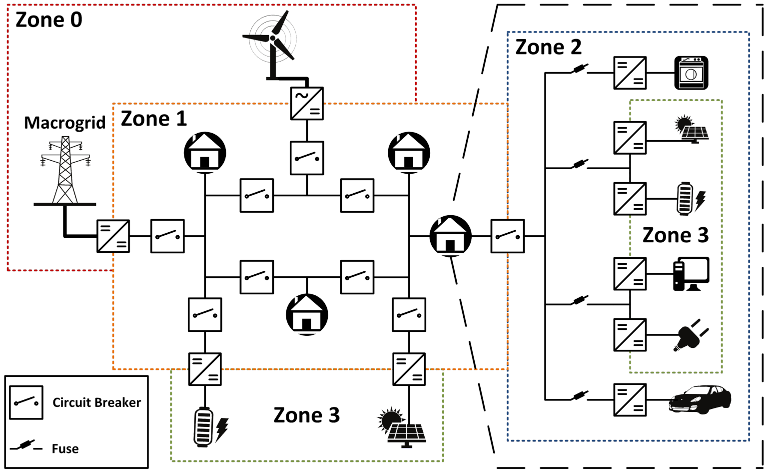
Short-circuit potential

Zone 0: Medium/high voltage (> 1500V) – highest short circuit

Zone 1: Microgrid level (350 – 1500 V) – high short circuit, low inertia

Zone 2: Nanogrid level (42 – 350 V) – low short circuit

Zone 3: Device level (< 42 V)- safe to touch (usb C)



Protection – galvanic isolation

Protection Tiers

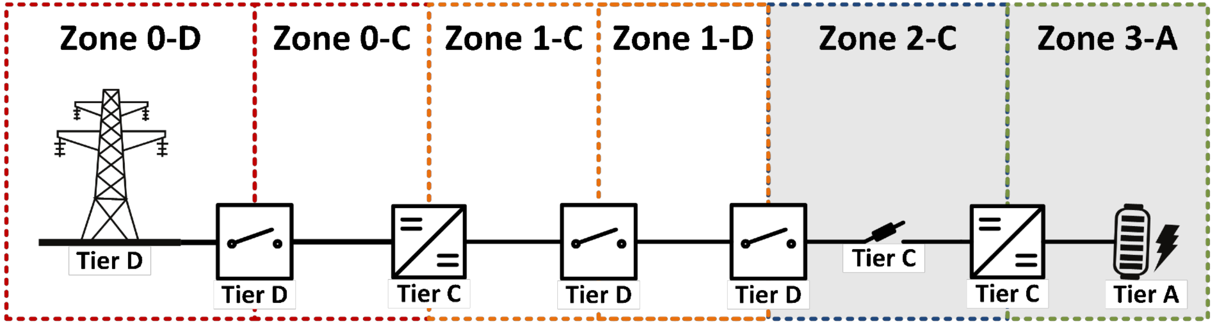
Provided protection:

Tier A: No guaranteed protection

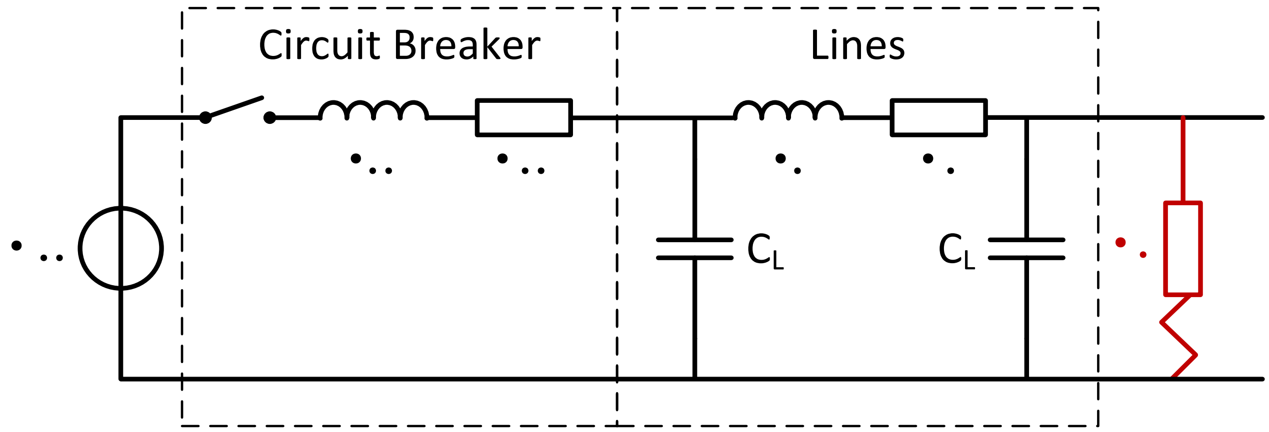
Tier B: Device protection – internal protection

