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DERlab
European Distributed Energy Resources Laboratories

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Bundesministerium für Forschung, Technologie und Raumfahrt
Finanziert von der Europäischen Union NextGenerationEU

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Workshop, 23. June 2025: Grid forming in Electrolysis Plants

Nils Wiese (Fraunhofer IEE):

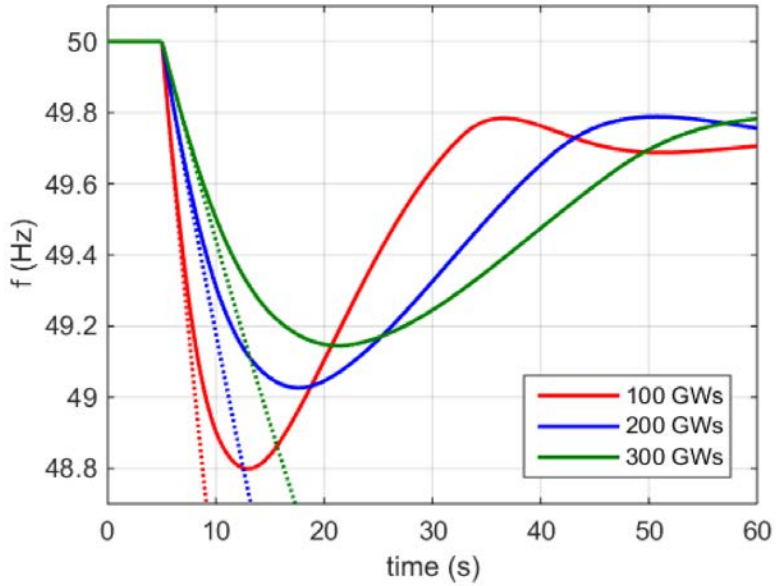
Inertia from Electrolyzers in Transmission Systems

Motivation

Historically, synchronous generators form the grid

Inertia is an integral part of operating the system stably

Minimum of inertia is required - always!



THE EFFECT OF THE AMOUNT OF KINETIC ENERGY ON THE BEHAVIOUR OF FREQUENCY AFTER A LOSS OF PRODUCTION WITH (SOLID) AND WITHOUT (DOTTED) FCR

Future system inertia

https://eepublicdownloads.entsoe.eu/cleandocuments/Publications/SOC/Nordic/Nordic_report_Future_System_Inertia.pdf

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Agenda

- Background Grid-Forming
- Challenges of Electrolyzers
- Grid-Forming Electrolyzer
- Case Study
- Conclusion

Why talking about grid-forming?

Increasing inverter-based generation (nowadays grid-following)

Sometimes, inverter-based generation (IBG) surpasses load in Germany

➡ lower inertia in the system (depending on RE penetration)

It can be expected that electrolyzers will run when RE penetration is high due to low electricity prices

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What is grid-forming?

Synchronous generators are physically grid-forming

Inverters can be grid-forming but might have limitations, like overcurrent

There is no unified definition of grid-forming

As GFM capabilities are programmed into the inverter, specific services can be implemented or not

➡ **A unit (eg. electrolyzer) might have a GFM control but cannot form the grid**

IBR Capabilities and services used for distinguishing GFL and GFM inverters by various research reports.

Capability/service	($\mathcal{R}1$) NREL	($\mathcal{R}2$) NERC	($\mathcal{R}3$) NGESO	($\mathcal{R}4$) ENTSO-E	($\mathcal{R}5$) AEMO
Voltage control, w/o reliance on external source	✓	✓	✓	✓	✓
Fault current and ride-through capability	✓	✓	✓	✓	✓
Contributing to system effective inertia and freq. response	✓	✓	✓	✓	✓
Reactive power support and voltage management	✓	✓	✓	✓	✓
System restoration and black-start	✓	✓	✓	✓	✓
Support power system island	✓	✓	✗	✓	✓
Contributing to fast frequency response	✓	✓	✓	✗	✓
Operation under weak/low system strength	✗	✓	✗	✓	✓
Commentary on use of phase-locked loop (PLL)	✓	✓	✓	✗	✗
Preventing adverse control interactions	✗	✓	✓	✓	✗
Damping and contributing to small-signal stability	✗	✓	✓	✓	✗
Harmonics and unbalance handling capability	✗	✓	✗	✓	✗
Withstand disturbance & active power oscillations	✗	✗	✓	✗	✓
Load disconnection and standalone mode	✗	✓	✗	✓	✗
Re-synchronization and grid reconnection	✗	✓	✗	✓	✗
Distinguishing bulk vs distribution levels	✓	✗	✗	✓	✗

Unifi consortium, Grid-forming Inverter Technology Specifications: A Review of Research Reports and Roadmaps

