EMC

EMI/EMC IN POWER ELECTRONICS

DIGISect

Power Electronics for PtX: Challenges and Opportunities

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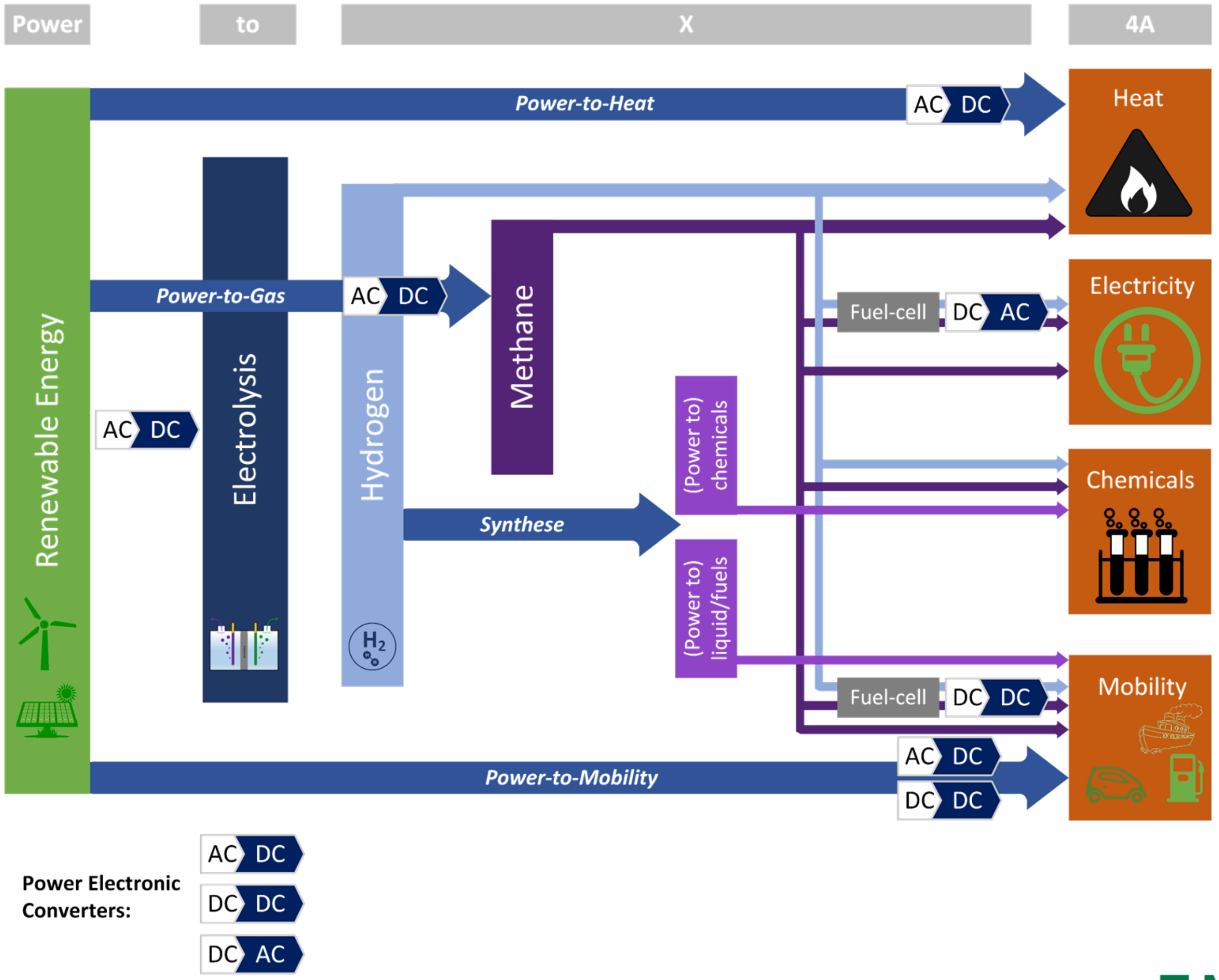
Outline

