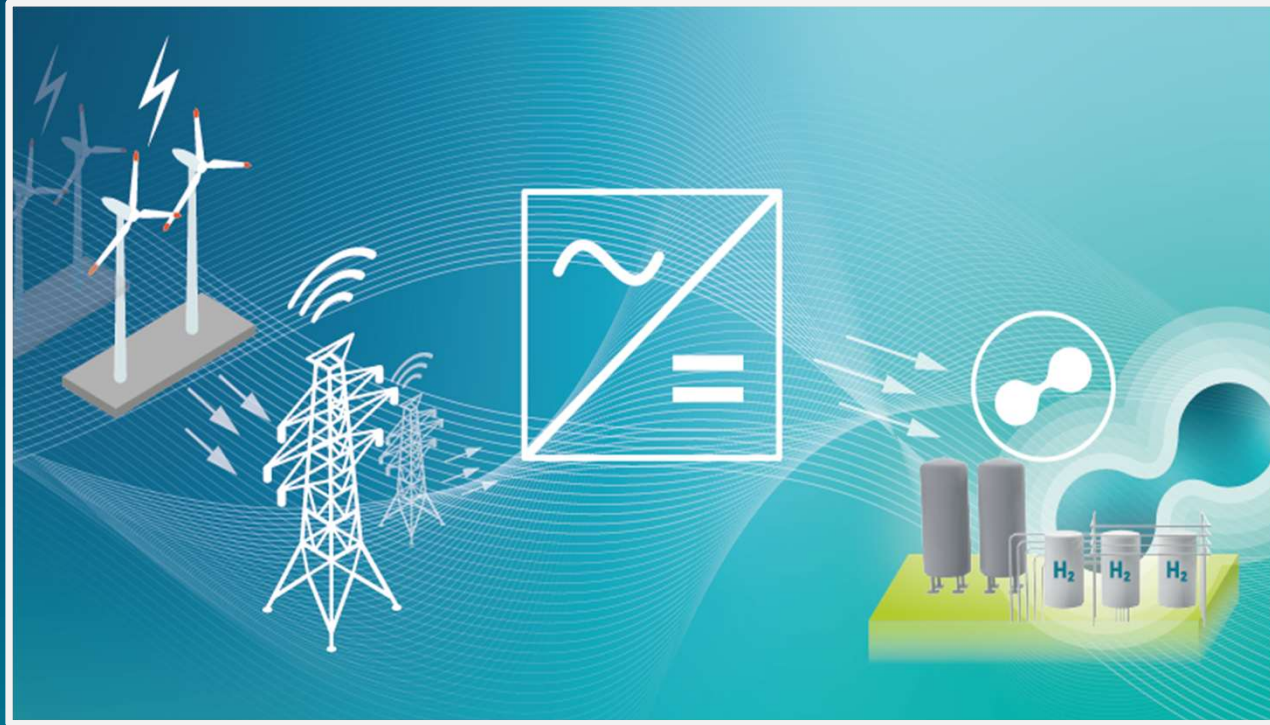




 **Fraunhofer**
IEE

**DERlab**
European Distributed Energy Resources Laboratories

HyLeiT Workshop #8: System Technology and Grid Integration of Hydrogen Plants

Nils Wiese (Fraunhofer IEE):

Grid Integration of Electrolyzers (Nils Wiese, Fraunhofer IEE)

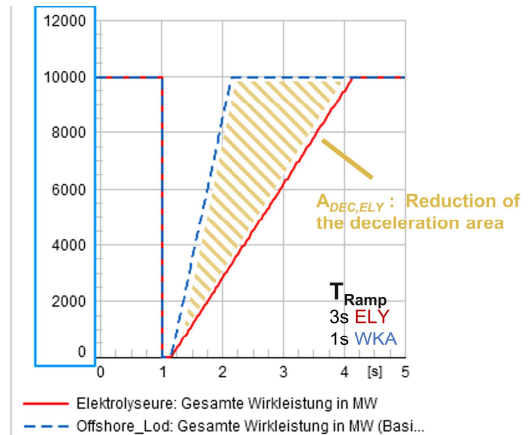
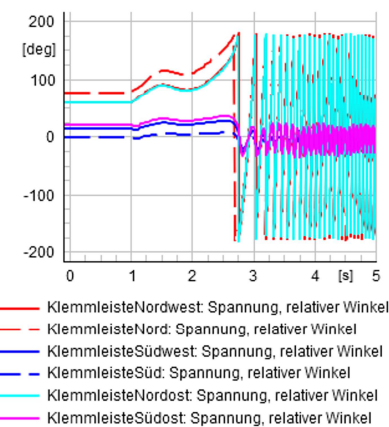
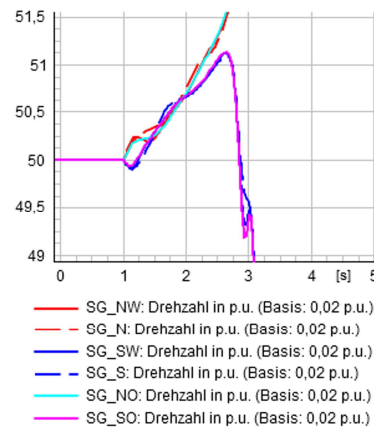
Background Grid Integration

10 GW electrolysis in 2030: Grid connection codes for electrolysis plants are required to ensure system stability. The electrolyzer plant must meet the requirements at the connection point.

