INL/CON-19-56096-Revision-0

Modeling Electrolysis-based H2 Production for Grid Service Assessment

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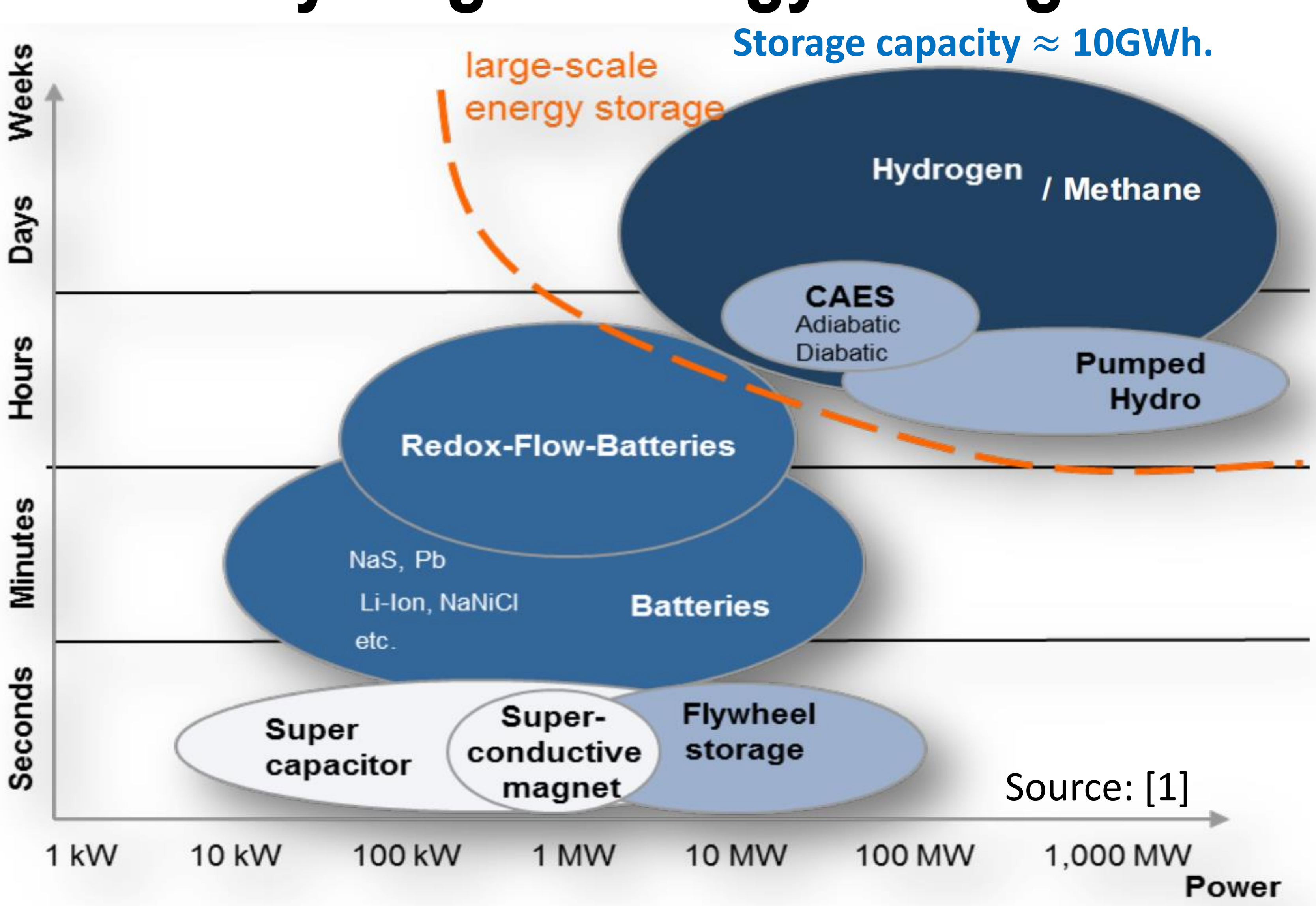
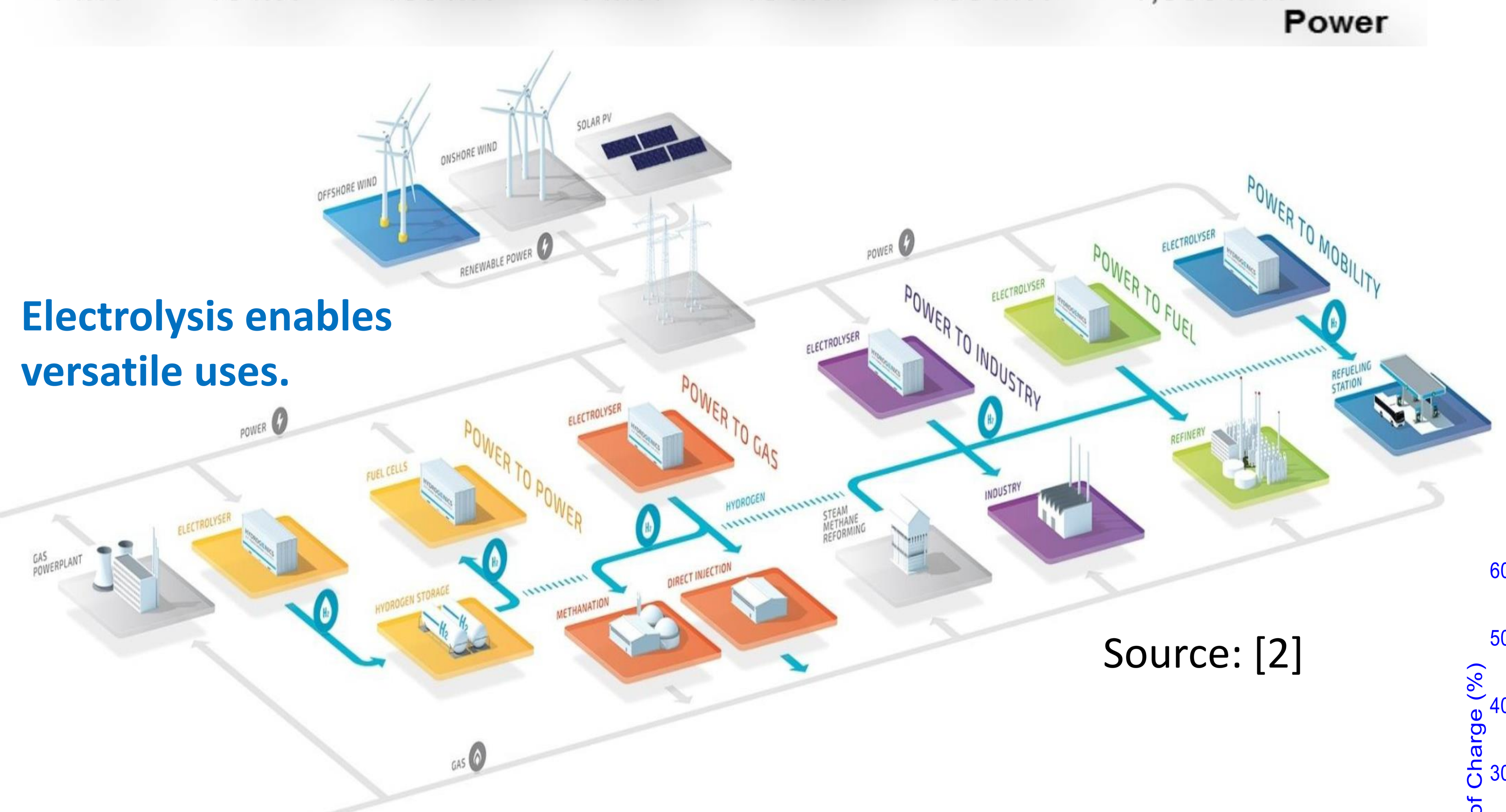
Hydrogen Energy Storage



