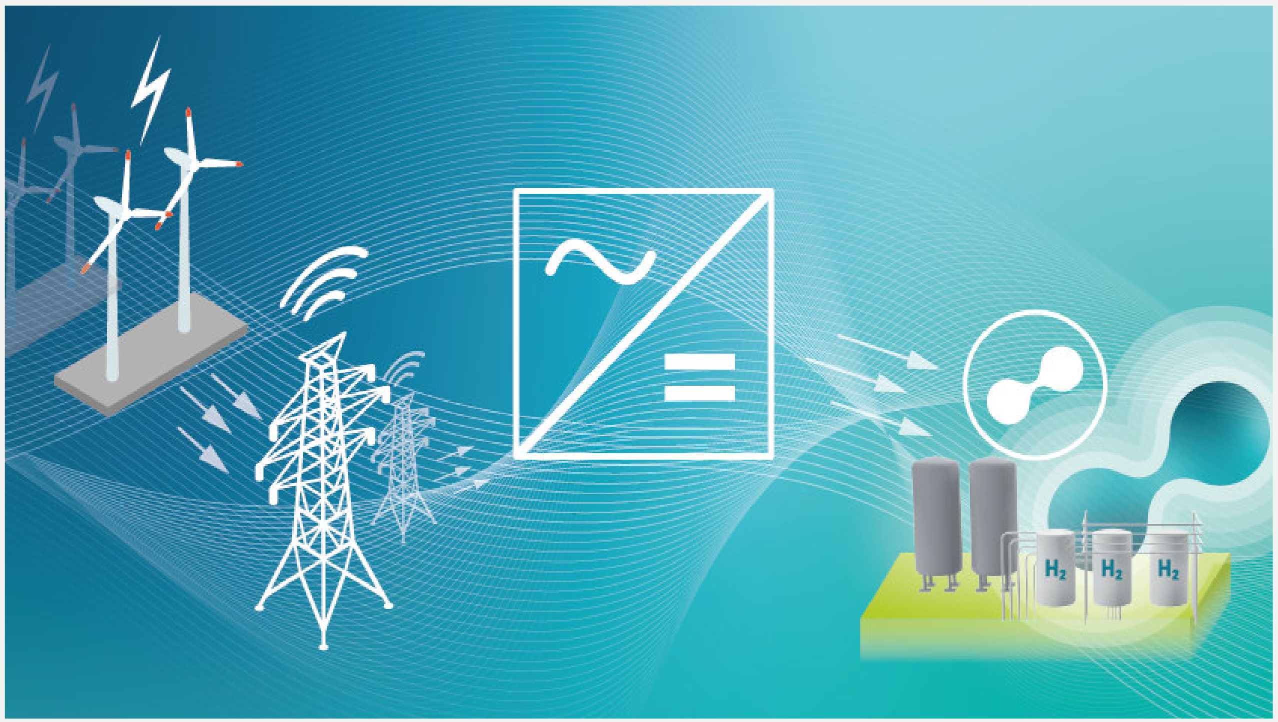


Workshop, 05. December 2023: Modelling of electrolysis plants for power system studies

Nils Wiese (Fraunhofer IEE):

Dynamic electrical models for power system integration

System Services

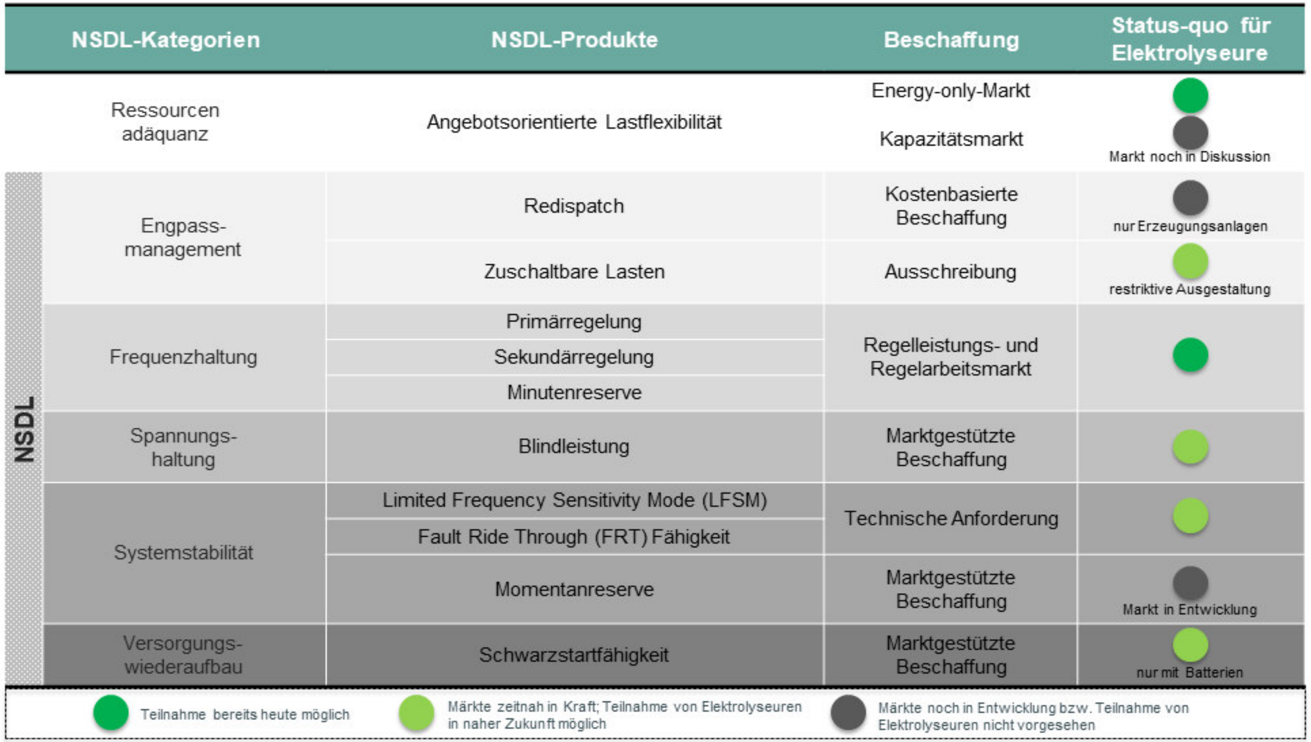
10 GW electrolysis in 2030: Grid connection codes for electrolysis plants are required to ensure system stability

The rectifier must meet the requirements of the connection point

Grid Codes and markets

In some cases, electrolysis plants must follow the volatile supply from renewable energies

