Flexibility and grid services from hydrogen electrolysers

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ESIG Workshop, Hydrogen Tutorial

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In a low-carbon, low-inertia, low-system strength grid…

- How do we model and assess electrolysers' capabilities to provide system balancing and dynamic services?
  - Focus here on active power balancing and frequency control ancillary services (FCAS)

- What types of dynamic supports can we get from electrolysers?

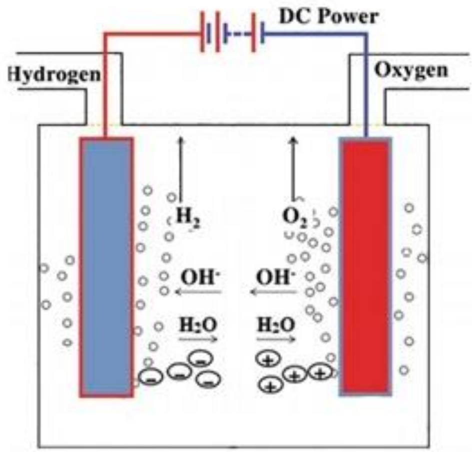
- What are the benefits and challenges?

An Overall View on Grid Integration of Hydrogen Electrolyzers

Downstream H_2 storage/process

H_2

Electrolysis stack



DC power

Power-electronics interface

Power

External grid

- ✓ Back-to-back converters
- ✓ DC-AC converters
- ✓ DC-DC converters

Wide range of applications!

- ✓ Proton Exchange Membrane (PEM)
- ✓ Alkaline
- ✓ Solid Oxide

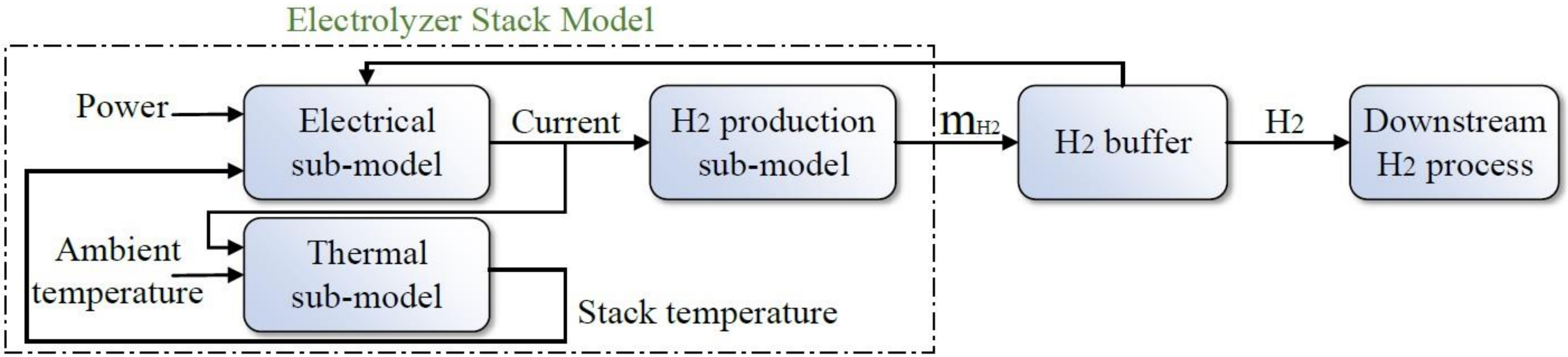
- ✓ Large-scale
- ✓ Small-scale

- ✓ AC bulk power system (transmission, renewable-rich, low-inertia)
- ✓ DC/AC micro-grids and distribution grids
- ✓ DC-link in renewable hubs (PV, wind)

Unified Dynamic Modelling Framework

- **Three** modelling components:
  - Electrolysis stack
  - Power-electronics interface and control
  - Downstream hydrogen process/buffer

- **Electrolysis stack**:
  - Electrical circuit representation
  - Hydrogen production sub-model
  - Thermal sub-model and its impact on converter control part



M. Ghazavi Dozein, A. Jalali and P. Mancarella, "Fast Frequency Response From Utility-Scale Hydrogen Electrolyzers," in *IEEE Transactions on Sustainable Energy*, 2021.

Power electronics interface and controls

- **Grid interface and controls**
  - Grid Following control
  - Virtual Synchronous Machine (VSM) control

- **FCAS type** (power reference setting strategy)
  - Contingency FCAS
    - Fast Frequency Response and Primary Frequency Response
      - droop control
      - sustained droop control
      - RoCoF-based control
  - Regulation FCAS
  - Virtual Inertia (from VSM control)

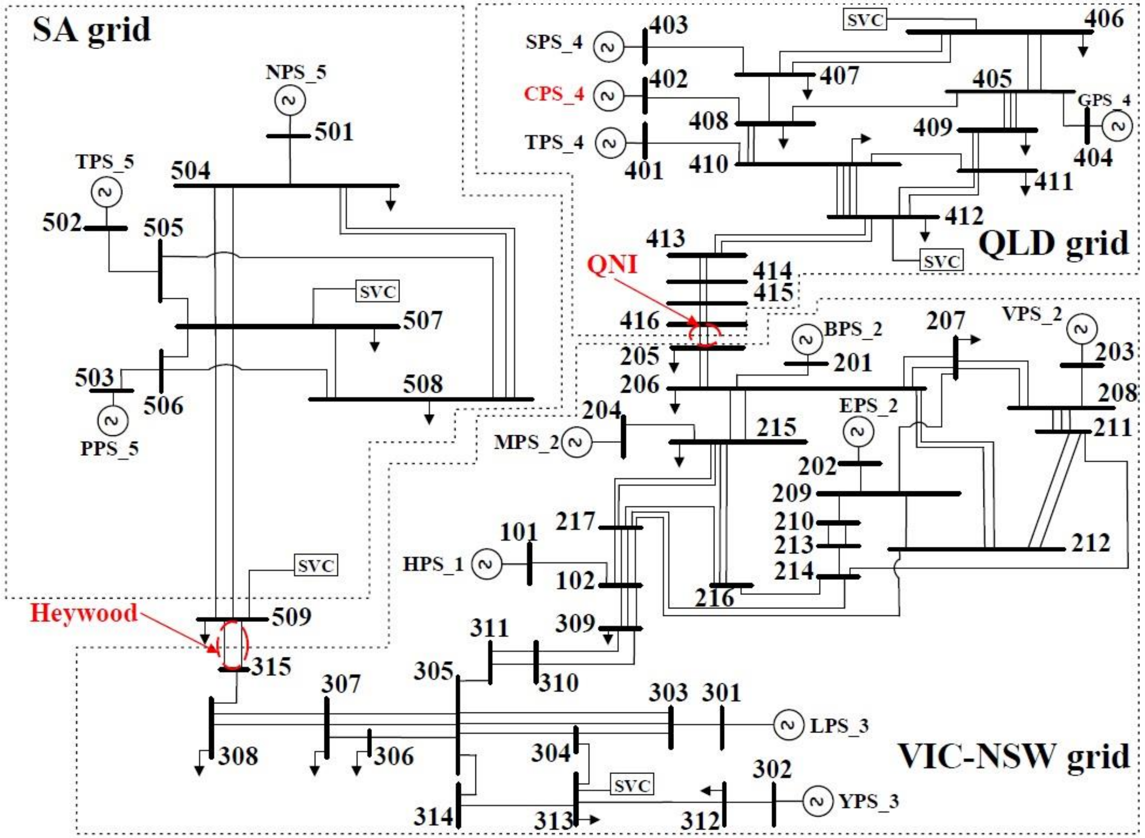
Case Studies (1/3): Fast Frequency Response from Electrolysers

Electrolyser benefits in low-inertia systems

- Electrolyser's frequency support capability in the context of Australian 50% renewable energy target by 2030
- **Contingency**: the largest generating unit outage in Queensland with total capacity of 667 MW at t=40s

Generation and load data

Case Study	*States*	*Synchronous Generation [GW]*	*Non-synchronous Generation [GW]*		*Load [GW]*
			PV	*Wind*	
Case-1	QLD	3.34	1.44	1.77	5.5
	VIC-NSW	11.4	5.58	5.36	17.6
	SA	1.12	0.48	1.07	2.3

