Control of renewable energy –hydrogen based energy systems for isolated and grid connected applications

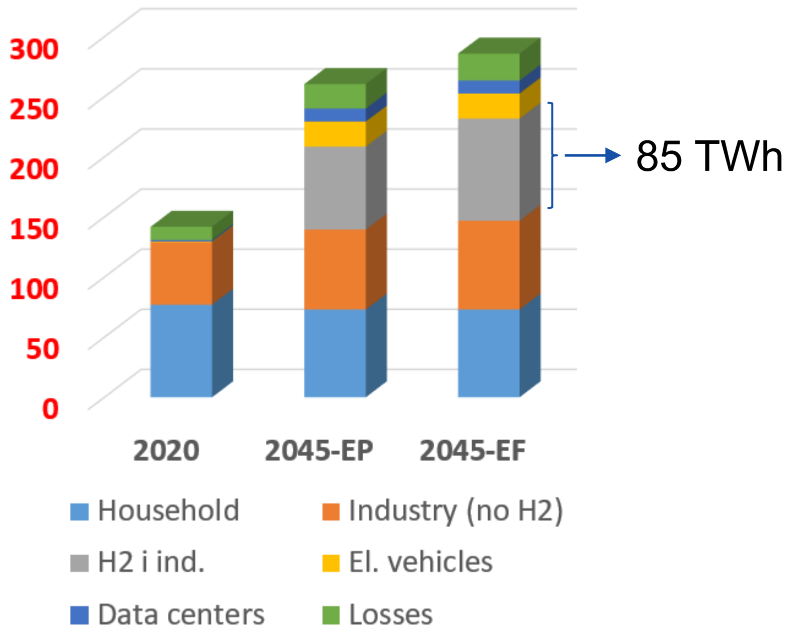
Qianwen Xu
Assistant Professor, KTH
Contact: qianwenx@kth.se

Outline

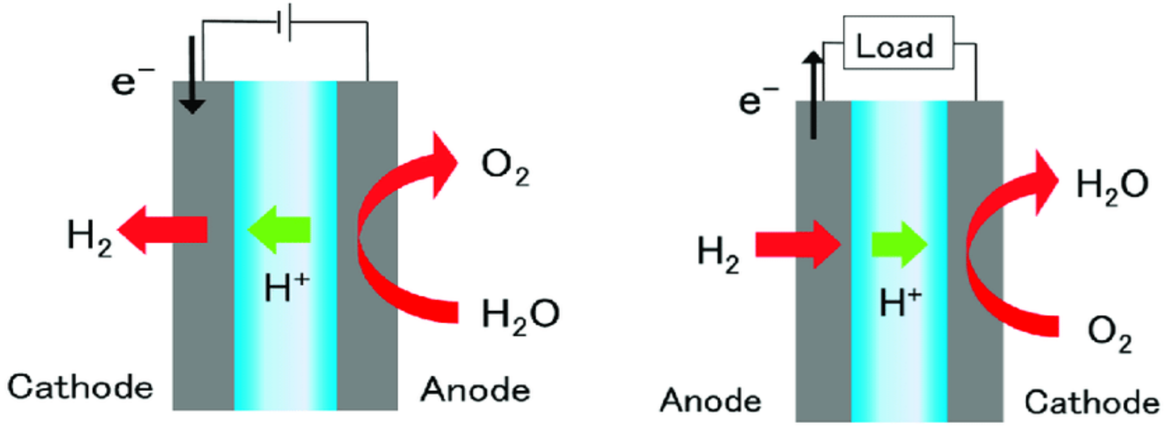
- Background
- Using hydrogen electrolyzer power electronics to balance high share of wind power
- Renewable energy-hydrogen based microgrid for sustainable Arctic communities
- Conclusion

Background

Electric consumption trend (TWh)



Seasonal and fluctuated



Expensive

Long-term energy storage

Environmental friendly

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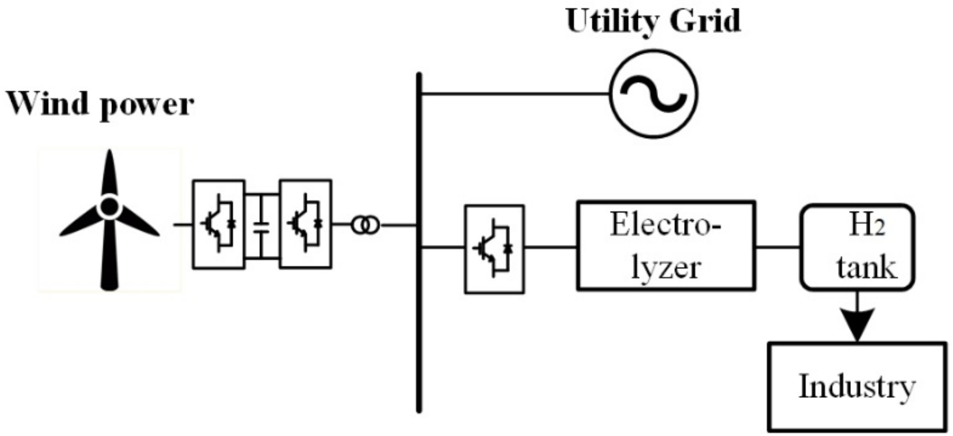
Using hydrogen electrolyzer for frequency control

- **Industry**: **profitable** green **hydrogen** production to decarbonize its processes (e.g., HYBRIT (SSAB, LKAB and Vattenfall) and H2 Green steel)
- **Grid**: Wide utilization of renewable energy
  - Variable generation
  - Lack of intrinsic inertia

Using hydrogen electrolyzer for frequency control to balance high share of renewable energy