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



	NSDL-Kategorien	NSDL-Produkte	Beschaffung	Status-quo für Elektrolyseure
	Ressourcen adäquanz	Angebotsorientierte Lastflexibilität	Energy-only-Markt Kapazitätsmarkt	🟢 ⚫ Markt noch in Diskussion
NSDL	Engpass-management	Redispatch	Kostenbasierte Beschaffung	⚫ nur Erzeugungsanlagen
		Zuschaltbare Lasten	Ausschreibung	🟩 restriktive Ausgestaltung
	Frequenzhaltung	Primärregelung	Regelleistungs- und Regelarbeitsmarkt	🟢
		Sekundärregelung		
		Minutenreserve		
	Spannungs-haltung	Blindleistung	Marktgestützte Beschaffung	🟩
	Systemstabilität	Limited Frequency Sensitivity Mode (LFSM)	Technische Anforderung	🟩
		Fault Ride Through (FRT) Fähigkeit		
		Momentanreserve	Marktgestützte Beschaffung	⚫ Markt in Entwicklung
	Versorgungs-wiederaufbau	Schwarzstartfähigkeit	Marktgestützte Beschaffung	🟩 nur mit Batterien

🟢 Teilnahme bereits heute möglich
🟩 Märkte zeitnah in Kraft; Teilnahme von Elektrolyseuren in naher Zukunft möglich
⚫ Märkte noch in Entwicklung bzw. Teilnahme von Elektrolyseuren nicht vorgesehen

Source: https://www.50hertz.com/Vertragspartner/Netzkunden/Netzanschluss

System Services

Example LVRT

Position paper from the German TSOs on FRT (fault-ride-through):

“If several gigawatts of load were to be suddenly and unplanned disconnected from the grid, this would not only have a massive impact on the power balance in the grid, but also on load flows and dynamic processes, which could jeopardize the stability of the grid with regard to the planned expansion of electrolysis plants. Voltage fluctuations (e.g. due to short circuits) cannot be completely ruled out at any grid node by the grid operator's existing technical measures. It is therefore necessary for system security that electrolysis plants can ride through these faults in the future (fault-ride-through).“

https://www.netztransparenz.de/de-de/%C3%9Cber-uns/Studien-und-Positionspapiere/FRT-Anforderungen

Grid Integration Studies

Preparation

Which system/grid is under investigation?

What are the test cases? (LVRT, frequency response etc.)

What are the functionalities are offered by rectifier and control?

What influence does the DC side have?

Dynamic test cases → dynmic models

Software: Simulink/PowerFactory etc.

Rectifier and its control and DC-Side can be simplified to varying degrees, like neglecting PLL-dynamics or rectifier topology.

Rectifier

Hardware and Control

Passive rectifier

- Diode

Active rectifier

- Thyristor
- IGBT etc.

Control

- Current controlled: conventional battery inverter (PV&Wind)
  needs grid voltage as reference
  penetration in power system is limited
- Voltage controlled: grid-forming control needed for replacement of synchronous generators
  provides (in case of a load/PV/Wind asymmetrical) instantenous reserve

Simplified Model

Cell model

Elektrolyzer-Stack

- No resistive load
- Characteristic similar to a diode
- Power depends on voltage
- System (dynamics) cannot only be described by the characteristic curve of a cell
- Simplified models are good for fast computation

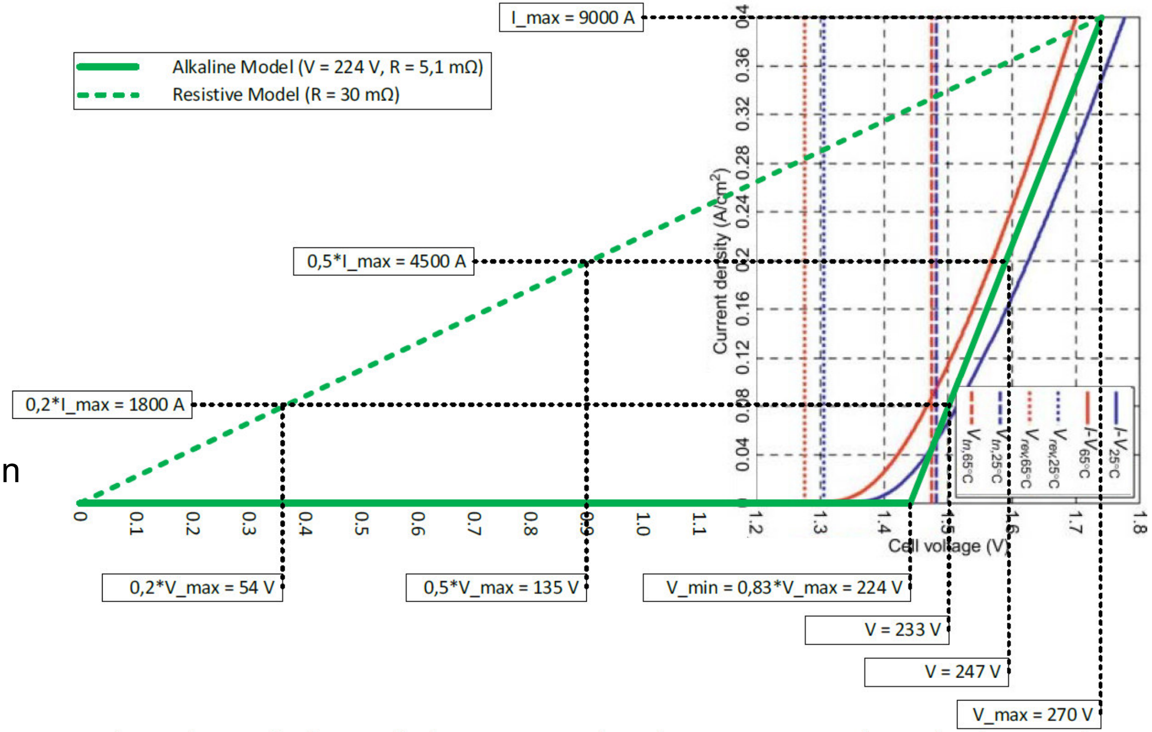


Fig. 1: Electrolyser alkaline cell characteristic [1] with approximated graphs for simulation model