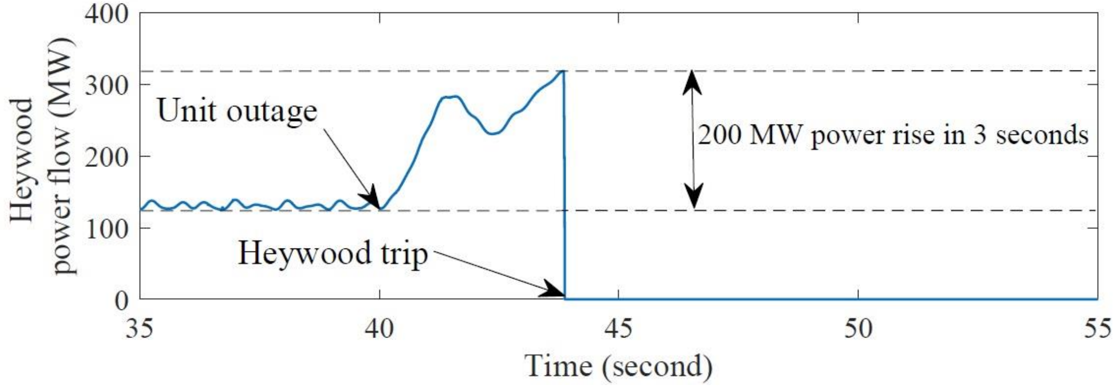


Modified 14-generator NEM grid with 50% renewable penetration

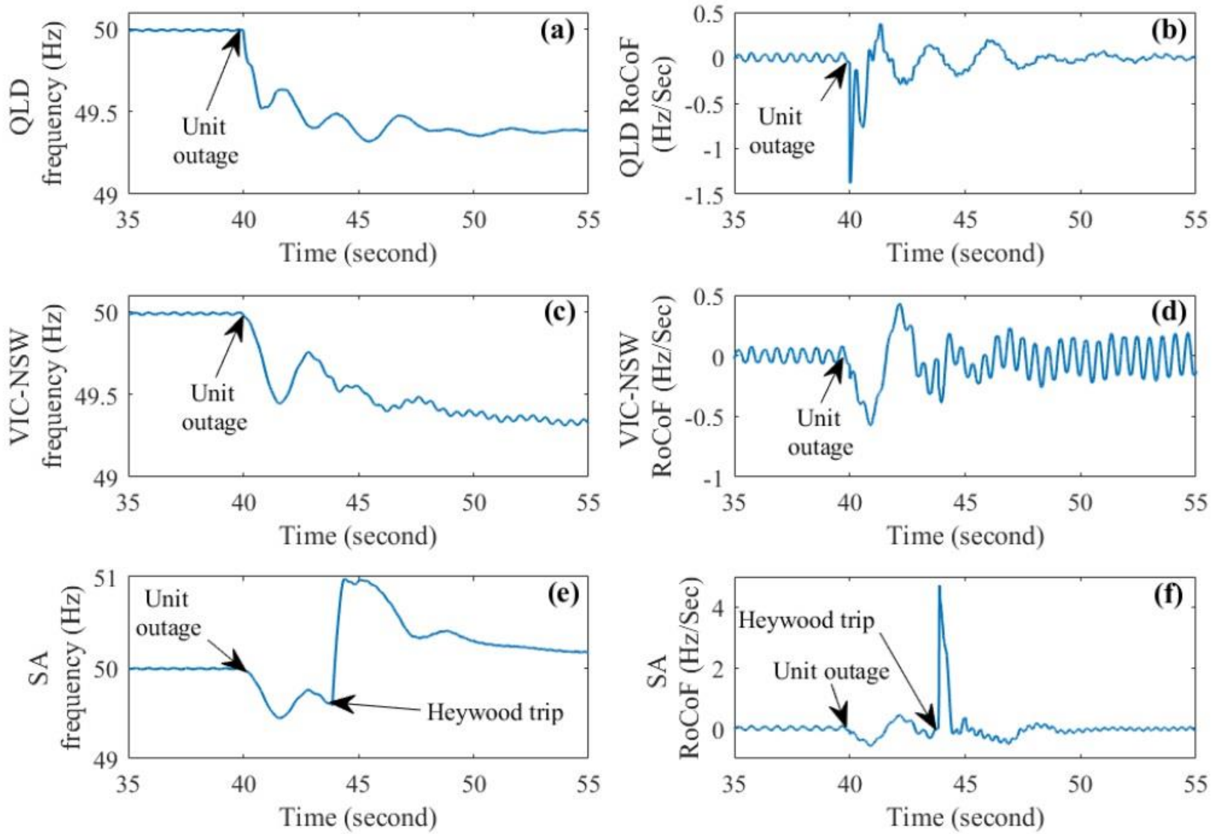
Case Studies (1/3): Fast Frequency Response from Electrolysers

Base case results (no electrolyser)

- **Different frequency dynamics** in States
- Significant **frequency drop** in all states (below 49.4 Hz)
- A **high RoCoF** value in Queensland



Heywood active power flow

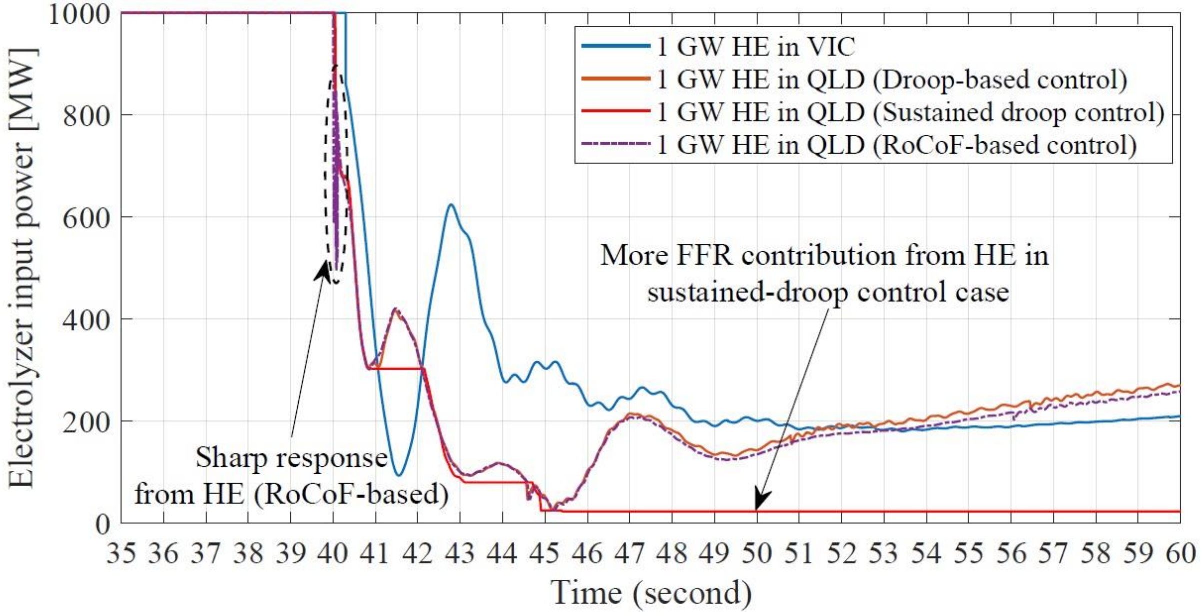


Frequency and RoCoF in States

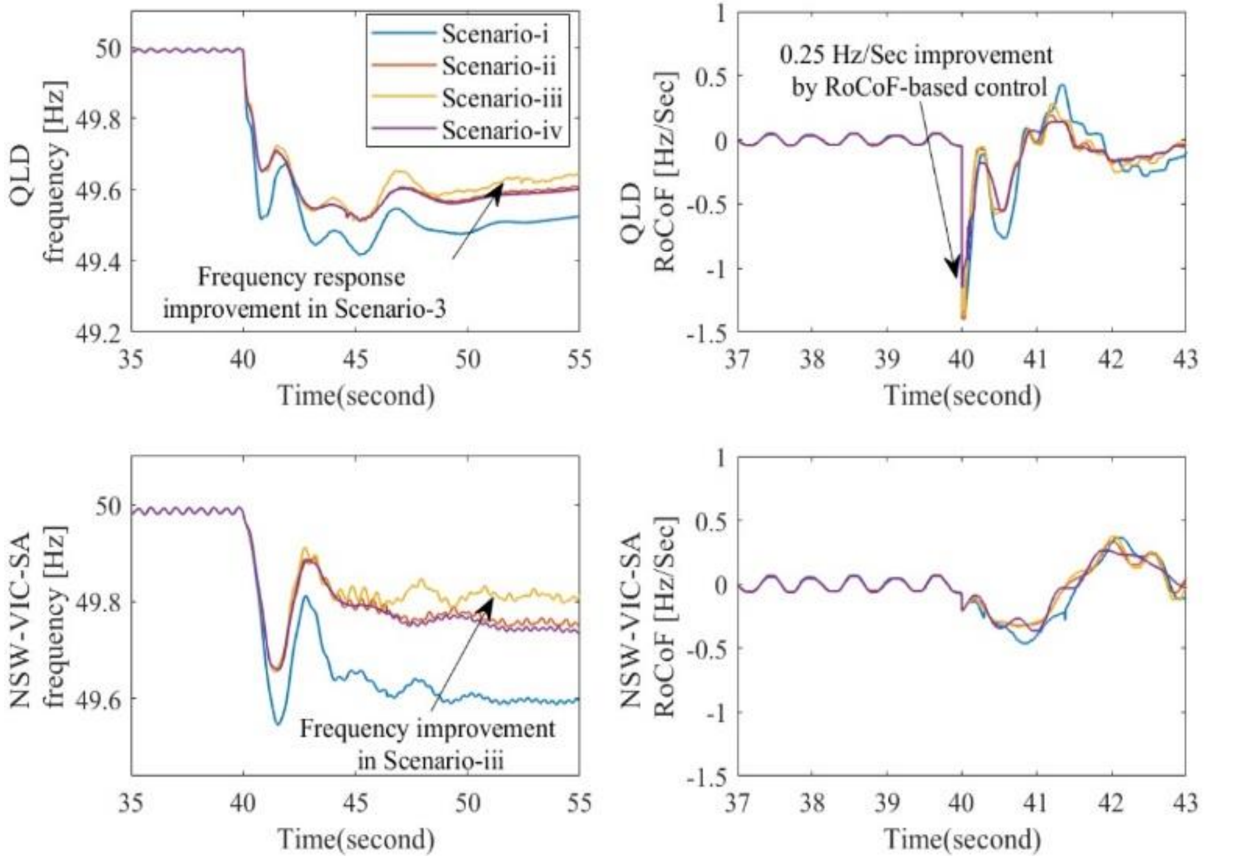
M. Ghazavi Dozein, A. Jalali and P. Mancarella, "Fast Frequency Response From Utility-Scale Hydrogen Electrolyzers," in *IEEE Transactions on Sustainable Energy*, 2021.