- 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

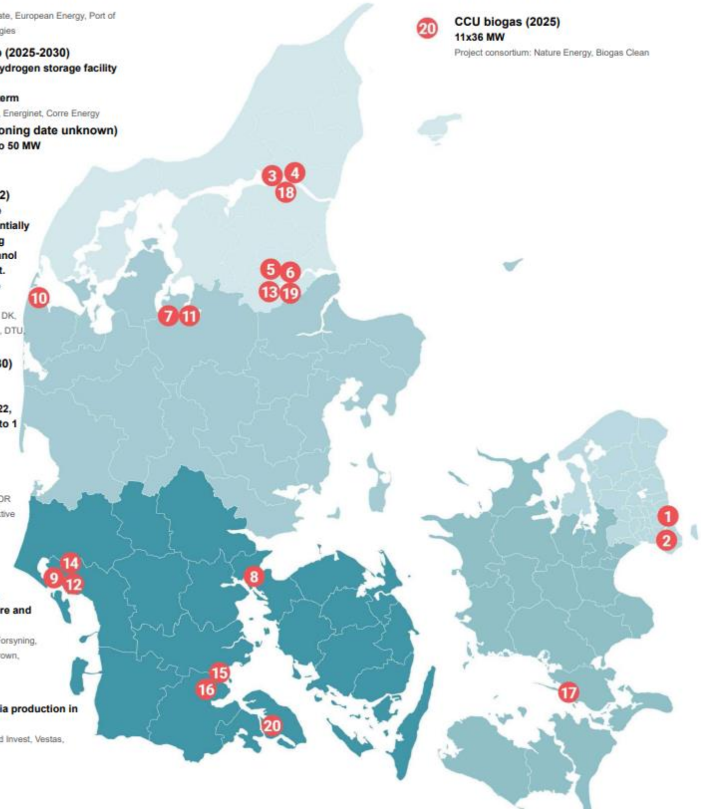


Introduction

Power-to-X Strategy

- National P2X Landscape

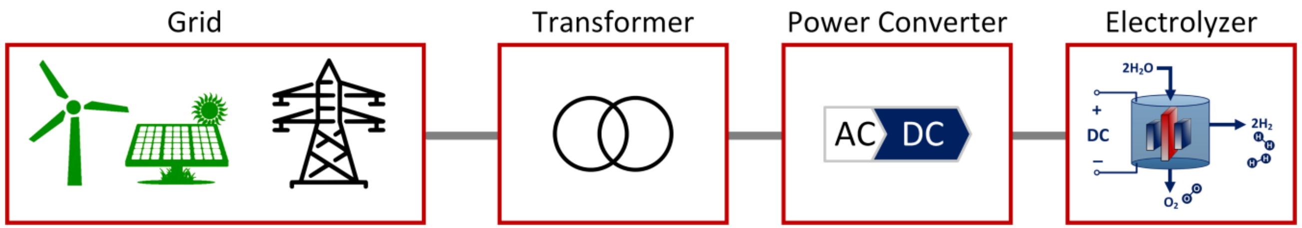
1. **H2RES (end of 2021)**
   2 MW electrolysis plant, Avedøreværket
   Project consortium: Ørsted, Everfuel Europe A/S, NEL Hydrogen A/S, GreenHydrogen A/S, DSV Panalpina A/S, Brintbranchen and Energinet Elsystemansvar A/S
2. **Green Fuels for Denmark (2023-2030)**
   Electrolysis plant, Greater Copenhagen
   10 MW in 2023, 250 MW in 2027 and 1.3 GW in 2030
   Project consortium: Ørsted, Copenhagen Airport, A.P. Møller-Mærsk, DSV Panalpina A/S, DFDS, SAS, COWI
3. **Power2Met (opened June 2020)**
   E-methanol plant, Aalborg University
   10-30 MW, funded through EUDP
   Project consortium: Green Hydrogen Systems, Re:Integrate, Aalborg University, Hydrogen Valley, E.ON, NGF Nature Energy, Drivkraft Denmark, Rockwool, Process Engineering, Holtec Automatic-Nord and Lillegaarden El
4. **Green CCU Hub (2024)**
   120 MW electrolysis plant in Aalborg for producing e-methanol for heavy road transport and shipping
   Project consortium: Re:Integrate, European Energy, Port of Aalborg, Blue World Technologies
5. **Green Hydrogen Hub (2025-2030)**
   350 MW electrolysis + hydrogen storage facility in Hobro/Viborg
   Up to 1 GW in the long term
   Project consortium: Eurowind, Energinet, Corre Energy
6. **Blue Seal (commissioning date unknown)**
   Electrolysis plant, Hobro 50 MW
   Ballard Power Systems
7. **GreenLab Skive (2022)**
   Electrolysis plant, Skive
   12 MW in 2022 and potentially up to 250 MW in the long term. Hydrogen + methanol for heavy road transport.
   Project consortium: GreenLab Skive A/S, Eurowind Energy, Everfuel, Eniig Holding, E.ON DK, GreenHydrogen, Re:Integrate, DTU, Energinet,
8. **HySynergy (2022-2030)**
   Electrolysis plant, Crossbridge Energy Fredericia, 20 MW in 2022, 300 MW in 2025 and up to 1 GW in the long term
   Project consortium: Everfuel Europe A/S, Crossbridge Energy Fredericia, Energinet Elsystemansvar, TVIS, TREFOR Elnet, EWII Energi A/S and Aktive Energi Anlæg A/S
9. **Høst (2025)**
   1 GW plant by the Port of Esbjerg for ammonia production for agriculture and shipping
   Project consortium: CIP, Din Forsyning, Esbjerg Havn, Arla, Danish Crown, Mærsk, DFDS
10. **REDDAP (2022)**
    10 MW plant for ammonia production in Lemvig
    Project consortium: Skovgaard Invest, Vestas, Haldor Topsøe
11. **Green HyScale (2024)**
    100 MW electrolysis plant, Skive, funded by the EU (Horizon 2020)
    Project consortium: GreenLab A/S, Green Hydrogen Systems A/S, Energy Cluster Denmark, Lhyfe, Siemens Gamesa, Equinor Energy A/S, DTU, Imperial College London, Quantafuel and Euroquality
12. **H2 Energy Europe (2024)**
    1 GW electrolysis plant for producing hydrogen for heavy road transport and other sectors
    Project consortium: H2Energy, Hyundai, Trafigura and others
13. **Eurowind Mariagerfjord (commissioning date unknown)**
    Two 35-50 MW electrolysis plants
    Project consortium: Eurowind
14. **European Energy (2023/24)**
    6 MW hydrogen plant in Esbjerg. Capacity may be expanded to 12 MW
15. **The Port of Aabenraa (2025)**
    100 MW electrolysis plant
    Project consortium: Linde Gas A/S, Port of Aabenraa
16. **The Port of Aabenraa (2023)**
    10,000 tonnes of methanol per year
    Project consortium: European Energy, Re:Integrate
17. **Vordingborg Biofuels (2024/25)**
    100,000 tonnes of e-methanol per year in Vordingborg
    Project consortium: Haldor Topsøe, Biofuel Technology, Vordingborg Havn
18. **Aalborg (2028)**
    300-400 MW electrolysis for methanol production
    Project consortium: CIP, RenoNord, Aalborg Forsyning
19. **HyBalance (opened September 2018)**
    Electrolysis plant, Hobro 1.2 MW
    Project consortium: Air Liquid, Hydrogenics, LBST, Neas Energy and Hydrogen Valley/CEMTEC
20. **CCU biogas (2025)**
    11x36 MW
    Project consortium: Nature Energy, Biogas Clean



Source: The Government's strategy for POWER-TO-X, Danish Ministry of Climate, Energy and Utilities, 2021.

INTRODUCTION

General Requirements for Power Electronics



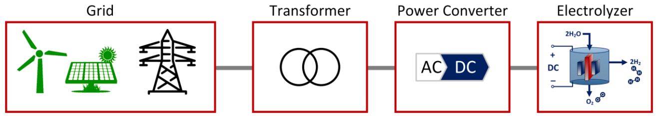
- Requirements
  - Input Voltage: 0.4 – 35 kV
  - Output Voltage: 350 – 1000V
  - Output Current: 1- 12 kA (< 5% ripple)
  - Output Power
    - < 1MW
    - 1MW < P < 5MW
    - > 5MW
  - Galvanic Isolation
  - Controllability: Output Current/Voltage
  - PF > 0.9
  - THDi:
    - < 30% (small systems)
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

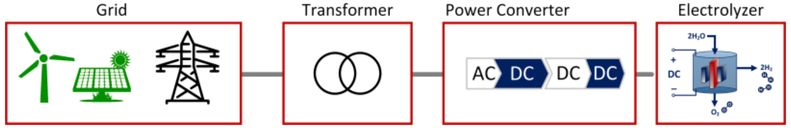
- Recent Future Trends
  - High efficiency requirement (> 98%)
  - Pushing to 1500V output
  - Higher power levels
  - Load dependent THDi & PF
  - High PF (>0.95) and low THDi (< 5%)
  - Scalability
  - Low foot-print and volume (reducing transformer size)
  - High reliability
  - Low cost [Euro/kW]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

Outline

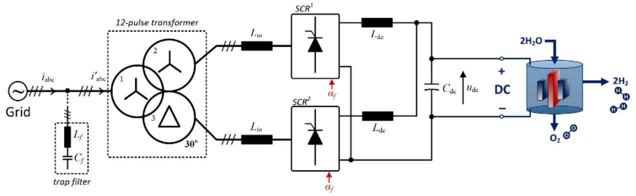
Topology Overview

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

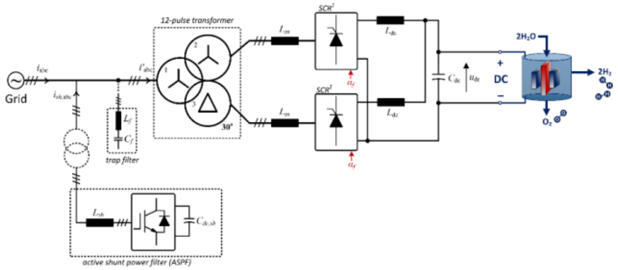




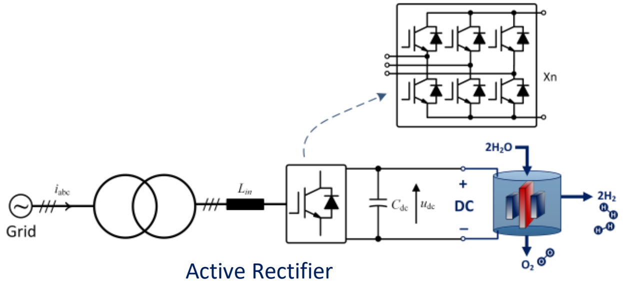
Single-stage power supplies



12-pulse Thyristor Rectifier (12-TR)

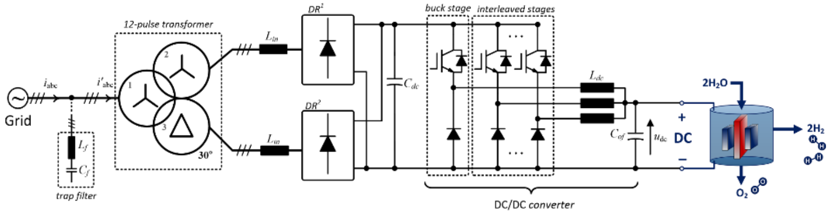


12-pulse Thyristor Rectifier with shunt power filter (12-TRSHF)