Tier C: Overcurrent protection – interrupted when specified current

Tier D: Current prevention protection



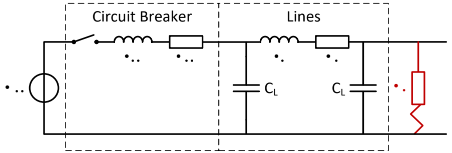
Low Voltage DC Faults

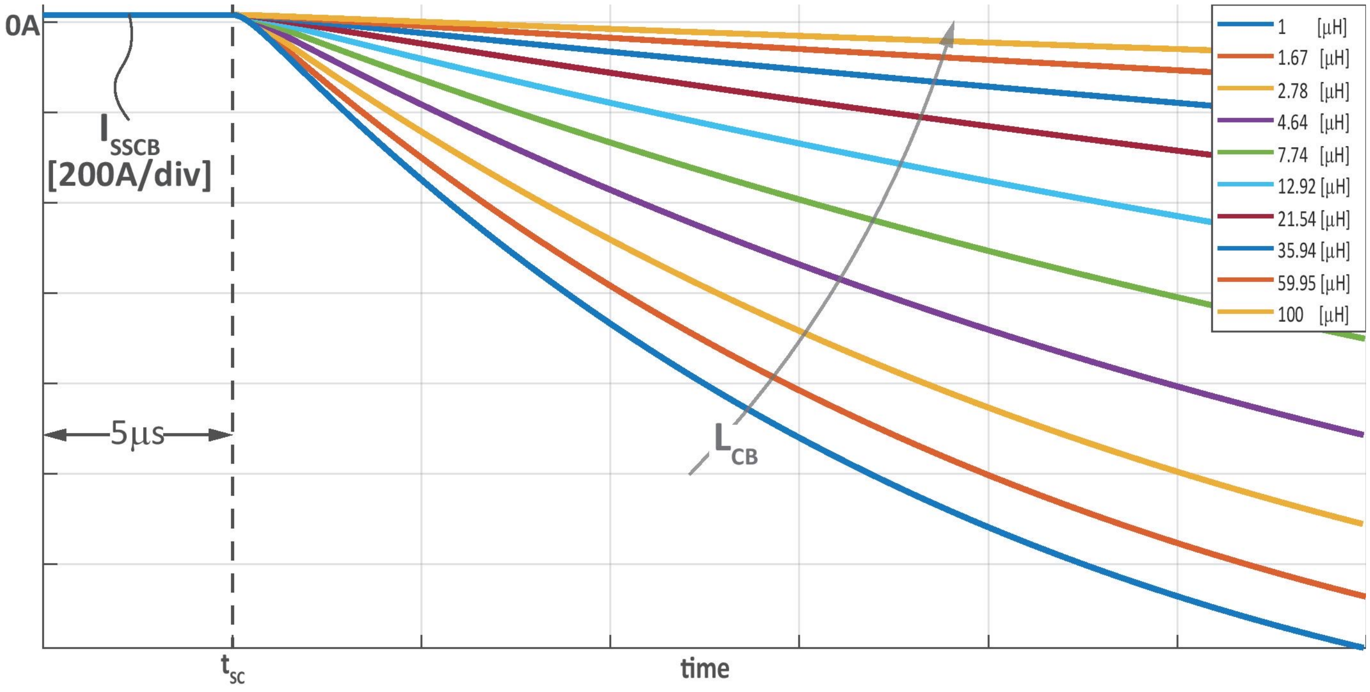


$$I_F(t) = \frac{U_{dc}}{R_{CB} + R_L + R_F}\left(1 - e^{-\frac{R_{CB}+R_L+R_F}{L_{CB}+L_L}t}\right)$$

Current limiting inductances and fast fault interruption are required to prevent the system from reaching its large steady-state currents

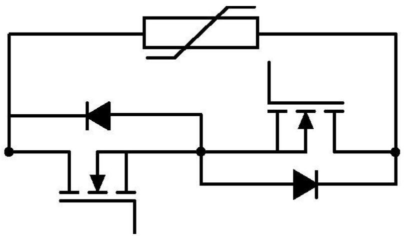
Low Voltage DC Faults



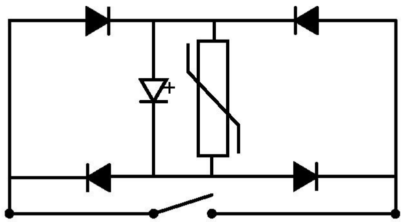


Current limiting inductances and fast fault interruption are required to prevent the system from reaching its large steady-state currents

