EMI/EMC IN POWER ELECTRONICS

Power Electronics for PtX: Challenges and Opportunities

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AAU Energy

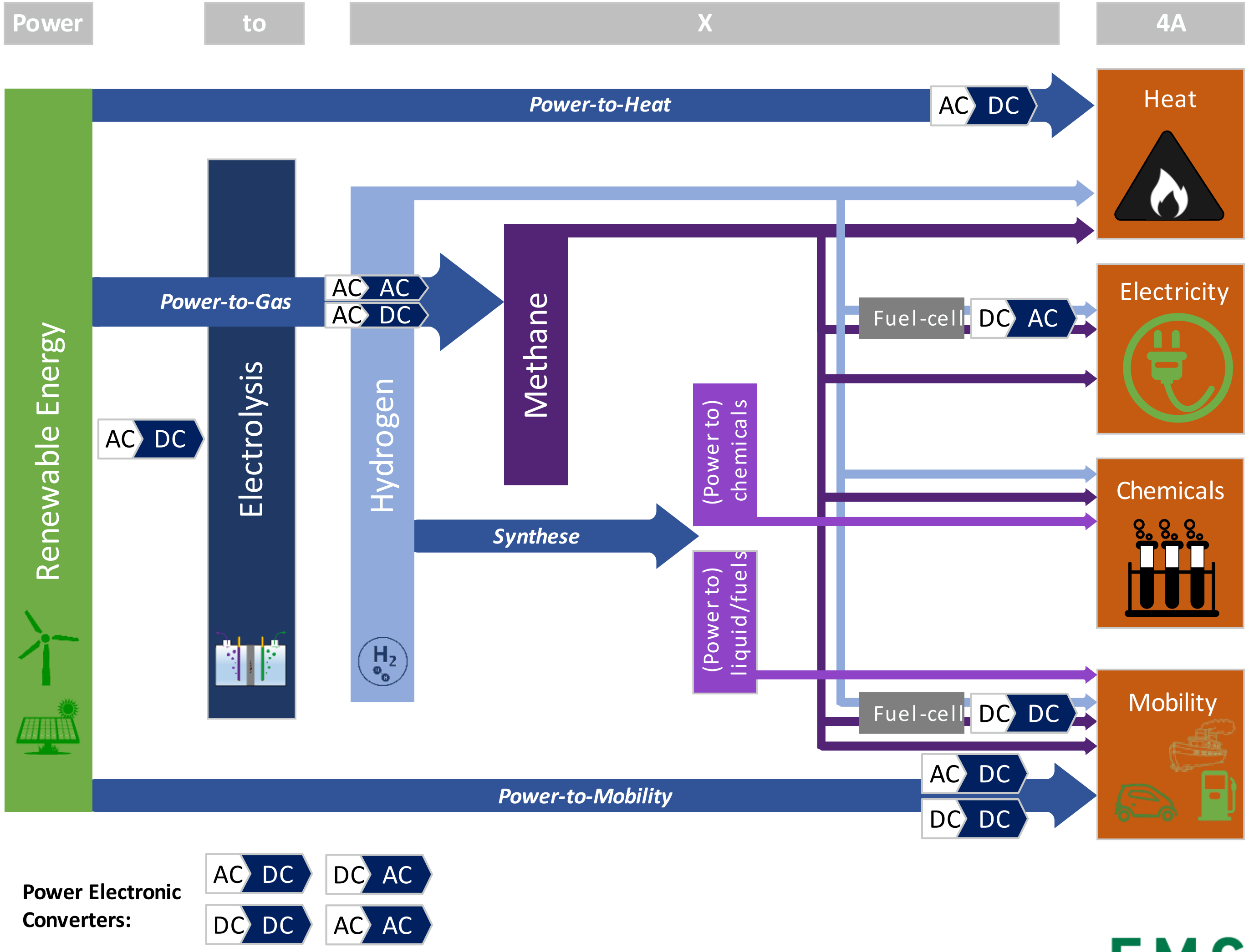
Outline

- Introduction
- Topology Overview
  - Electrolysis
  - Methane Reforming
- Challenges and Opportunities
- Conclusion

INTRODUCTION

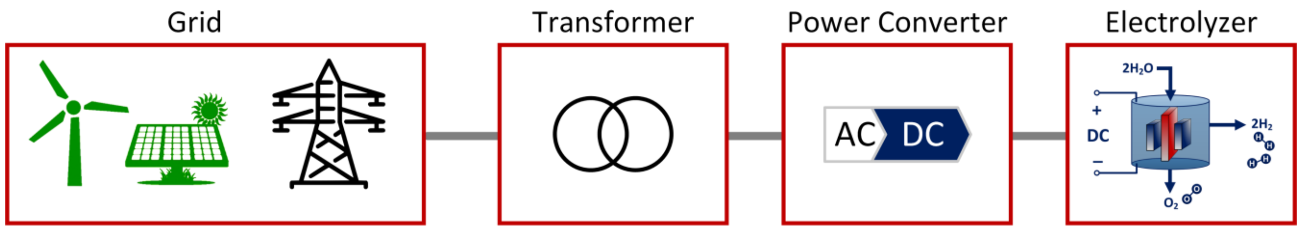
P2X and Role of Power Electronics

- Power electronic converters are needed across the whole powertrain



INTRODUCTION

General Requirements for Power Electronics



- Requirements
  - Input Voltage: 0.4 – 35 kV
  - Output Voltage: 350 – 1000V
  - Output Current: 1- 12 kA (< 5% ripple)
  - Output Power
    - < 1MW
    - 1MW < P < 5MW
    - > 5MW
  - Galvanic Isolation
  - Controllability: Output Current/Voltage
  - PF > 0.9
  - THDi:
    - < 30% (small systems)
    - < 5% (large systems)

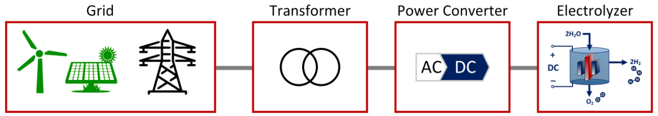
- Recent Future Trends
  - High efficiency requirement (> 98%)
  - Pushing to 1500V output
  - Higher power levels
  - Load dependent THDi & PF
  - High PF (>0.95) and low THDi (< 5%)
  - Scalability
  - Low foot-print and volume (reducing transformer size)
  - High reliability
  - Low cost [Euro/kW]
  - Ancillary services

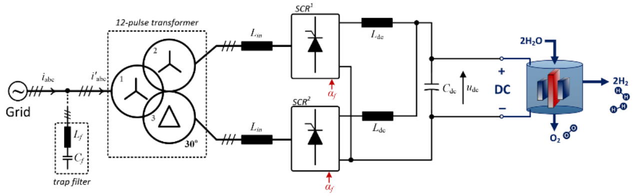
Outline

TOPOLOGY OVERVIEW

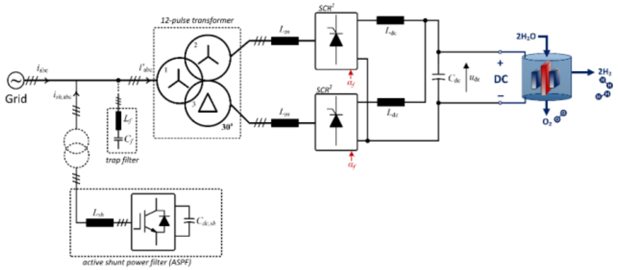
State-of-the-Art (general classification):