Electrolyzers will often run if renewable penetration is high due to low prices

- high inverter penetration
- stability challenges

➔ Dynamic grid studies on the interaction of electrolysis plants with grid equipment, loads and generation plants are required



Results of short-circuit simulation

Source: Perspective of the 4 german TSOs – DERlab Workshop 09.20.24

Grid Codes and System Services

Requirements are available: [TAB for electrolyzers \(4TSOs Germany\)](#)

Selection of requirements:

Minimum frequency requirements

2.2 Robustness against frequency gradients

2.3 Robustness against temporary voltage changes(fault ride through, FRT), e.g.

- No grid disconnection within the time-defined voltage limits permitted.
- 3-pole grid faults: 3 consecutive undervoltage events within 30 minutes.

2.4 Fast recovery of the active power demand after a grid fault, e.g.

- Increase in the active current demand to 90% of the pre-fault value when the voltage recovers with in the voltage band of $U_{ref} \pm 10\%$.
- A maximum recovery time of 1s is permissible.

Voltage requirements

2.9 Dynamic grid support (e.g. dynamic reactive current injection)

2.10 Reactive power (operating point-dependent PQ diagram)

Grid Codes and System Services

Requirements pose a challenge for electrolyzer plants development/integration

- reactive power, ramp rates, degradation etc.

The whole plant must be grid code compliant -> offers the possibility to use other components to support.

There is no clear indication on how the requirements should be fulfilled (e.g. by including STATCOM, battery into the plant).

Elektrolyzer-Model

System (dynamics) consider both the characteristic curve of a cell and the dynamics of the interfacing converter - RMS

Elektrolyzer-Stack Modeling

- Characteristic similar to a diode
- Power depends on voltage
- Further aspect that need to be considered:
 - Ramp-rates (electrolyzer technology – PEM, AEL, etc.)

Converter Modeling

- Rectifier technology
- Controller
 - LFSM
 - LVRT
- Ramping constraints

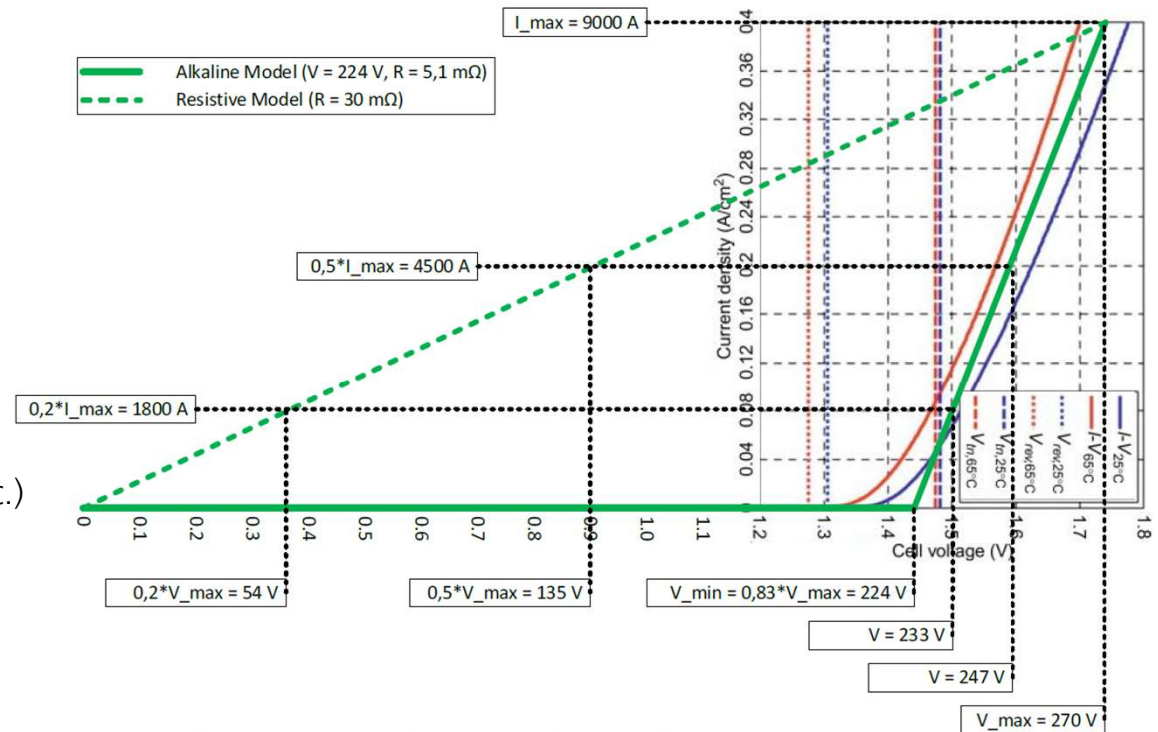


Fig. 1: Electrolyser alkaline cell characteristic ¹ with approximated graphs for simulation model

<https://www.sciencedirect.com/topics/engineering/alkaline-water-electrolysis>
Alkaline Water Electrolysis - an overview | ScienceDirect Topics