Inertia procurment in Germany

Inertia counteracts frequency changes

Inertia procurement categorises inertia in positive and negative

Electrolyzers could be used to provide positive inertia in case of falling grid frequency

IBG could provide negative inertia in case of a rising grid frequency

Draft of a concept for the specifications and technical requirements of the transparent, non-discriminatory and market-based procurement of the non-frequency-linked system service "Inertia of local grid stability" ("instantaneous reserve")

Entwurf eines Konzeptes für die Spezifikationen und technischen Anforderungen der transparenten, diskriminierungsfreien und marktgestützten Beschaffung der nicht frequenzgebundenen Systemdienstleistung „Trägheit der lokalen Netzstabilität" („Momentanreserve") gem. § 12h Abs. 1 S. 1 Nr. 2, Abs. 5 EnWG

Link

Electrolyzers with GFM control?

National target of 10 GW electrolysis in 2030

➡ High potential for system services

Electrolyzers are loads and cannot form the grid, but might offer inertia or other system services

Limitations might lead to asymmetrical inertia provision

Challenges of GFM electrolyzers

Electrolysis plants are limited in dynamic behavior depending on the plant design
- Chemical Process
- Rectifier Topology
- Plant control (safety)

Limitations
- Ramp-up/down
- current and minimal operating point

Complementation with other components needed (to fulfill german grid codes today)

Limited experience with large-scale electrolyzer systems (e.g. degradation due to dynamic operation)

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GFM electrolyzer with PEM cell model

- PEM electrolyzer cell model
  - Water transport due to electroosmotic drag and diffusion
  - Ohmic resistance depends on membrane water content
  - Dynamics of double layer overpotential
  - Constant temperature due to thermal inertia

DSL model in PowerFactory (RMS)

$$U_{\mathrm{cell}} = E_0 + \eta_{\mathrm{act}}^{\mathrm{an}} + \eta_{\mathrm{act}}^{\mathrm{ca}} + R_{\Omega}\, I$$

Input: current
Output: voltage

Rating
- 0-1000A
- Scaled up to 20.4 MW

N. Wiese, D. Ghosh, P. Kretschmer, S. Eberlein and D. Strauß-Mincu, "Grid-Forming Controlled Electrolyzer with LVRT Capability and Asymmetric Inertia Provision," 2024 International Conference on Smart Energy Systems and Technologies (SEST), Torino, Italy, 2024.

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GFM electrolyzer with PEM cell model

Virtual synchronous machine

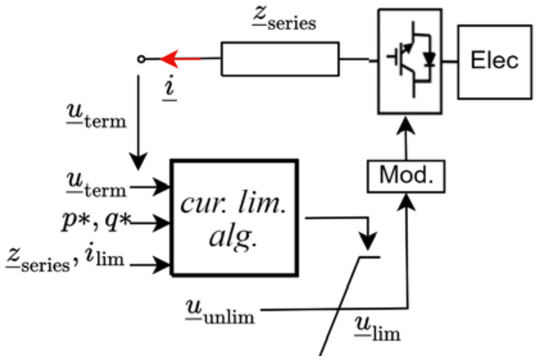
Power ramp up limiter

Current limitation by limiting voltage over series impedance

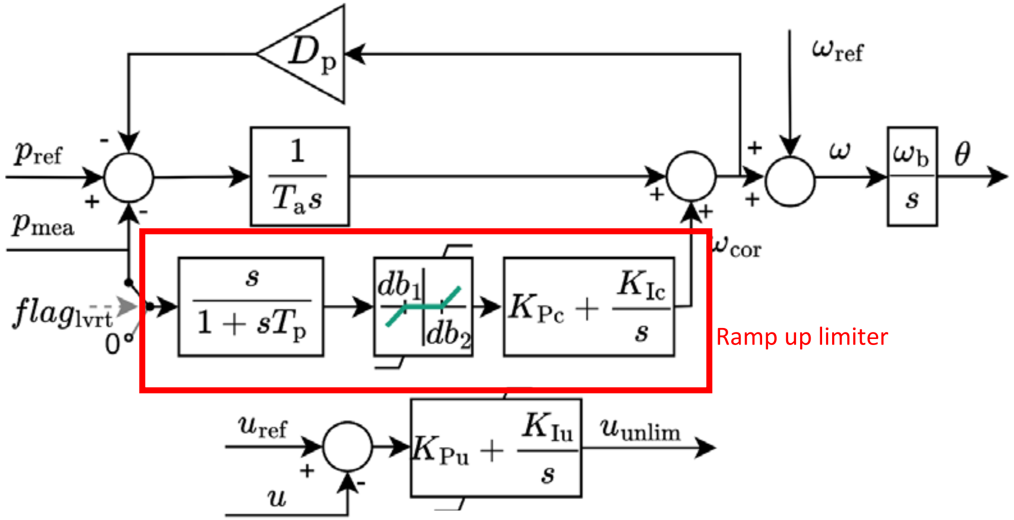
Reactive power is prioritized (can be chosen freely)