Case Studies (1/3):
Fast Frequency Response from Electrolysers

- The following PEM electrolyser scenarios are studied:
  - i) 1GW HE in VIC grid, droop control
  - ii) 1 GW HE in QLD grid, droop control
  - iii) 1 GW HE in QLD grid, sustained droop control
  - iv) 1 GW HE in QLD grid, RoCoF-based control



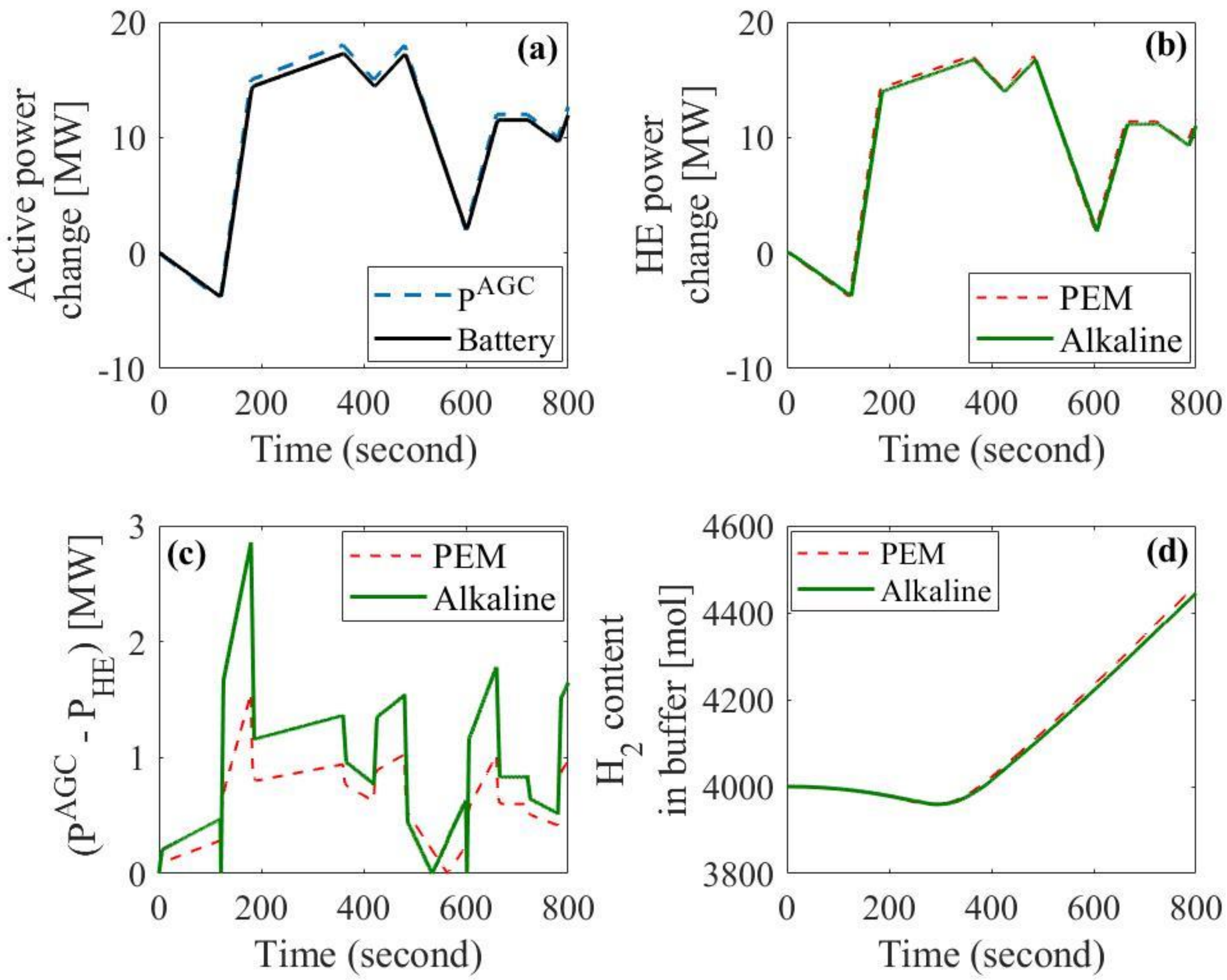
Primary frequency response from electrolysers



System dynamics in different scenarios

M. Ghazavi Dozein, A. Jalali and P. Mancarella, "Fast Frequency Response From Utility-Scale Hydrogen Electrolyzers," in *IEEE Transactions on Sustainable Energy*, 2021.

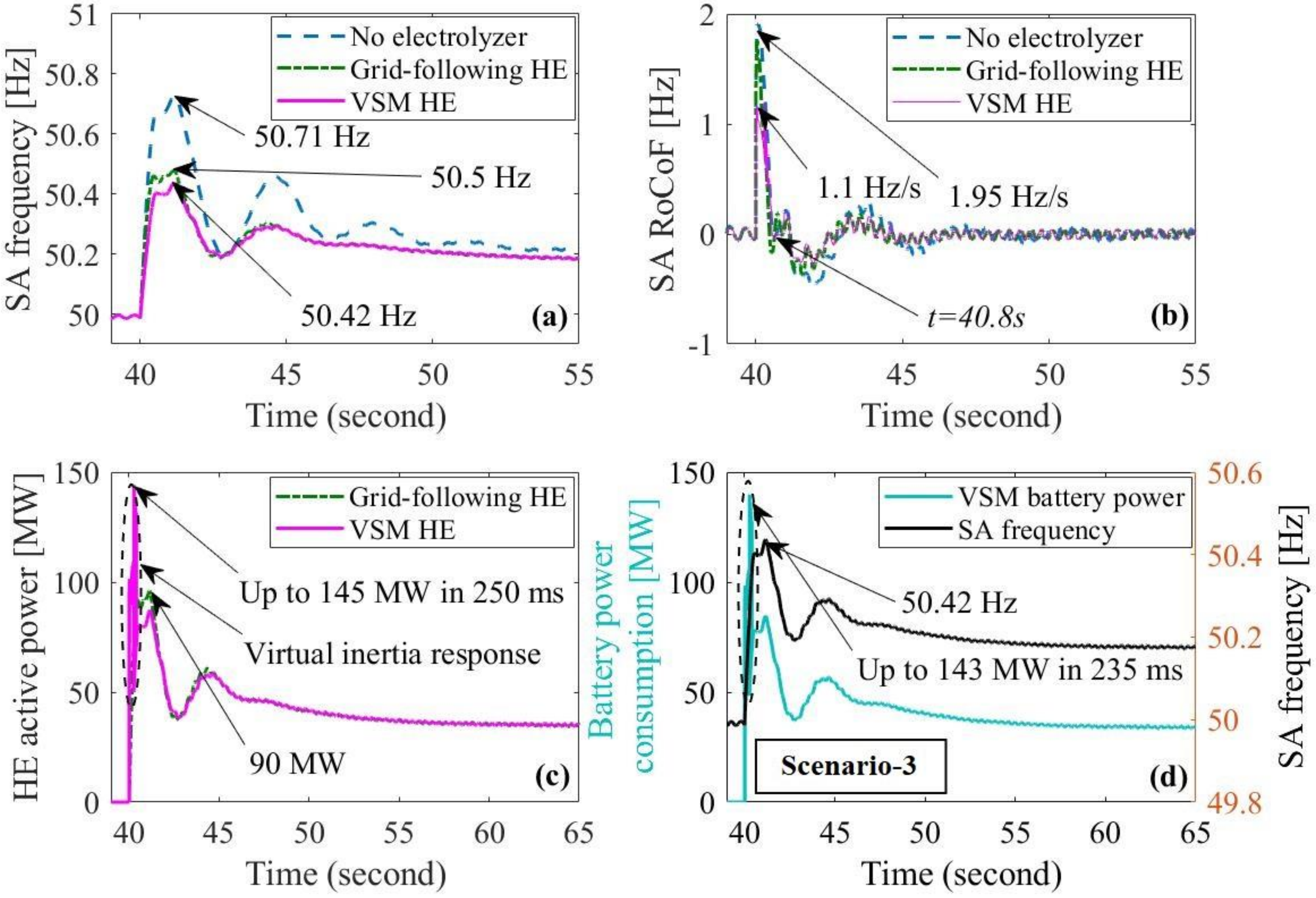
Case Studies (2/3): Regulation FCAS from Electrolysers



M. Ghazavi Dozein, A. M. De Corato, and P. Mancarella, "Virtual Inertia Response and Frequency Control Ancillary Services from Hydrogen Electrolyzers," *Under Review, IEEE Transactions on Power Systems,* 2021.

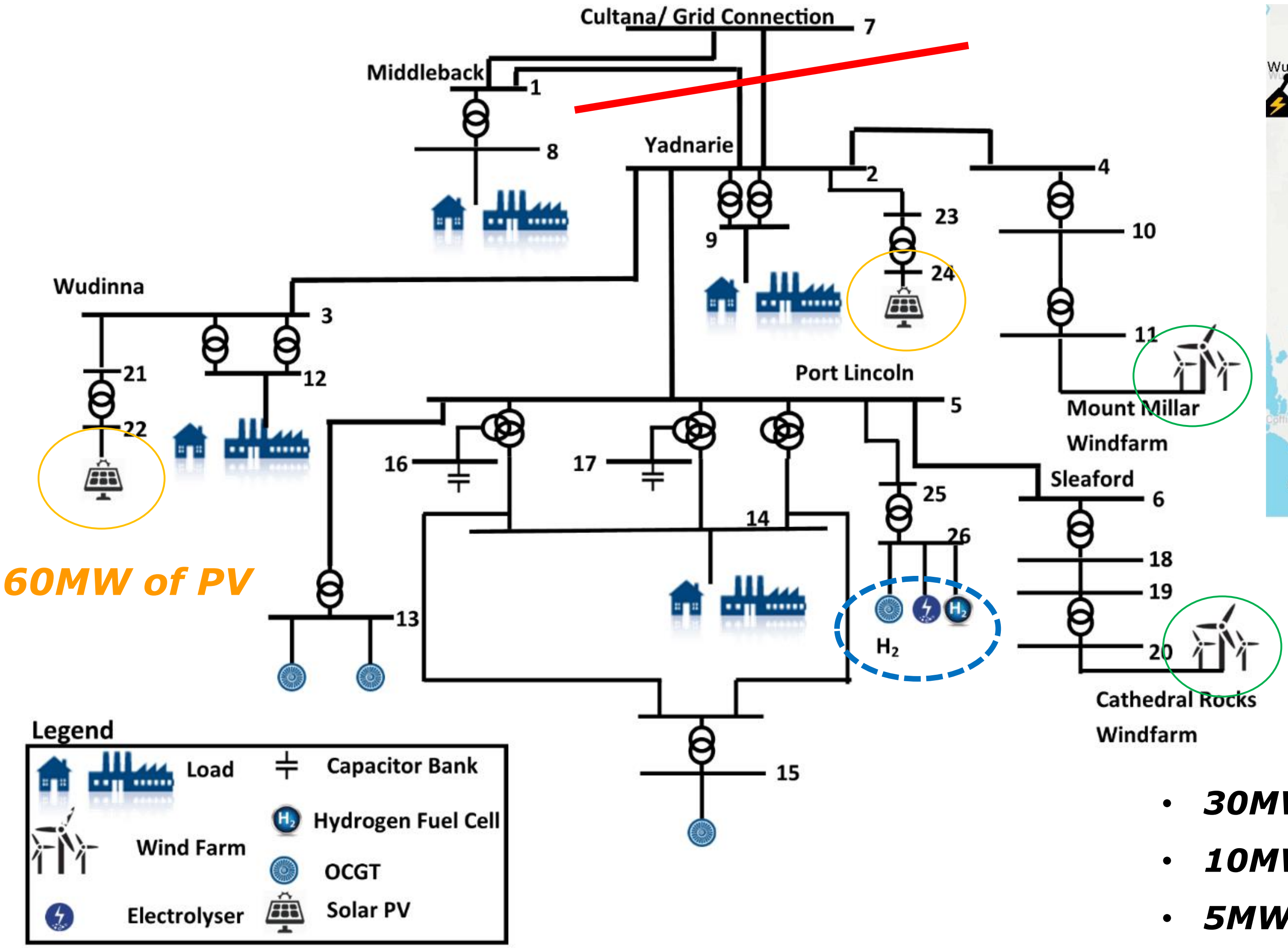
Case Studies (3/3): Virtual Inertia Response from Electrolysers