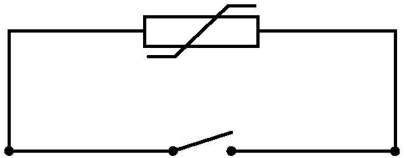
Protection Devices



~ 1 μs



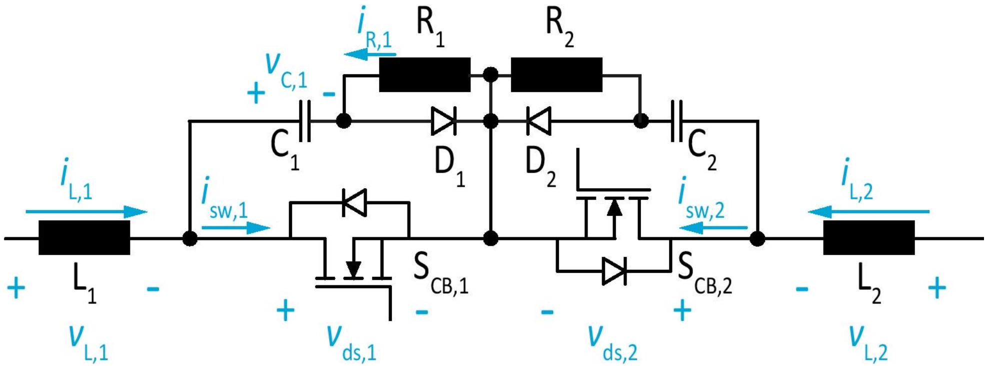
~ 1 ms

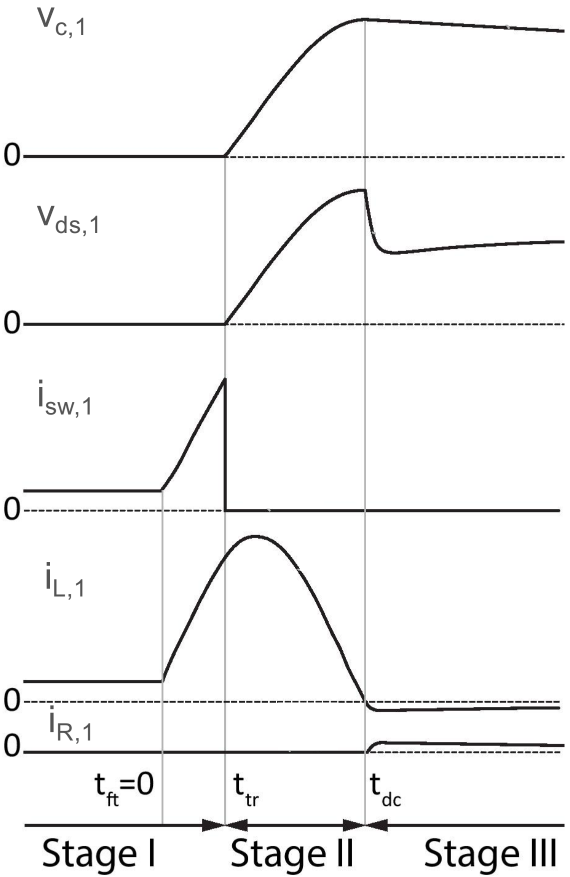


~ 10 ms

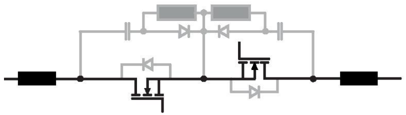
Type	Speed	Reliability	TCO
Hybrid CB	-	-	-
Solid-state CB	+	+	+