Source: [1]

Electrolysis enables versatile uses.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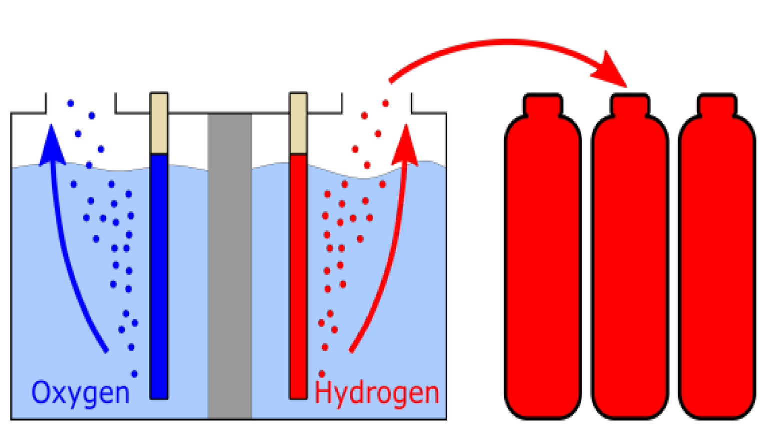
Electrolyzer Model



i: current density. I: current
i_0: exchange current density
n: number of electrons transferred
α_a, α_c: transfer coeff. anode, cathode
F: Faraday's constant
$\eta = (V - V_{eq})$: overpotential. V: voltage
R: gas constant. T: temperature
N_c: number of electrolyzer cells in series
η_F: Faraday efficiency
V_tn: thermoneutral voltage
P_{elec}: electric power. P_{comp}: compression power
E_{H_2}: Low heating value of hydrogen
$\dot{m}_{H_2}$: mass flow of produced hydrogen

- Reaction for hydrogen production in the electrolyzers

Oxidation and reduction reactions at the anode and cathode:

$$2H_2O(l) \longrightarrow O_2(g) + 4H^+ + 4e^-, \;\; 2H^+ + 2e^- \longrightarrow H_2(g)$$

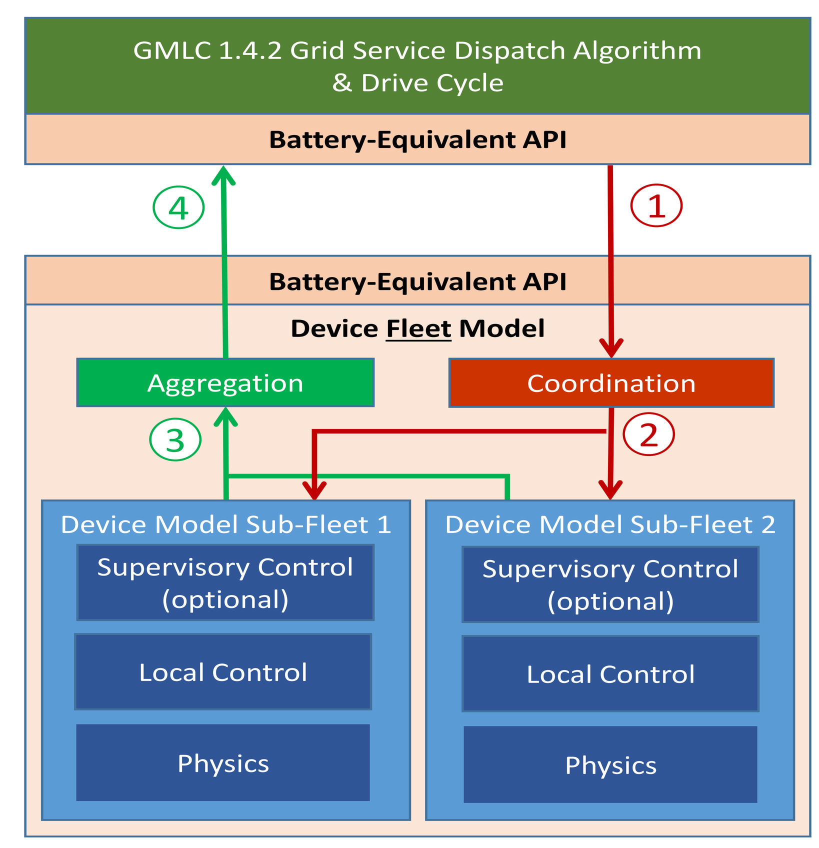
- $i - V$ curve. Butler-Volmer Equation:

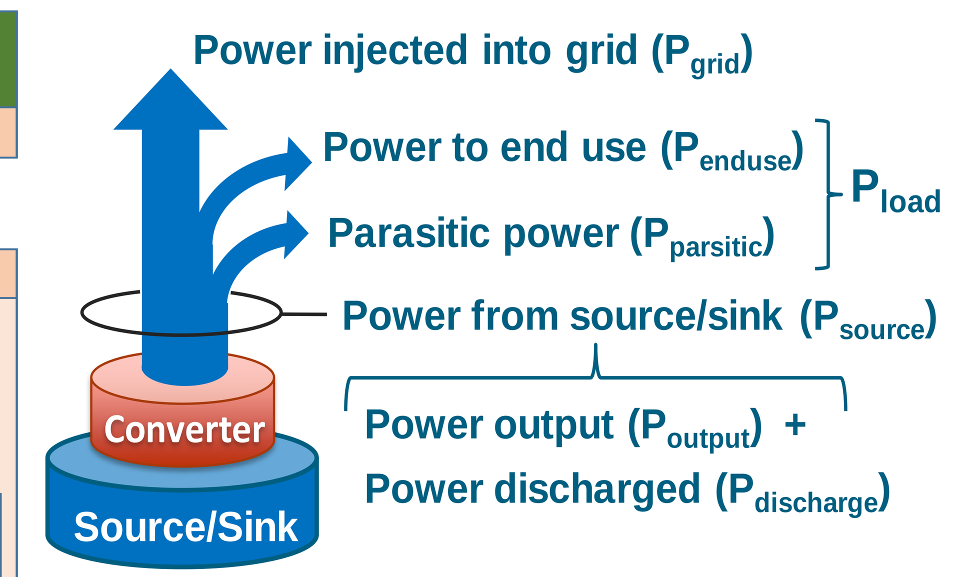
$$i = i_0\left\{exp\left(\frac{\alpha_a nF\eta}{RT}\right) - exp\left(\frac{\alpha_c nF\eta}{RT}\right)\right\}$$

- Hydrogen production rate, voltage and charging efficiencies:

$$H_{2g} = \frac{N_c I}{2F}\eta_F \qquad \eta_V = \frac{V_{tn}}{V} \qquad \eta_{ch} = \frac{E_{H_2}\dot{m}_{H_2}}{P_{elec} + P_{comp}}$$

Battery Equivalent Model (BEM)