Elektrolyzer-Park

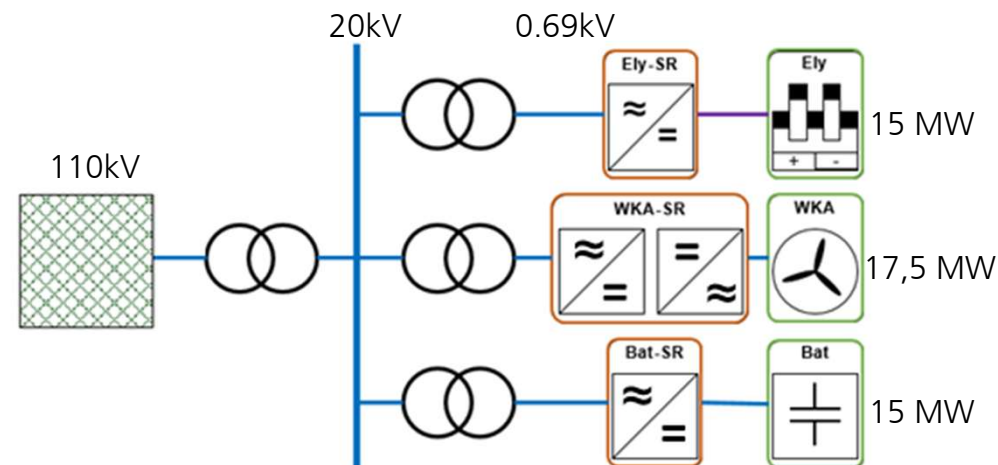
Park – GFL unit control

- Elektrolyzer
- 7 Wind power plants
- Battery
- Park controller

The Park controller manages power exchange to HV grid.

LFSM and LVRT are triggered by local measurements.

Simulation in PowerFactory



Park with park controller

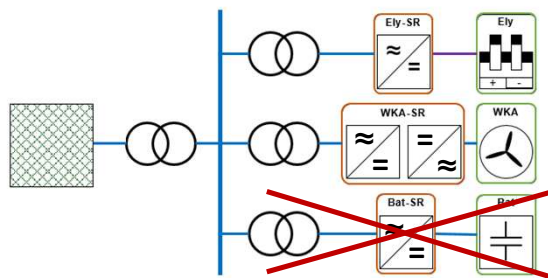
Elektrolyzer-Park

Test case 1

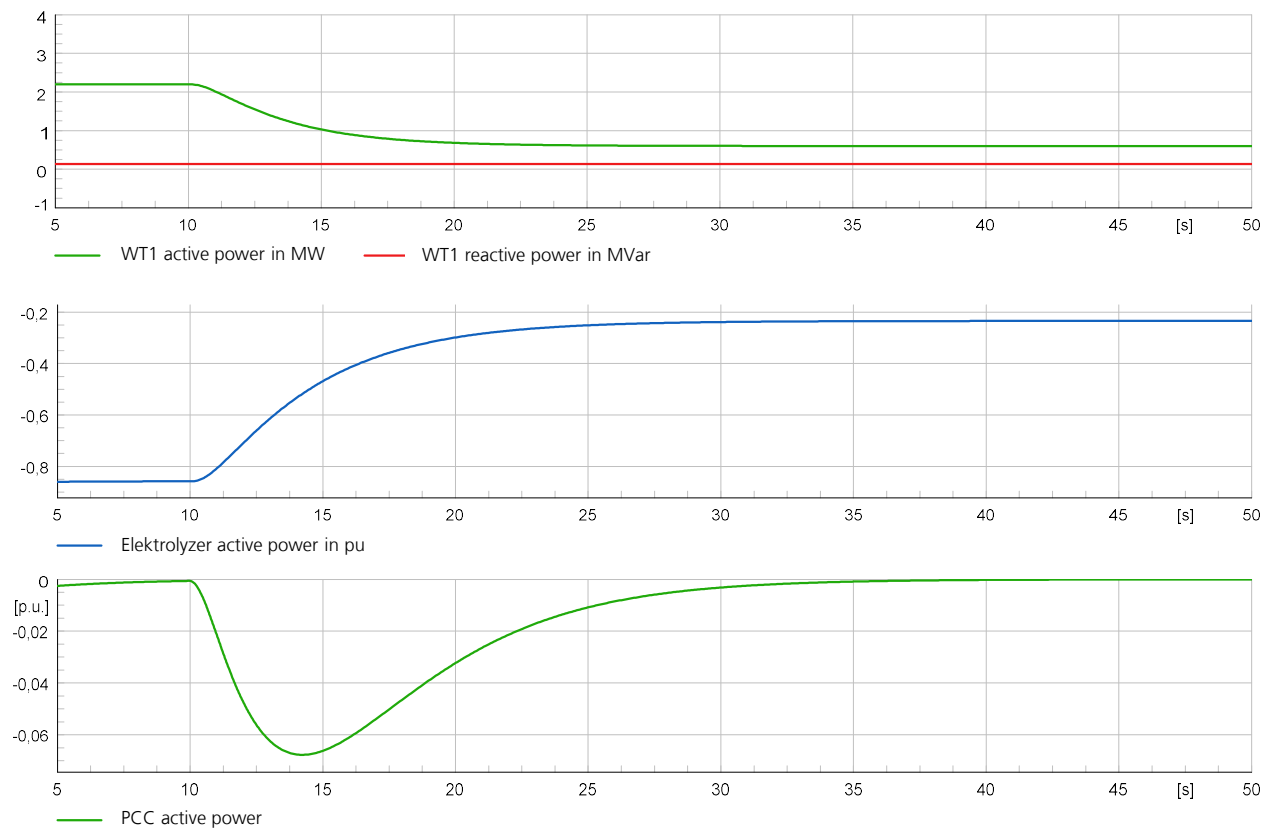
- Decrease in wind speed; battery SOC 0%