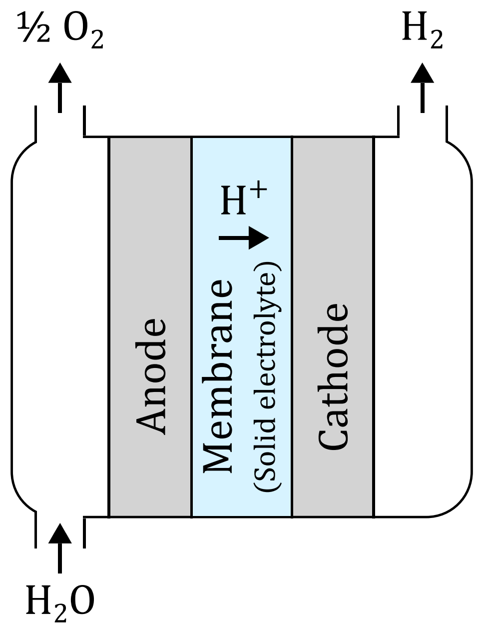
Swedish Energy Agency



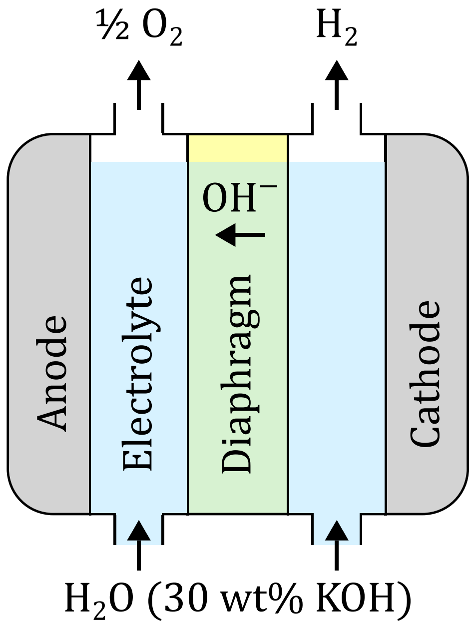
Using hydrogen electrolyzer for frequency control

➢ Electrolyzer technologies

Alkaline electrolyzer (AEL)



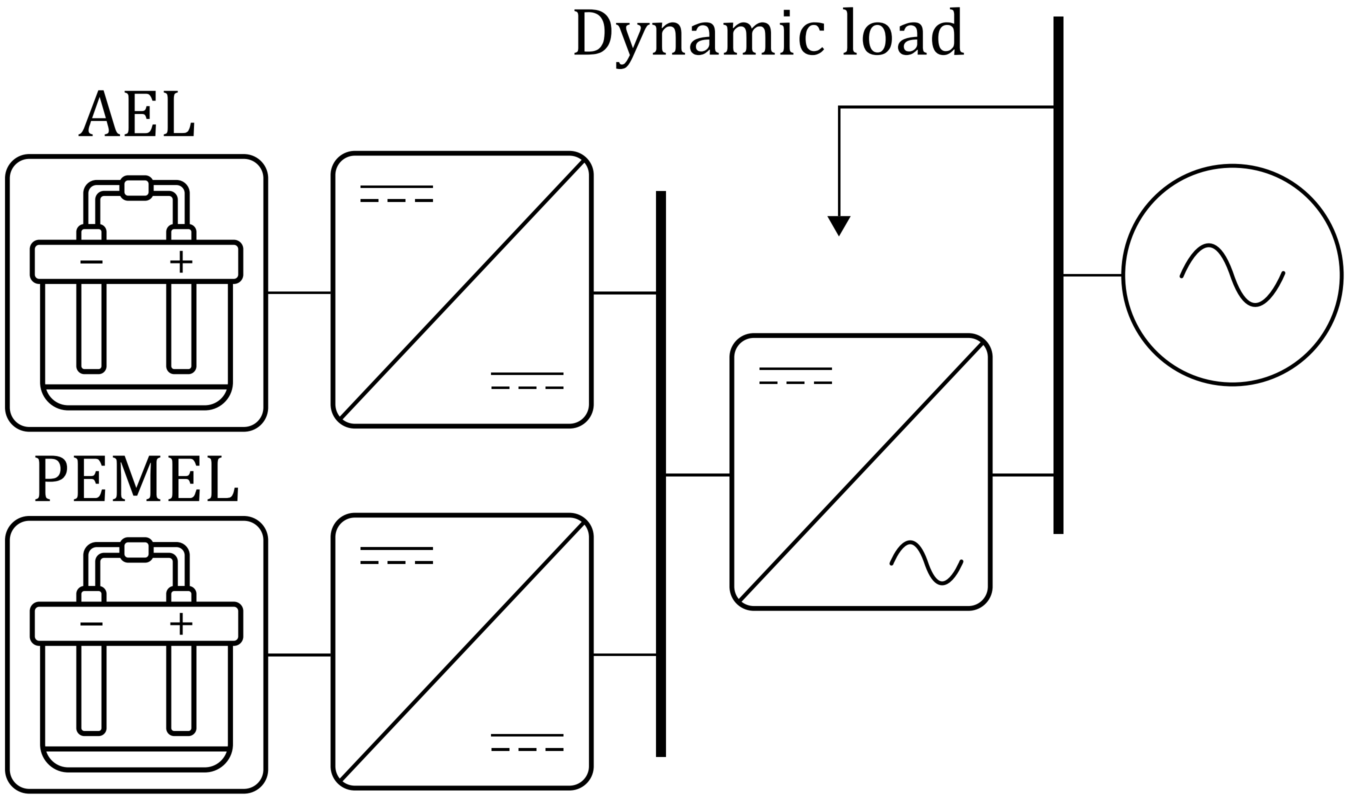
Proton Exchange Membrane Electrolyzer (PEMEL)



Parameter	AEL	PEMEL
CAPEX (USD/kWe)	500 - 1400	1100 - 1800
Lifetime (operating hours)	60000 - 90000	30000 - 90000
Load range (%)	10 - 110	0-160
Settling time	seconds	tens of ms