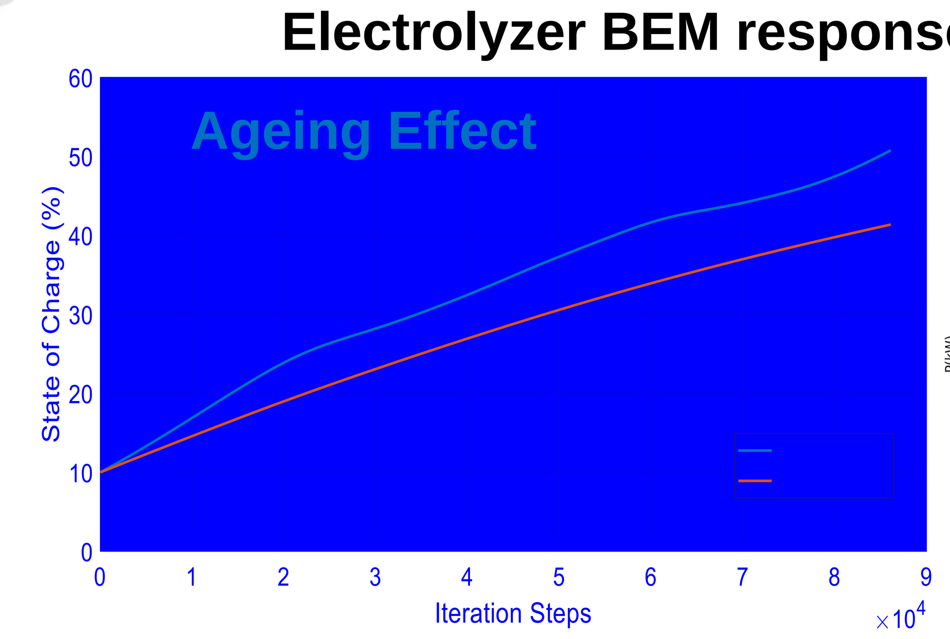
GitHub Repository

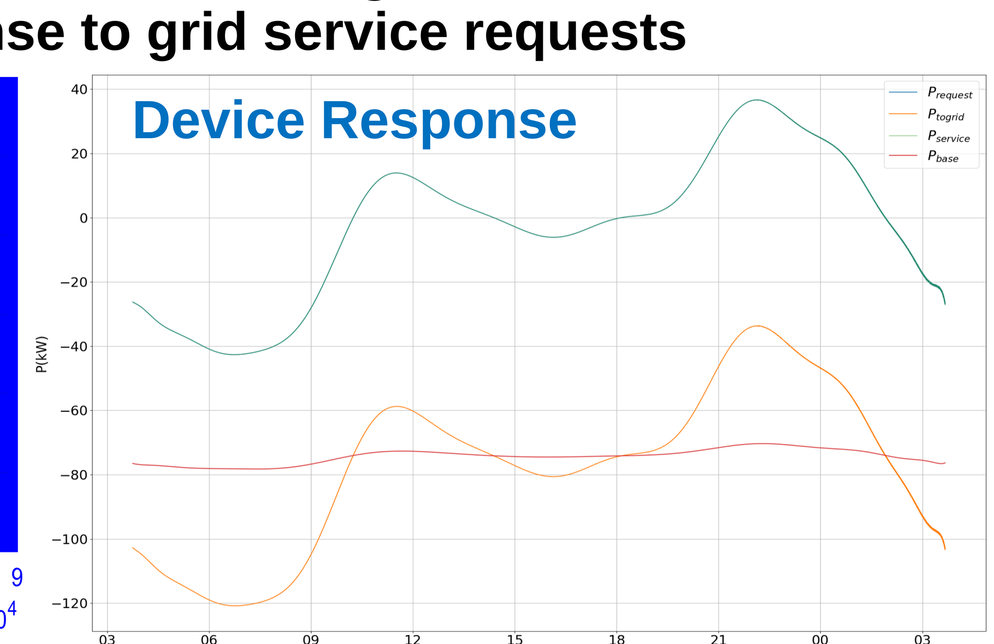
https://github.com/GMLC-1-4-2/battery_interface