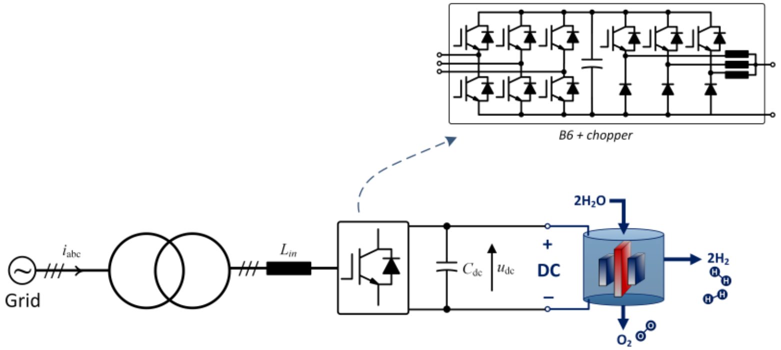


Active Rectifier

Double-stage power supplies



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



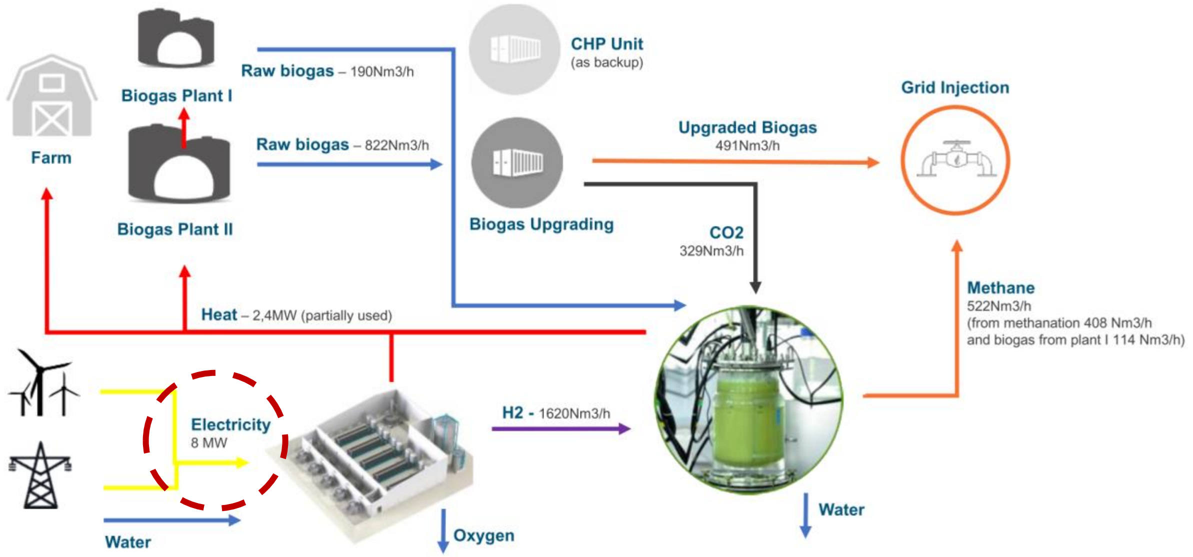
Active Rectifier-fed buck converter

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 Project with NEL Hydrogen



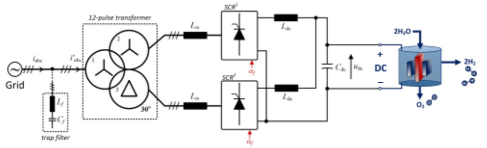
The integrated P2G solution

Topology Overview

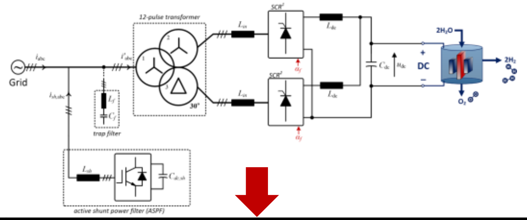
State-of-the-Art (Comparison):

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

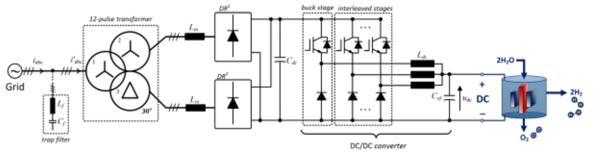
12-pulse Thyristor Rectifier (12-TR)



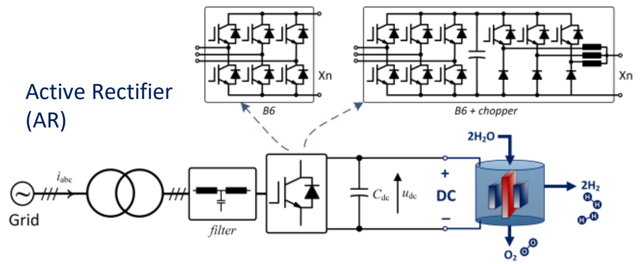
12-pulse Thyristor Rectifier with shunt power filter (12-TRSHF)

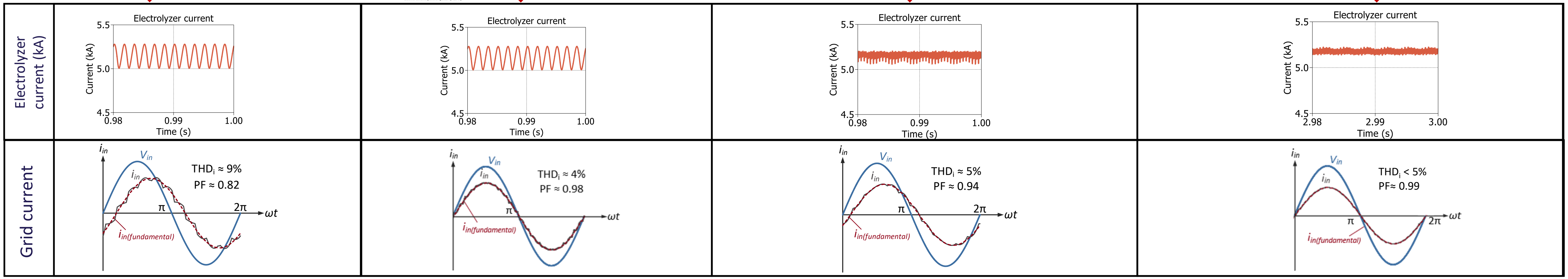


12-pulse Diode Rectifier with multi-phase chopper (12-DRMC)



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.