Single-stage power supplies

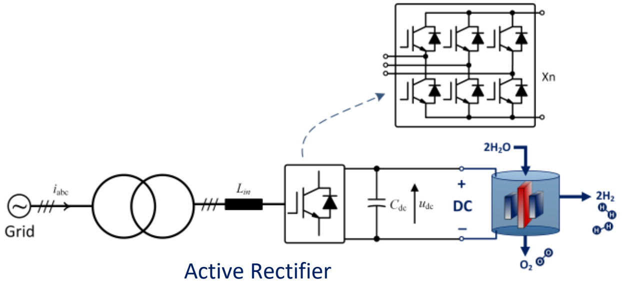




12-pulse Thyristor Rectifier (12-TR)

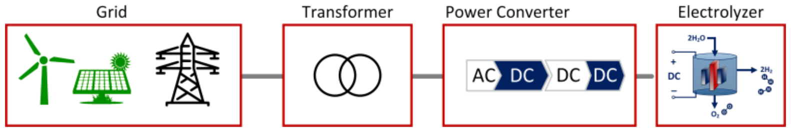


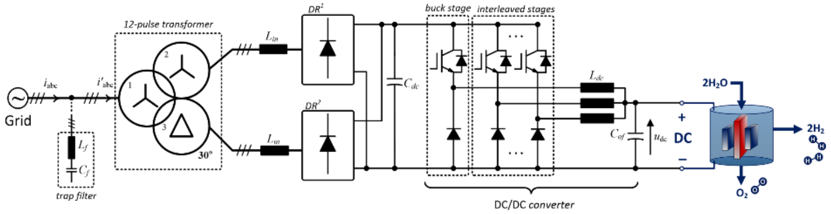
12-pulse Thyristor Rectifier with shunt power filter (12-TRSHF)



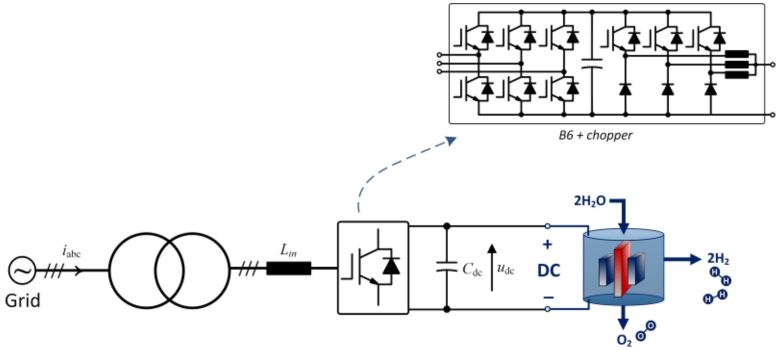
Active Rectifier

Double-stage power supplies





12-pulse Diode Rectifier with multi-phase chopper (12-DRMC)



Active Rectifier-fed buck converter

Ref: M. Chen, S. F. Chou, F. Blaabjerg, P. Davari, "Overview of Power Electronic Converter Topologies Enabling Large-Scale Hydrogen Production via Water Electrolysis". *Appl. Sci.* 2022.
A. Abdelhakim and F. Canales, "Power Electronics Role in Future Hydrogen Systems", APEC 2023.

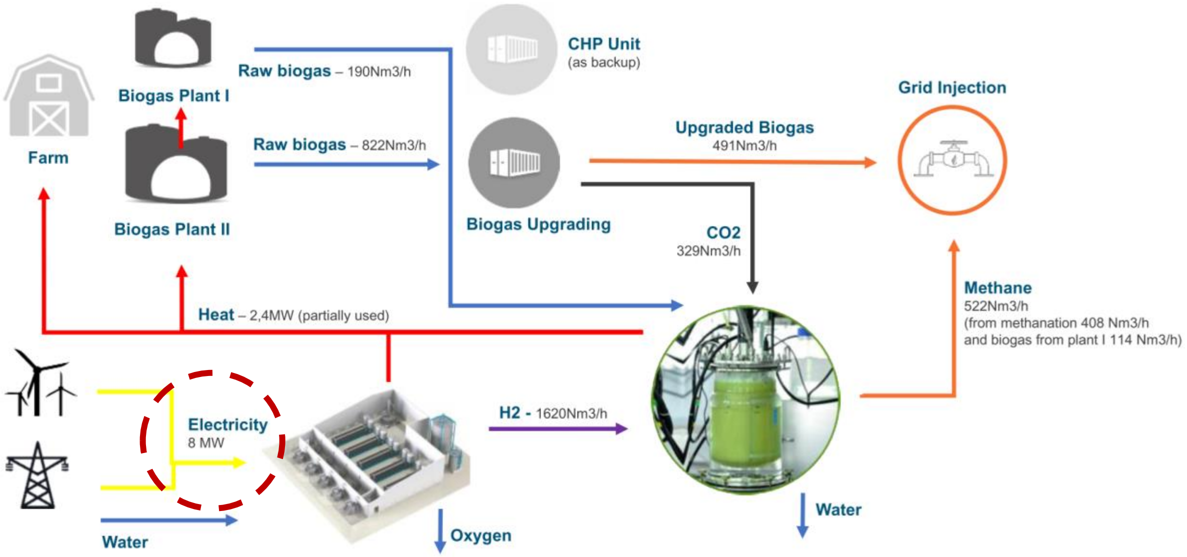
TOPOLOGY OVERVIEW

BioCat Project

EUDP

BioCatProject
POWER-TO-GAS VIA BIOLOGICAL CATALYSIS

- EUDP Project with NEL Hydrogen



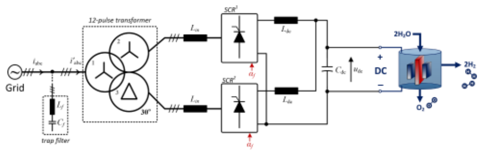
The integrated P2G solution

Topology Overview

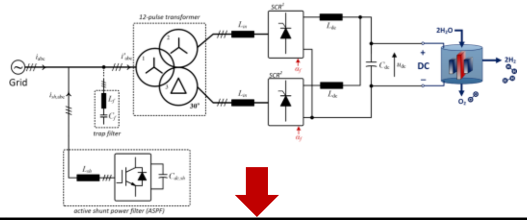
State-of-the-Art (Comparison):

BioCat Project (EUDP) – 5 MW case study @BOL

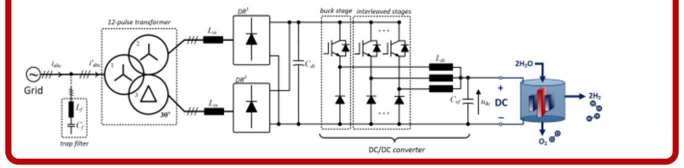
12-pulse Thyristor Rectifier (12-TR)



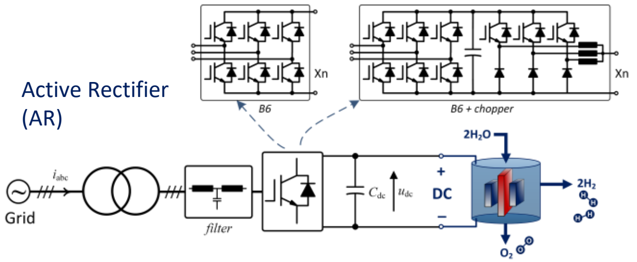
12-pulse Thyristor Rectifier with shunt power filter (12-TRSHF)