→ Reduction in the output of the wind turbine

→ Reduction of hydrogen production



Park with park controller



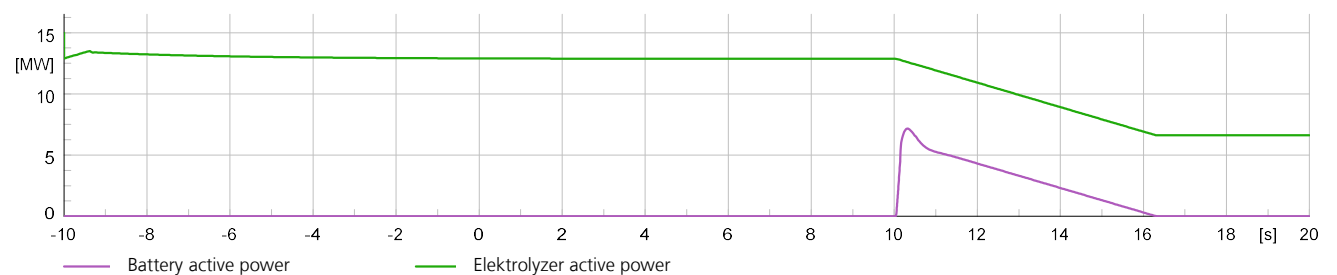
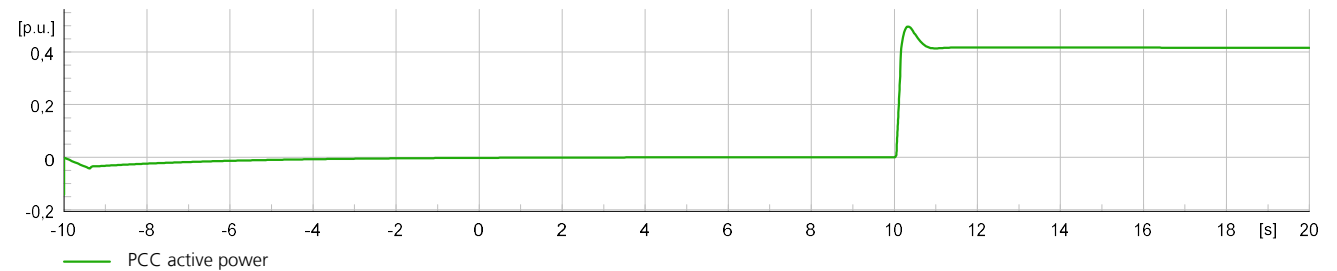
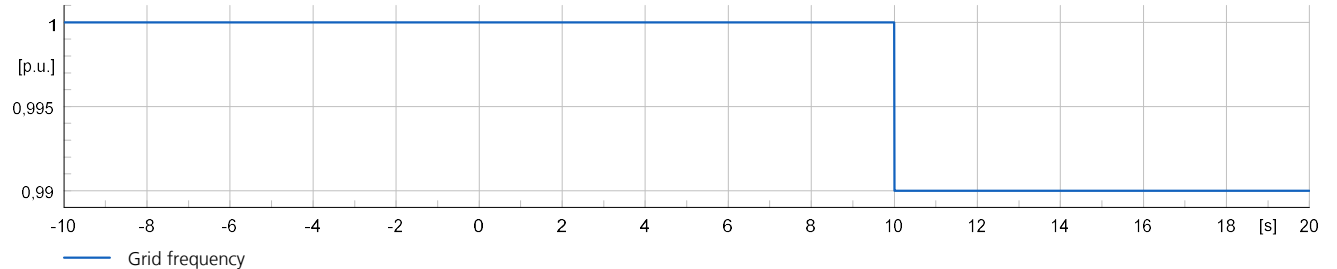
Elektrolyzer-Park

Test case 2

- -0,5 Hz frequency step, wind generation operating at MPP

- Fast response thanks to battery (downward limitation of the electrolyzer ramp)
- Battery compensates electrolyzer, esp. relevant in partial load operation of electrolyzer
- Overshoot comes from the frequency measurement

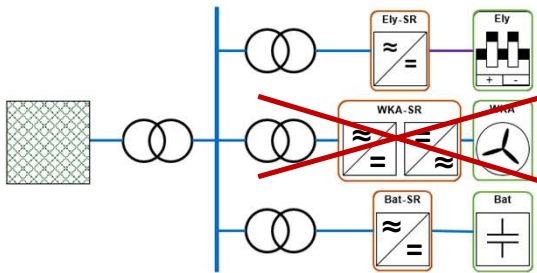
In the event of a positive frequency step (not shown on the slide), the wind turbines could reduce the feed-in.