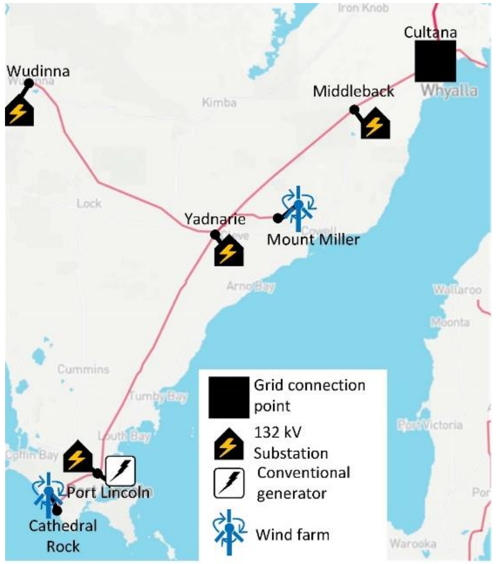
- **Contingency**: Heywood interconnector trips at *t*=40s
- Before the trip, 110 MW was being transferred from SA to VIC
- 150 MW PEM electrolyser in SA
  - ✓ Grid-following
  - ✓ VSM control
- Scenario-3: 150 MW VSM battery



M. Ghazavi Dozein, A. M. De Corato, and P. Mancarella, "Virtual Inertia Response and Frequency Control Ancillary Services from Hydrogen Electrolyzers," *Under Review, IEEE Transactions on Power Systems,* 2021.

Ongoing applications: Hydrogen-RES energy hubs





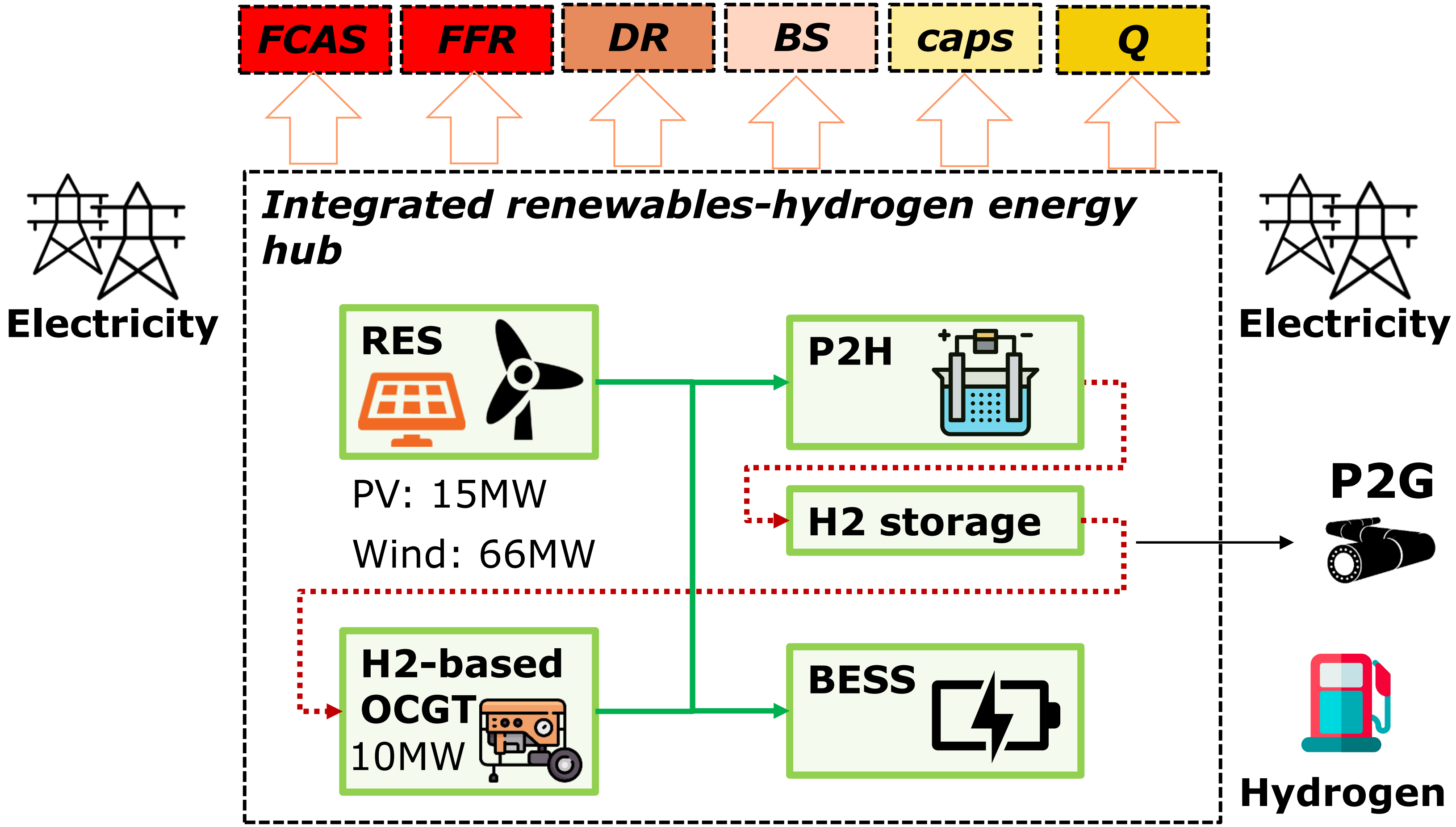
60MW of PV

136MW of Wind

- ***30MW Electrolyser***
- ***10MW H2 OCGT***
- ***5MW Fuel Cell***
- ***100MWh of H2 Storage***
- ***73MW OCGT***

J. Naughton *et al.*, "Optimization of Multi-Energy Virtual Power Plants for Providing Multiple Market and Local Network Services", *Electric Power Syst. Research*, 2020

RES-hydrogen grid and market services



J. Naughton *et al.*, "Optimization of Multi-Energy Virtual Power Plants for Providing Multiple Market and Local Network Services", *Electric Power Syst. Research*, 2020

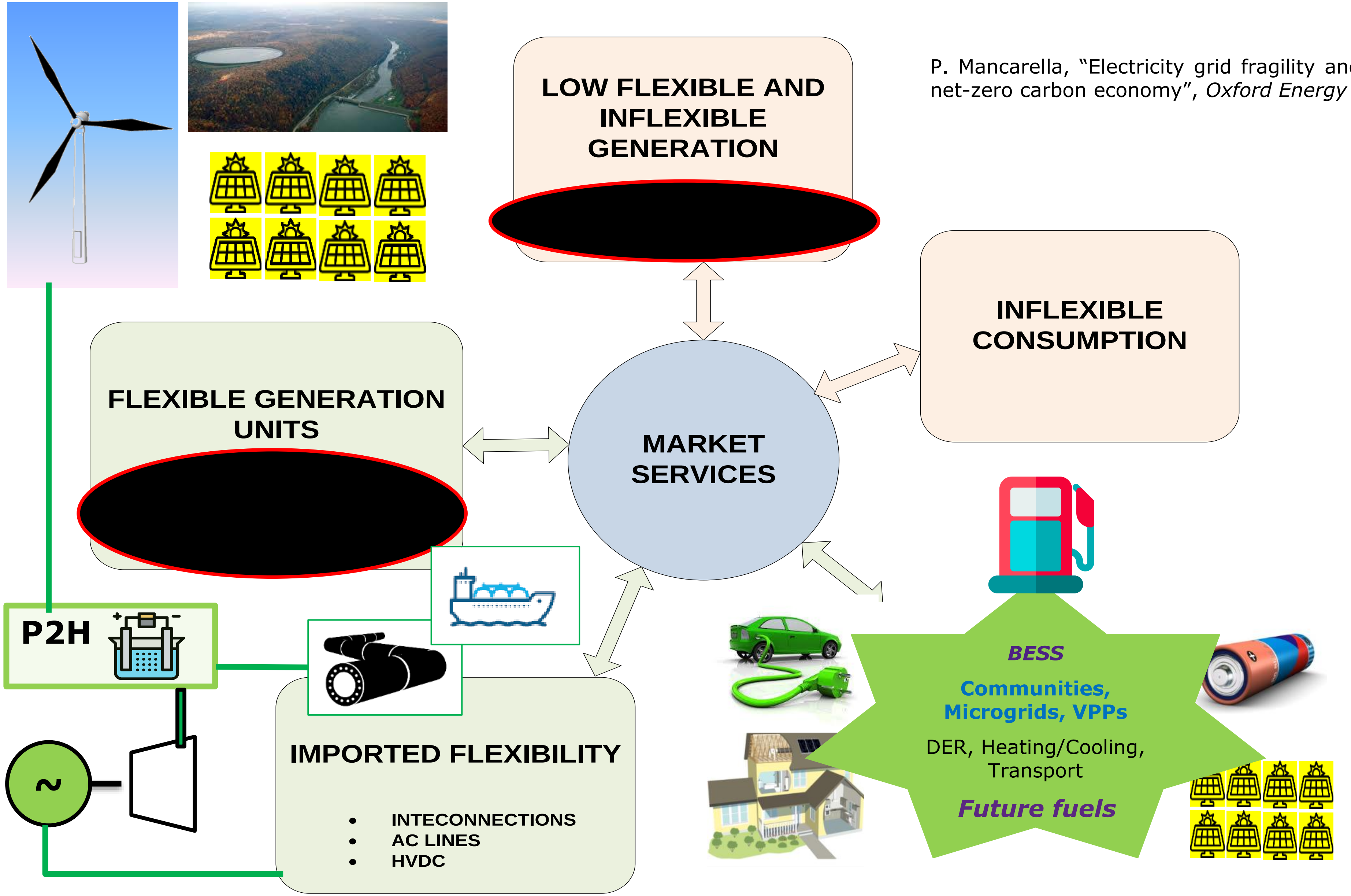
S. Riaz and P. Mancarella, "Modelling and characterization of flexibility from DER", *IEEE Transactions on Power Systems*, 2021