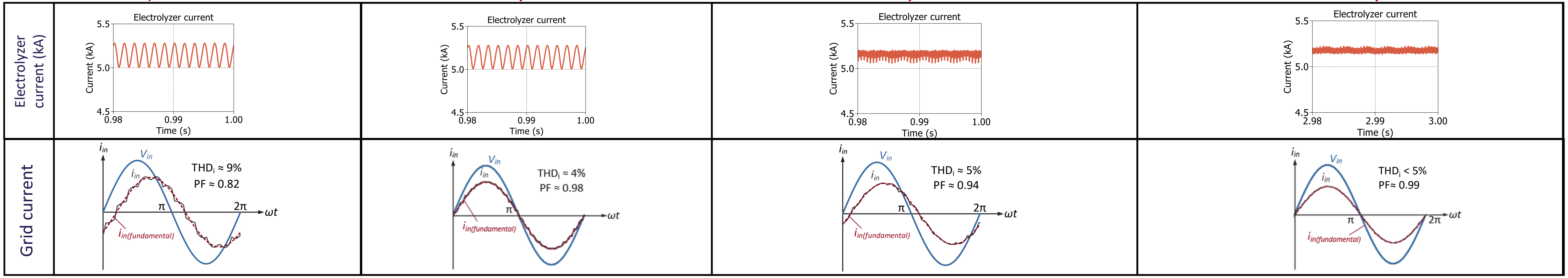


12-pulse Diode Rectifier with multi-phase chopper (12-DRMC)



Active Rectifier (AR)





	Power Quality	Efficiency	Cost	Reliability	Control Complexity	Footprint
12-TR	–	+	+	++	+	–
12-DTRMC	Δ	Δ	+	+	Δ	–
12-TRSHF	+	Δ	-	Δ	–	–
AR	++	Δ	-	Δ	–	–

Ref: M. Chen, S. F. Chou, F. Blaabjerg, P. Davari, "Overview of Power Electronic Converter Topologies Enabling Large-Scale Hydrogen Production via Water Electrolysis". *Appl. Sci.* 2022.

Topology Overview

State-of-the-Art (Industrial Solutions):

12-Thyristor Rectifier	12-Diode Rectifier with Multiple Chopper	Two-level active rectifier
		
KraftPowerCon Sweden	AEG Power Solutions Germany	SMA Germany
❑ Nominal Output: 1000 V, 1500 A ❑ Power: 1.5 MW ❑ Efficiency: >98%	❑ Nominal Output: 1000 V, 1250 A ❑ Power: 1.25 MW-10 MW ❑ Efficiency: >97%	❑ Nominal Output: 1500 V, 2000 A ❑ Power: 1-3 MW ❑ Efficiency: >97%

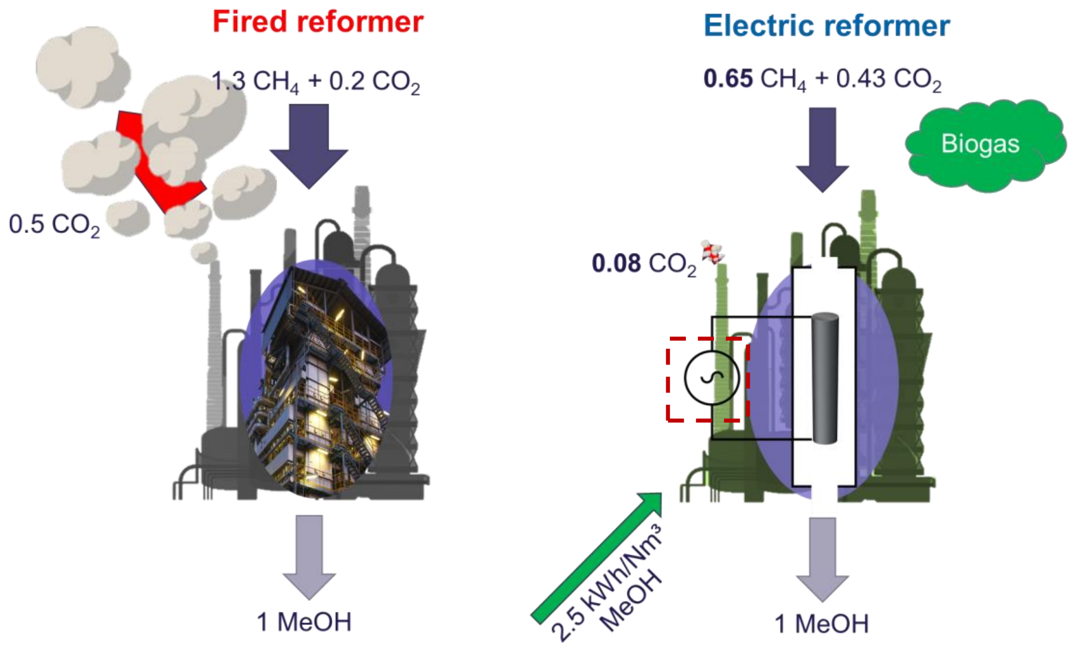
TOPOLOGY OVERVIEW

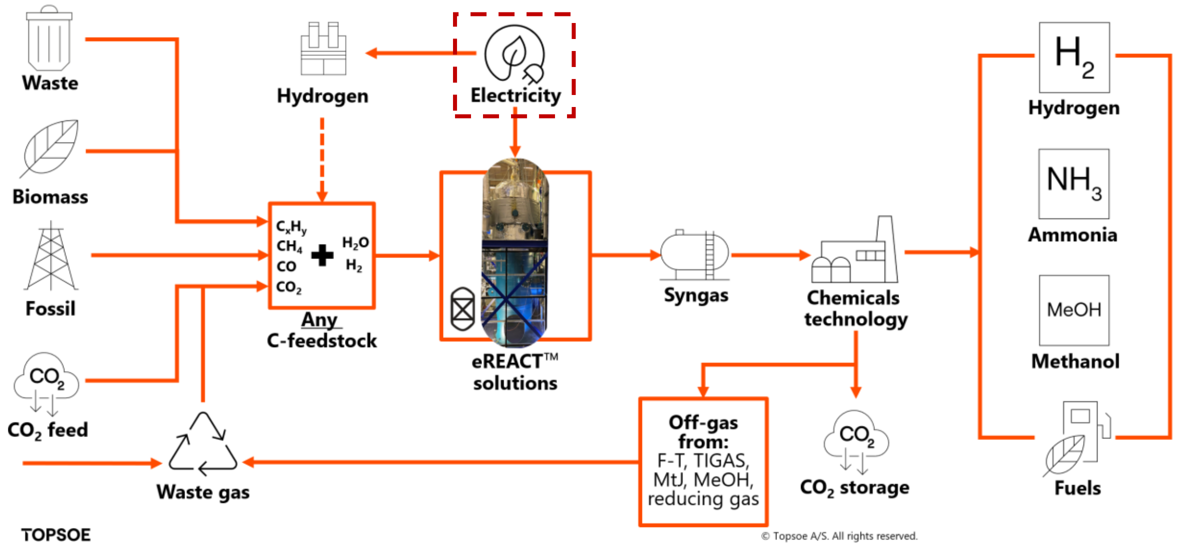
eREACT Technology

EUDP

- Electrically driven steam methane reforming technology (eSMR)
- EUDP Project with Haldor Topsøe A/S
  - (Pilot Site Foulum)

- ❑ Green Methane based on renewables
- ❑ Integration of methanol as an energy vector
- ❑ Contribution to balancing the electricity grid