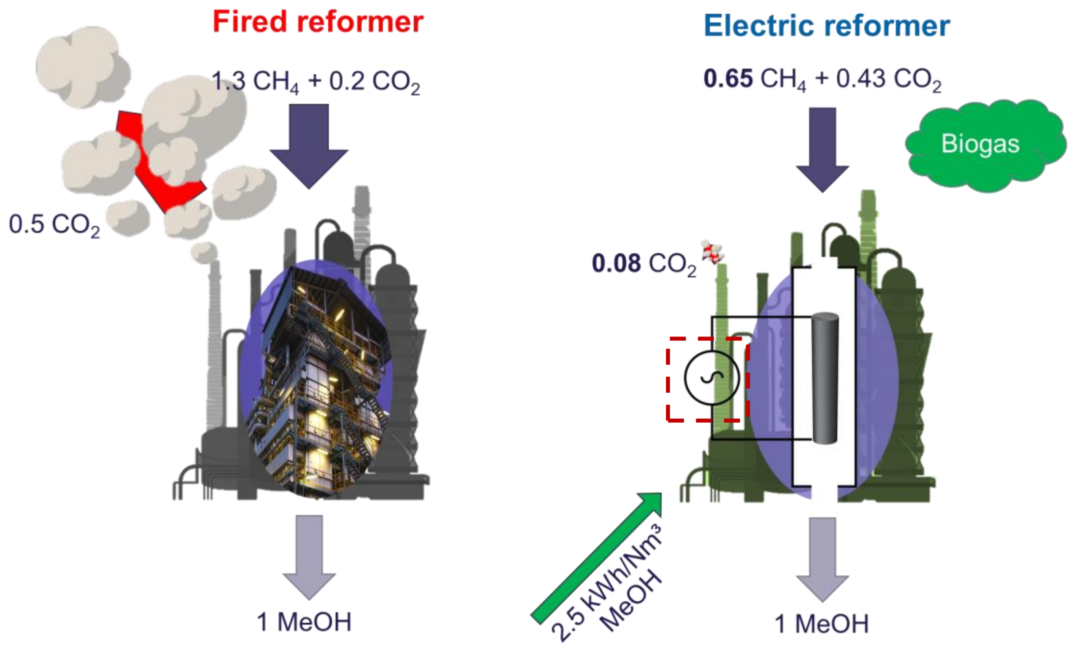
Topology Overview

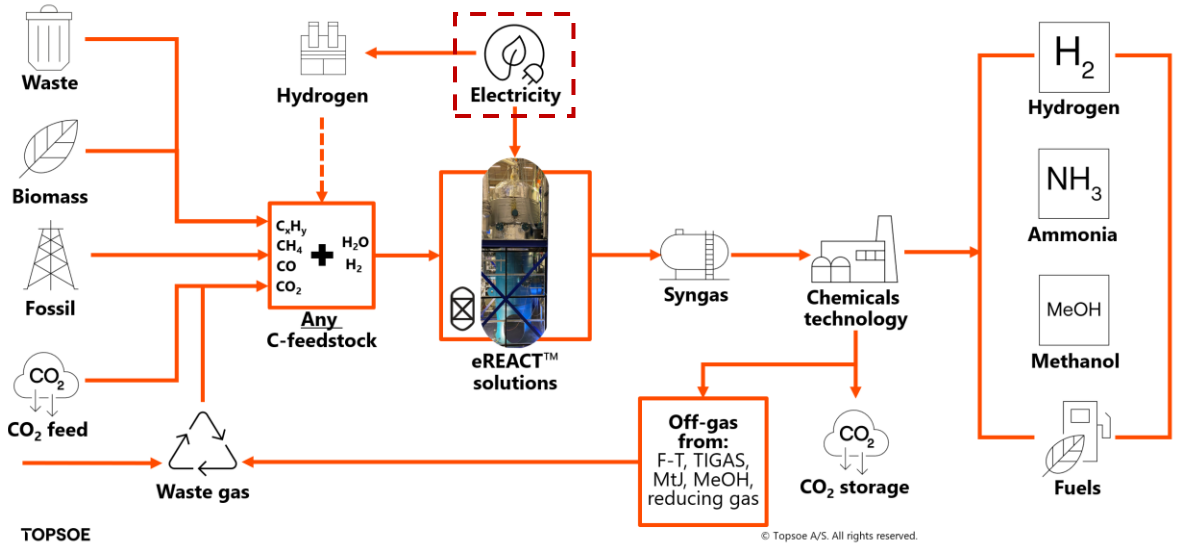
eREACT Technology

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



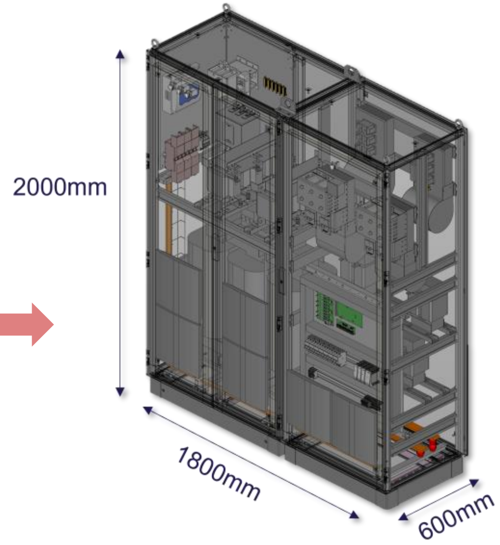


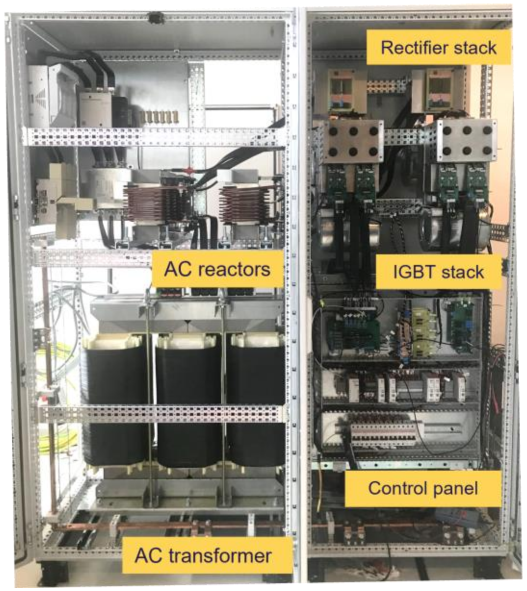
TOPOLOGY OVERVIEW

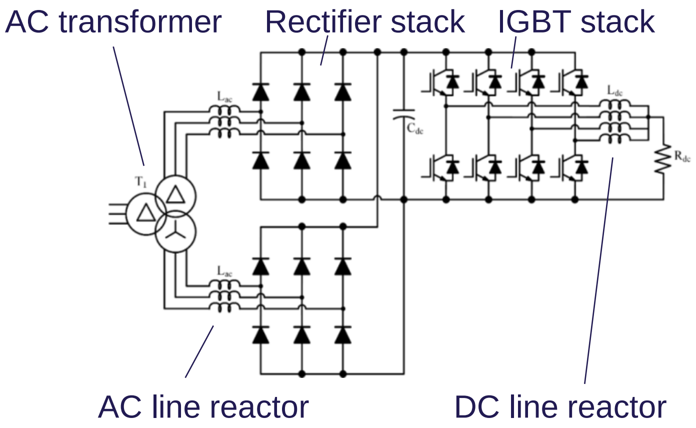
eREACT Technology

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

Pilot Site in Foulum







- **Specifications**

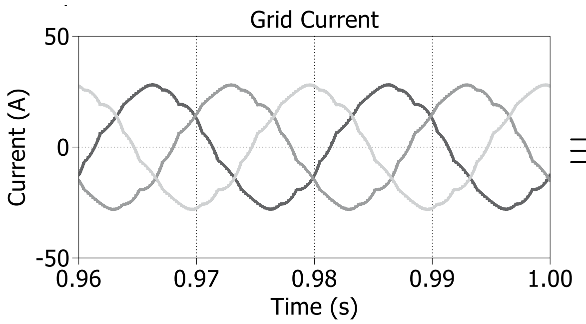
- Input AC Voltage:	400 V
- Output DC Voltage:	150 V (Pilot)
- Output DC Current:	850 A (Pilot)
- Output Power:	128 kW (Pilot)

- Galvanic Isolation
- Controllability: Output Voltage/ Output Current

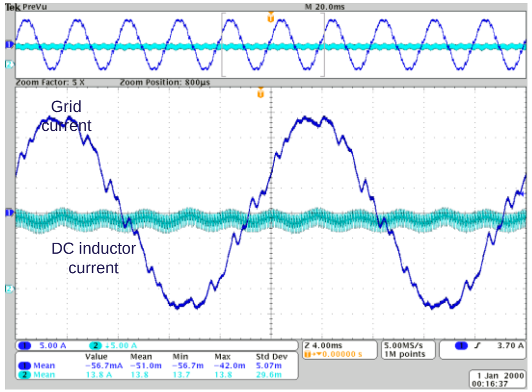
TOPOLOGY OVERVIEW

eREACT Technology

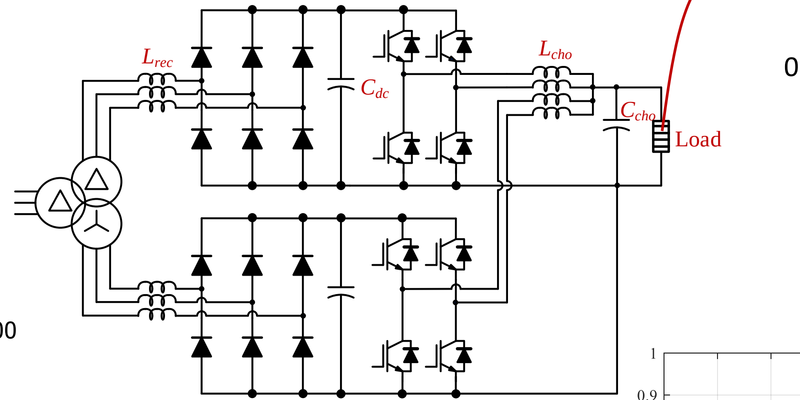
12-Diode Rectifier with Multiple Chopper (12-DRMC):



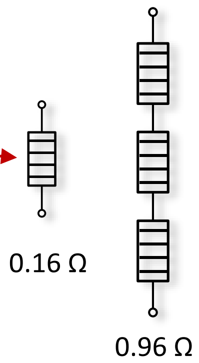
Grid current @ 0.96 MW (Output: 960V, 1000 A)