https://www.sciencedirect.com/topics/engineering/alkaline-water-electrolysis

Alkaline Water Electrolysis - an overview | ScienceDirect Topics

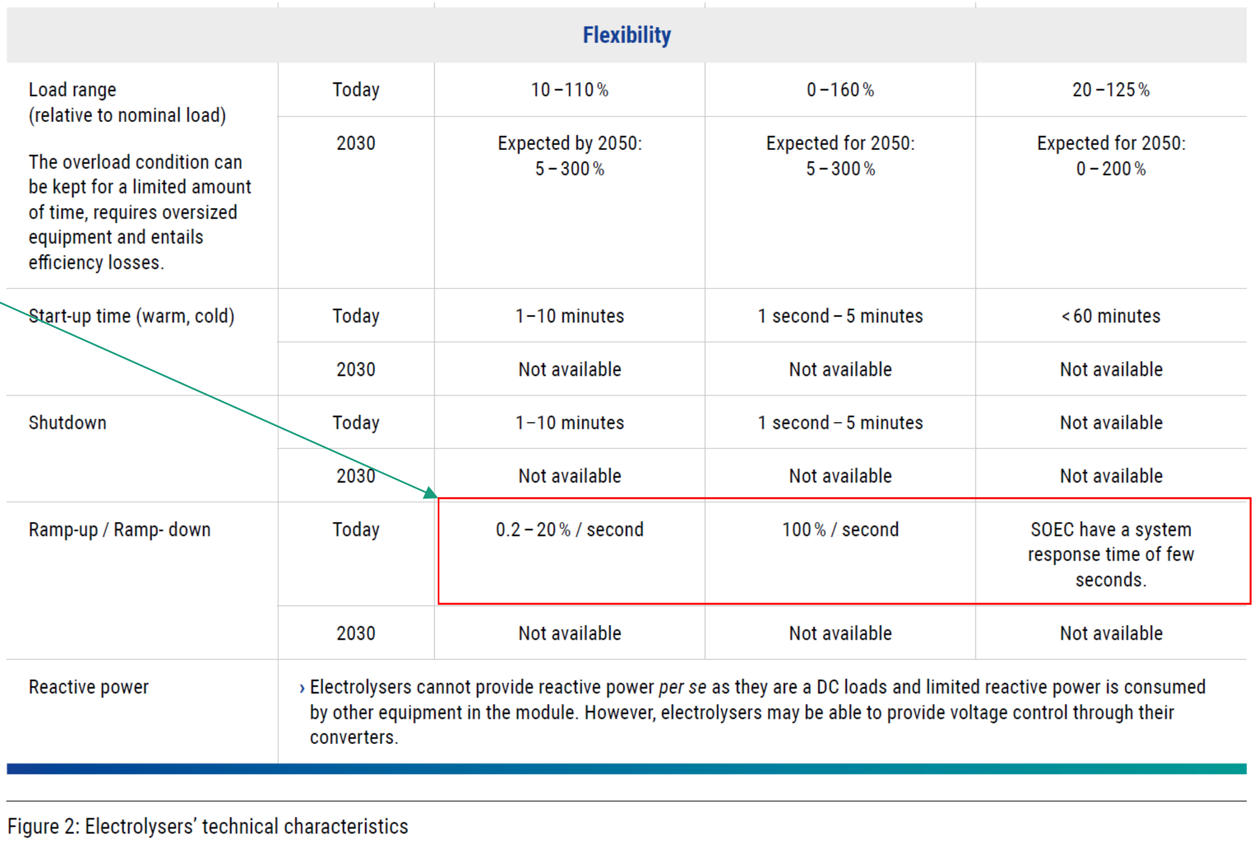
Simplified Model

Limitations

Plant behavior

- Dynamics depend on technology
- Ramp-up relevant for behavior after AC-faults/LFSM

- Q-support depending on rectifier

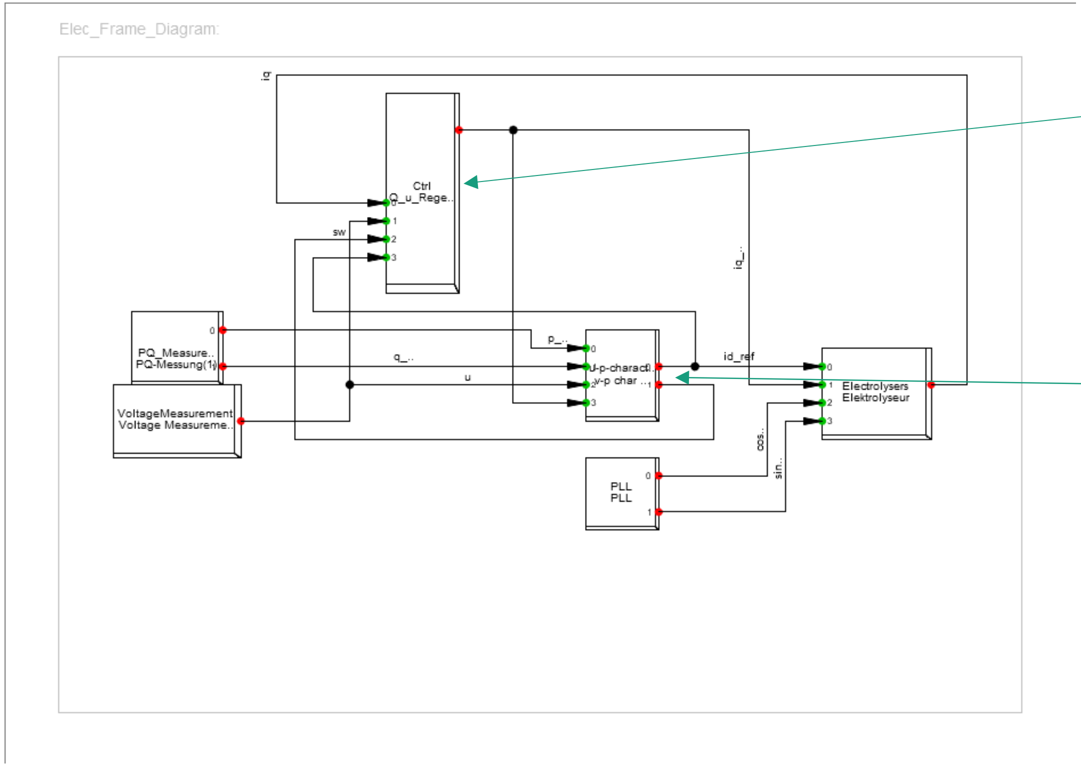


		Alkaline	PEM	SOEC
Flexibility				
Load range (relative to nominal load) The overload condition can be kept for a limited amount of time, requires oversized equipment and entails efficiency losses.	Today	10 – 110 %	0 – 160 %	20 – 125 %
	2030	Expected by 2050: 5 – 300 %	Expected for 2050: 5 – 300 %	Expected for 2050: 0 – 200 %
Start-up time (warm, cold)	Today	1 – 10 minutes	1 second – 5 minutes	< 60 minutes
	2030	Not available	Not available	Not available
Shutdown	Today	1 – 10 minutes	1 second – 5 minutes	Not available
	2030	Not available	Not available	Not available
Ramp-up / Ramp- down	Today	0.2 – 20 % / second	100 % / second	SOEC have a system response time of few seconds.
	2030	Not available	Not available	Not available
Reactive power	› Electrolysers cannot provide reactive power *per se* as they are a DC loads and limited reactive power is consumed by other equipment in the module. However, electrolysers may be able to provide voltage control through their converters.			