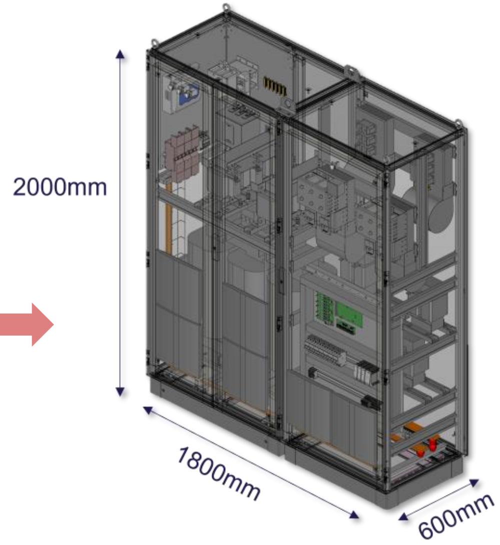


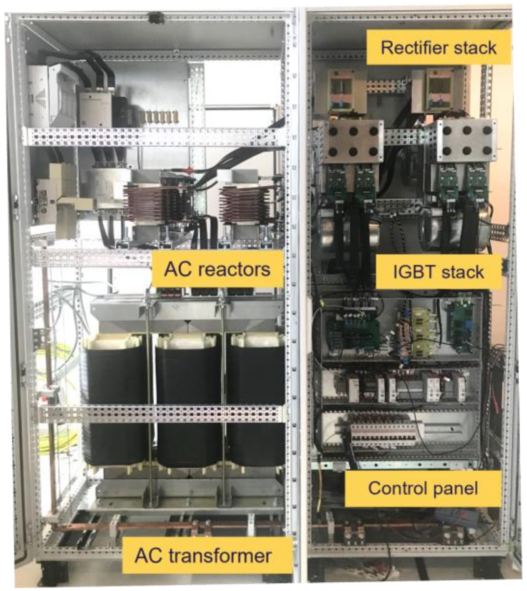
Topology Overview

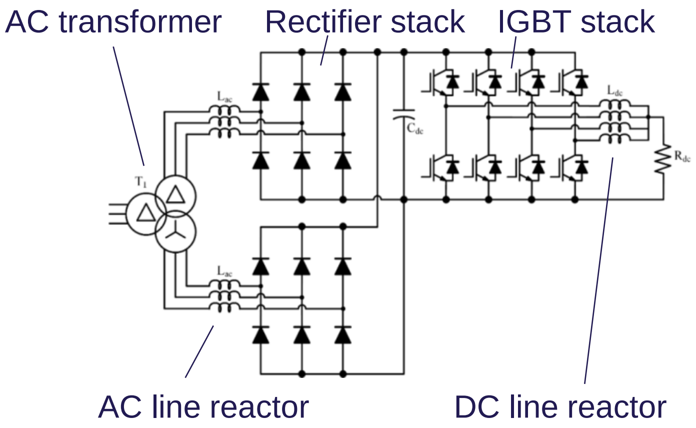
eREACT Technology

12-Diode Rectifier with Multiple Chopper (12-DRMC):

Pilot Site in Foulum





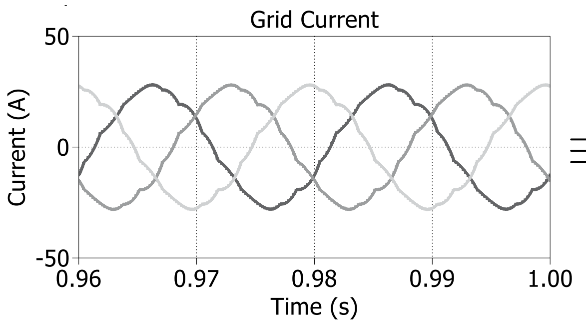


- **Specifications**
  - Input AC Voltage: 400 V
  - Output DC Voltage: 150 V (Pilot)
  - Output DC Current: 850 A (Pilot)
  - Output Power: 128 kW (Pilot)
  - Galvanic Isolation
  - Controllability: Output Voltage/ Output Current

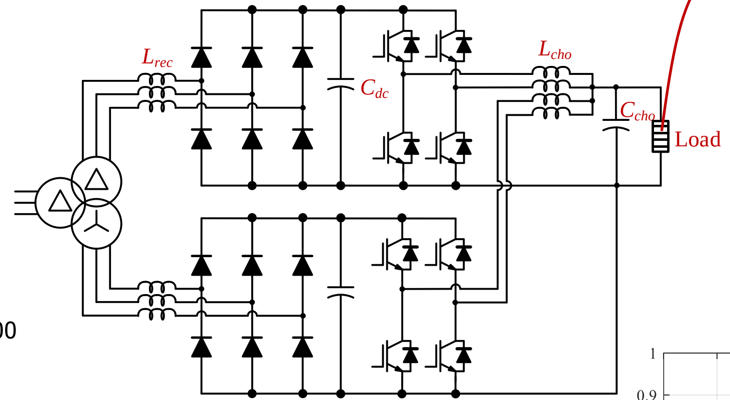
Topology Overview

eREACT Technology

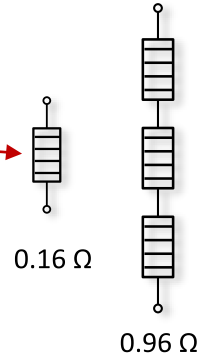
12-Diode Rectifier with Multiple Chopper (12-DRMC):

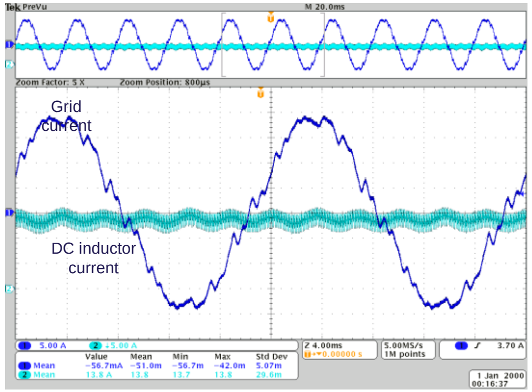


Grid current @ 0.96 MW (Output: 960V, 1000 A)

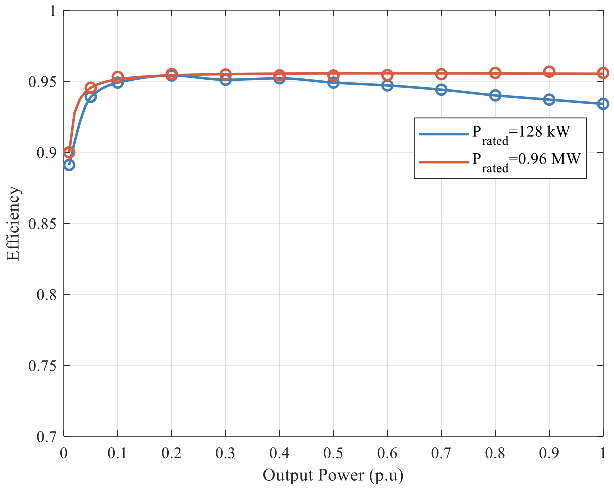


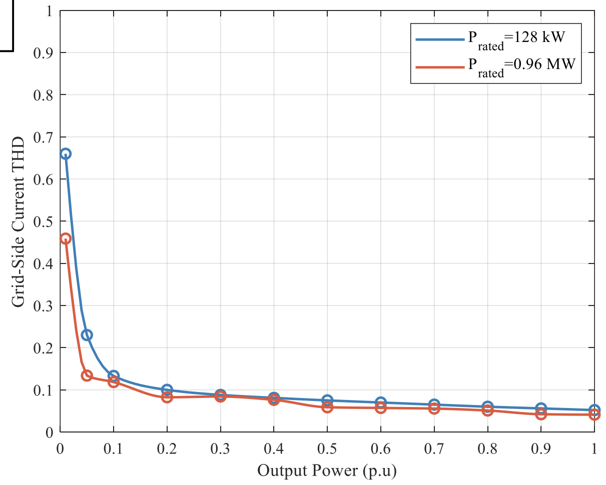
Series string for 1MW

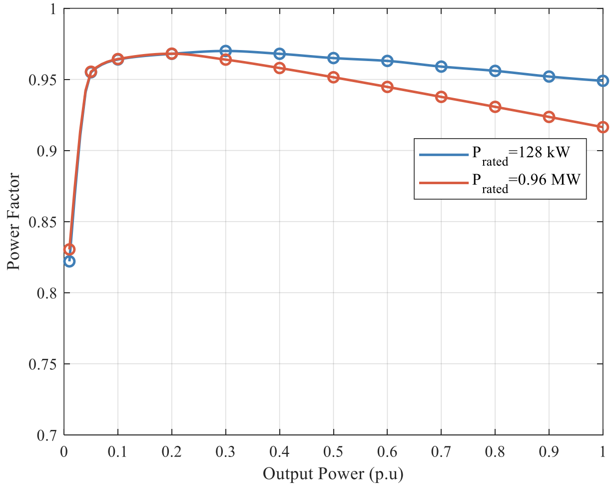




Grid current (experiment)