Active power setpoint adjustment during fault

Power ramp up limited after fault



Current limitation approach



GFM controller

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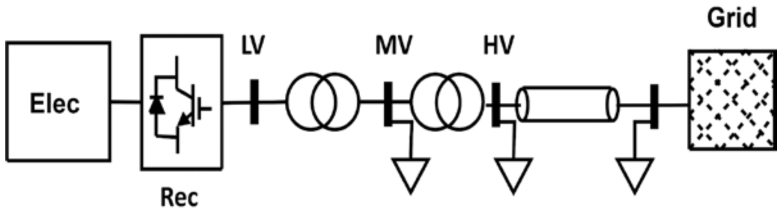
GFM electrolyzer with PEM cell model

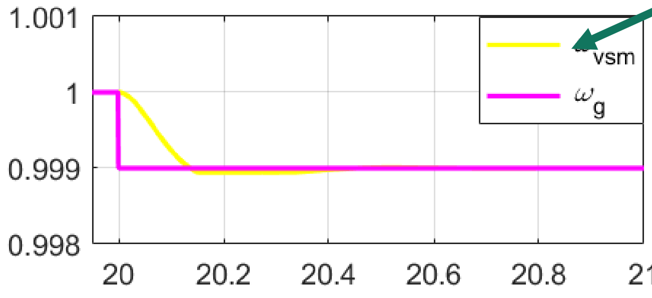
Test cases for frequency changes and short-circuit

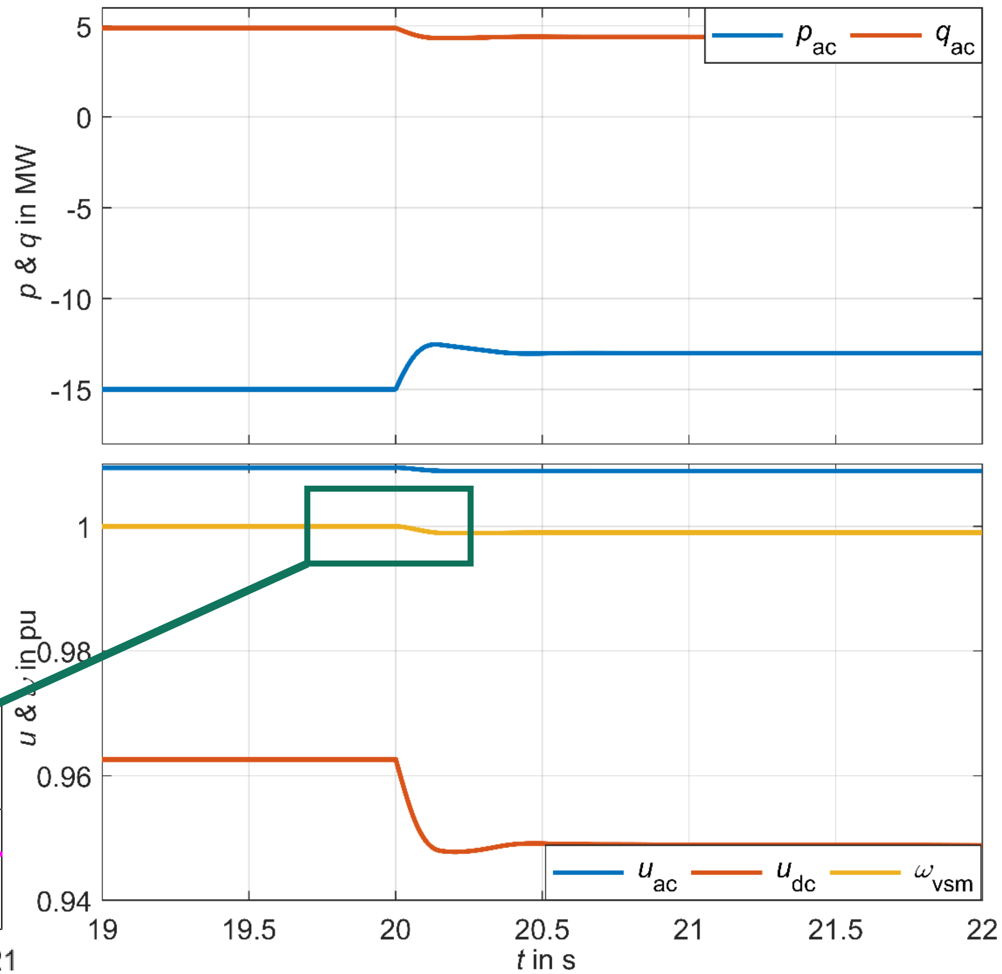
Full inertia provision in case of negative frequency jump (less power cosumption)