SSCB operation

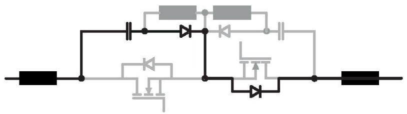




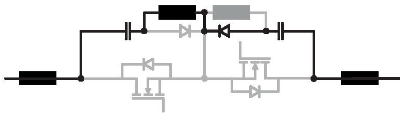
Stage I



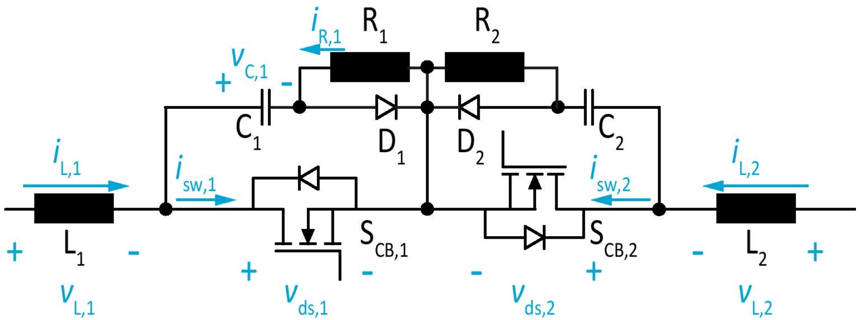
Stage II



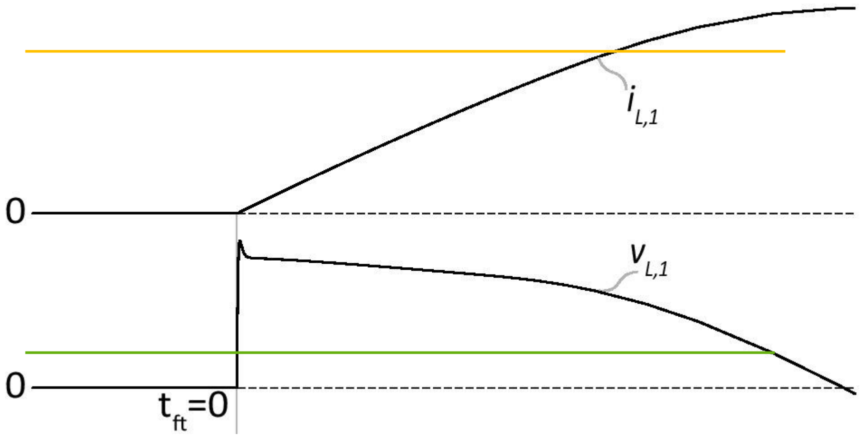
Stage III



SSCB Detection Methods

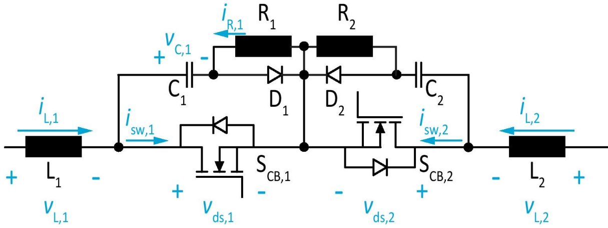


Overcurrent Detection

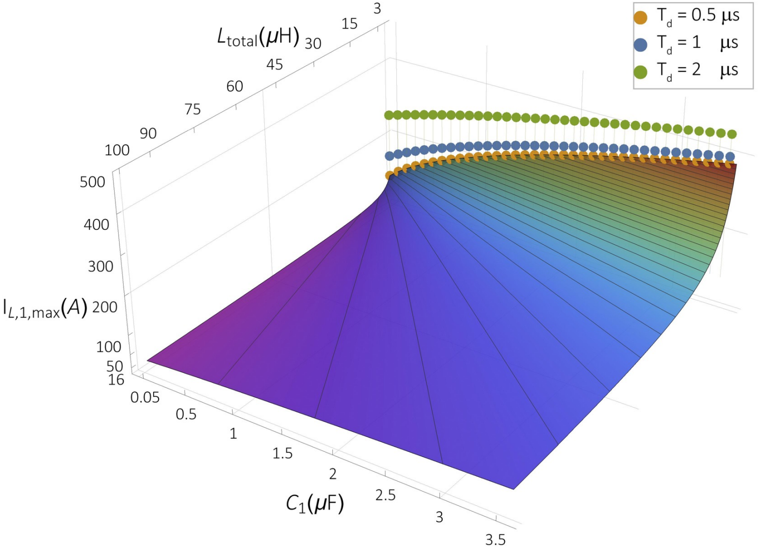


Rate-of-change-of-current Detection

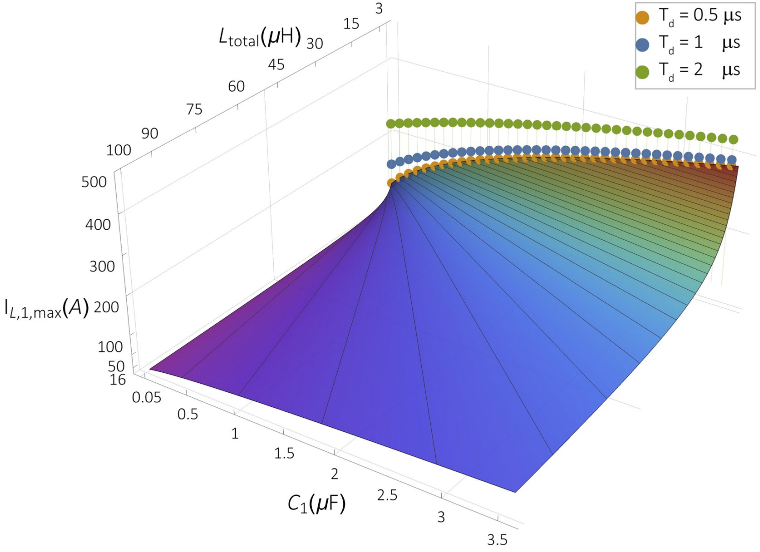
SSCB Design Constraints



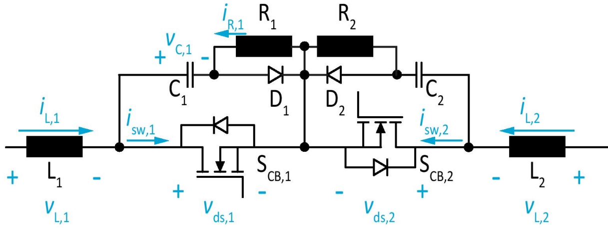
Overcurrent Detection