Figure 2: Electrolysers' technical characteristics

ENTSO-E: Potential of P2H technologies to provide system services

Simplified Model



Q(v) control

Elec. Characteristic with limitation (Q prio and ramp up)

Simplified Model

Plant behavior 1

- Presettable characteristic curve
- Direct switch-off in the event of undervoltage

Plant behavior 2

- Presettable characteristic curve
- Reactive power support

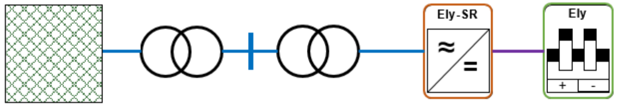
Simplified model in PowerFactory

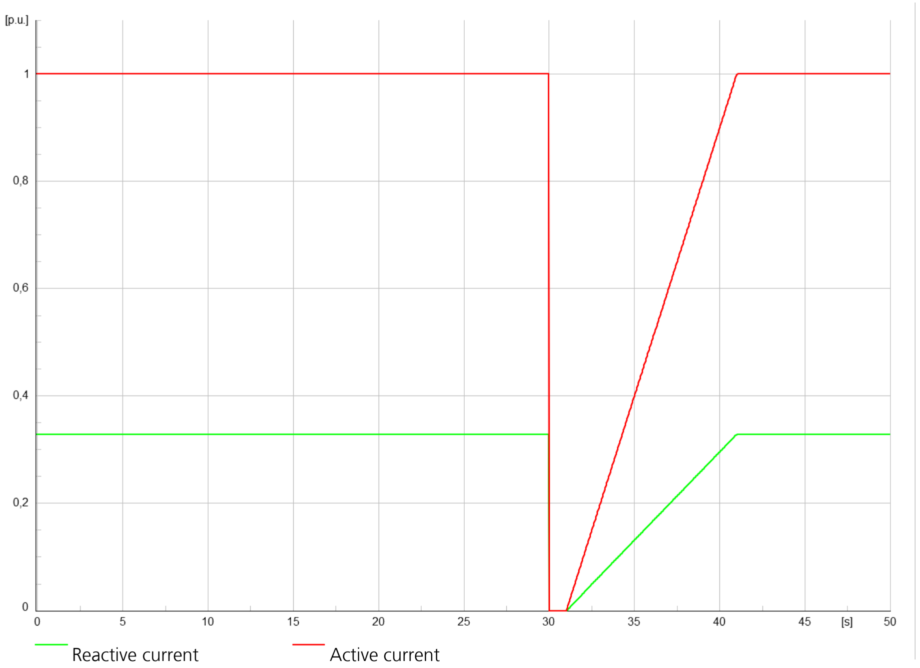
LVRT

Plant behavior 1

- Reactive power can be preset
- Q increases after fault with constant power factor

- No Voltage support during fault!

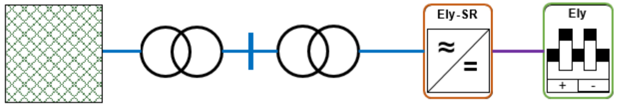




Simplified model in PowerFactory

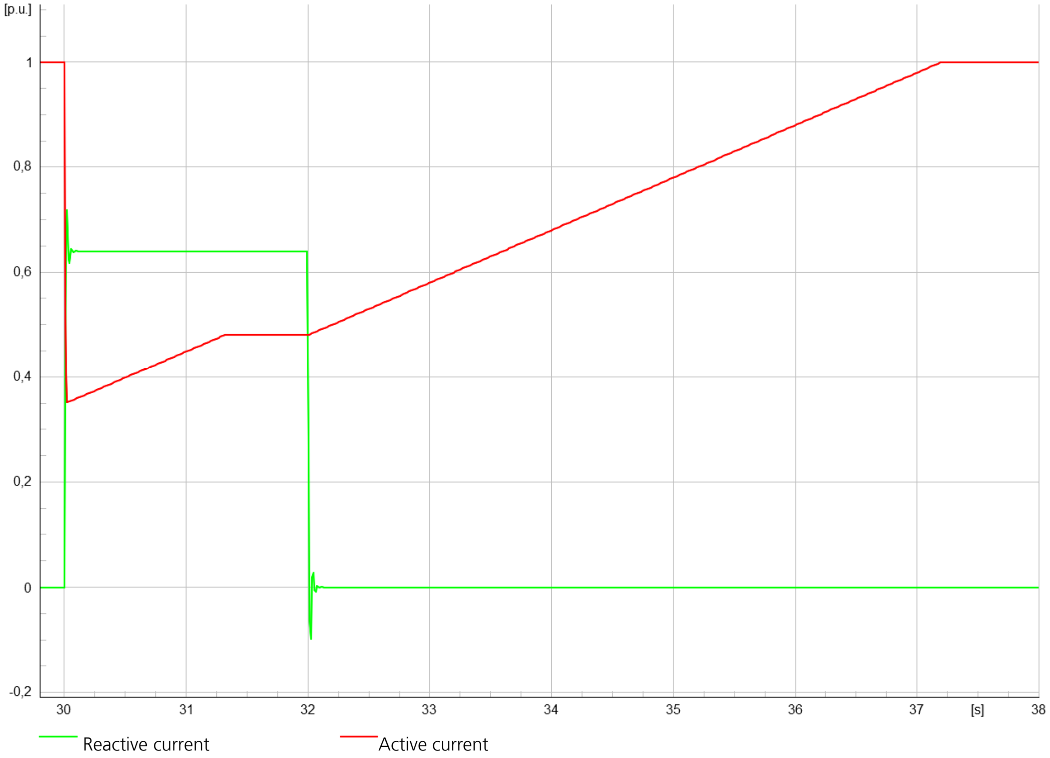
LVRT

FRT = 1



Plant behavior 2

- Reactive power can be preset
- Q is prioritized in the event of a fault
- P according to characteristic curve