Electrolyzer voltage declines



Test system





Frequency decrease

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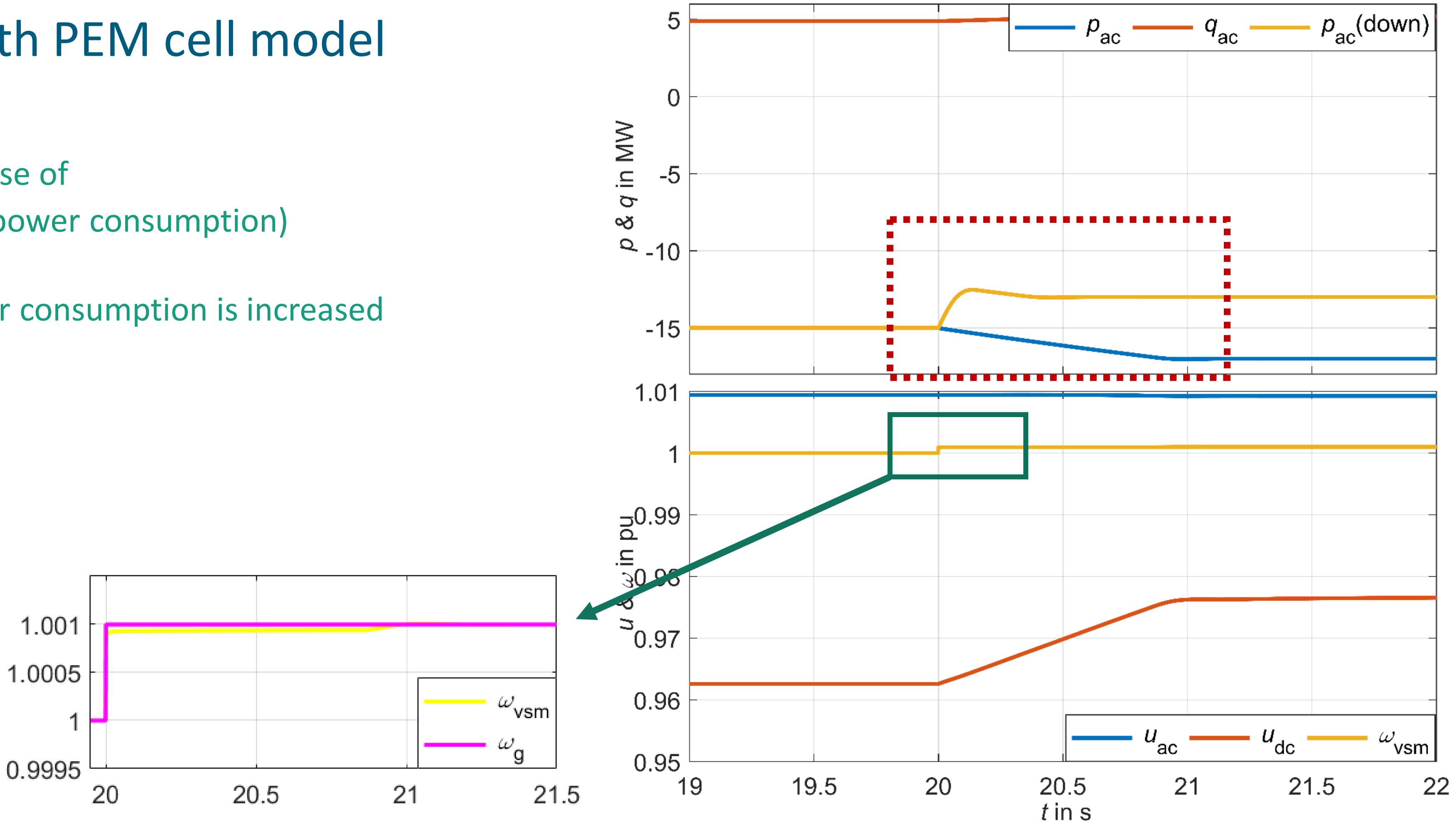
GFM electrolyzer with PEM cell model

Gradient limited inertia provision in case of increased grid frequency (increase of power consumption)

Electrolyzer voltage increases as power consumption is increased



Frequency increase

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GFM electrolyzer with PEM cell model