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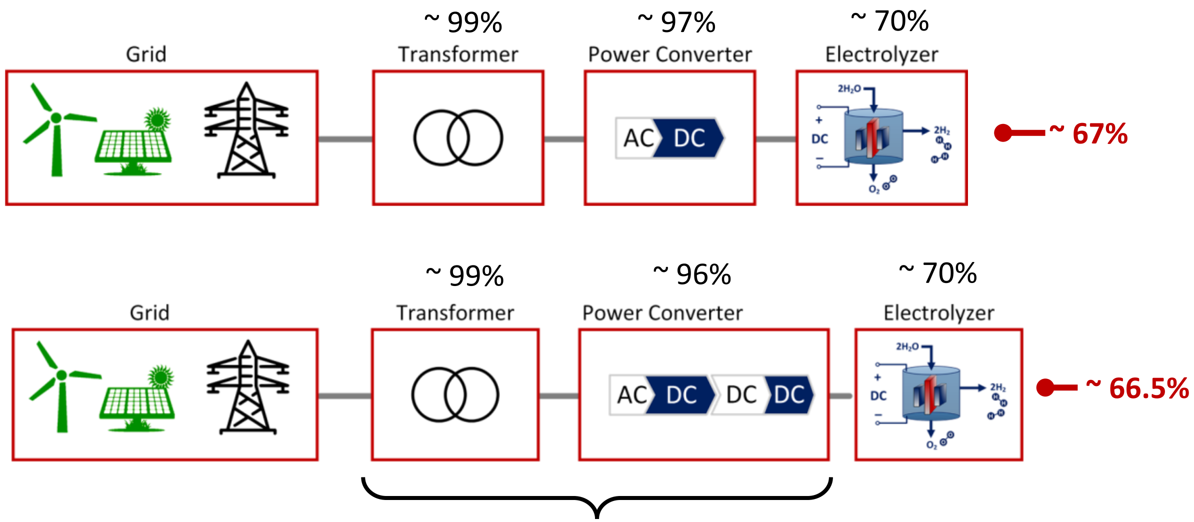
Challenges & Opportunities

Design for Higher Performance



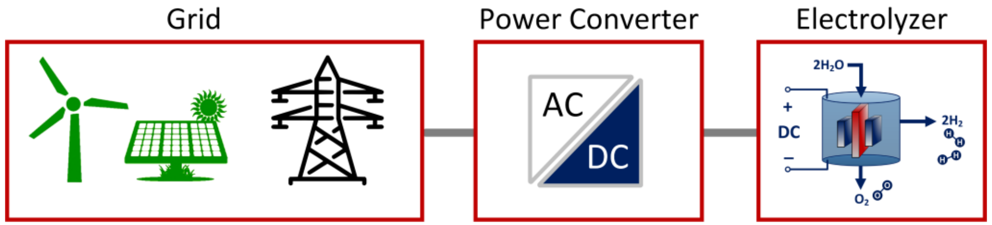
Impact on:

- Total system cost (Euro/kW)
- Electrolyzer efficiency and lifetime (current ripple)
- Overall system foot-print and volume
- Materials saving (e.g., less copper mass → CO_2 reduction)
- Scalability to cover different stack sizes (time-to-market + savings on R&D effort)

CHALLENGES & OPPORTUNITIES

Modular Multi-cell Rectifier (MMR)

Next Generation Power Converter



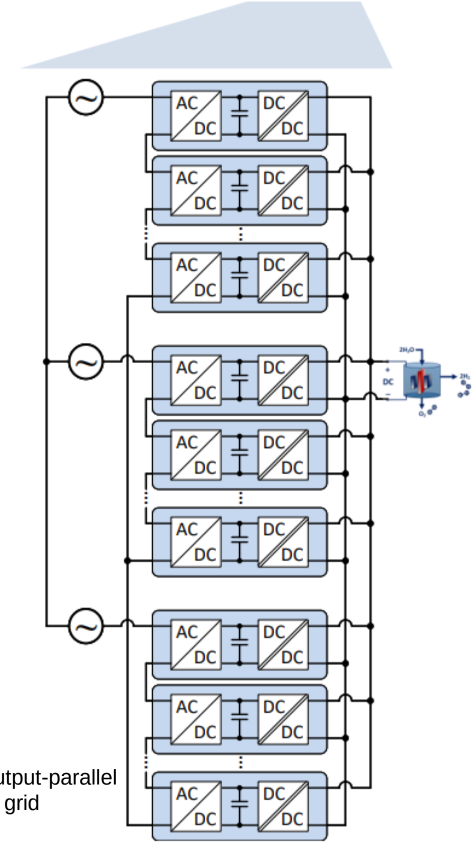
+ Solid-State Transformer (SST) = no LFT
+ High power density
+ Reliable (Redundancy)
+ THDi < 5%
+ PF ≈ 0.99

+ Scalable to any stack size
+ Efficiency can be further improved (MV SiC)
+ Load independent performance

- Cost comparing to LFT-based solutions
- High control complexity
- High component counts
- Lack of technology standardization

CHARACTERISTIC PERFORMANCE INDICES FOR 1000 kVA LFT-BASED AND SST-BASED SOLUTIONS IN AC/DC APPLICATIONS. [*]

	LFT	AC/DC factor	SST
Losses [W/kVA]	32.7	×0.53	17.3
Volume [l/kVA]	4.5	×0.35	1.6
Weight [kg/kVA]	3.9	×0.32	1.3

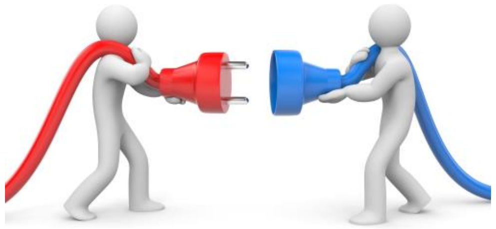


Input-series output-parallel (ISOP) for MV grid

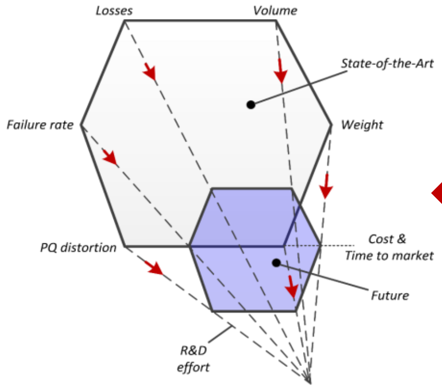
[*] J. E. Huber and J. W. Kolar, "Volume/weight/cost comparison of a 1MVA 10 kV/400 V solid-state against a conventional low-frequency distribution transformer," *2014 IEEE Energy Conversion Congress and Exposition (ECCE)*, 2014.