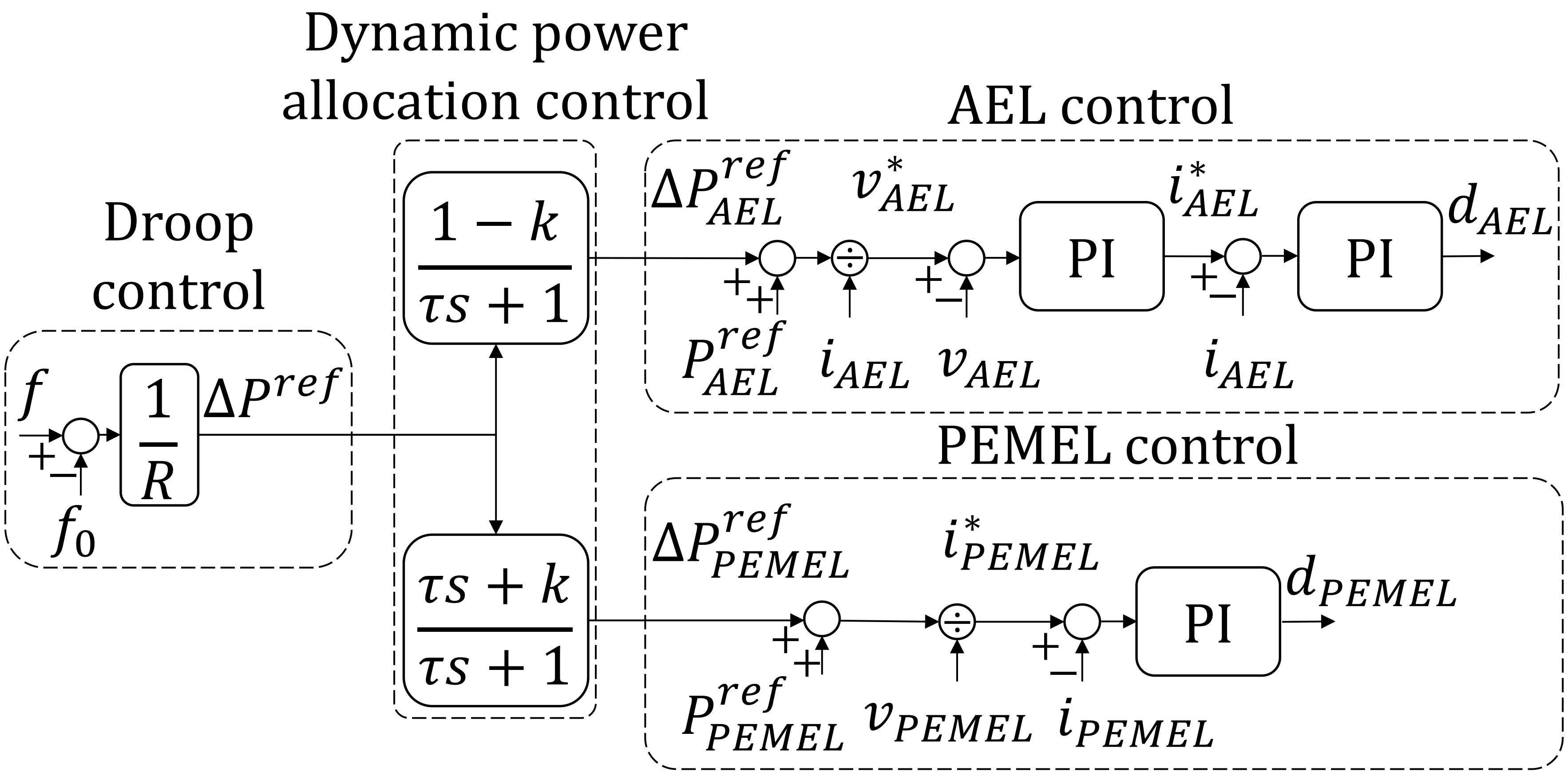
Using hydrogen electrolyzer for frequency control

- Proposed hybrid **AEL+PEMEL** system for frequency control: **cost effective** solution to provide **frequency regulation**



Using hydrogen electrolyzer for frequency control

➢ **Proposed dynamic power sharing strategy**



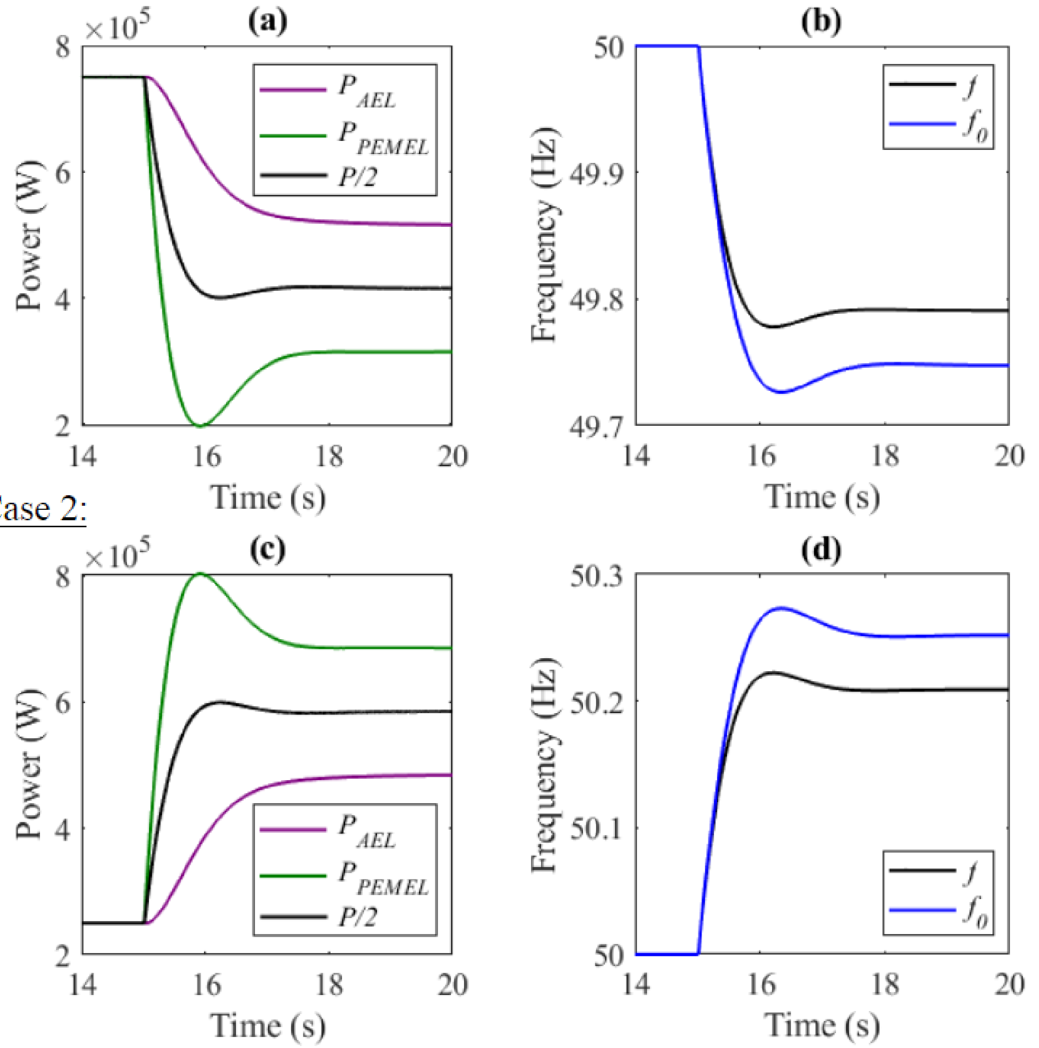
Using hydrogen electrolyzer for frequency control