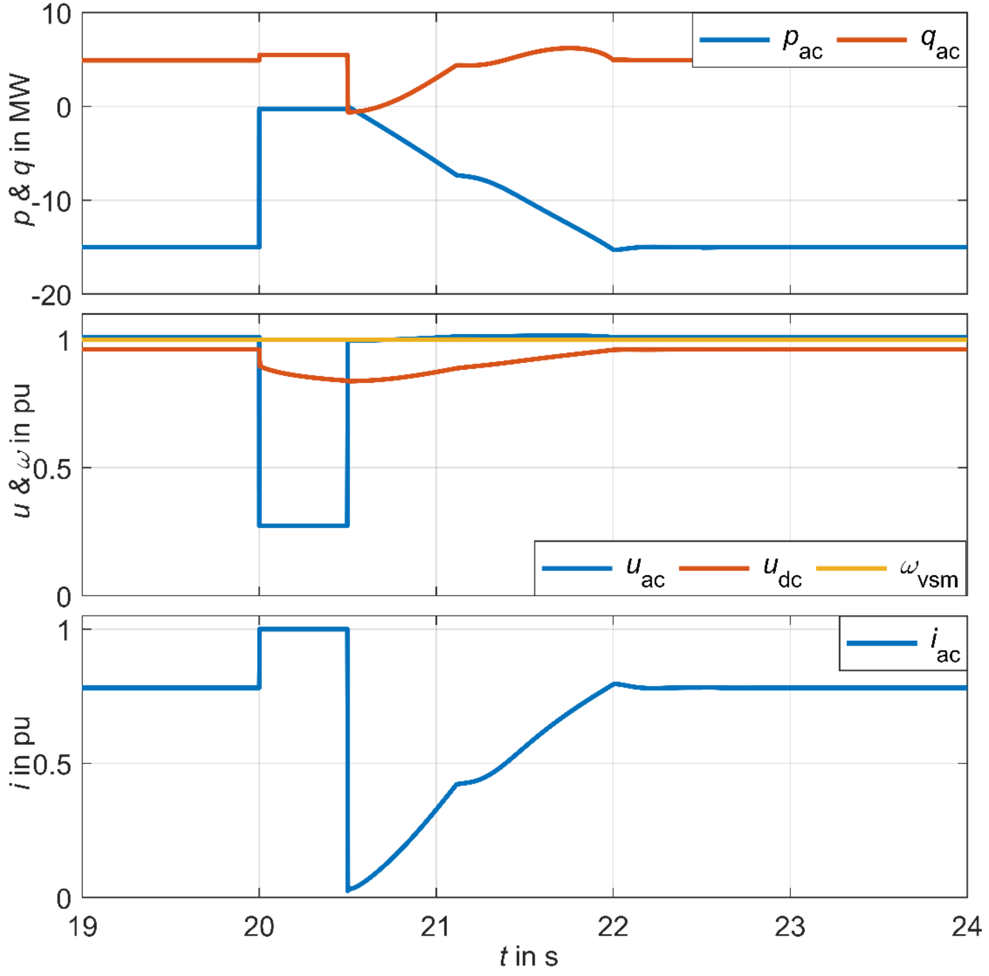
Current is limited

Electrolyzer voltage (DC) reacts fast at the beginning

Active power is ramped up after fault respecting the set limit

Good transient stability

Limitation is stopped after reaching pre-fault power



LVRT

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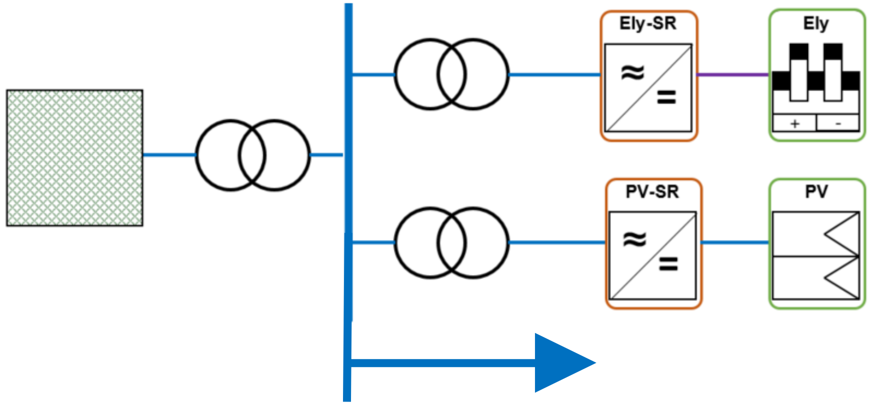
GFM electrolyzer in a park

Goal: Overall system provides instantaneous reserve

Combination of electrolyser and PV

Both equipped with grid-forming control

Provision of instantaneous reserve in "preferred direction"