Key Remarks

- The modelling and studies presented here are based on **a unified dynamic modelling framework** for utility-scale electrolysis plants we recently proposed
- **PEM electrolysers** have great **potential** in providing
  - **Fast frequency response (and** primary frequency response**)**
  - **Regulation** FCAS
  - **Virtual inertia response** (if equipped with **virtual synchronous machine** control)
- **Alkaline electrolysers** have great **potential** in providing **regulation** FCAS
- Frequency control from electrolysers **may reduce the need for frequency control-oriented battery installation**
- **Market opportunities** are becoming mature
- Possible **challenges** in providing frequency control from electrolysers
  - Limited converter capacity
  - Interactions with operational constraints in hydrogen production → **cross-sector planning** is required

Sustainability, reliability and resilience in future grids

P. Mancarella, "Electricity grid fragility and resilience in a future net-zero carbon economy", *Oxford Energy Forum*, 2020



Acknowledgments

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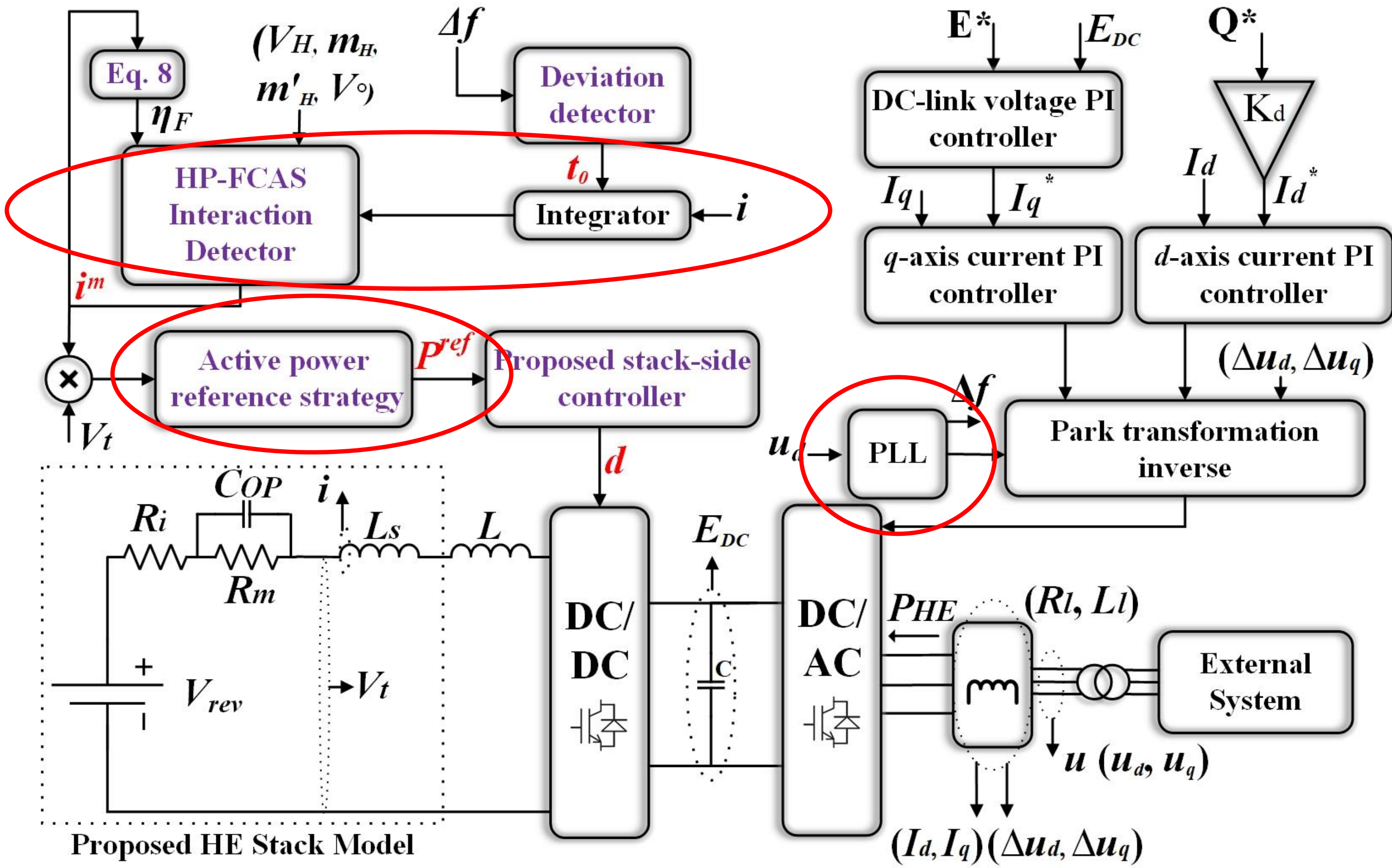
HE Dynamic Model including Power-Electronics Interface and Control

- ***Grid-following*** **control**
  - **Synchronization via phase-locked loop (PLL)**
- **Reactive power** control via grid-side (DC/AC) converter
- **Active power** control via stack-side (DC/DC) converter
- Consideration of **H_2 operational constraints** in converter control loops
- **Active power reference** strategy for frequency stability response provision



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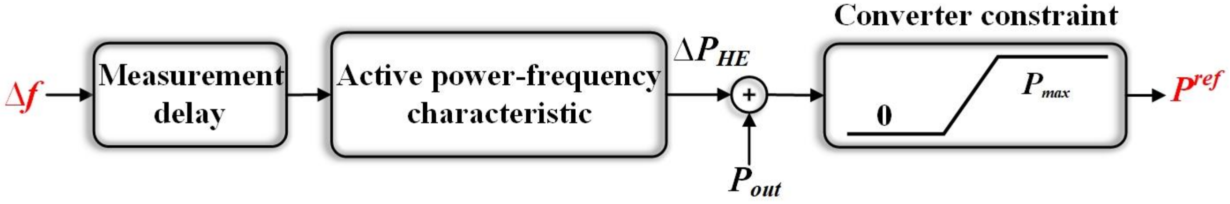
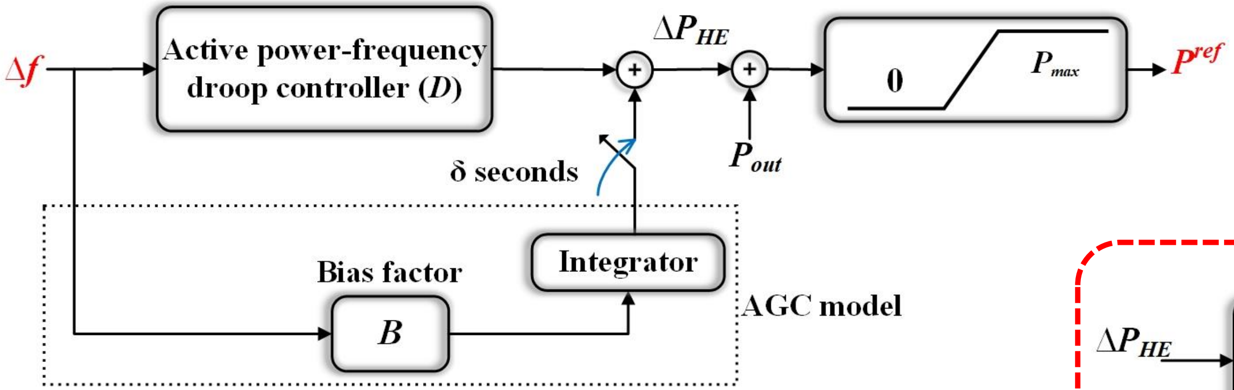
Active Power Reference Strategy (1/2)



(a)