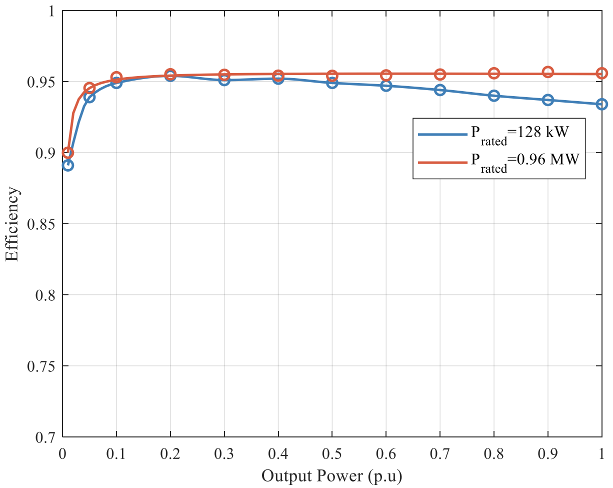


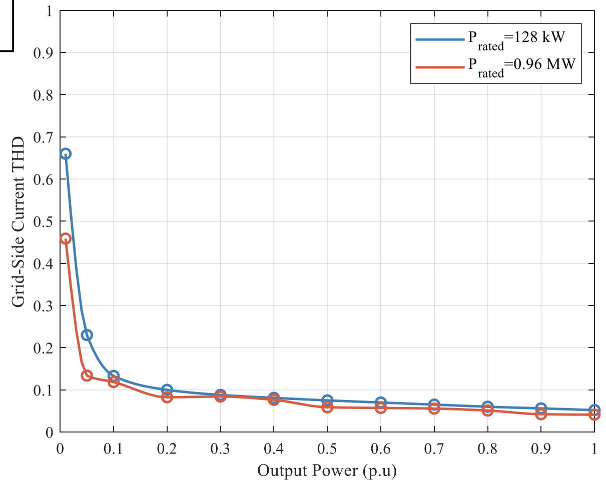
Grid current (experiment)

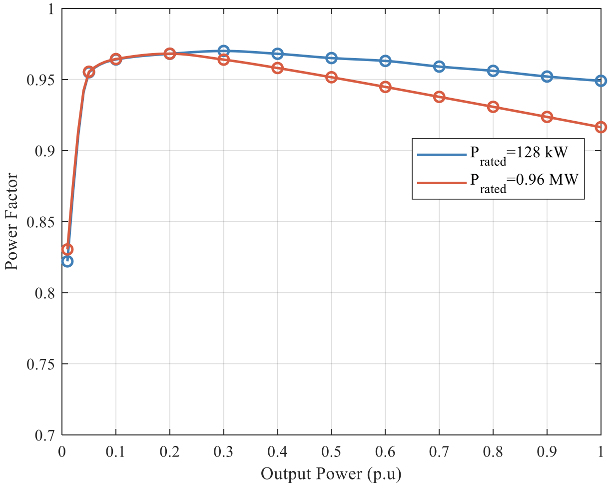


Series string for 1MW





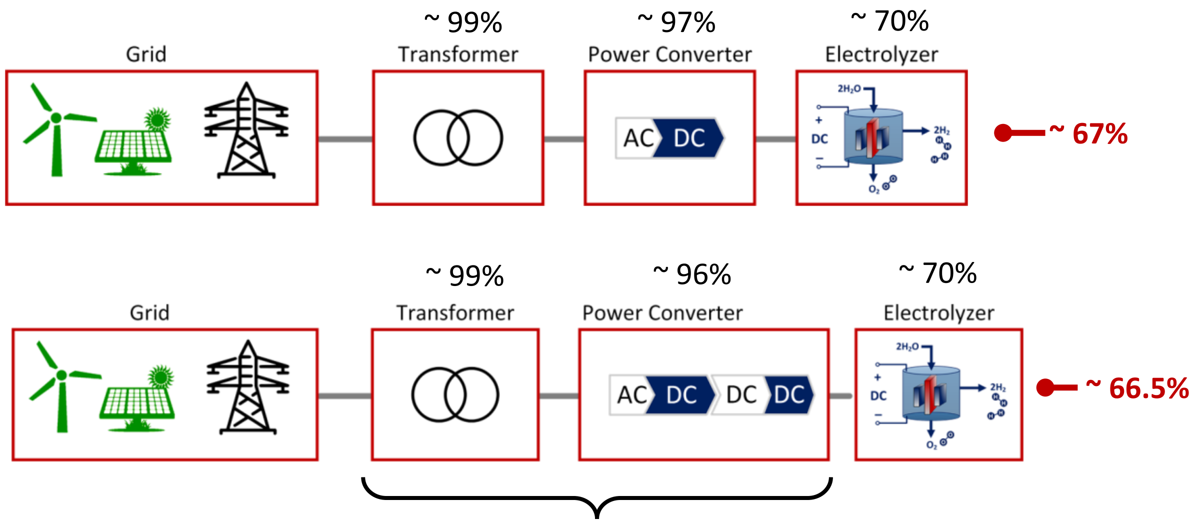




Outline

Challenges & Opportunities

Design for Higher Performance

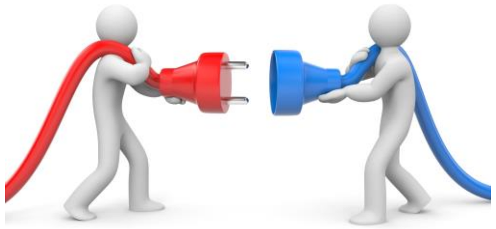


Impact on:

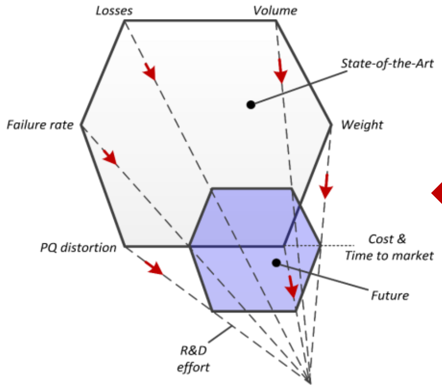
- Total system cost (Euro/kW)
- Electrolyzer efficiency and lifetime (current ripple)
- Overall system foot-print and volume
- Materials saving (e.g., less copper mass → CO_2 reduction)
- Scalability to cover different stack sizes (time-to-market + savings on R&D effort)

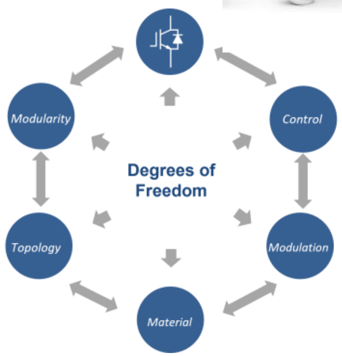
Challenges & Opportunities

Design for Higher Performance

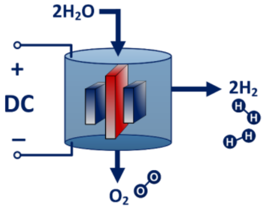


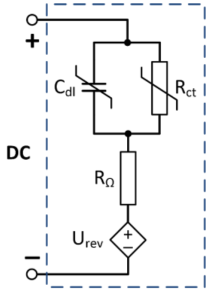
Power electronic

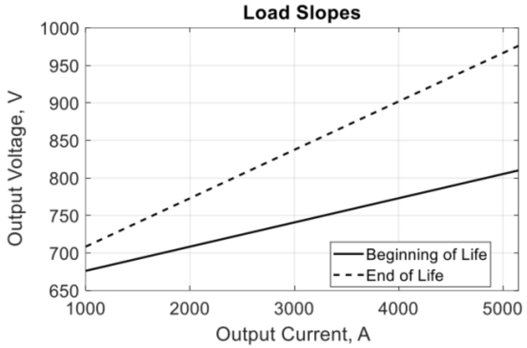




Electrolyzer







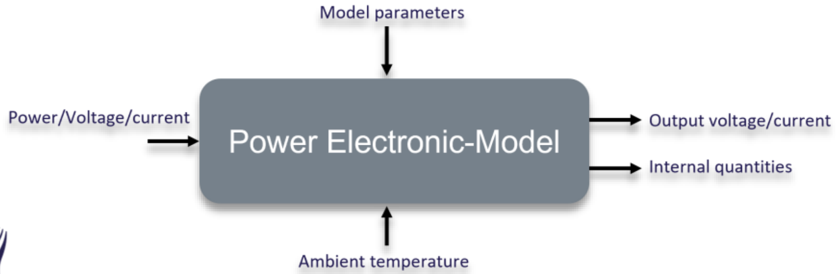
Aging-depended electric characteristic

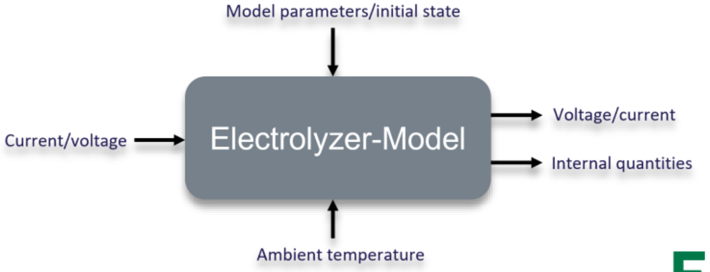
- Efficient and Scalable
- Modular and reliable
- High power quality and grid compatible
- **Strong need for Digital Twin models**