➢ Simulation results

Parameter	Case 1	Case 2
P_{AEL}^{ref} (GW)	0.75	0.25
P_{PEMEL}^{ref} (GW)	0.75	0.25
ΔP_l (GW)	+3.5	−3.5
ΔP_G^{ref} (GW)	1.5	4
τ (s)	0.66	
k	0.65	
R (Hz/GW)	0.313	
P_G^{base} (GW)	40	
T_R (s)	0.2	
T_T (s)	0.3	
H (s)	5	
D (p.u.)	10	
R_G (p.u.)	0.1	
f_0 (Hz)	50	
v_{dc}^{ref} (V)	1200	
Q^{ref} (VAr)	0	
Sampling frequency (kHz)	100	

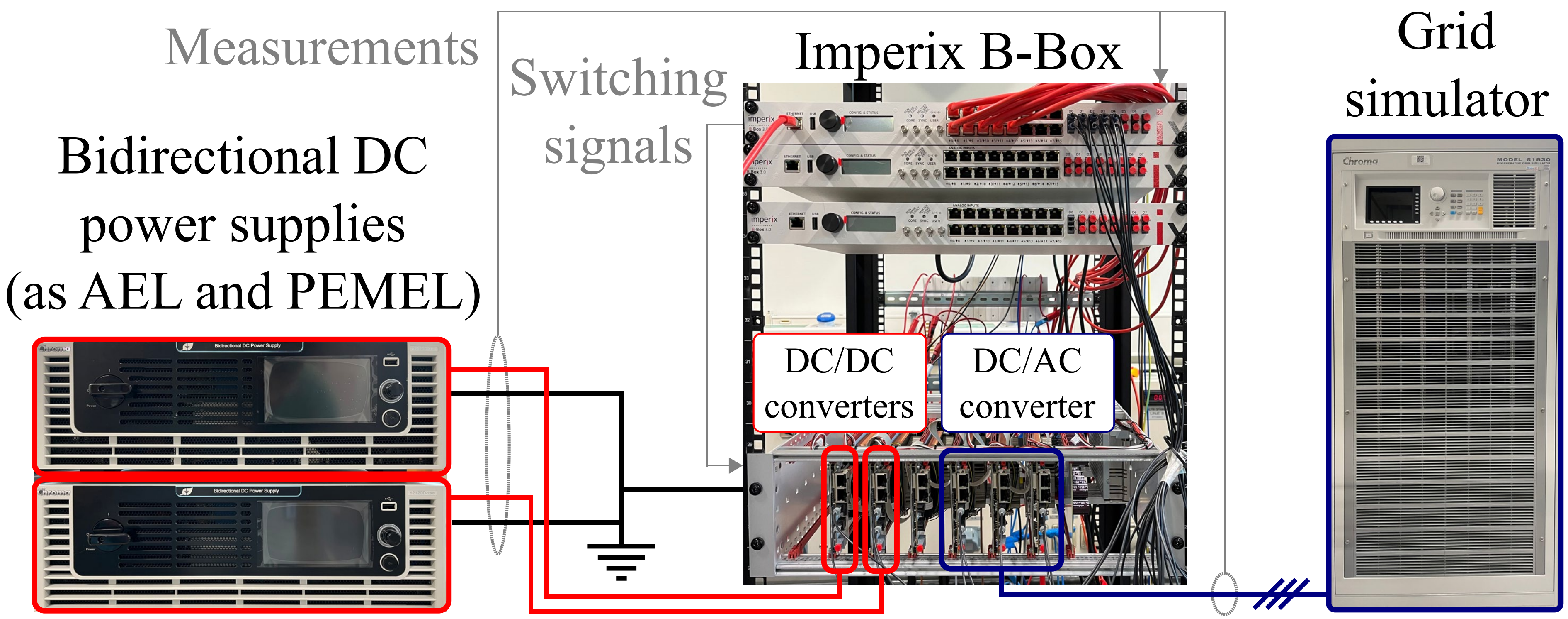
Case 1:

Case 2:



Using hydrogen electrolyzer for frequency control

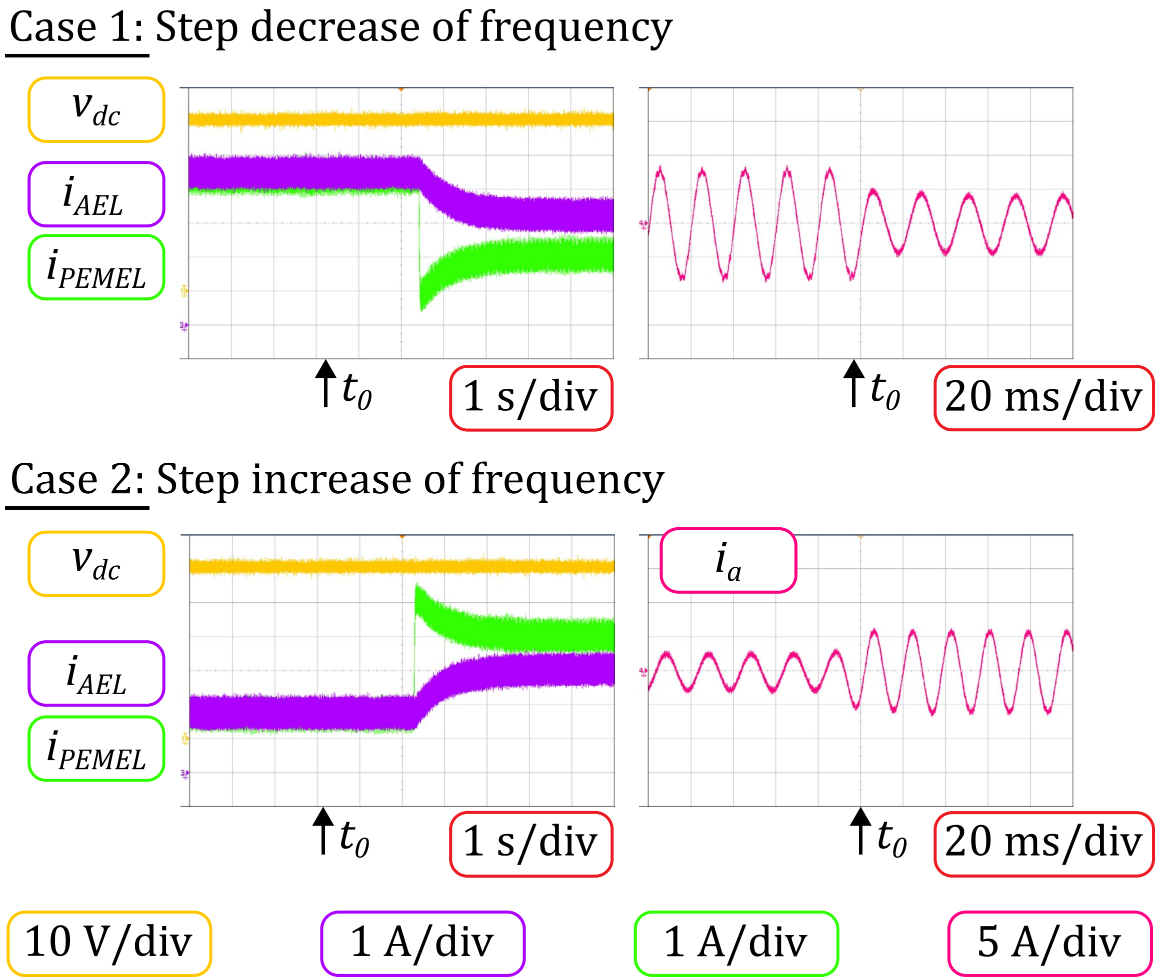
➢ **Experimental setup**



Using hydrogen electrolyzer for frequency control

➢ Experimental results

Parameter	Case 1	Case 2
P_{PEMEL}^{ref} (W)	125	50
Δf (Hz)	-5	$+5$
P_{AEL}^{ref} (W)	125	50
P_{PEMEL}^{ref} (W)	125	50
Δf (Hz)	-5	$+5$
τ (s)	0.66	
k	0.65	
R (Hz/W)	0.05	
f_0 (Hz)	50	
v_{dc}^{ref} (V)	50	
Q^{ref} (VAr)	0	
Sampling frequency (kHz)	20	
Switching frequency (kHz)	20	
Voltage AEL PS (V)	25	
Voltage PEMEL PS (V)	25	
Phase voltage GS (V)	14.4	



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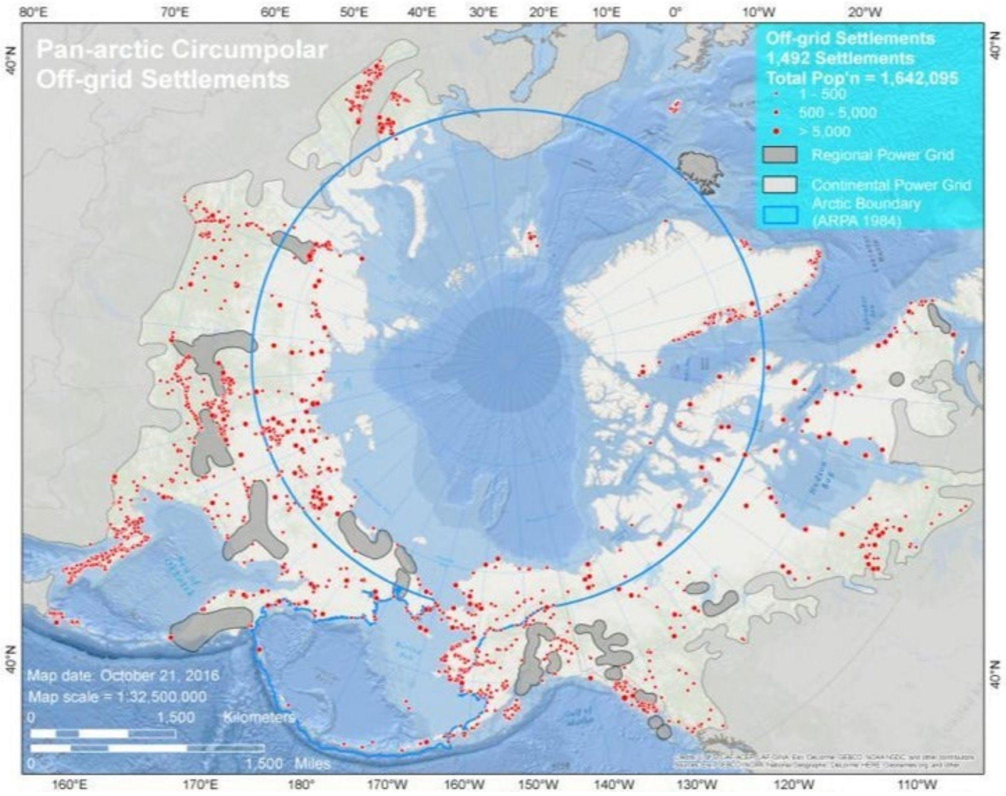
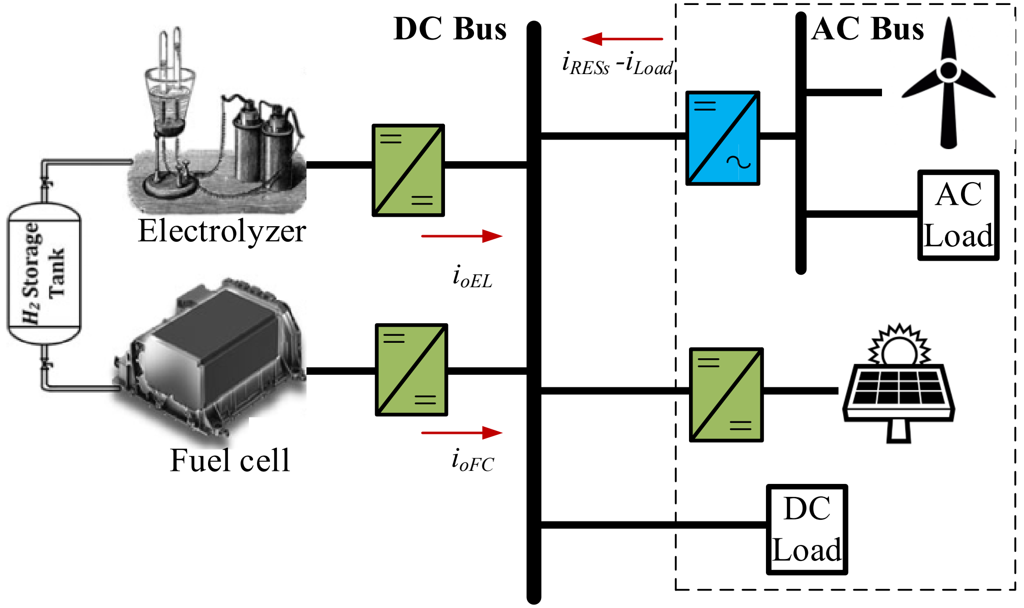
Renewable energy-hydrogen based microgrid for sustainable communities