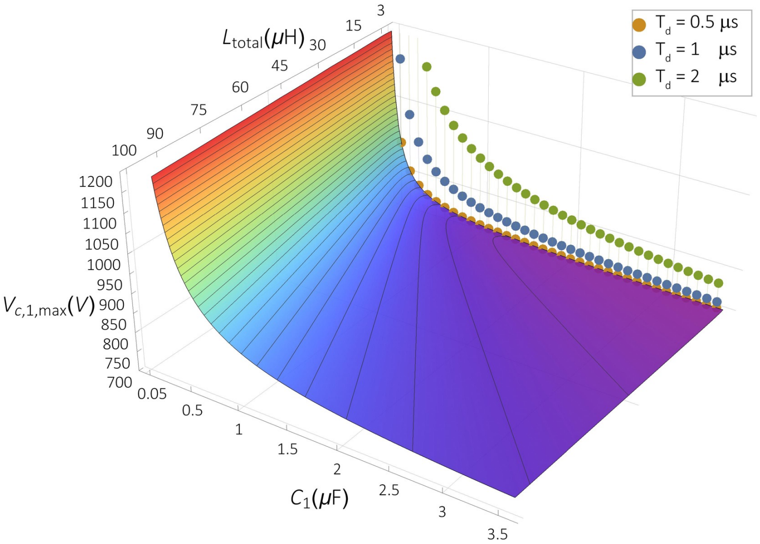
Rate-of-change-of-current Detection



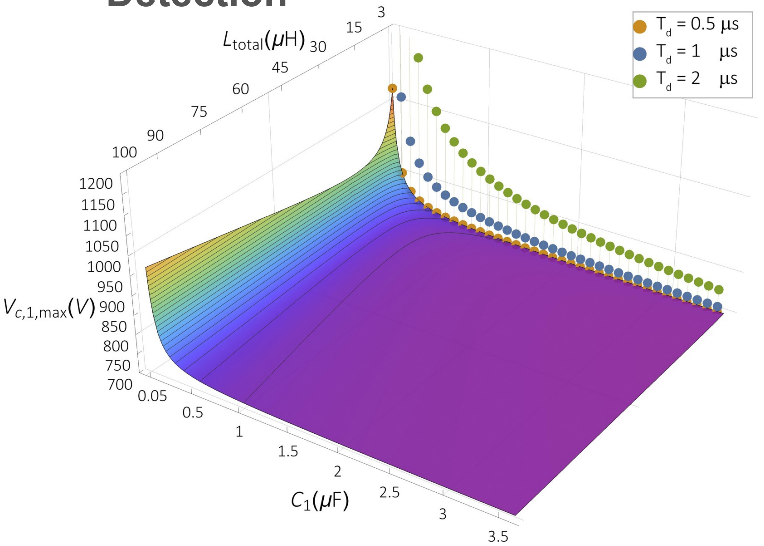
SSCB Design Constraints



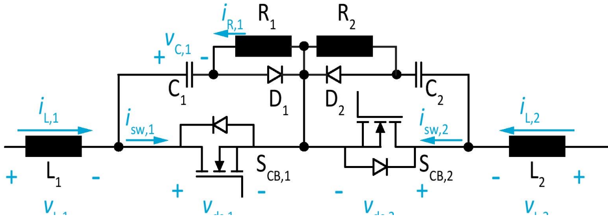
Overcurrent Detection

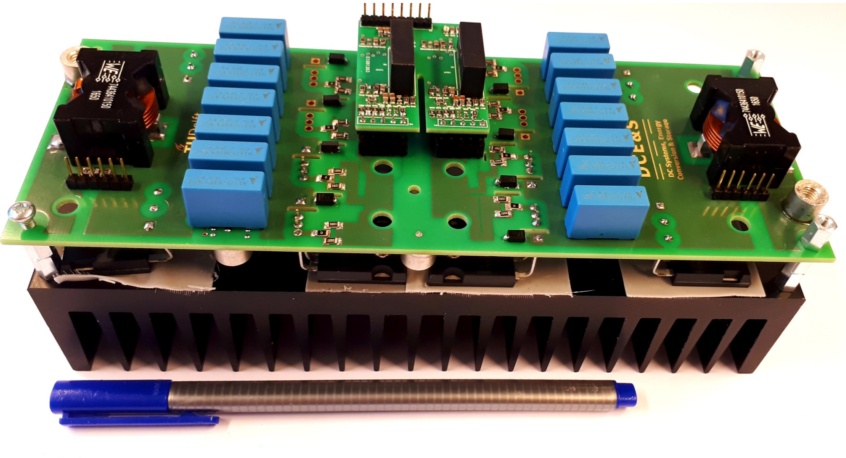


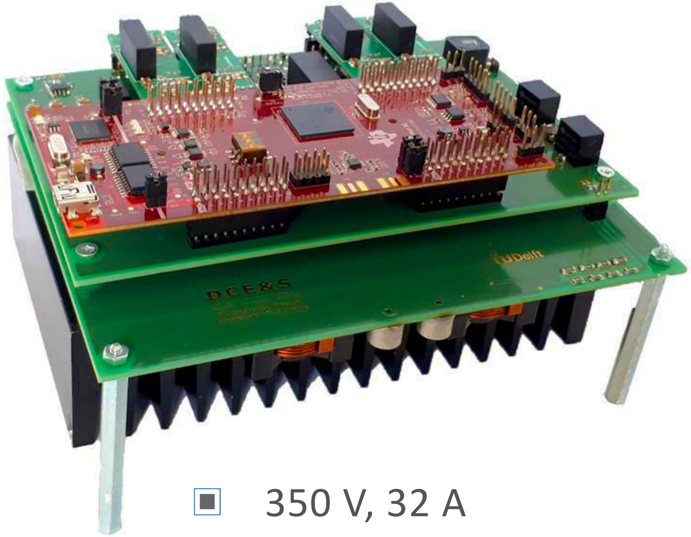
Rate-of-change-of-current Detection



SSCB Prototype 1







350 V, 32 A

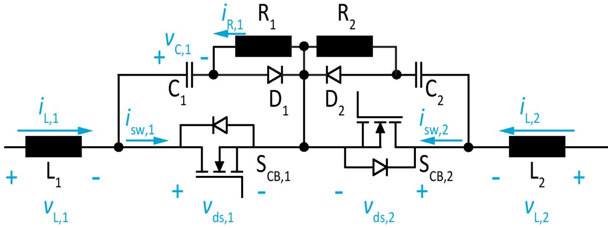
Si Mosfets

8 mΩ

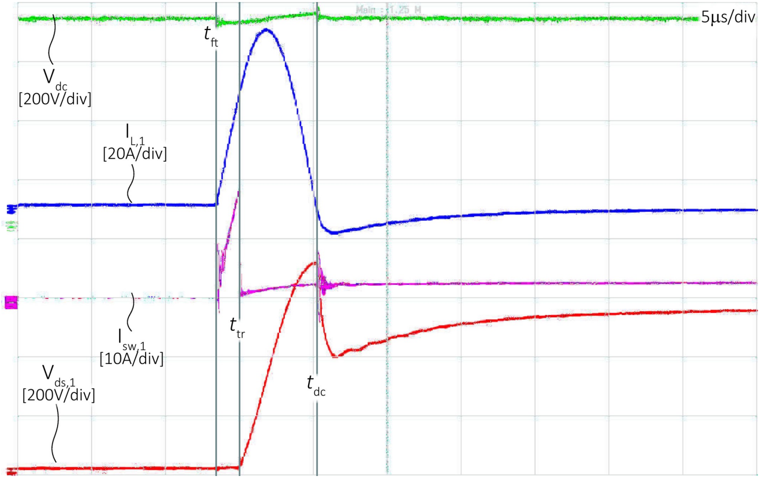
270x75x60 mm

- 350 V, 32 A
- SiC Mosfets
- <100 µH
- Overcurrent (v_{ds})