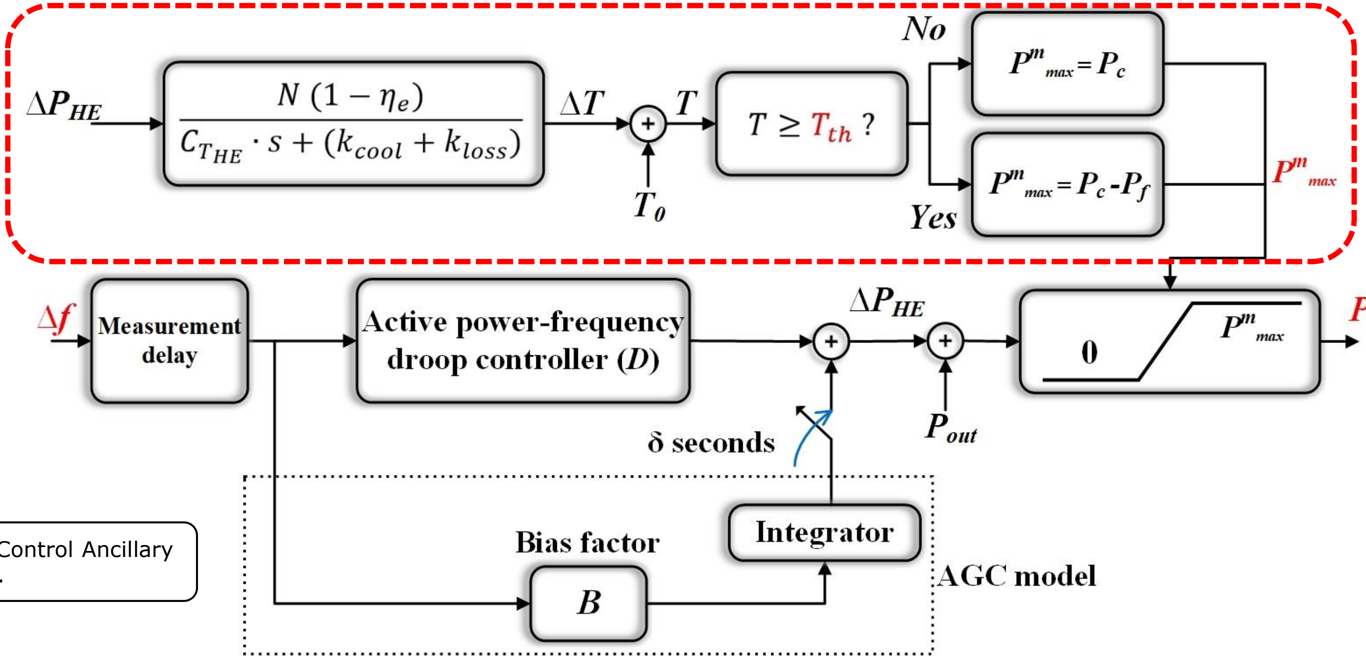
(b)

(a) **Contingency** FCAS

(b) **Contingency** and **Regulation** FCAS

(c) FCAS for **long time durations** (**thermal** sub-model impacts)

M. Ghazavi Dozein, A. Jalali and P. Mancarella, "Fast Frequency Response From Utility-Scale Hydrogen Electrolyzers," in *IEEE Transactions on Sustainable Energy*, 2021.



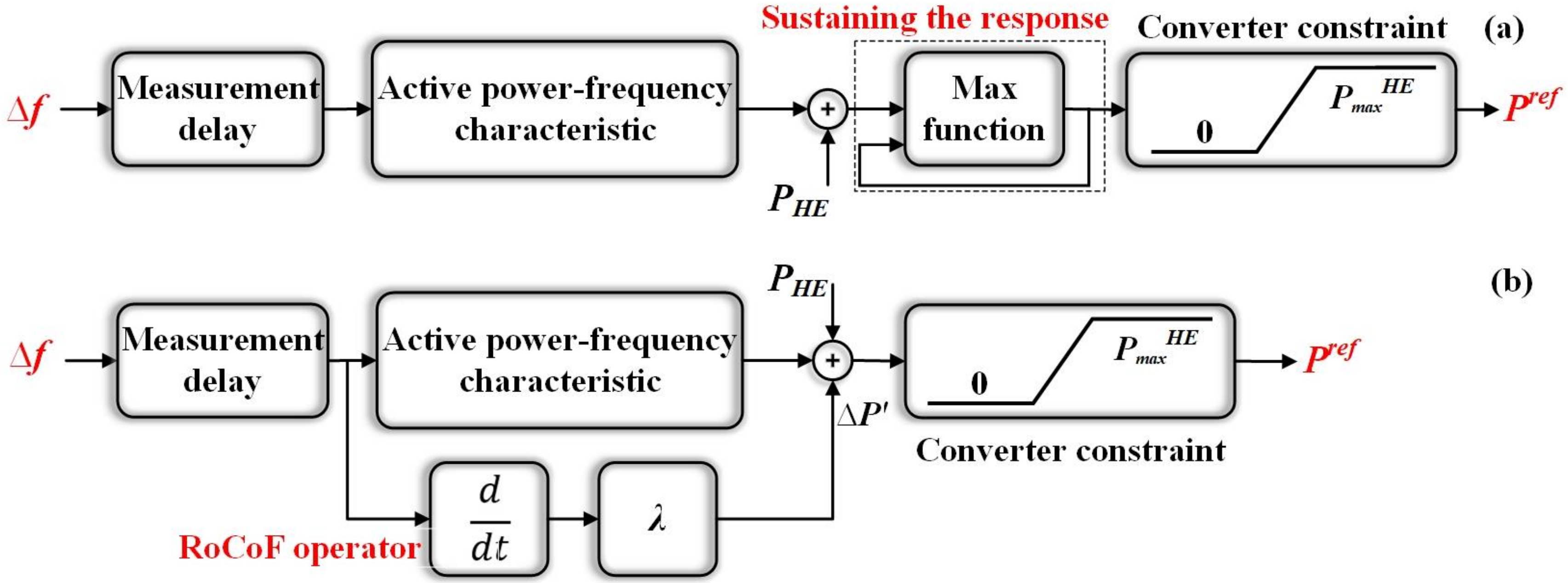
(c)

M. Ghazavi Dozein, A. M. De Corato, and P. Mancarella, "Virtual Inertia Response and Frequency Control Ancillary Services from Hydrogen Electrolyzers," *Under Review, IEEE Transactions on Power Systems,* 2021.

FCAS= Frequency Control Ancillary Services

Active Power Reference Strategy (2/2)

- **Sustained droop response** via the strategy presented in (a)
- **RoCoF-based response** via the strategy presented in (b)
- Both strategies can further be developed to account for **thermal** sub-model impacts



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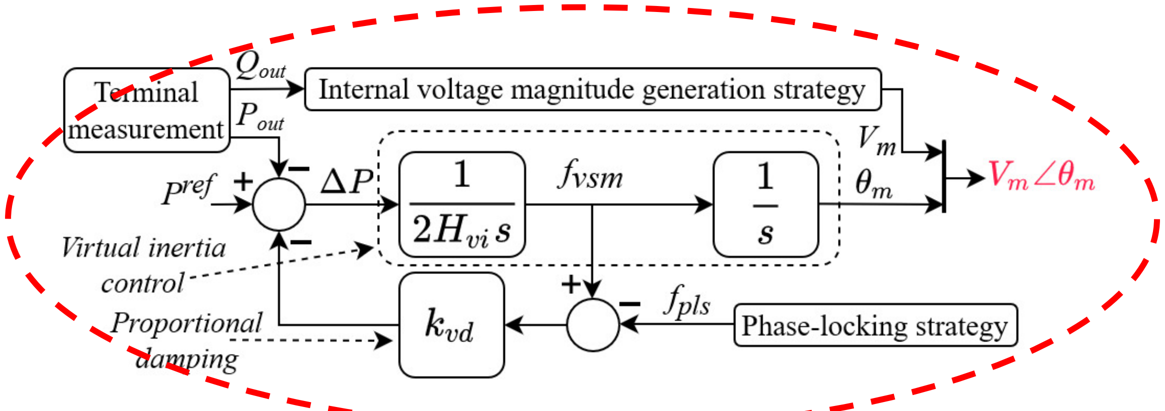
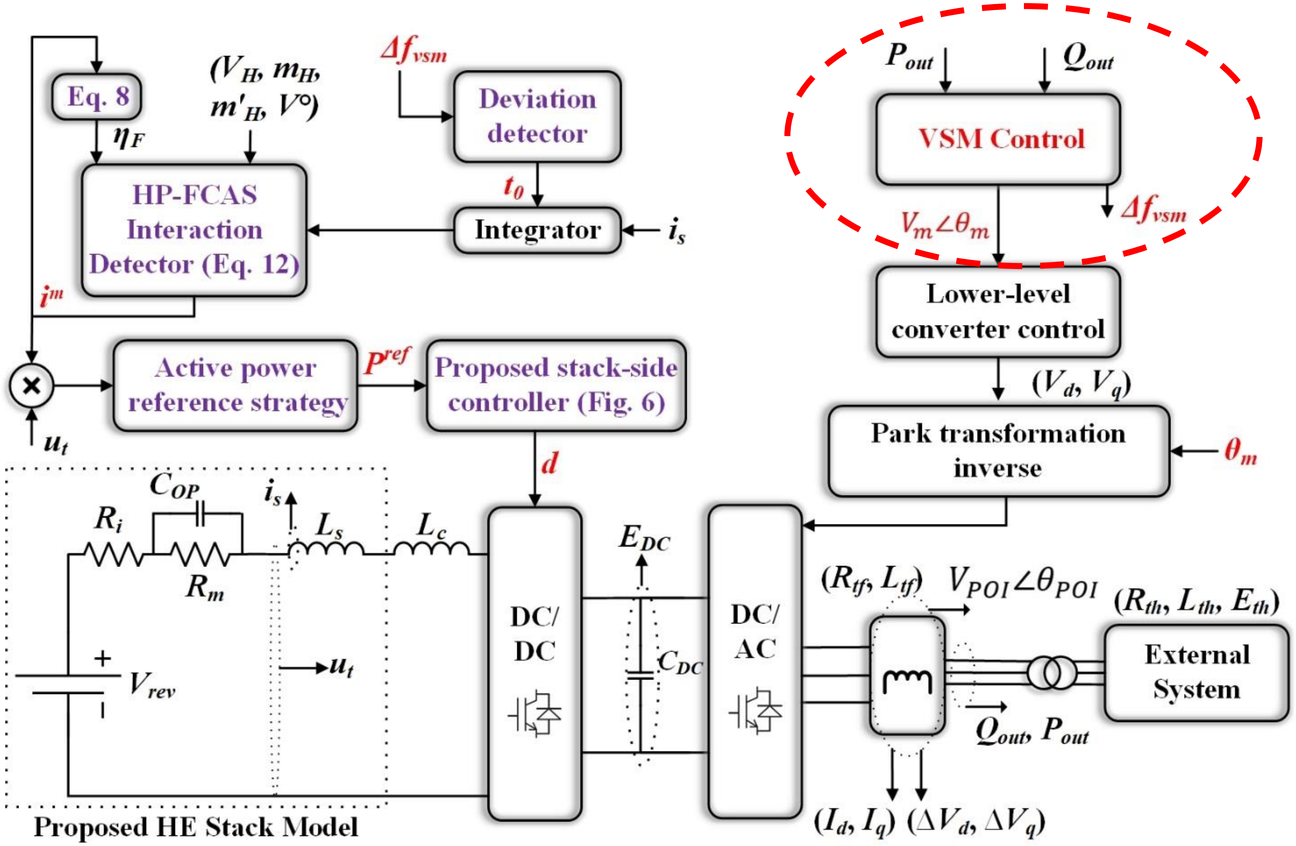
HE Dynamic Model including Power-Electronics Interface and Control