➢ Proposed renewable energy-hydrogen based microgrid

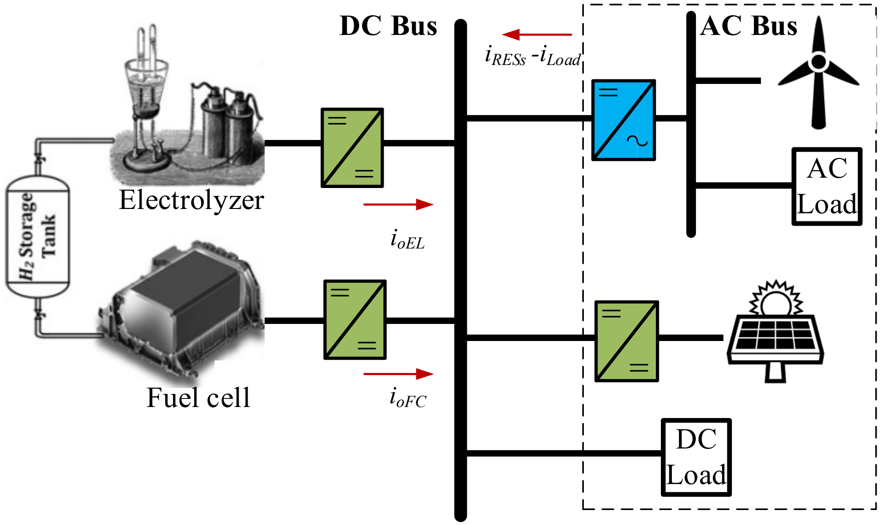
Arctic areas

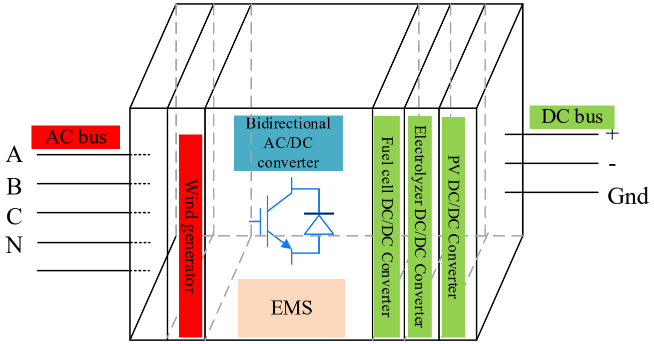




Renewable energy-hydrogen based microgrid for sustainable communities

➢ Proposed renewable energy-hydrogen based microgrid





Efficiency and lifecycle of electrolyzer and fuel cell

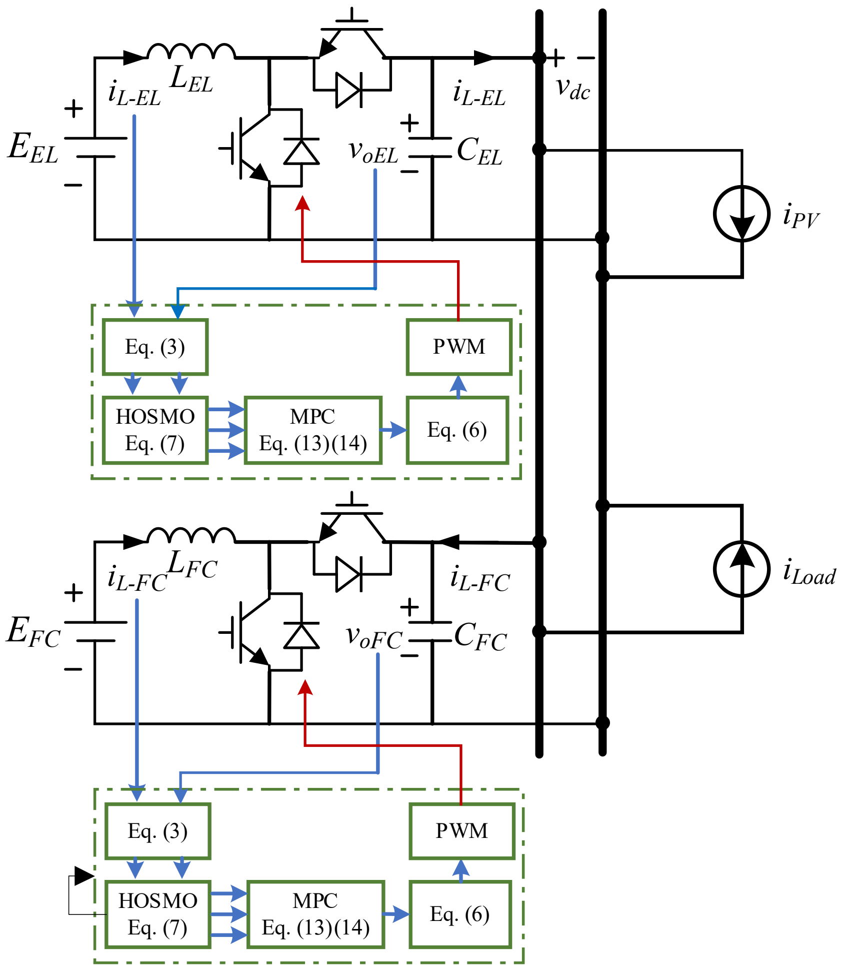
Low inertia and instability

Sustainable and economic requirement

Complex deployment and expertise requirement

Renewable energy-hydrogen based microgrid for sustainable communities

➢ Proposed composite MPC based control



Model transform

Eq. (3)
$$\begin{cases} \dot{x}_{1i} = x_{2i} + D_i \\ \dot{x}_{2i} = v_i \end{cases}$$