Chemistry-aware Digital Twin models

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

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





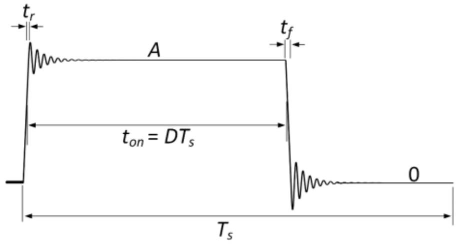
CHALLENGES & OPPORTUNITIES

Digital Twin Modeling

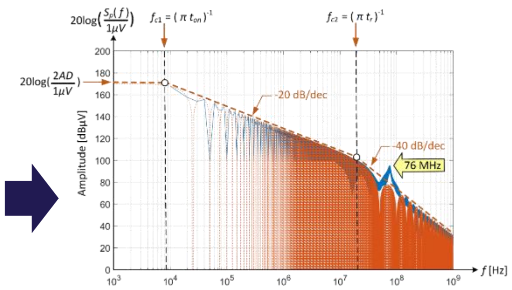
Innovation Fund Denmark | DANMARKS FRIE FORSKNINGSFOND

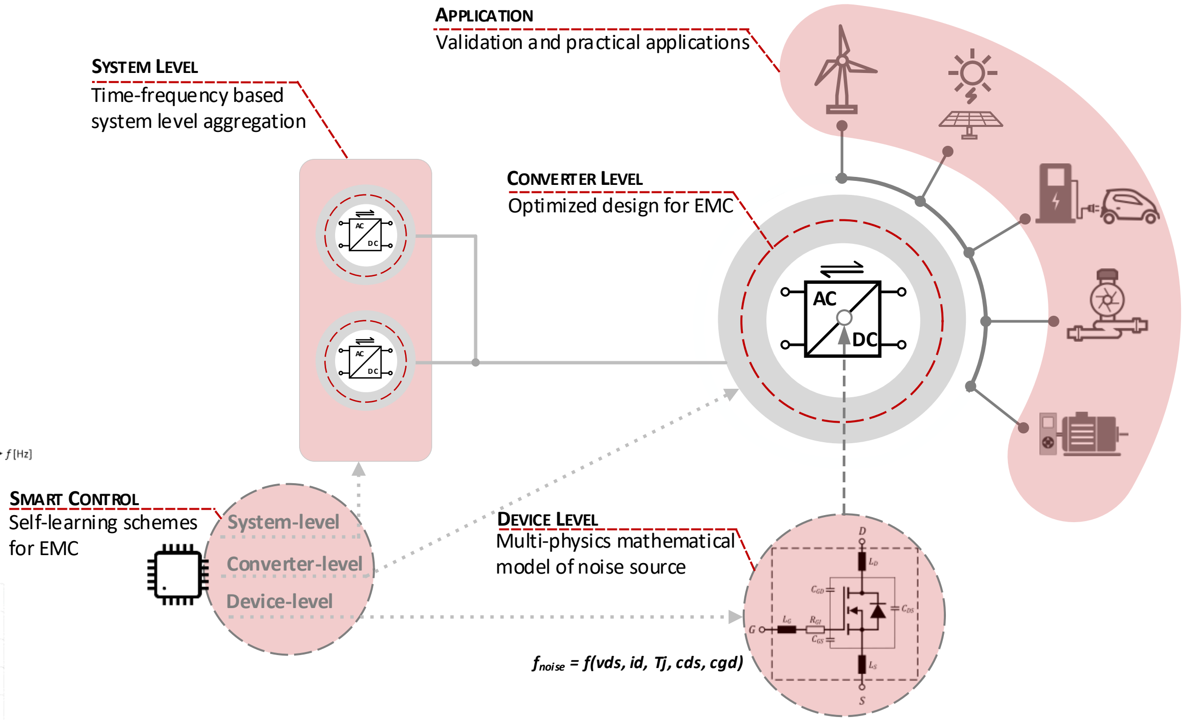
Our Methodology:

@ Device Level

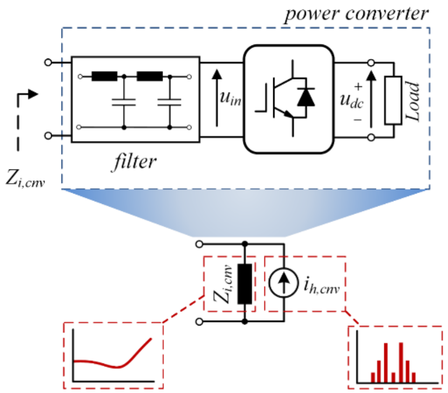


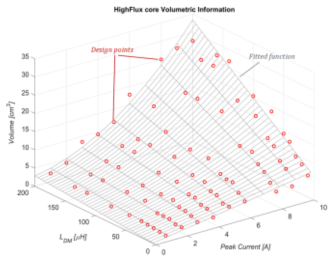
$$s_{pr}(t) = \begin{cases} A\frac{t}{t_r}, & 0 \le t \le t_r \\ A + A_o e^{-\alpha t}\sin[2\pi f_o(t-t_r)], & t_r \le t \le DT_s \\ \frac{-A}{t_r}(t - DT_s - t_r), & DT_s \le t \le DT_s + t_r \\ -A_o e^{-\alpha(t-DT_s-t_r)}\sin[2\pi f_o(t-t_r-DT_s)], & DT_s + t_r \le t \le T_s \end{cases}$$

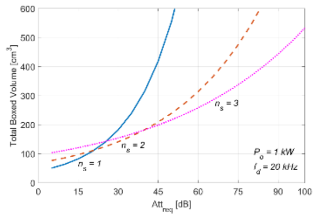


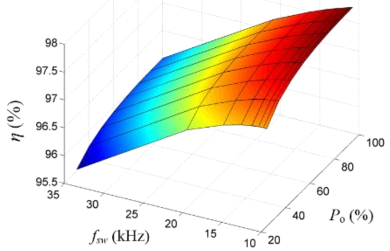


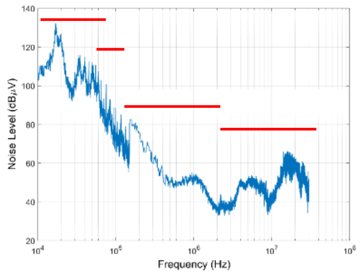
@ Converter Level

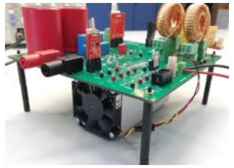












Challenges & Opportunities

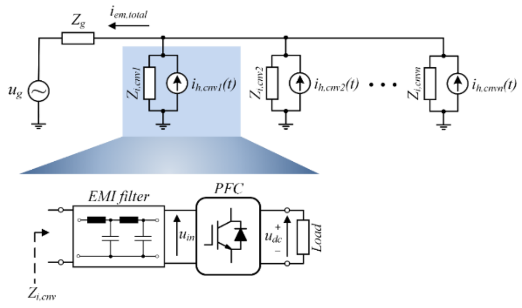
Digital Twin Modeling

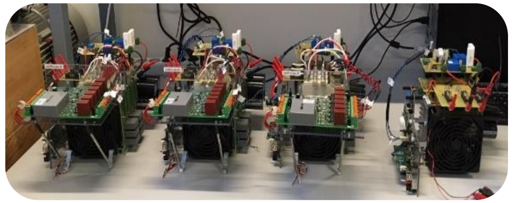
Innovation Fund Denmark

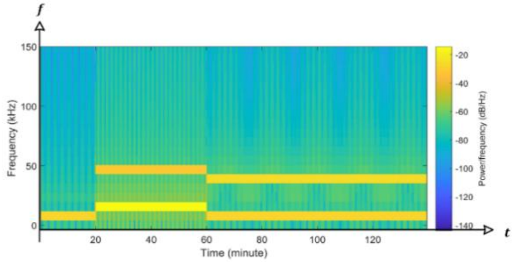
DANMARKS FRIE FORSKNINGSFOND

Our Methodology:

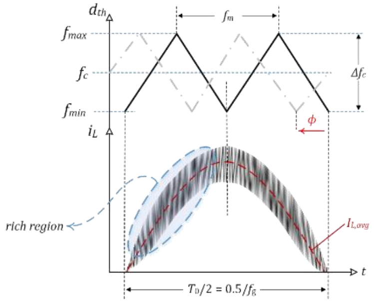
@ System Level

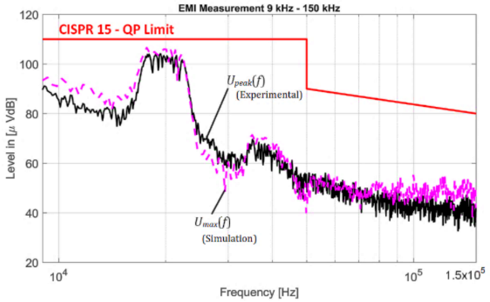


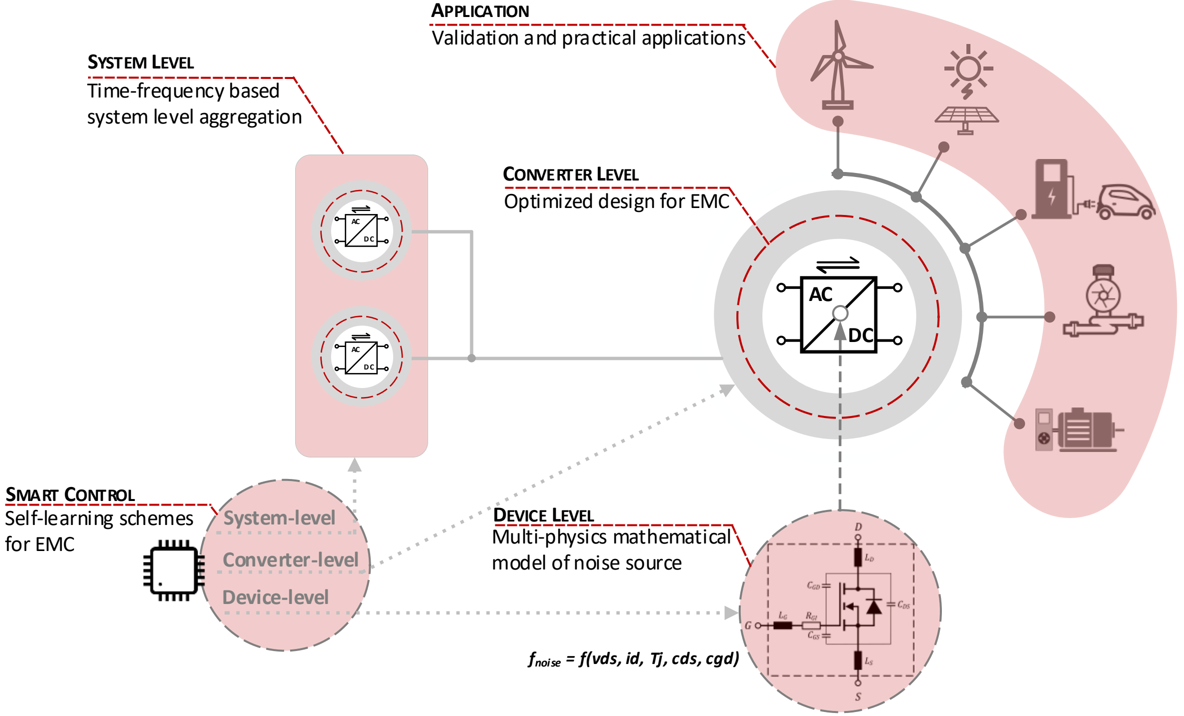


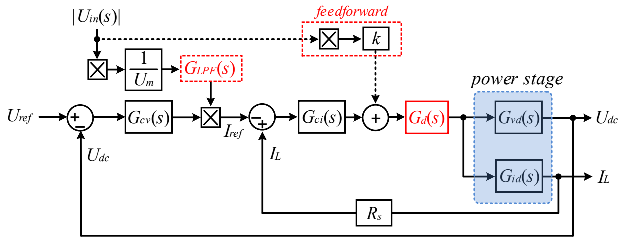


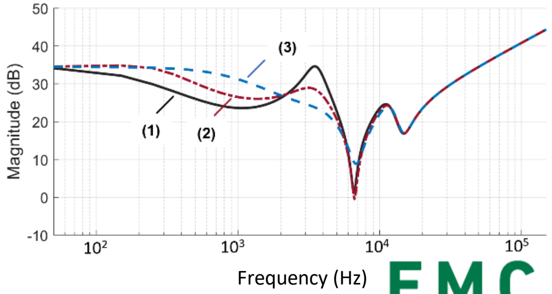
@ Smart Control/Modulation











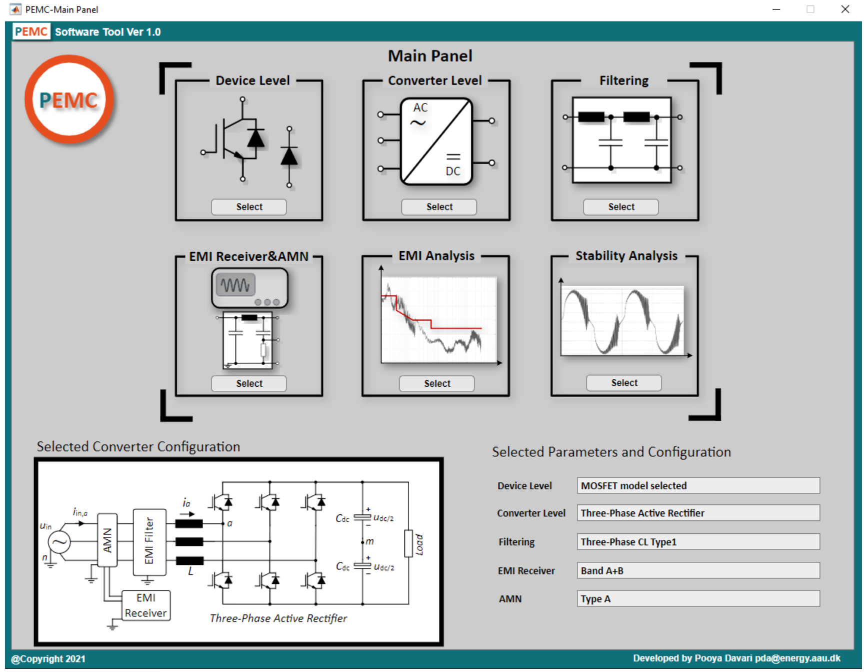
CHALLENGES & OPPORTUNITIES

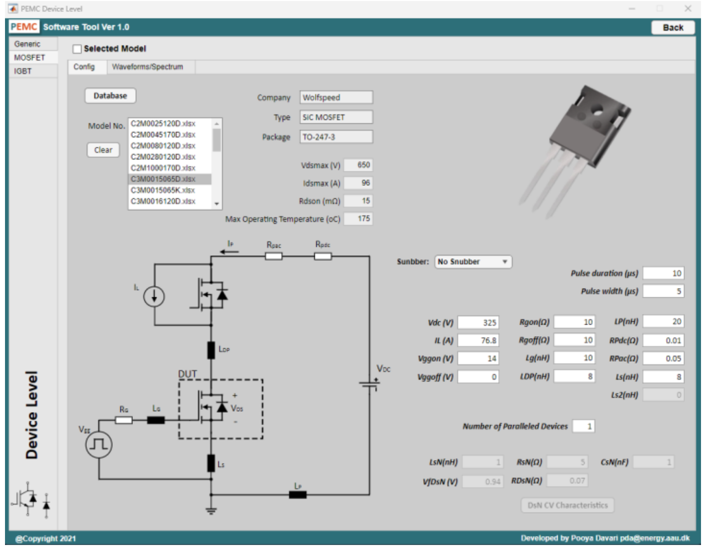
PEMC Software-Tool

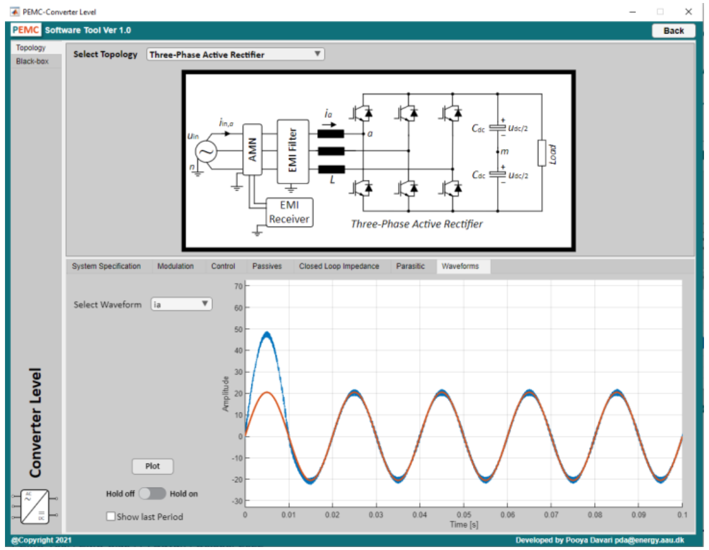
PEMC

POWER ELECTRONICS SOFTWARE TOOL FOR ELECTROMAGNETIC INTERFERENCE PRE-COMPLIANCE

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

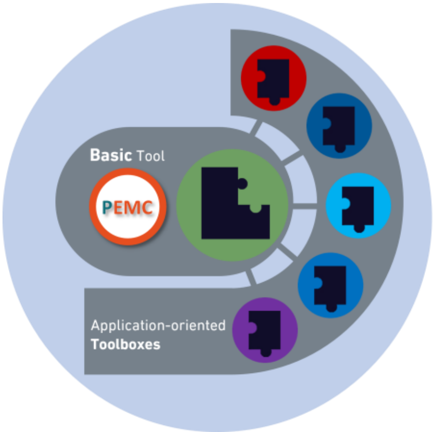


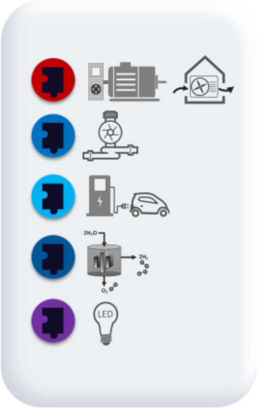




- ❑ **25%-40%** product development cost reduction
- ❑ **30%** faster time-to-market