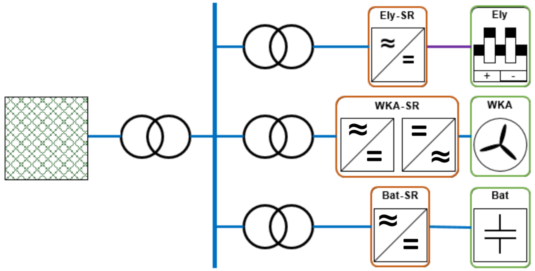


Initial overshoot of iq leads to excessive limitation of id

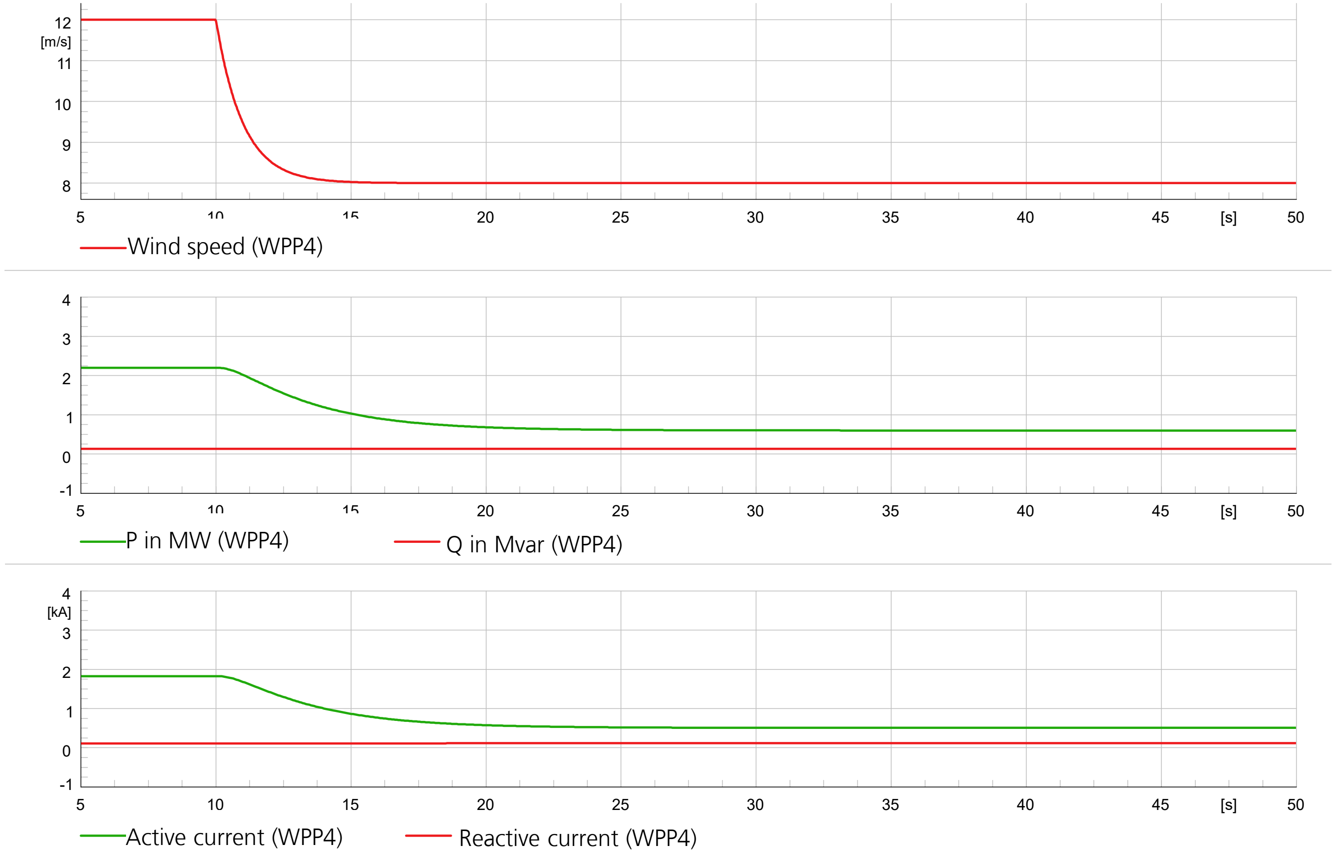
Simplified model

Park with power loss

- Wind speed decreases
- Reduction of wind power plant active power output



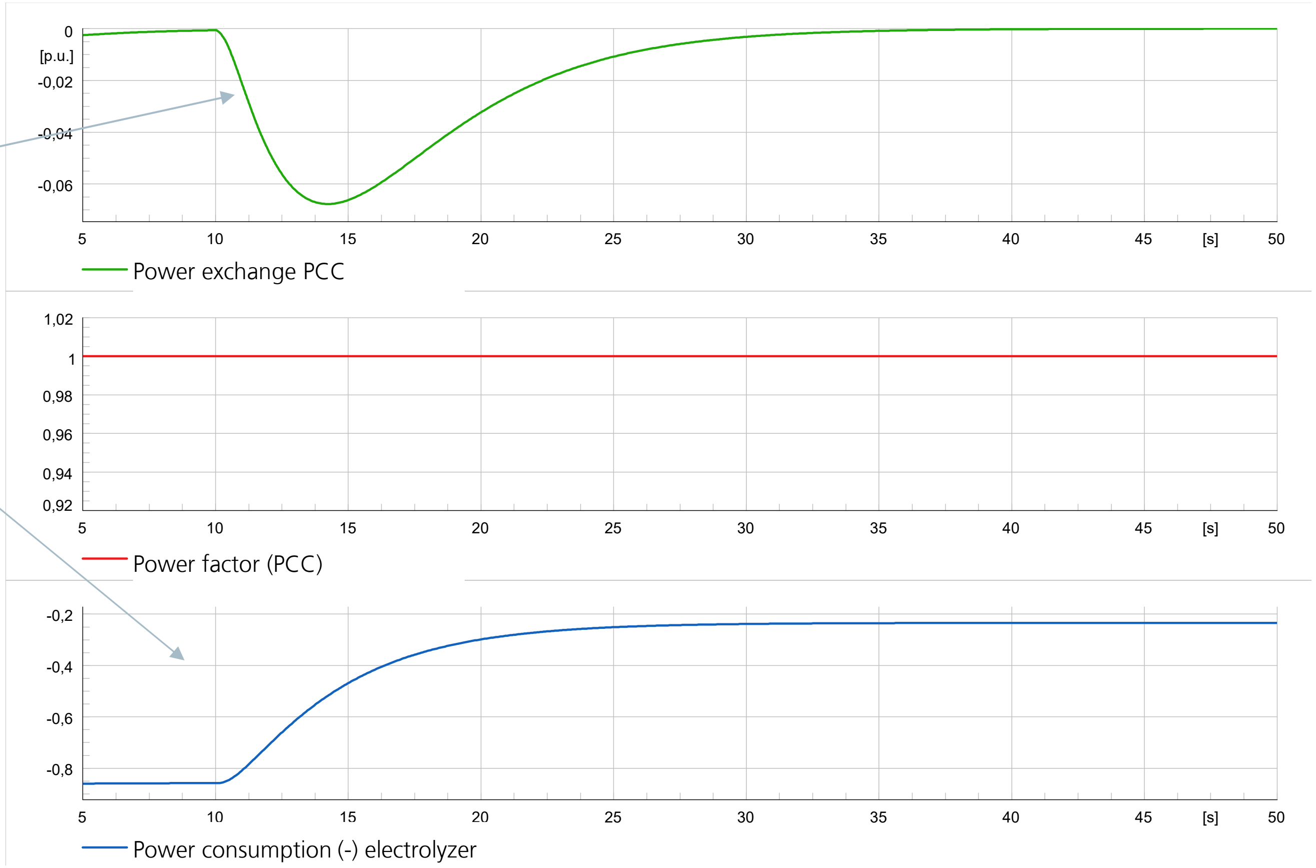
Park with park controller



Simplified model

Park with power loss

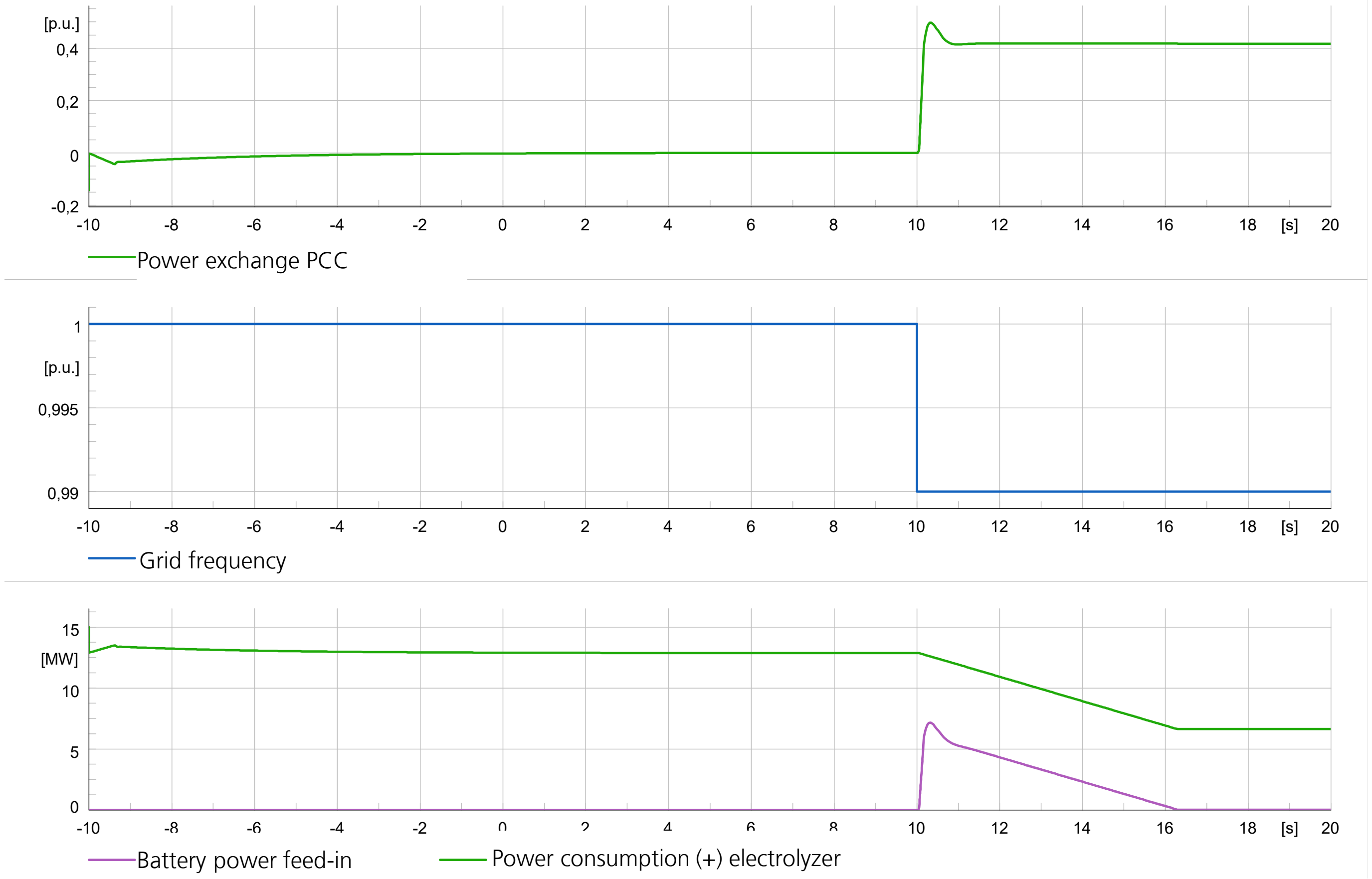
- Power exchange is controlled to 0
- Reduction of hydrogen production by electrolyzer



Simplified model

Park and frequency drop

- -0.5 Hz frequency jump
- Faster response thanks to battery (limitation of electrolyzer ramp down)
- Battery compensates electrolyzer (measurement of P elec. required)
- Overshoot comes from frequency measurement



Voltage Controlled Electrolyzer

Grid-forming control

- Instantenous reserve in case of falling frequency
- LVRT with Q support
- Can respect ramp up/current limits

DC-Side

- DLL from IEE PEM cell model
- Scaled up by series and parallel connections of cells