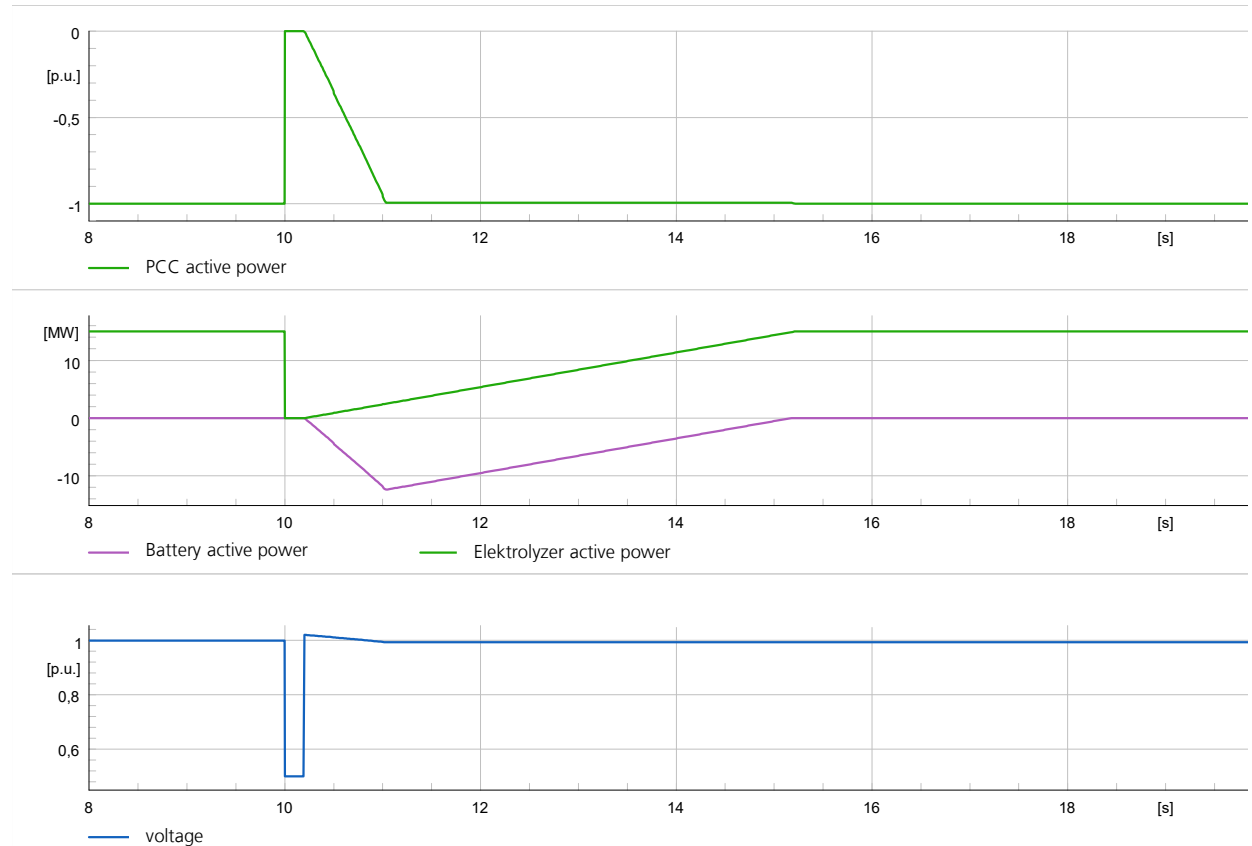
Elektrolyzer-Park

Test case 3

- No wind, voltage drop of 50% over 200ms
- **LVRT without wind generation**
- **Battery absorbs power after fault clearing**
(depends on operating point)
- **Fast active power recovery**



Park with park controller



Inertia procurement in Germany

Inertia counteracts frequency changes in the first milliseconds

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")

Original text:

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](#)

Challenges of GFM electrolyzers

Electrolysis plants are limited in dynamic behavior depending on the plant design

- Chemical Process
- Rectifier Topology
- Balance of Plant

Limitations considered by controller

- active power ramp-up/down
- current
- minimal operating point

Complementation with other components (battery, STATCOM..) needed to fulfill current German grid codes.

Limited experience with large-scale electrolyzer systems with GFM control → possible impact on unit's lifetime (e.g. cells degradation due to dynamic operation).

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
- Input: current
Output: voltage
- Rating
0-1000A
Scaled up to 20.4 MW

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

DSL model in PowerFactory (RMS)

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.

GFM electrolyzer with PEM cell model

Virtual synchronous machine

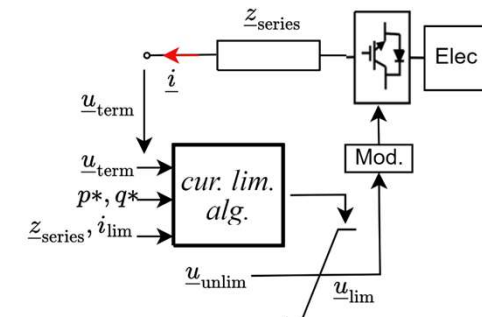
Power ramp-up limiter (asymmetric inertia)