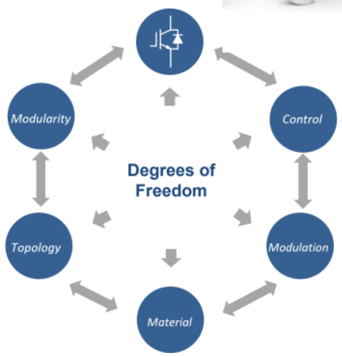
Challenges & Opportunities

Design for Higher Performance



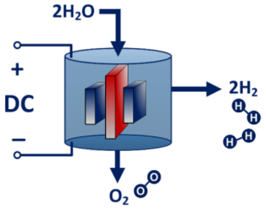
Power electronic

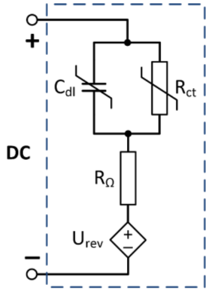


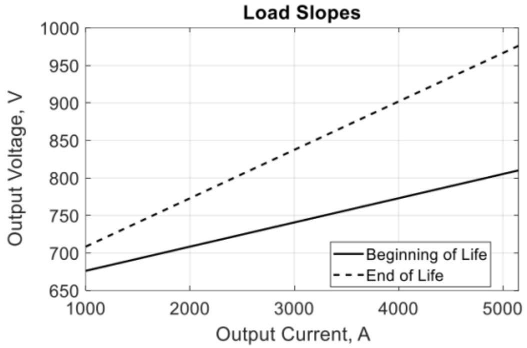


- Efficient and Scalable
- Modular and reliable
- High power quality and grid compatible
- **Strong need for Digital Twin models**

Electrolyzer





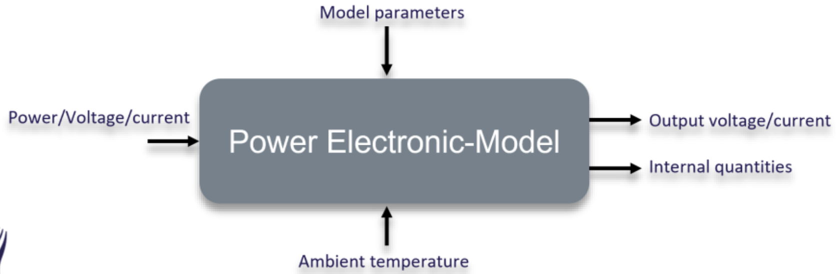


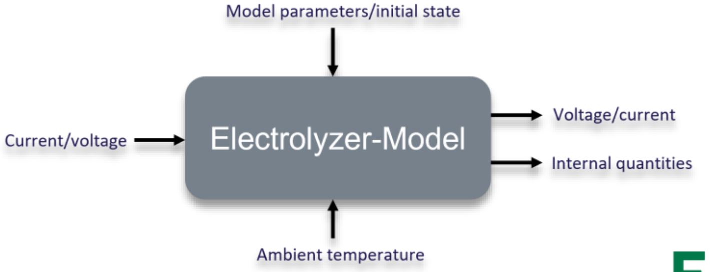
Aging-depended electric characteristic

- Predicting efficiency and reliability
- Exploring new materials for better life-time and efficiency
- Accelerating development time
- **Strong need for Digital Twin models**

Chemistry-aware Digital Twin models

- Energy efficient solutions
- Lifetime prediction and improvement
- Dynamic behavior
- Hybrid solutions with battery storage
  - Better utilization
  - Grid ancillary services





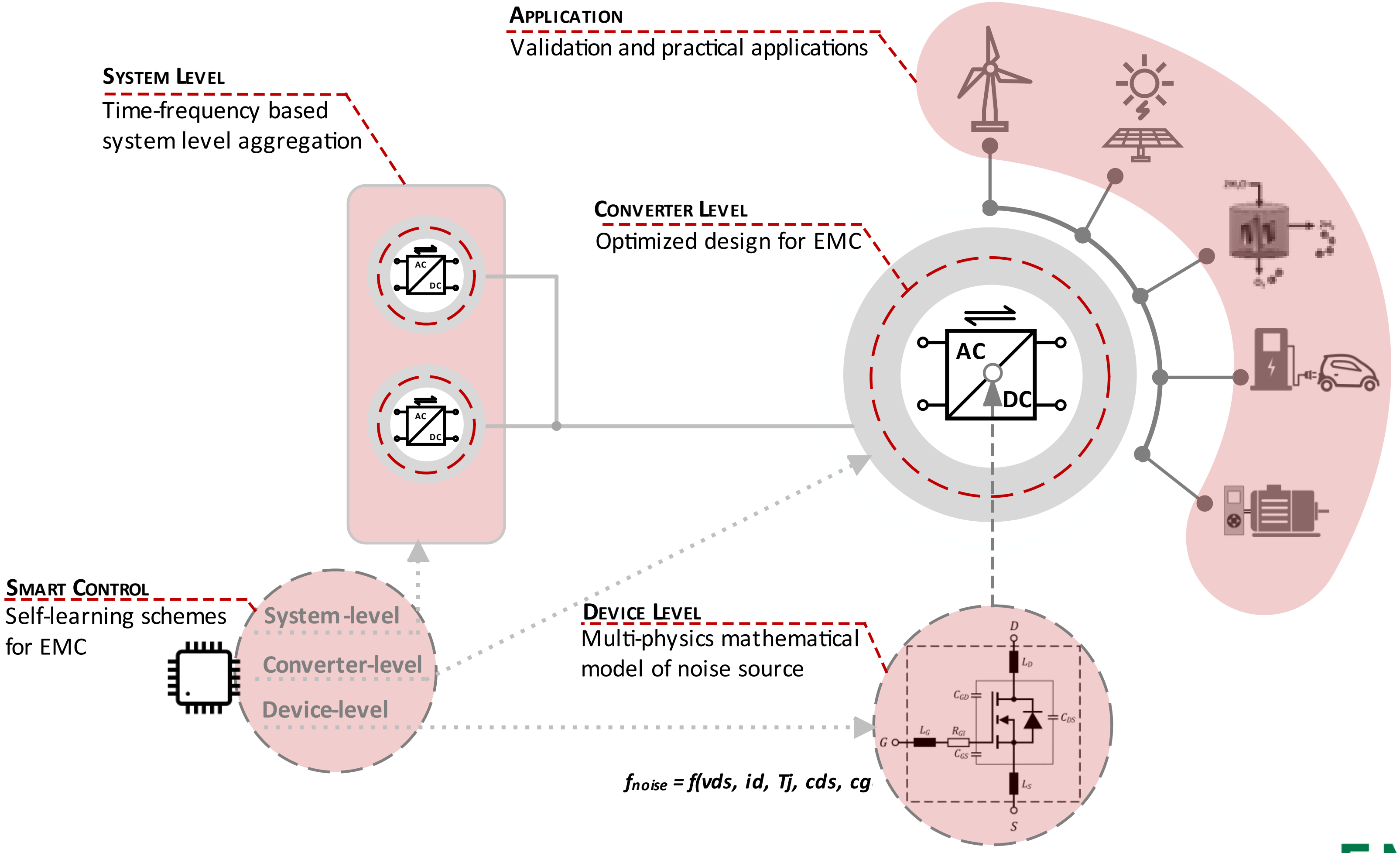
Challenges & Opportunities

Digital Twin Modeling

Innovation Fund Denmark

DANMARKS FRIE FORSKNINGSFOND

Our Methodology:



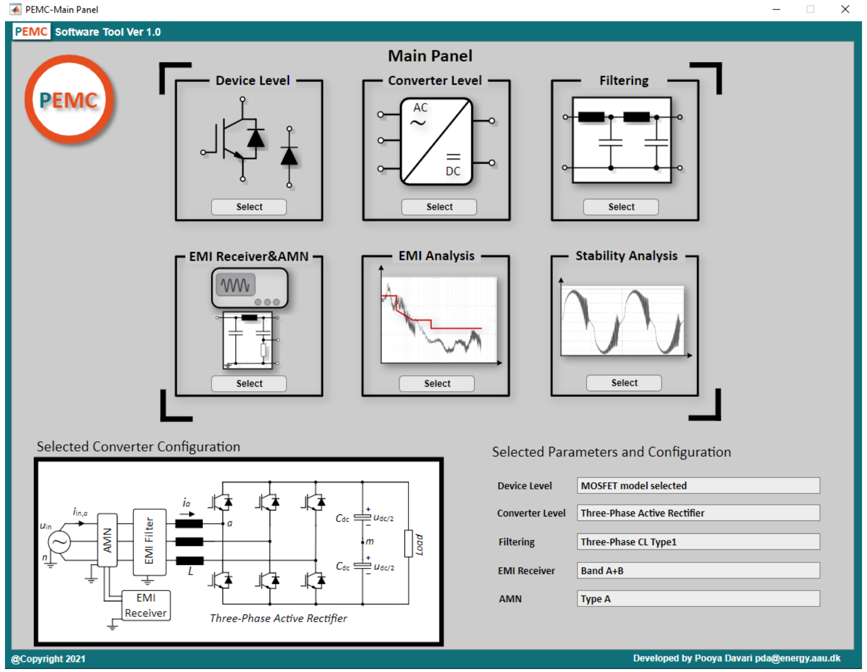
Challenges & Opportunities

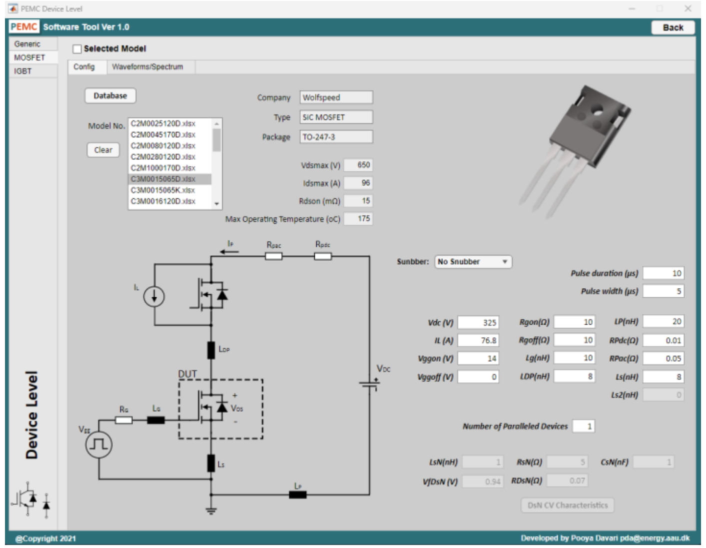
PEMC Software-Tool

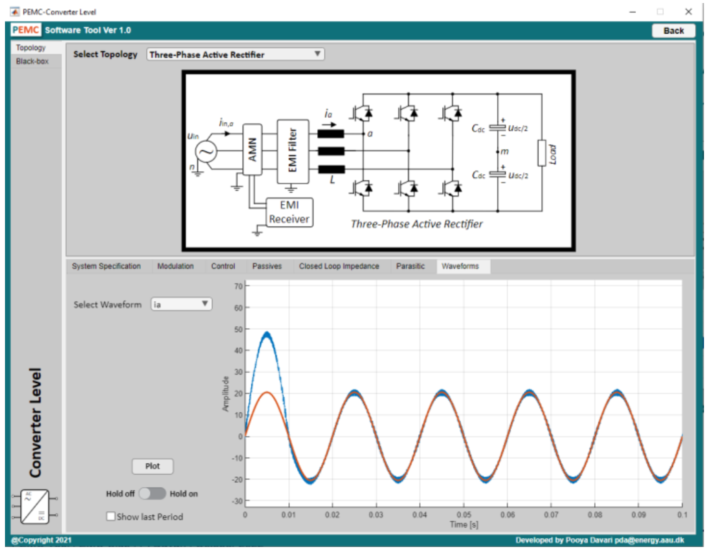
PEMC

Power electronics software tool for ElectroMagnetic interference pre-Compliance

The tool is developed based on Power Electronics **Digital Twin** concept.

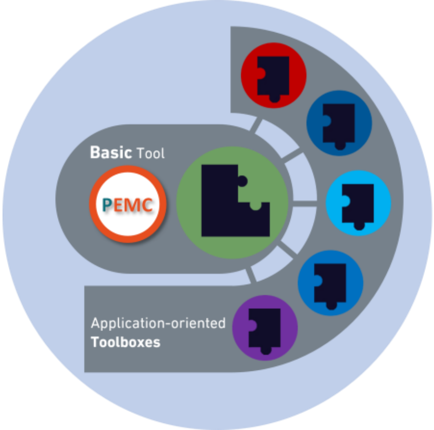


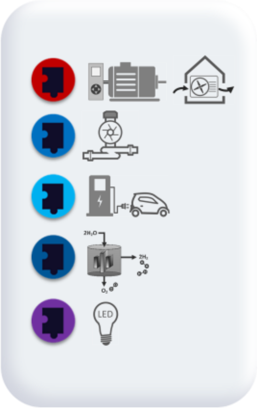




- ❑ **25%-40%** product development cost reduction
- ❑ **30%** faster time-to-market
- ❑ Up to **20 times** faster simulation time compared to existing commercial software tools
- ❑ **Focused** solely on power electronic converters

- ✓ Large collection of power converter topologies (suitable for different application areas)
- ✓ Full dynamic simulation
- ✓ Control and efficiency optimization
- ✓ Optimized design following grid compatibility standards