Electrolyzer park

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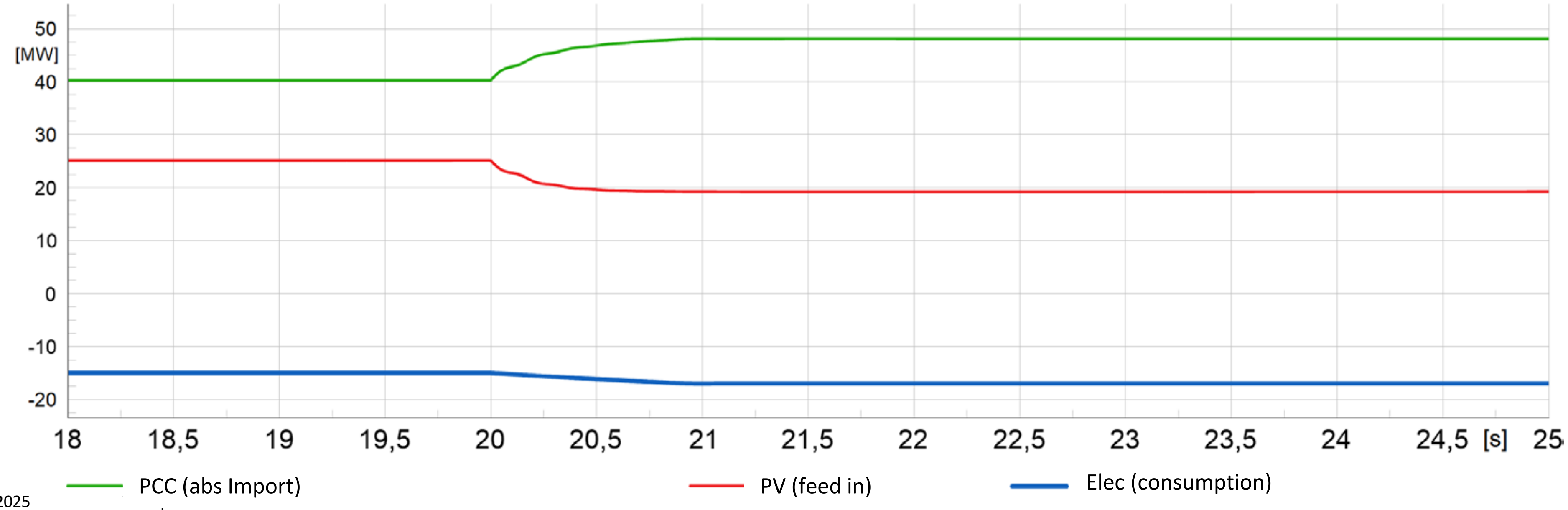
GFM electrolyzer in a park

Frequency jump by +50mHz

PV reacts quickly

Contributions complement each other at the grid connection point



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Study in the german transmisson system

Network model based on simBench EHV network

Grid expansion was taken into account

Dynamic plant models integrated

Analysis of the influence of electrolysis plants

9 GW of electrolyzers

Test case: Loss of generation (Wind in North Germany)

Meinecke, Steffen, et al. "Simbench—a benchmark dataset of electric power systems to compare innovative solutions based on power flow analysis." *Energies* 13.12 (2020): 3290.

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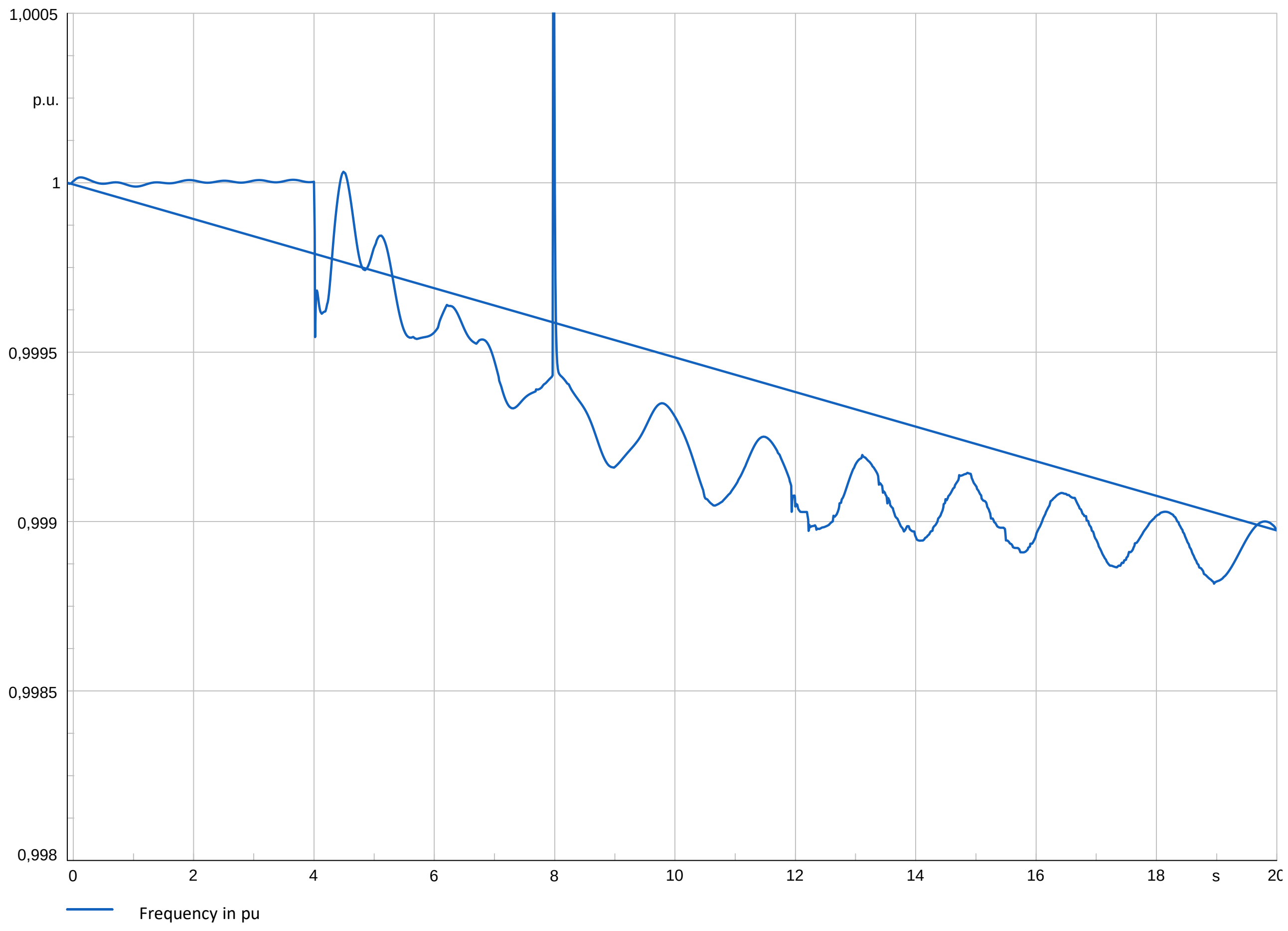
Study in the german transmisson system