- ❑ Up to **20 times** faster simulation time compared to existing commercial software tools
- ❑ **Focused** solely on power electronic converters

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



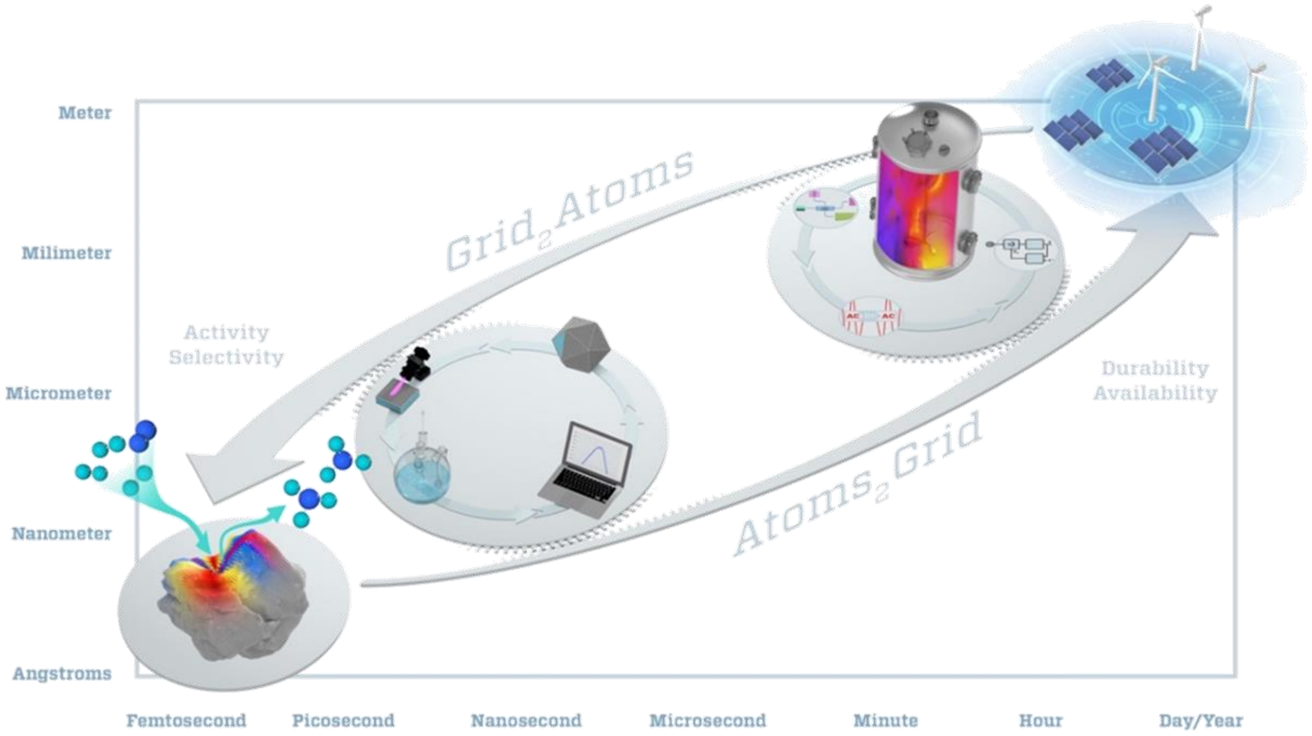


ACCELERATING P2X

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

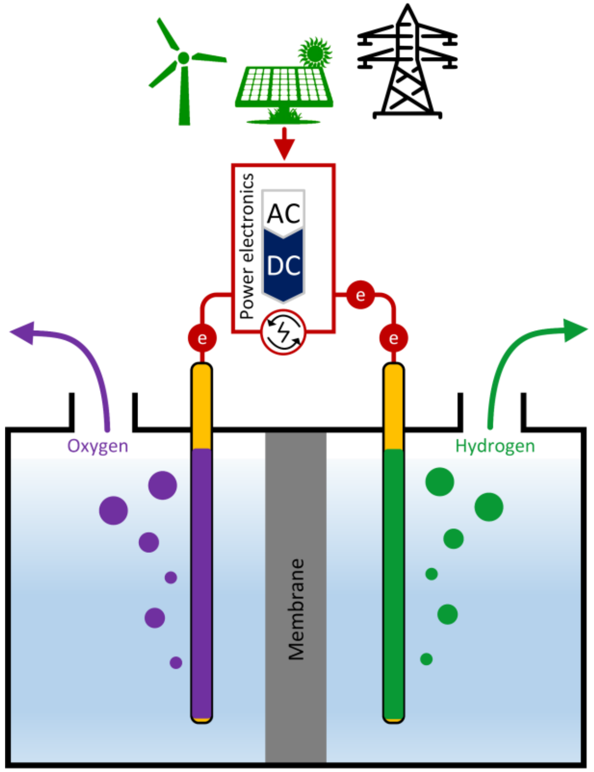


- Digital twins at multiple scales
- Coupling data from experiments and models
- Change conditions at one scale and track effect up/down in scale
- Determine consequences
  - Efficiency and selectivity
  - Durability at system level

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



Aalborg University
AAU Energy

EMC

EMI/EMC IN POWER ELECTRONICS
RESEARCH GROUP

Thank you!

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