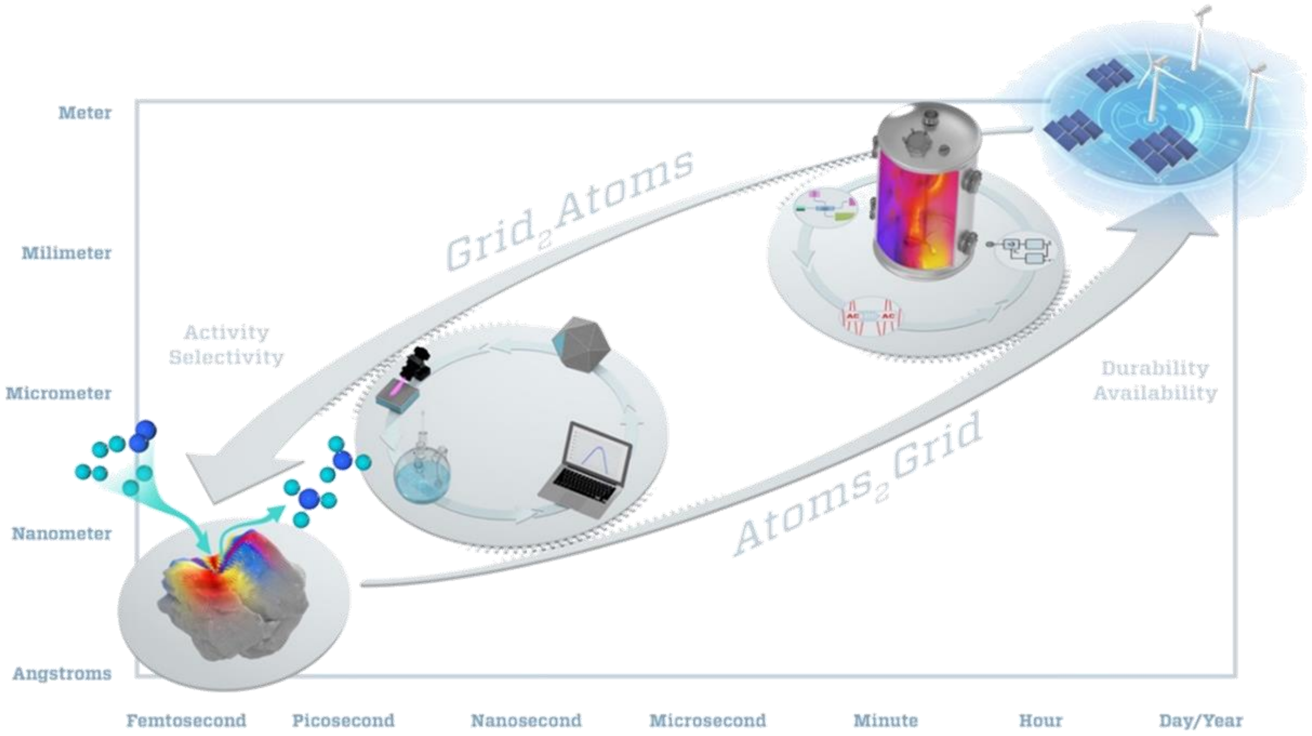


Accelerating P2X

CAPeX New Pioneer Center

Center leader: Tejs Vegge, DTU, Co-lead: Frede Blaabjerg, AAU

- Educate and mentor the next generations of P2Xperts and 50-60 PhDs and 50-60 postdocs by establishing the CAPeX Academy and three international fellowship programs



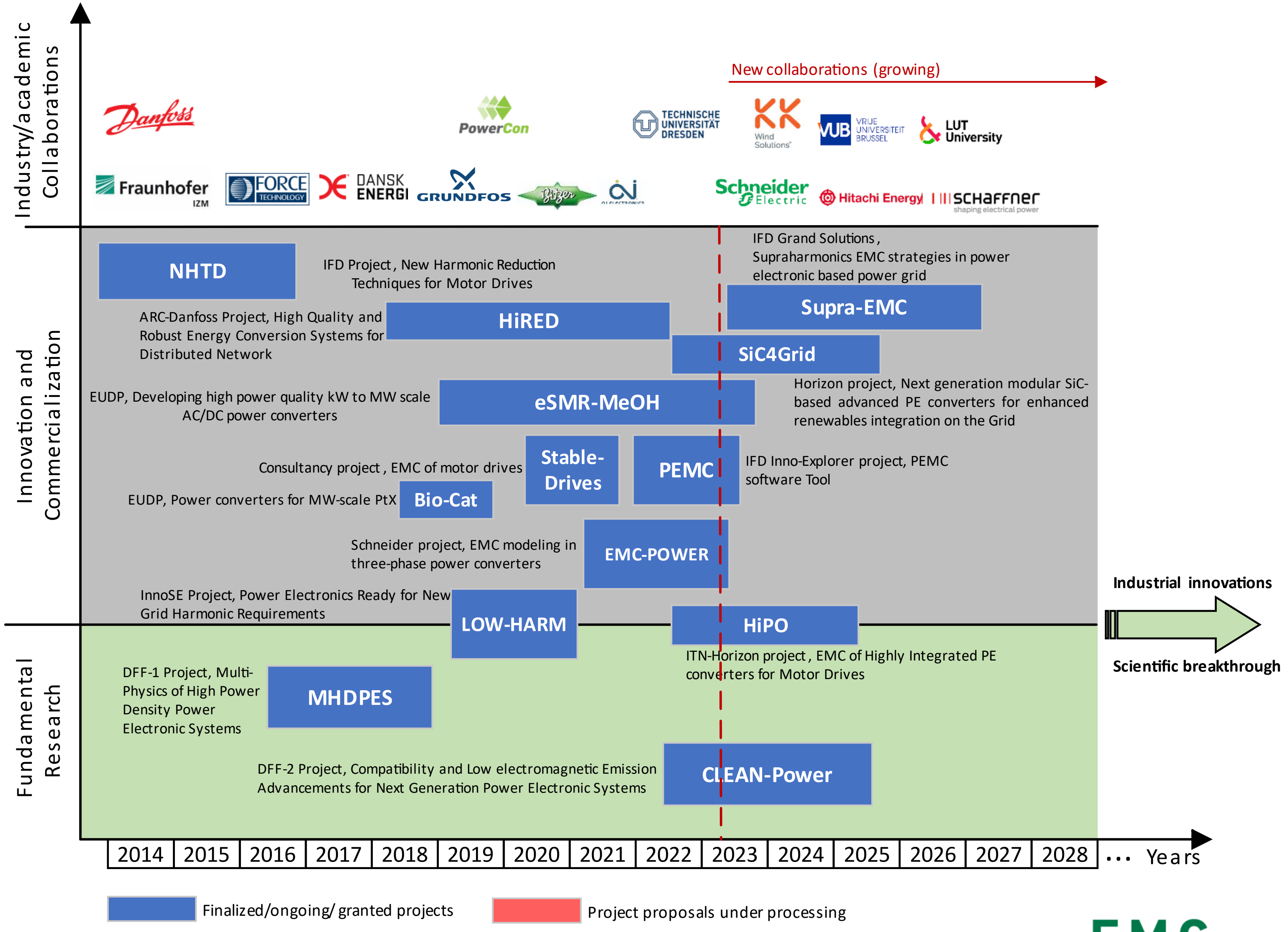
- Digital twins at multiple scales
- Coupling data from experiments and models
- Change conditions at one scale and track effect up/down in scale
- Determine consequences
  - Efficiency and selectivity
  - Durability at system level

EMC RG

Research Activities and Industrial Collaborations

- We are open to national and international collaborations with **academia** and **industry**.

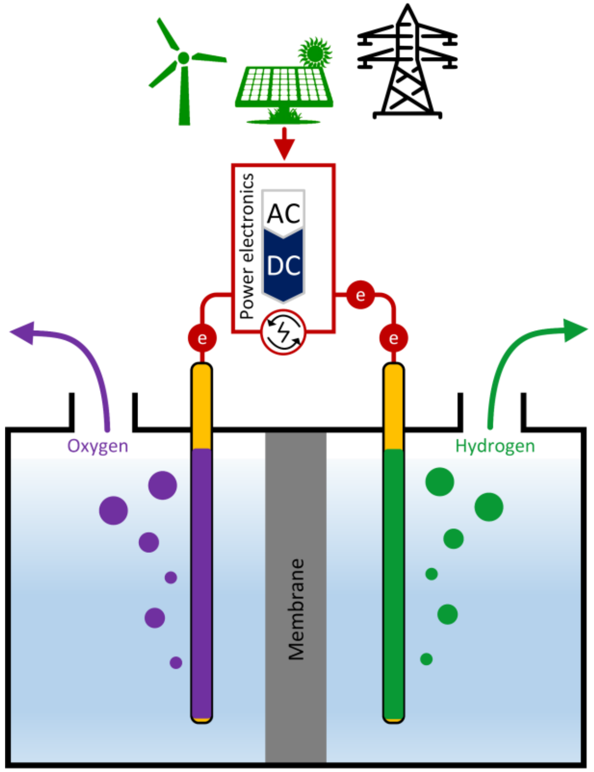
Link (Projects)



Conclusion

Role of Power Electronics in P2X

- The green transition hinges on more efficient, durable, cost-effective and scalable design for Power2X
- Power electronic converters will impact the system total costs of ownership and production
- System efficiencies and reliabilities require further improvement
- Lack of confidence in utilizing new technologies
- Faster processes are needed to understand and develop new components, devices and systems
  - ➢ Digital-twin modeling and Virtual-oriented simulation
  - ➢ Open-access databases
  - ➢ Unified/standard modeling approach
  - ➢ Power hardware in-the-loop (PHIL) simulation



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RESEARCH GROUP

Thank you!

https://www.energy.aau.dk/research/research-groups/emc