Current limitation by limiting voltage over series impedance

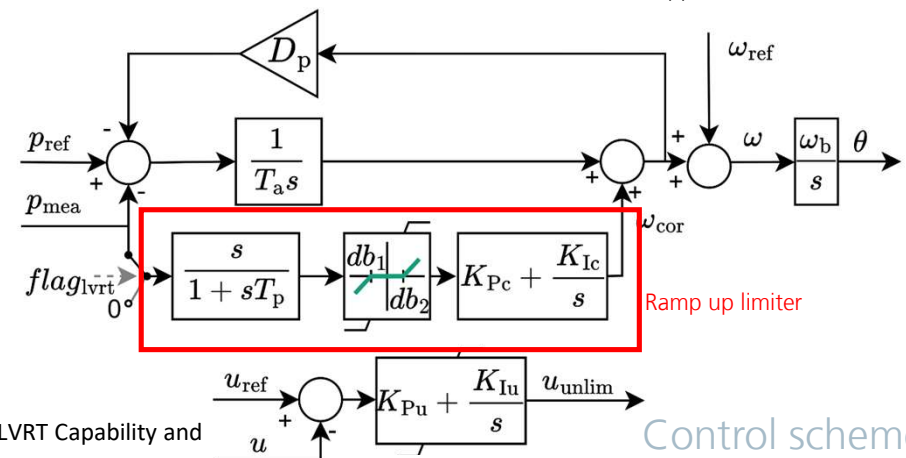
Reactive power is prioritized (can be chosen freely)

Active power setpoint adjustment during fault

Power ramp up limited after fault



Current limitation approach



Control scheme

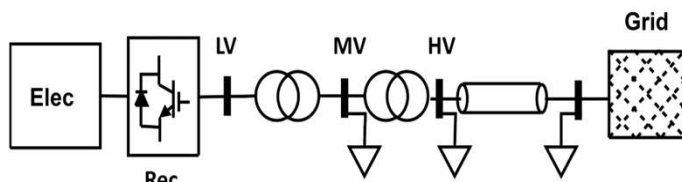
N. Wiese, D. Ghosh, P. Kretschmer, S. Eberlein and D. Strauß-Mincu, "Grid-Forming Controlled Electrolyzer with LVRT Capability and Asymmetric Inertia Provision," 2024 International Conference on Smart Energy Systems and Technologies (SEST), Torino, Italy, 2024.

GFM electrolyzer with PEM cell model

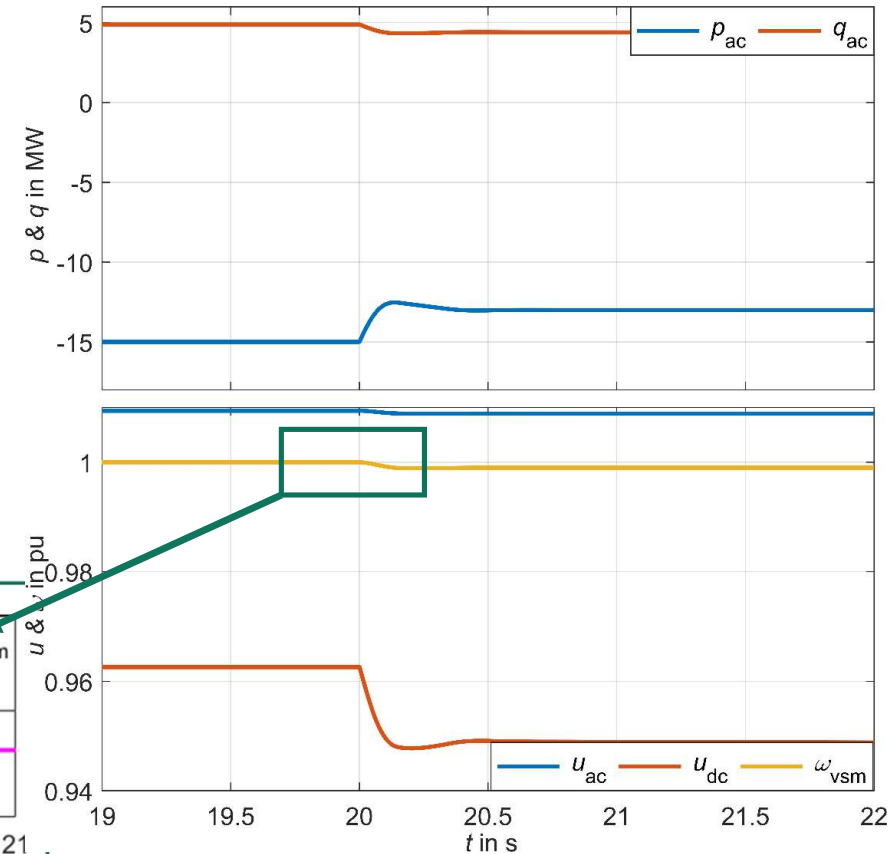
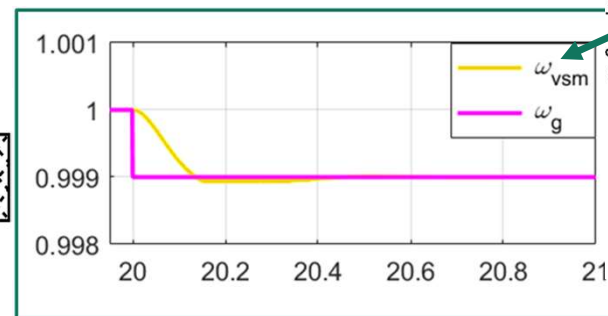
Test cases for frequency changes