Electrolyzer without system services:

Frequency measured in North Germany

High Wind penetration

Decline in frequency



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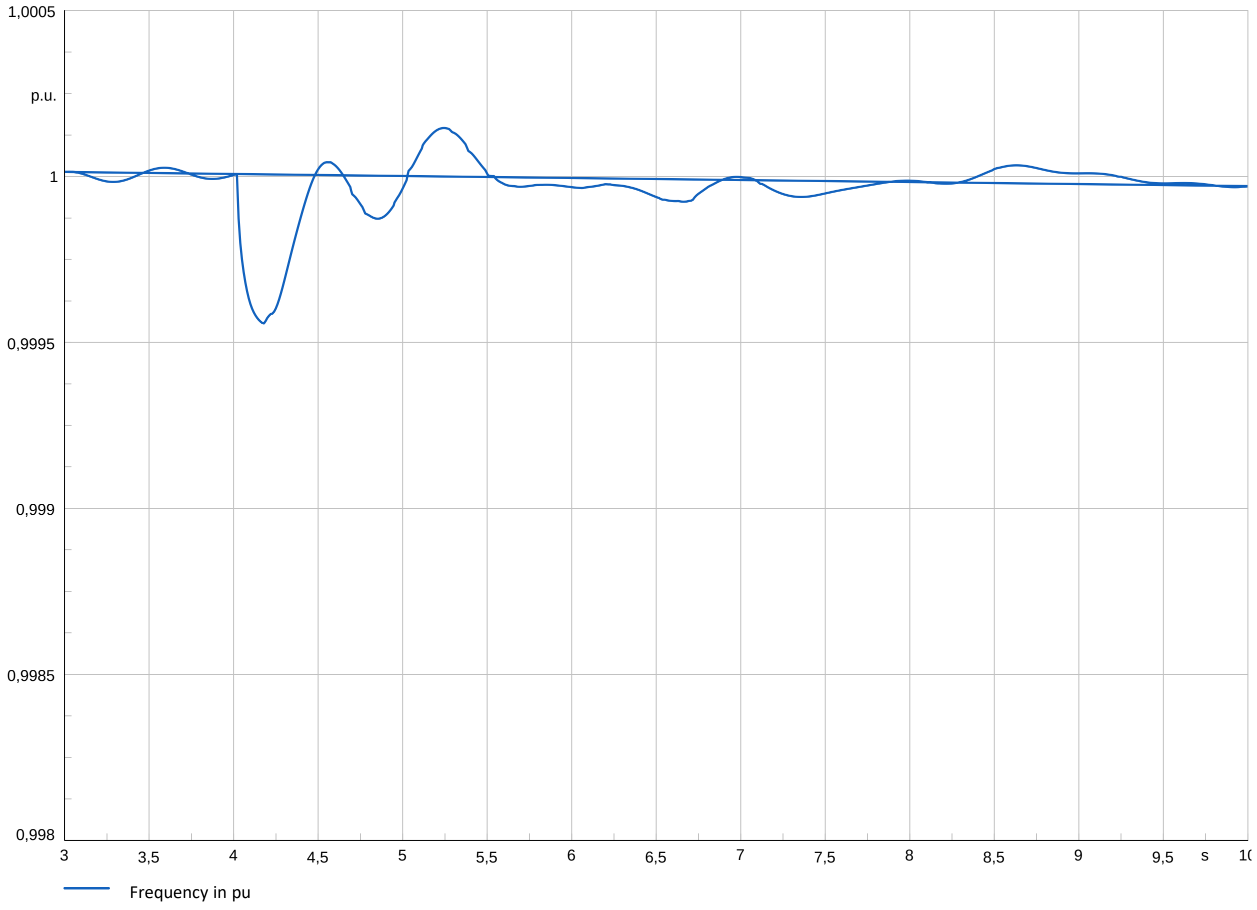
Study in the german transmisson system