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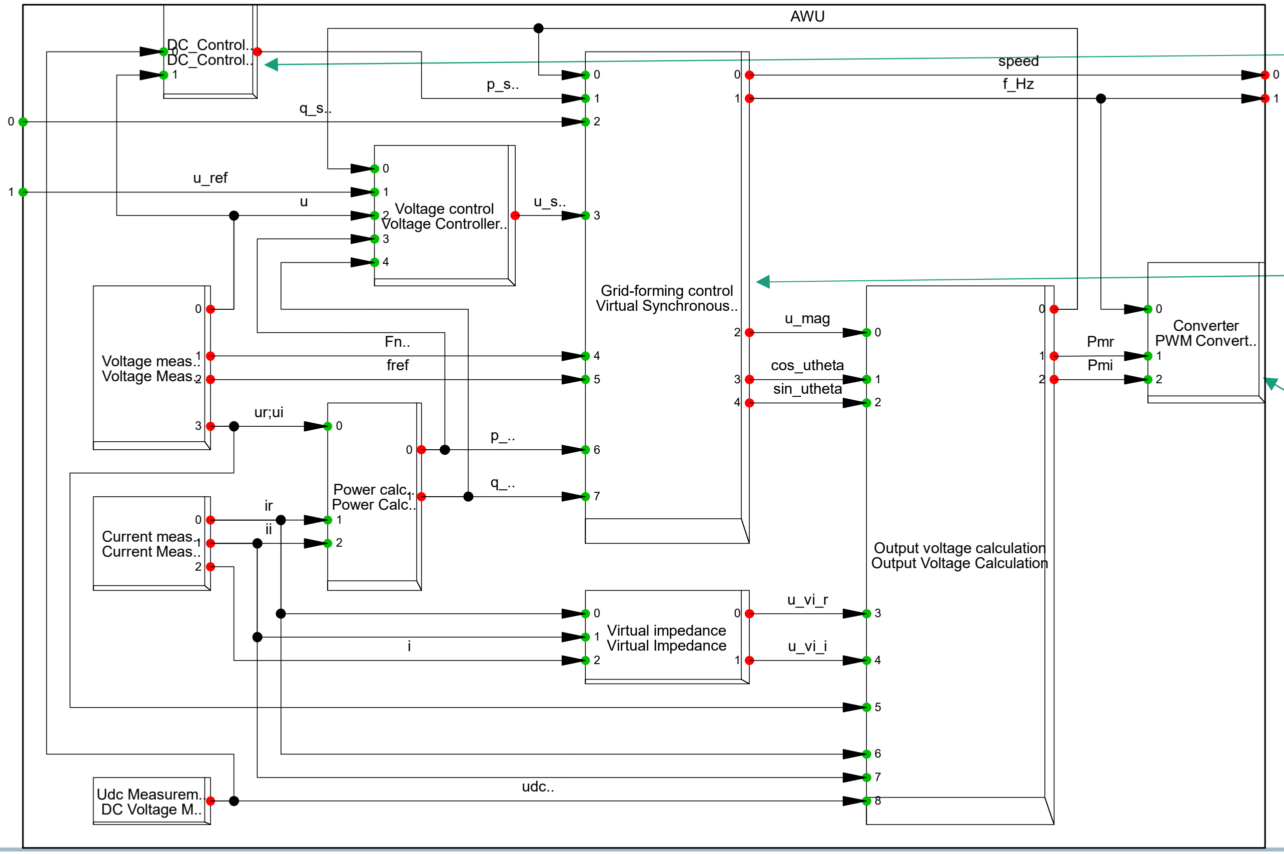
PEM-electrolyzer with gird-forming control

PowerFactory model from library with extensions

Grid-forming Converter Frame: Frame for grid-forming control of a PWM converter with DC control



Power control – Control of hydrogen production

VSM (virtual synchronous machine – grid-forming control)

PWM converter from PF ("boost" configuration)

RMS/EMT simulation possible

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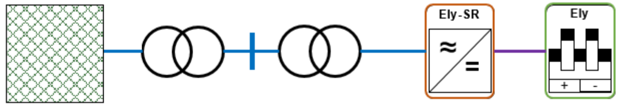
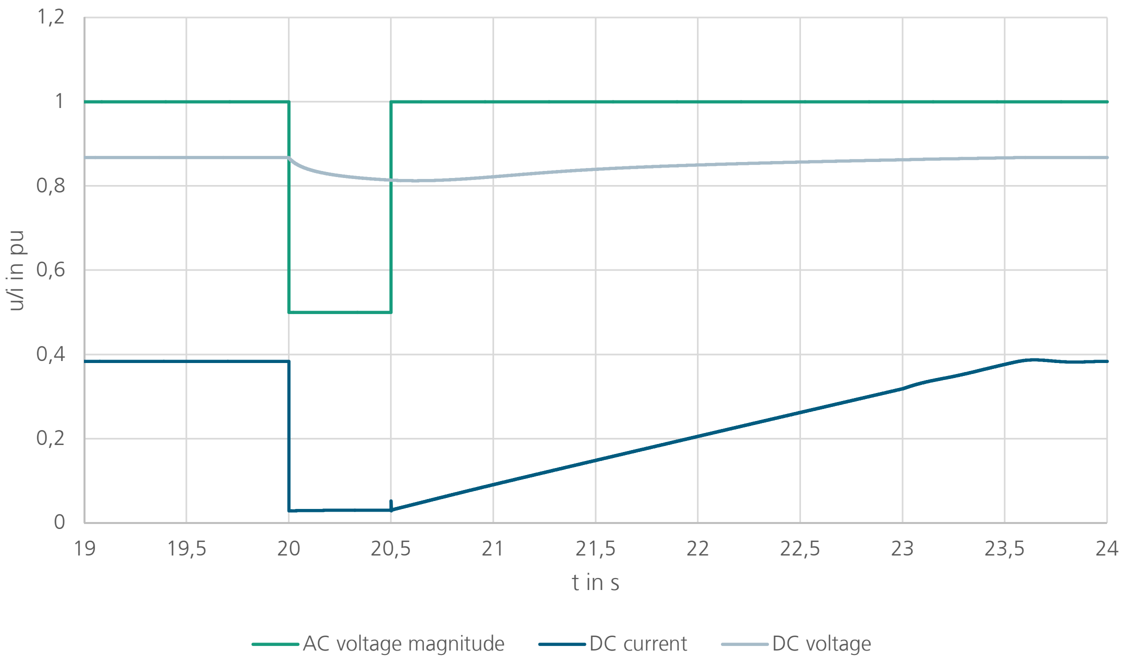
PEM-electrolyzer with gird-forming control

LVRT

- Short-circuit in the grid
- DC voltage decreses
- Slow power increse according to ramp-up limit