Higher-order sliding mode disturbance observer (HOSMO) design

Eq. (7)
$$\begin{aligned}
\dot{z}_{10i} &= v_{10i} + x_{2i}, \dot{z}_{11i} = v_{11i}, \dot{z}_{12i} = v_{12i}, \dot{z}_{13i} = v_{13i} \\
v_{10i} &= -3L_i^{1/4}\operatorname{sig}^{3/4}(z_{10i} - x_{1i}) + z_{11i} \\
v_{11i} &= -2L_i^{1/3}\operatorname{sig}^{2/3}(z_{11i} - v_{10i}) + z_{12i} \\
v_{12i} &= -1.5L_i^{1/2}\operatorname{sig}^{1/2}(z_{12i} - v_{11i}) + z_{13i} \\
v_{13i} &= -1.1L_i\operatorname{sign}(z_{13i} - v_{12i}) \\
\hat{D}_{1i} &= z_{11i}, \widehat{\dot{D}}_{1i} = z_{12i}, \widehat{\ddot{D}}_{1i} = z_{13i}
\end{aligned}$$

MPC control law design

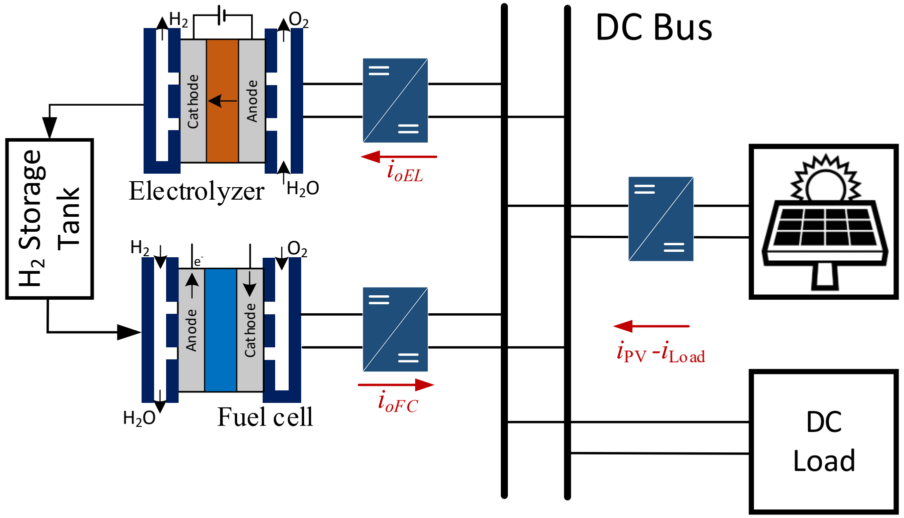
Eq. (13)
Eq. (14)
$$v_{mpci} = \mathcal{I}\left[\tilde{V}_{is} - \mathcal{T}_3^{-1}\mathcal{T}_2^{\top}(\bar{X}_i - \bar{X}_{is})\right] = v_s - K(\bar{X}_i - \bar{X}_{is})$$
$$\begin{aligned}
v_i &= v_{mpci} - \begin{bmatrix} k_{1i} & 1 \end{bmatrix}\hat{D}_i \\
&= v_{is} - k_{0i}(x_{1i} - x_{1is}) - k_{1i}(x_{2s} - x_{2s} + \hat{D}_i)
\end{aligned}$$

Control transform back

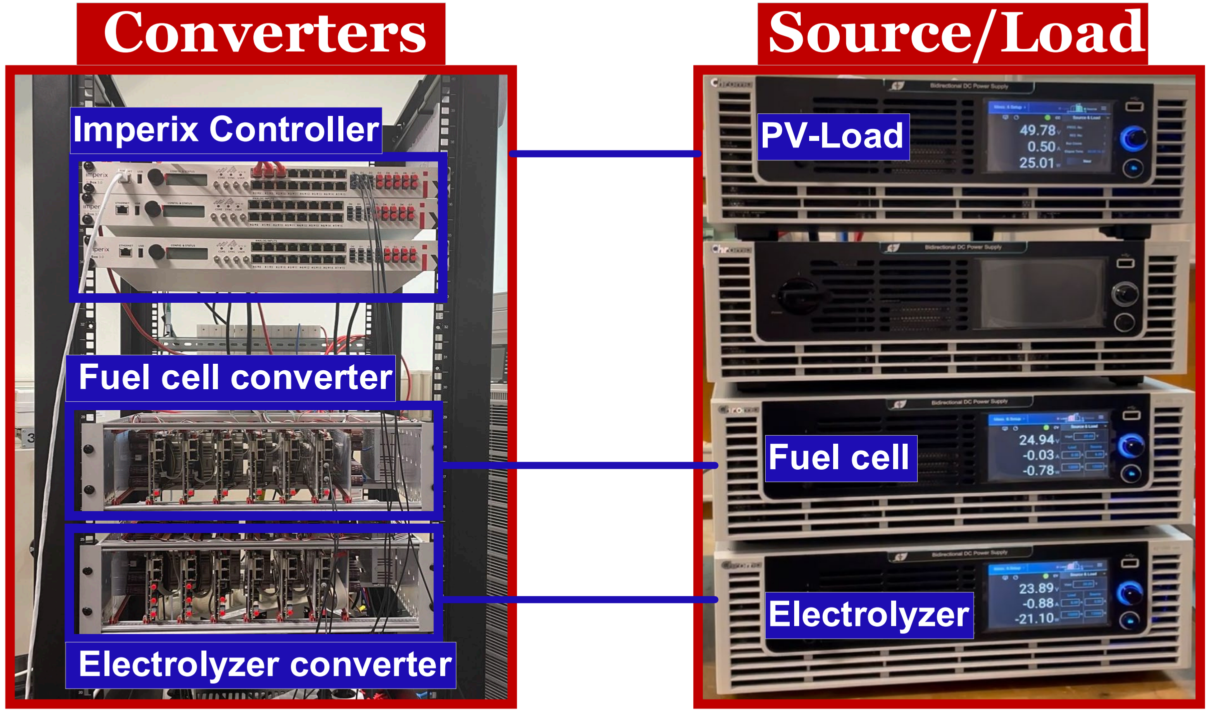
Eq. (6)
$$d_i = 1 - \left(\frac{E_i^2}{L_i} - v_i\right) \Big/ \left(\frac{E_i v_{oi}}{L_i}\right)$$