With GFM electrolyzer:

Elec. acceleration time constant: 10s

Voltage control active

Small frequency deviation



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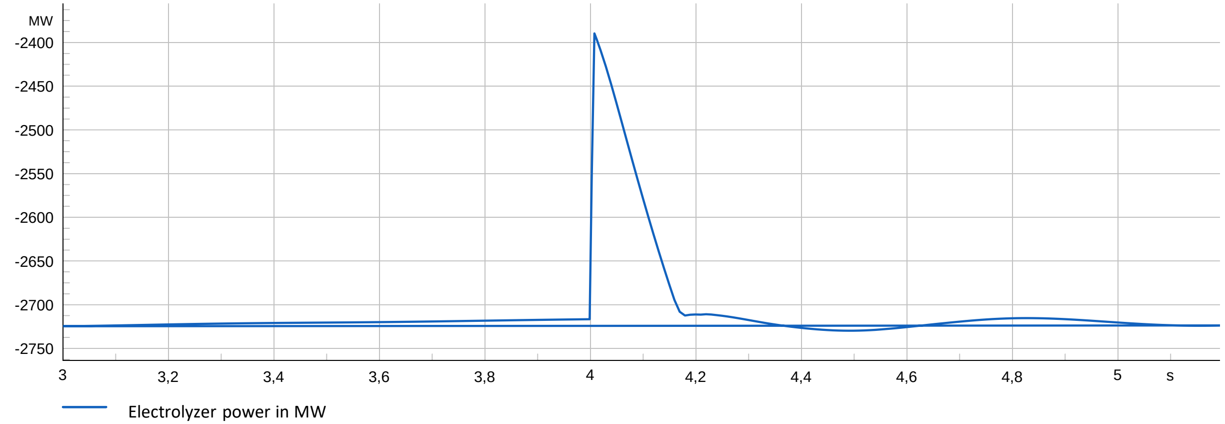
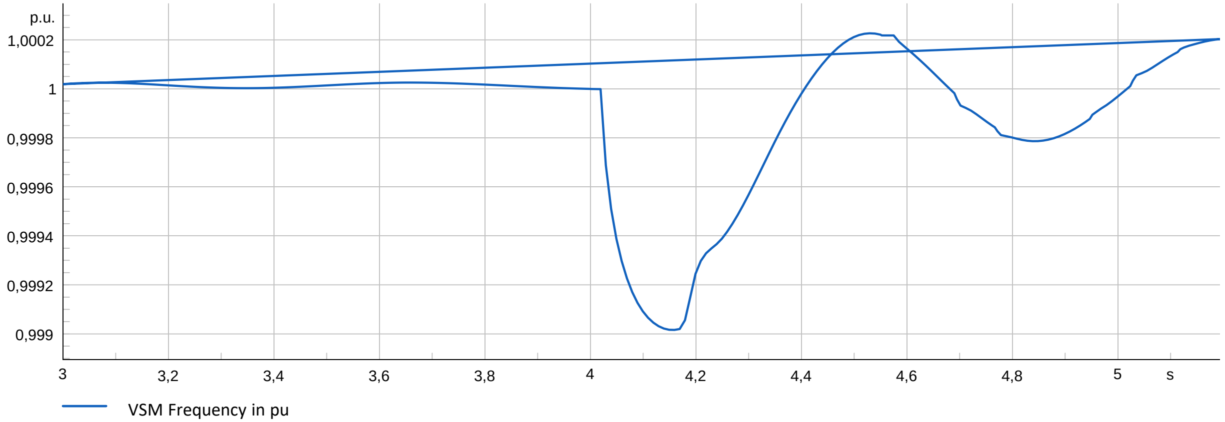
Study in the german transmisson system

With GFM electrolyzer:

Electrolyzer reduces consumption

Brings back pre-event power slower





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Conclusion

Electrolyzers have a high potential for system services like inertia

Challenges remain due to technical and economic reasons and limited experience

Electrolyzers could stabilize the grid in moments with high RE penetration

Contact

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