- ***Virtual synchronous machine (VSM) control***
  - **Internally** supplied by a **voltage phasor** for synchronization purposes
- **Virtual inertia response** provision in addition to FCAS



VSM control



Electrolyser dynamic model equipped with VSM control

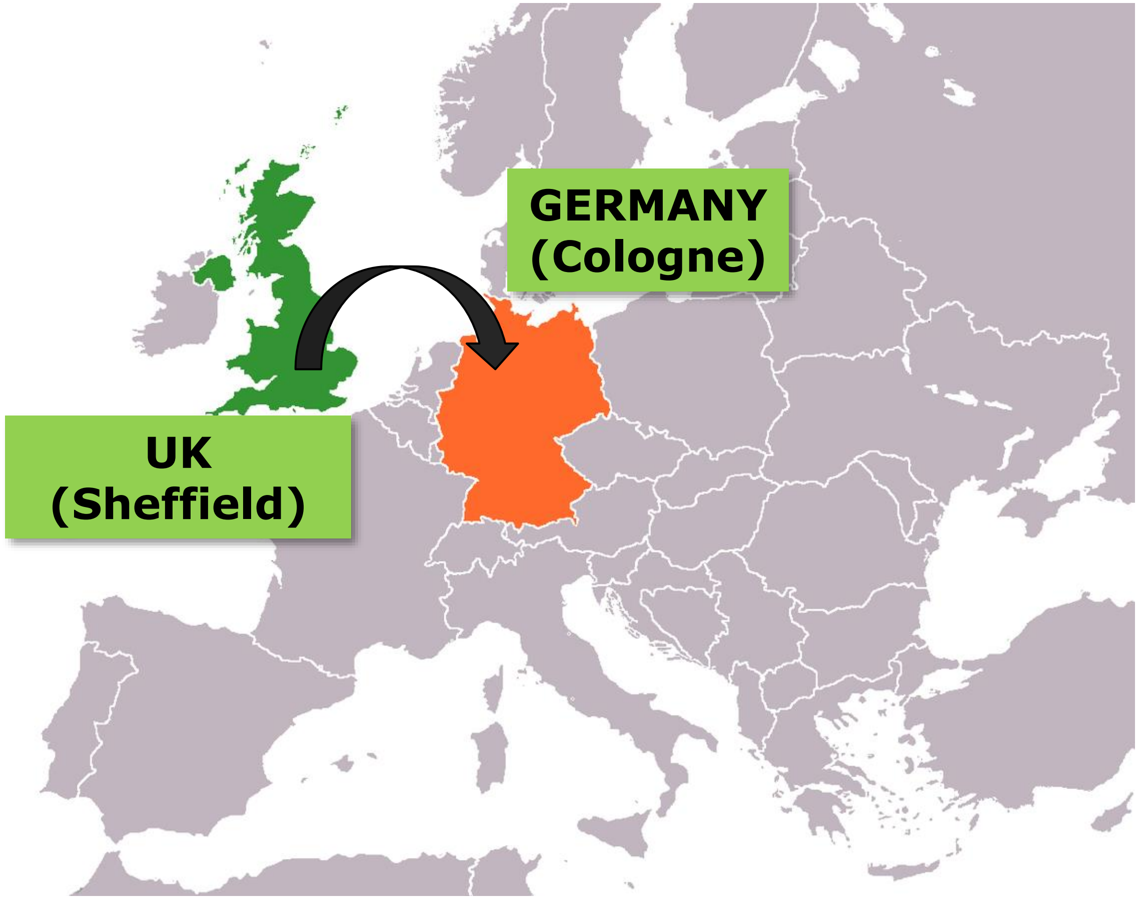
M. Ghazavi Dozein, A. M. De Corato, and P. Mancarella, "Virtual Inertia Response and Frequency Control Ancillary Services from Hydrogen Electrolyzers," *Under Review, IEEE Transactions on Power Systems,* 2021.

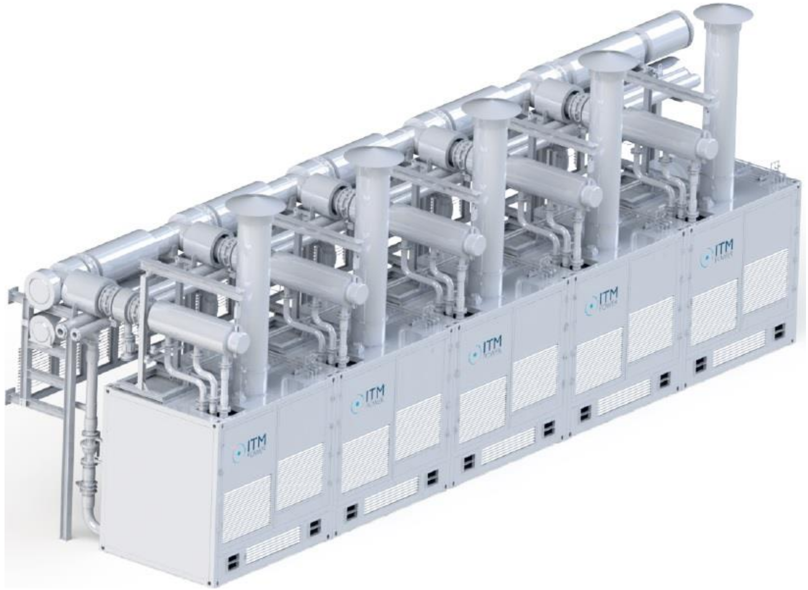
FCAS= Frequency Control Ancillary Services

Real-Life Examples (1/3)

ITM POWER Energy Storage | Clean Fuel

REFHYNE





World's largest PEM electrolyser

Capacity: 100 MW (initially 10 MW), plan for 1000+ MW

Structure: Modular electrolyser

Voltage level: 11 kV (each module)

Grid application: Grid balancing, frequency stability, and voltage stability and control

Response time: in the order of milliseconds

Further information: www.itm-power.com/refhyne

Real-Life Examples (2/3)

ENERGIE PARK MAINZ

Number of electrolysers: 3

Type: PEM (Siemens)

Rating: 1.3 MW, peak power up to 2 MW each

Voltage level: 22 kV

Ramp up/down time: in the order of second(s)

Grid application: Grid balancing and system frequency supports

Further information: www.energiepark-mainz.de

Real-Life Examples (3/3)

Project: HyStock

Country: the Netherlands

Technology: 1 MW PEM electrolyser + 1 MW PV

Grid application: ancillary service provision

Further information: www.energystock.com

Project: H2Future

Country: Austria

Technology: 6 MW PEM electrolyser

Grid application: frequency stability supports

Further information: www.h2future-project.eu

Project: Ontario IESO

Country: Canada

Technology: MW scale PEM and alkaline electrolysers (e.g., 2.5 MW)