Renewable energy-hydrogen based microgrid for sustainable communities

➢ Experimental prototype



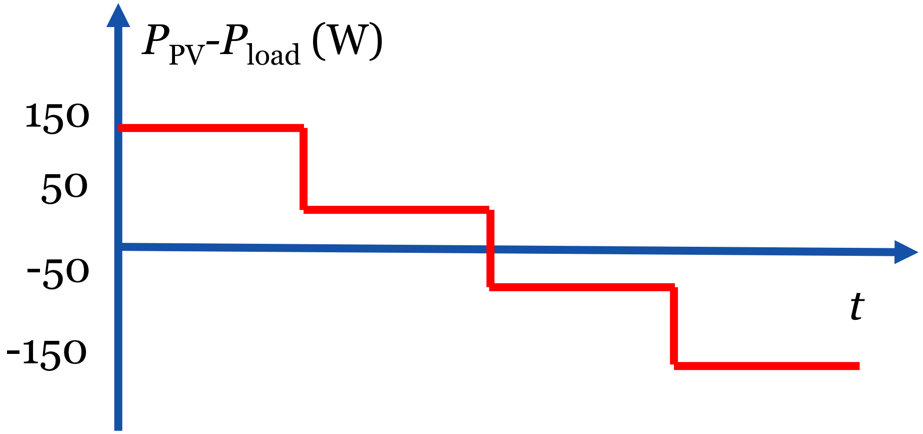
Schematic of PV-hydrogen based DC microgrid

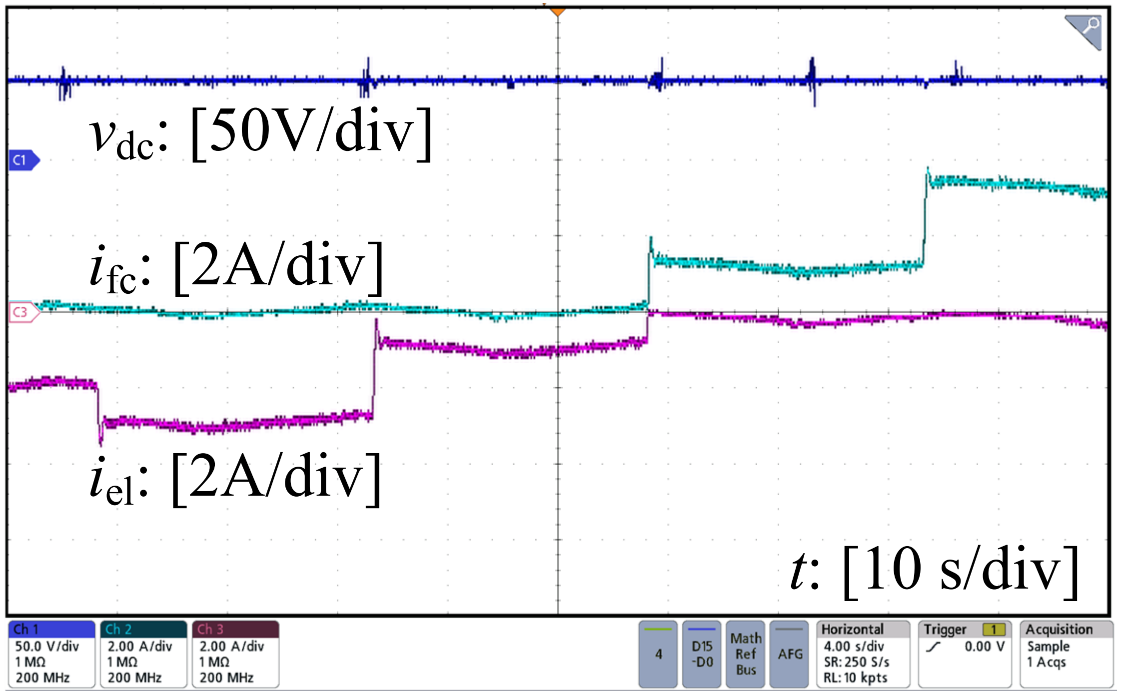


Experiment setup of PV-hydrogen based DC microgrid

Renewable energy-hydrogen based microgrid for sustainable communities

➢ Experimental results





Conclusion

- A design and dynamic power sharing strategy for hybrid electrolyzer systems for frequency control for the grid with a high share of renewable energy
- A modular design and advanced control strategy is developed for renewable energy-hydrogen systems for sustainable electricity supply in Arctic regions.

Award

Winner of ”Nordic Energy Challenge 2022”

“With a descriptive demonstration and a well-reasoned selection of sources, the winning candidate demonstrates good understanding of the barriers and opportunities faced by Arctic remote energy grids.
With a clear technical approach, the project is targeting specific barriers for integrations of multi-technical energy sources and storage of energy in hydrogen.
The project intends to develop proof of concept for different (known) technologies/hardware to better overcome problems for microgrids. Hence, the project proposal could have a very high degree of innovation.”
By Klaus Skytte, CEO at Nordic Energy Research;


NORDIC ENERGY CHALLENGE 2022

FIRST PLACE

Awarded to Qianwen Xu

Renewable energy-hydrogen based microgrid for sustainable Artic communities

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Klaus Skytte
CEO, Nordic Energy Research

Nordic Energy Research

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Thank you very much for your attention!

https://www.kth.se/profile/qianwenx

M.A. Torres, Q. Xu, M. Zhang, S. Lennart, A. Cornell, Dynamic Power Allocation Control for Frequency Regulation Using Hybrid electrolyzer Systems. 38th Annual IEEE Applied Power Electronics Conference and Exposition (APEC), Orlando, Florida, 2023, accepted

M. Zhang and Q. Xu, An MPC Based Power Management Method for Renewable Energy Hydrogen Based DC Microgrids. 38th Annual IEEE Applied Power Electronics Conference and Exposition (APEC), Orlando, Florida, 2023, accepted