- ROCOC

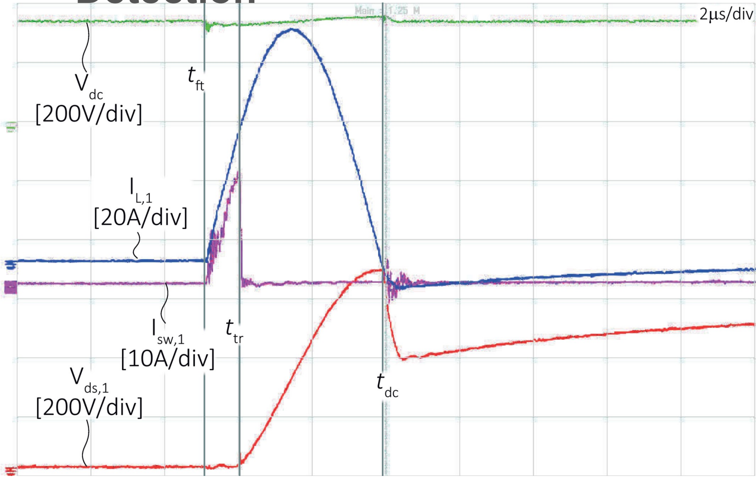
Testing



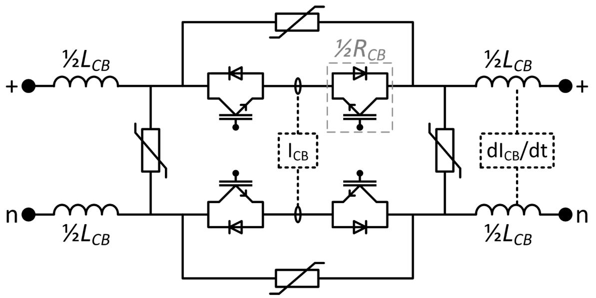
Overcurrent Detection



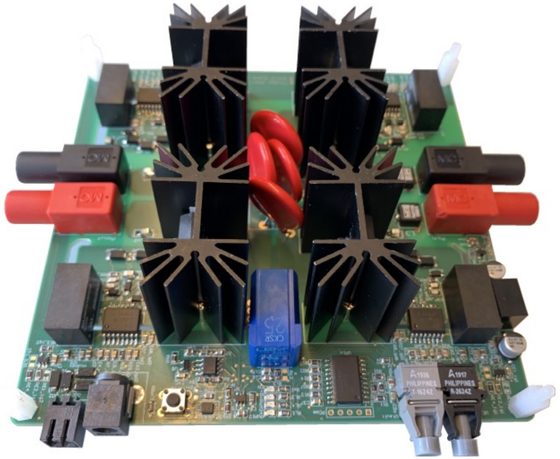
Rate-of-change-of-current Detection



SSCB Prototype 3. MOV



Parameter	Acronym	Value
Nominal voltage	U_{nom}	350 [V]
Nominal current	I_{nom}	16 [A]
On-state resistance per pole	R_{CB}	130 [mΩ]
Current limiting inductance	L_{CB}	1.0 [μH]
Fault clearing time	t_{CB}	1.0 [μs]



Selectivity in LVDC Systems

Major challenges for selectivity in low voltage DC systems:

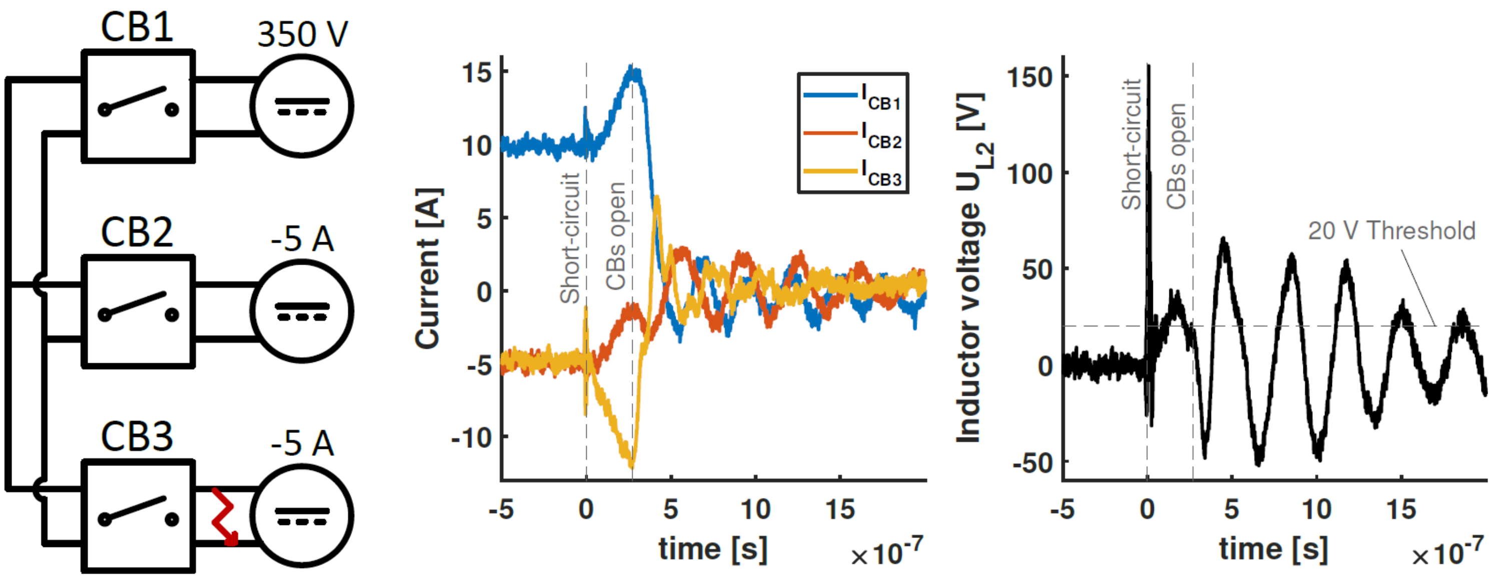
Fast fault interruption

Radial and meshed structures

Changing grid topology

The **fast propagation of the fault** throughout the system and the **commutation of inductive currents** encumbers selectivity.

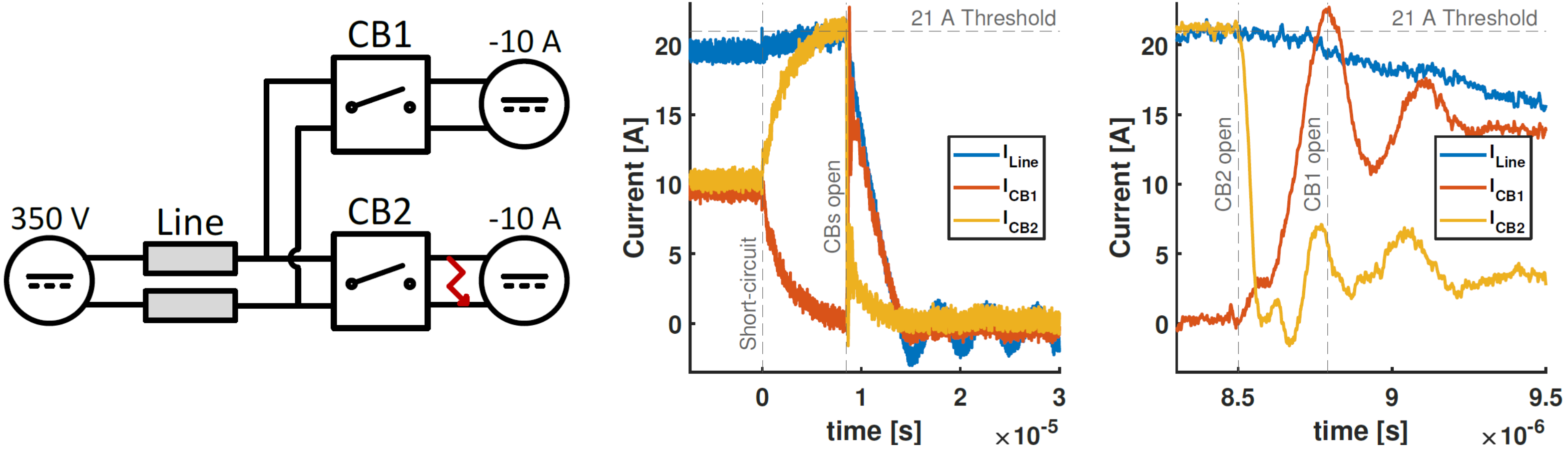
Fast Fault propagation



This situation occurs in, for example, an islanded household nanogrid.