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

Electrolyzer DC voltage declines



Test system

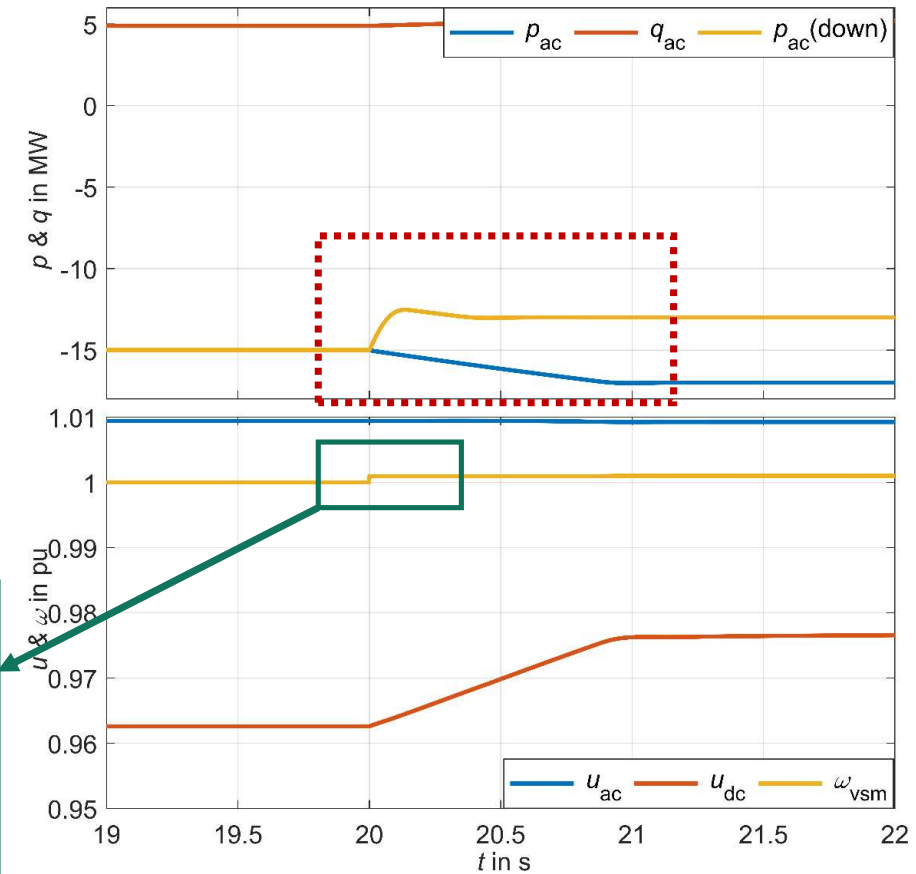
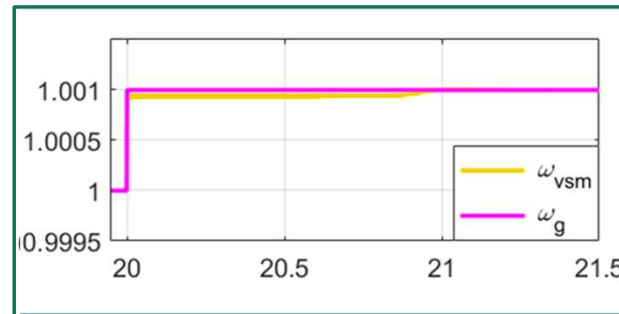