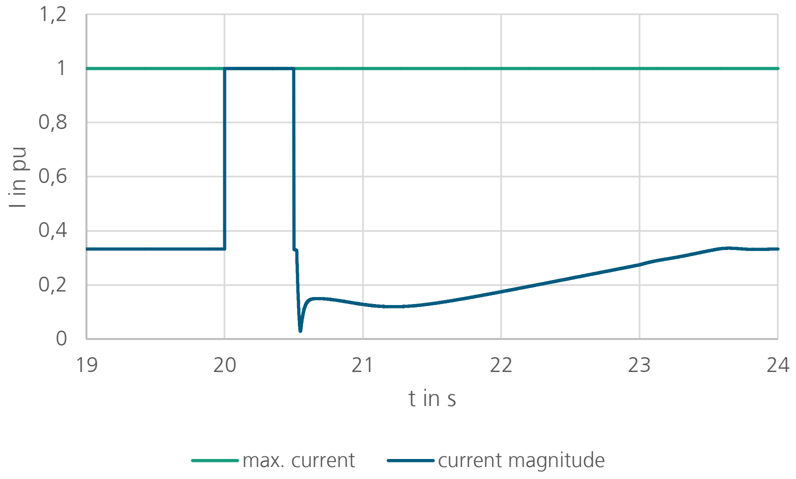


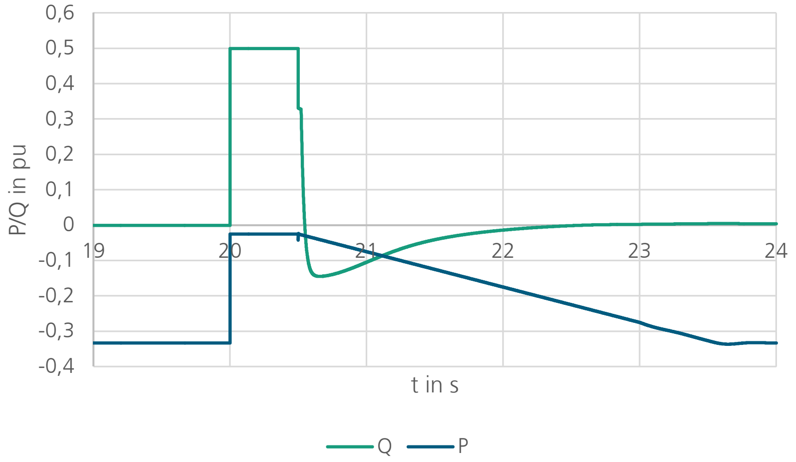


PEM-electrolyzer with gird-forming control

LVRT

- Current limitation active
- Adapted limitation (reactive current setpoint)
- Q prioritized



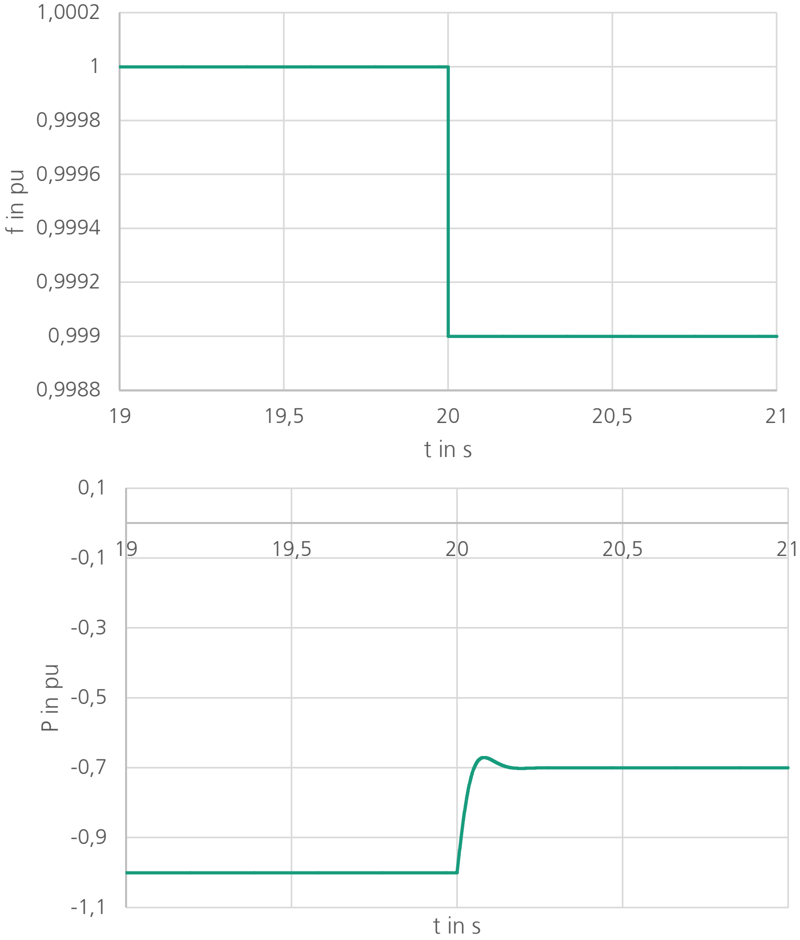


PEM-electrolyzer with gird-forming control

Frequency drop

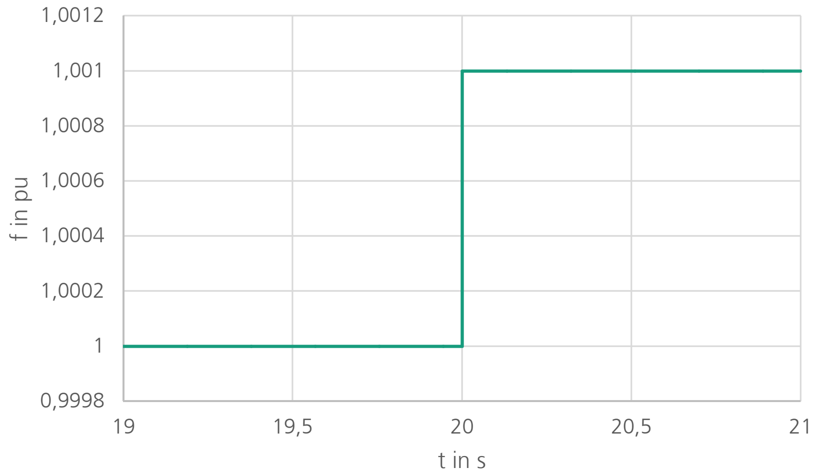
- Frequency drop in the grid

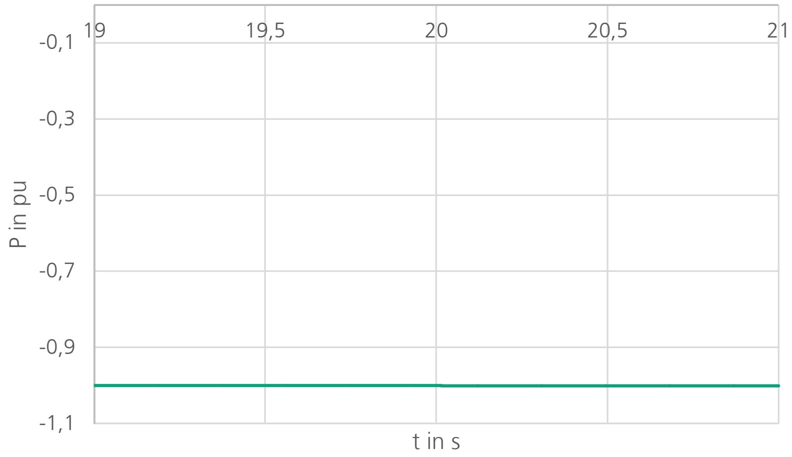
- Grid-forming control reduces power consumption instantaneously! –
- It provides instantaneous reserve



PEM-electrolyzer with gird-forming control

- Frequency increase in the grid
- Grid-forming control blocks inst. reserve by additional controller respecting ramp-up limits





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Conclusion

Grid integration studies with electrolyzers needed in order to ensure system stability

Different model approaches for different studies

Rectifier, control and DC-side must be taken into account

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