In such a system the fault propagates quickly and the set thresholds (in this case the di/dt thresholds) are exceeded in all groups, before the SSCB in the faulted group can react.

Commutation of Inductive Currents



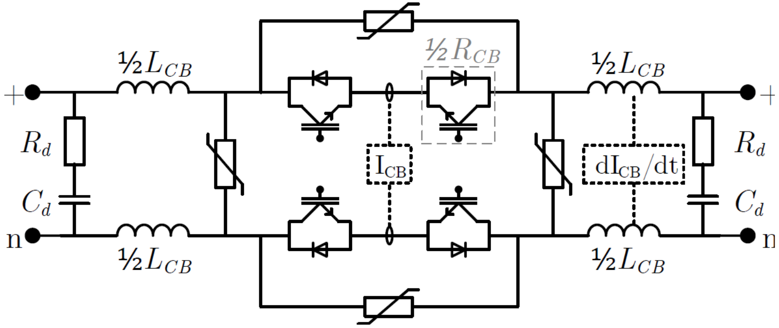
This situation occurs, for example, a connected household nanogrid.

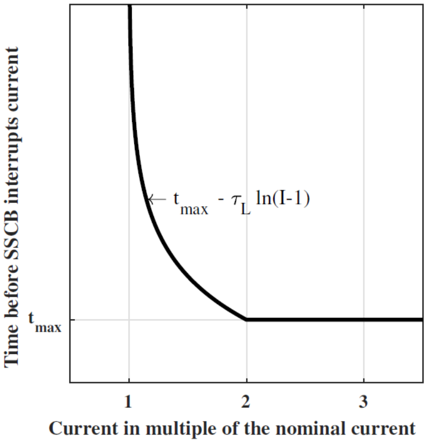
In such a system the inductive (pre-fault) current from the faulted section will flow in the non-faulted sections of the grid after fault clearing. This can cause the unnecessary tripping of non-faulted groups.

Plug and Play Protection Scheme

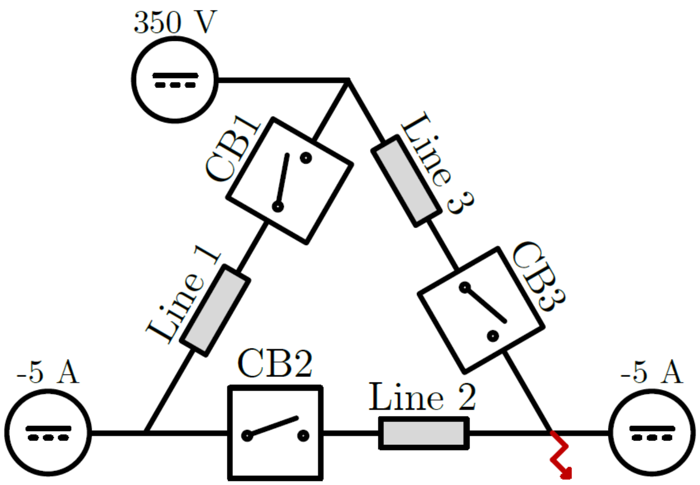
Fast fault propagation is solved by modifying the topology of the SSCB, such that it forms an LCR filter that delays propagation.

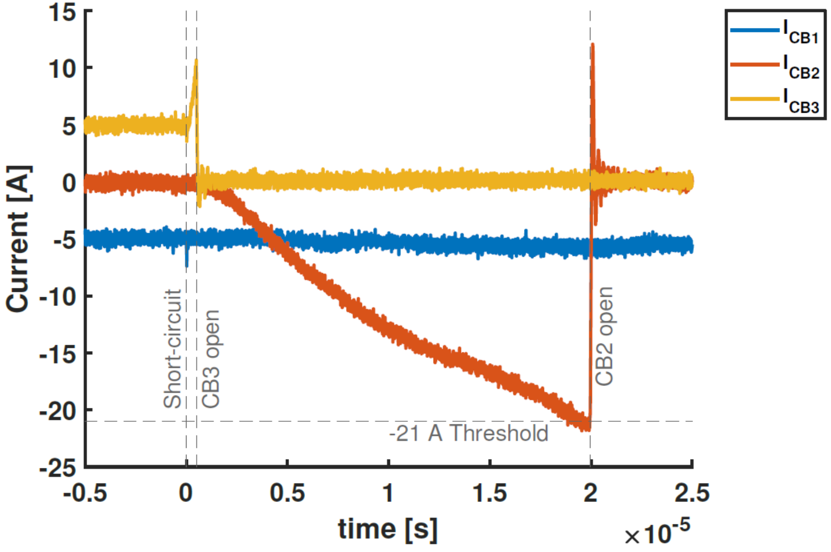
Commutation of inductive currents is ignored by employing a well-designed time-current characteristic.





Plug and Play Experimental Results



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Баярлалаа
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tapadh leat
спасибо
faafetai lava
vinaka
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blagodaram
dank je
misaotra
matondo
paldies
grazzi
thank you
gracias
хвала
kiitos
dankie
nanni
nandri
dhanyavad
mauruuru
köszönöm
bedankt
bayarlalaa
gràçie
hvala
enkosi
asante
manana
obrigada
tenki
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