Frequency decrease

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

GFM electrolyzer with PEM cell model

Test case voltage drop

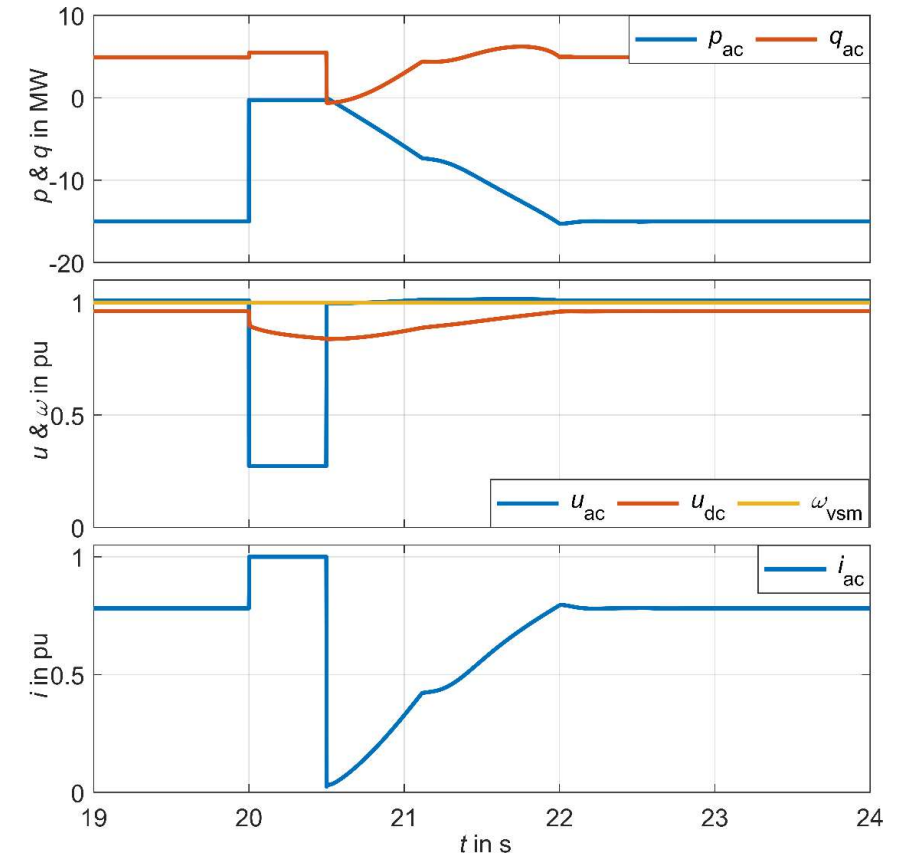
Current is limited

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

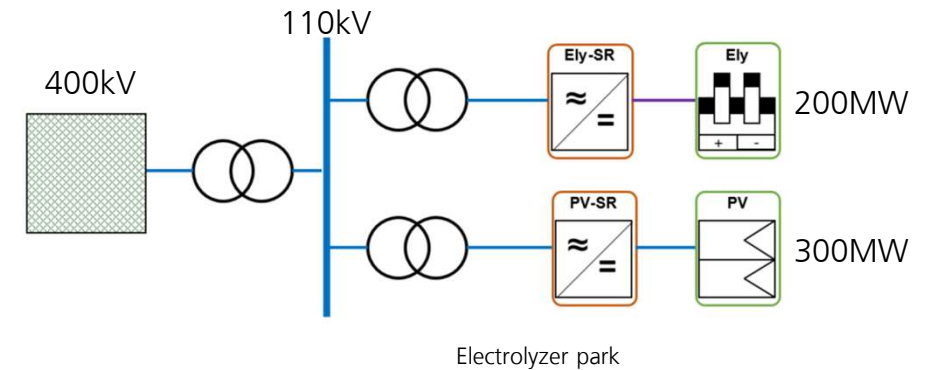
GFM electrolyzer in a park

Goal: Overall system provides instantaneous reserve

Combination of electrolyzer and PV

Both equipped with grid-forming control (GFM)

Provision of asymmetric instantaneous reserve by each unit

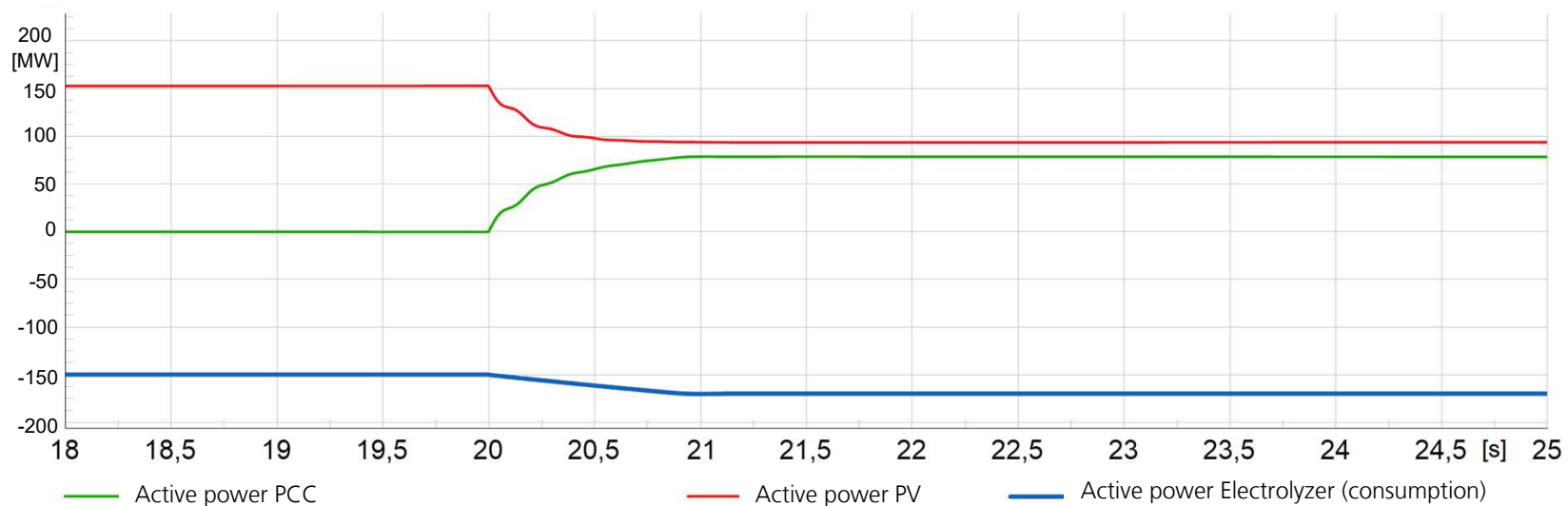


GFM electrolyzer in a park

Frequency step by +50mHz

PV reacts quickly

Contributions complement each other at the grid connection point (increase consumption)



Conclusion

High shares of electrolyzers → relevant dynamic behavior for power systems stability → regulated by grid codes

Dynamic electrolyzer RMS models with GFM and GFL controls have been developed,

→ Control and functionalities according to

- Grid code requirements (FRT)
- Units constraints (P ramp-up rate)

Case studies have been performed in different power park configurations

→ Electrolyzers with appropriate controls can have a stabilizing effect on power system stability.

→ Electrolyzers need to be complemented with other units with appropriate controllers (battery, STATCOM) to provide system services (asymmetric inertia).

Work in progress focusing on the impact of large scale integration of electrolyzer.

Future research: realistic complex dynamic models of large electrolyzers for large scale grid integration studies.

Contact

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