Grid application: frequency regulation

Further information: www.cummins.com

Project: HyBalance

Country: Denmark

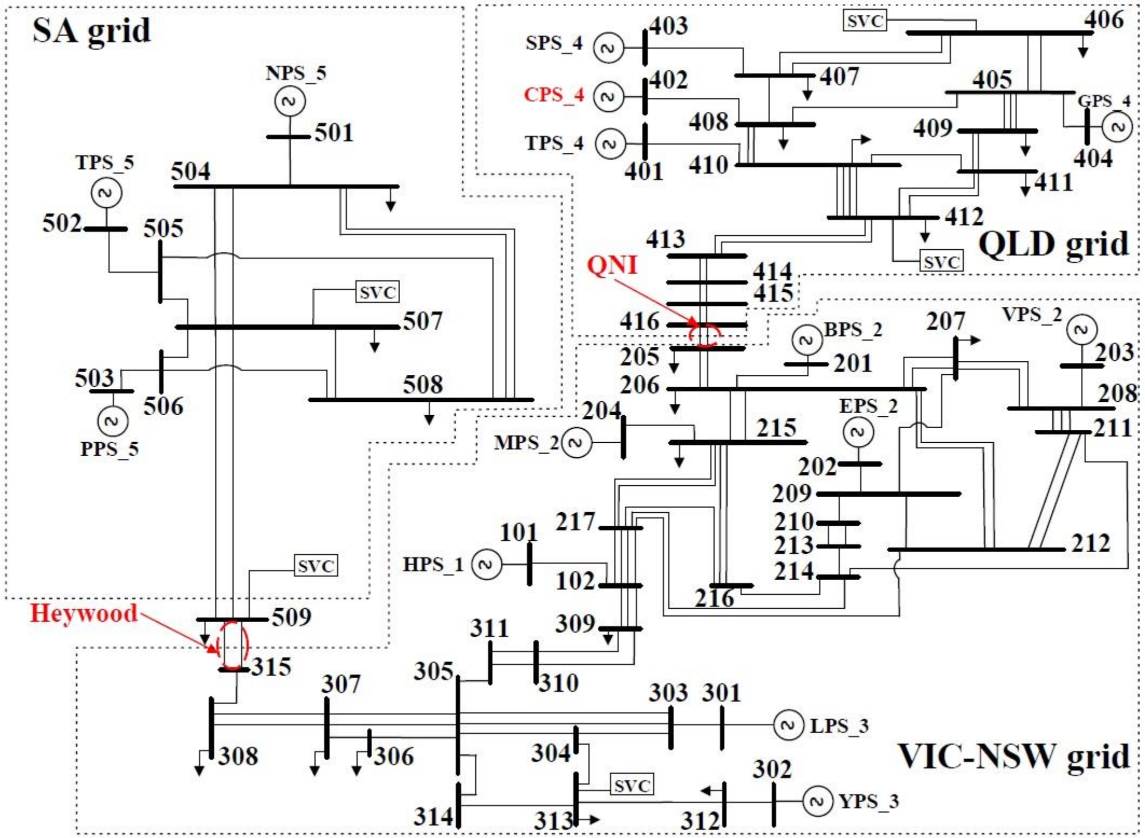
Technology: 1.2 MW PEM electrolyser

Grid application: grid balancing

Further information: www.hybalance.eu

Case Studies: FFR Interaction with Operational/Converter Constraints

- **Contingency**: the Heywood trip at *t*=40s. Before the trip, 110 MW was being transferred from SA to VIC
- The following cases are studied:
  - ✓Case-1: System with **no electrolyzer**
  - ✓Case-2: 1 GW electrolyzer in SA, **no converter overloading capability**
  - ✓Case-3: 1 GW electrolyzer in SA with **10% converter's overloading capability**
  - ✓Case-4: 1 GW electrolyzer in SA grid, and **modelling of hydrogen buffer and downstream H_2 process**



Modified 14-generator NEM grid with 50% renewable penetration

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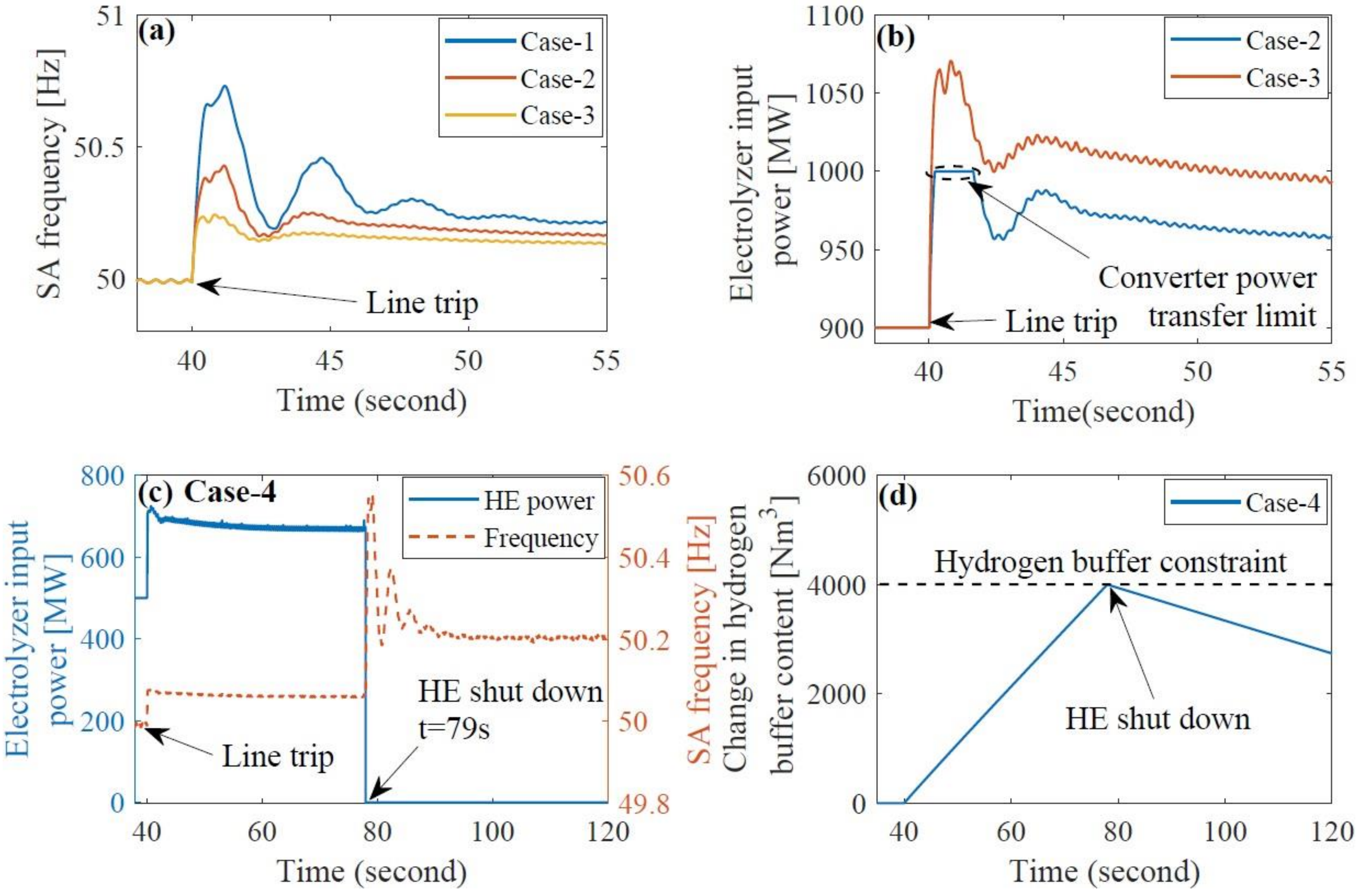

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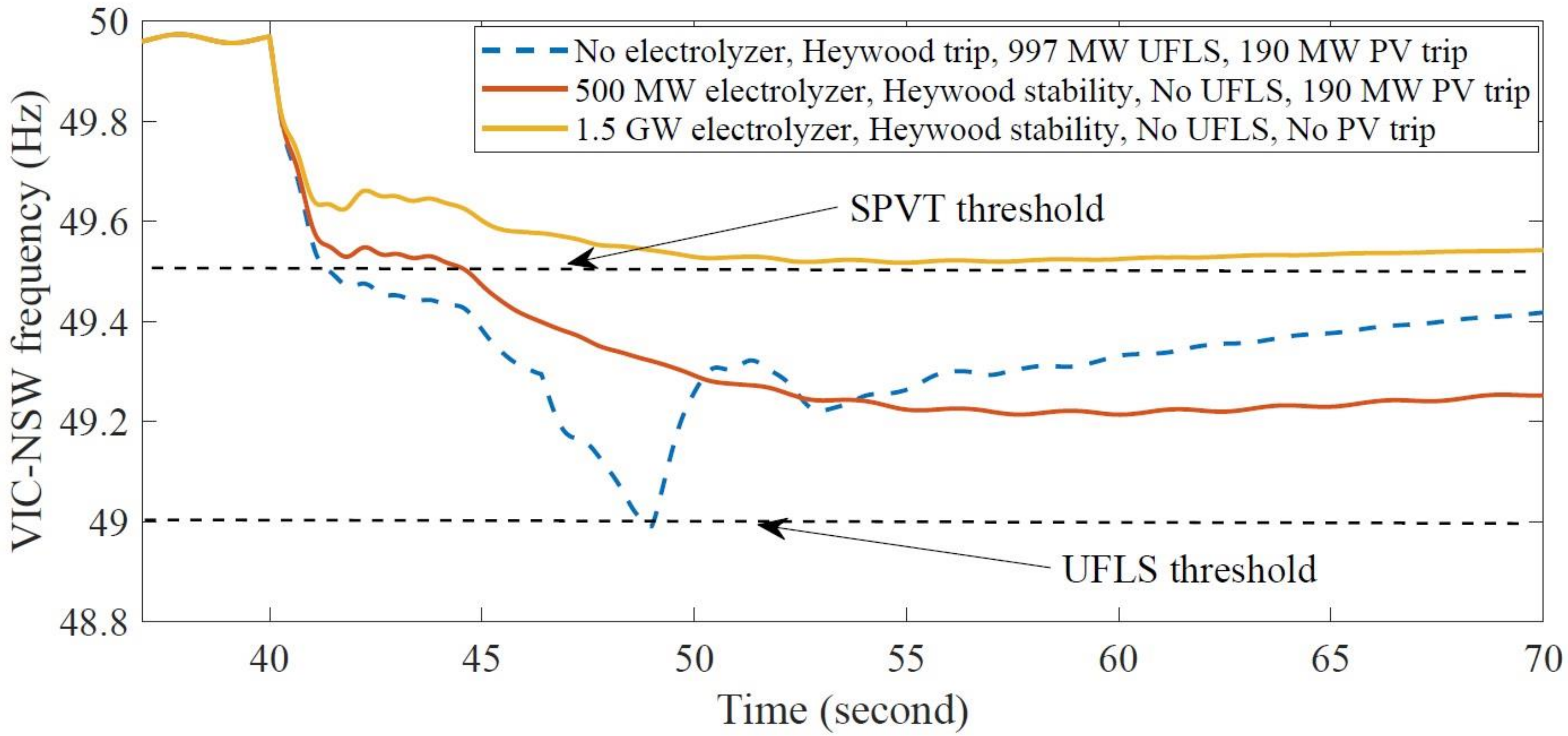
Take-Home Messages

- There are **two potential challenges** in fast frequency response provision from electrolysis plants
  - **Limited converter capacity**
    - Solution: converter overloading
  - **Operational constraints in downstream hydrogen process/buffer**
    - Hydrogen-electricity cross-sector planning for system security supports

Case Studies: Frequency Resilience Support from Electrolysers

- We have investigated the frequency resilience benefits from electrolysers in the context of the August 2018 separation event in Australia



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Take-Home Message: Prevention of cascading failures via frequency control from electrolysers