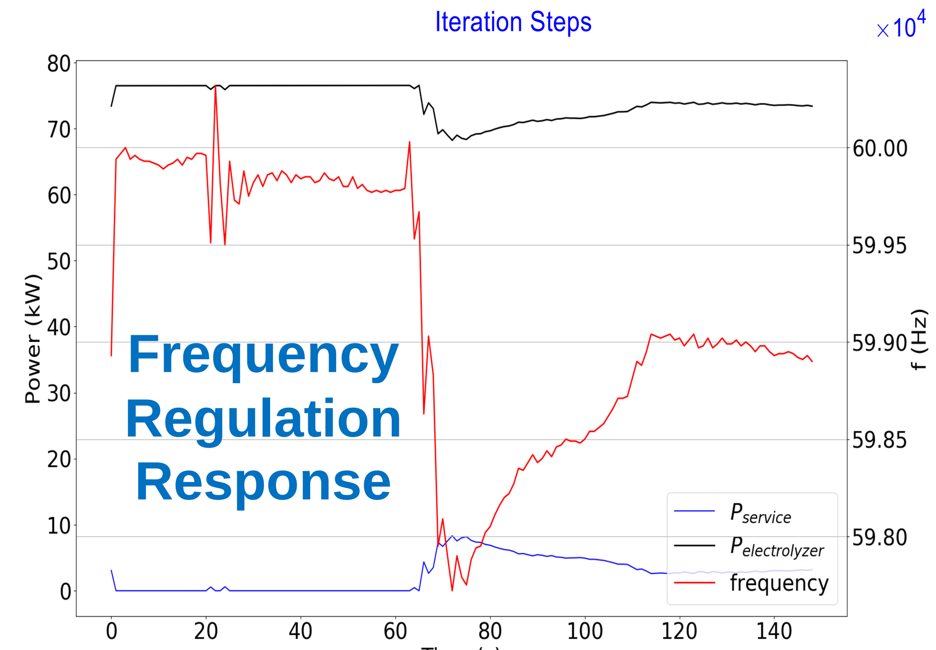
Parameter	Electrolyzer Model	Battery-Equivalent Model
Power	Operating voltage (V) Operating current (I)	Input power P_{in}
Storage capacity	Tank(s) capacity (p_{max})	Maximum state of charge SoC_{max}
Energy stored	Pressure in the storage tank(s)	Current state of charge SoC_{actual}
Operation time	continuous	Only if grid service is requested
Efficiency	Electrolyzer efficiency (η_e)	$\eta = \frac{Stored\ energy\ (H_2)}{Power\ supply * t}$

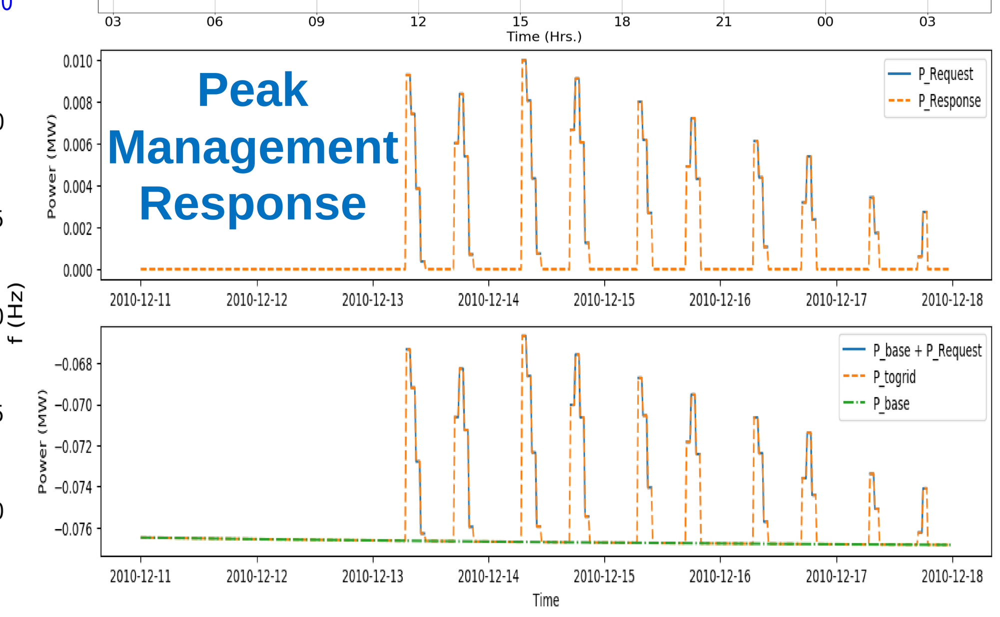
Results and Analysis

Electrolyzer BEM response to grid service requests

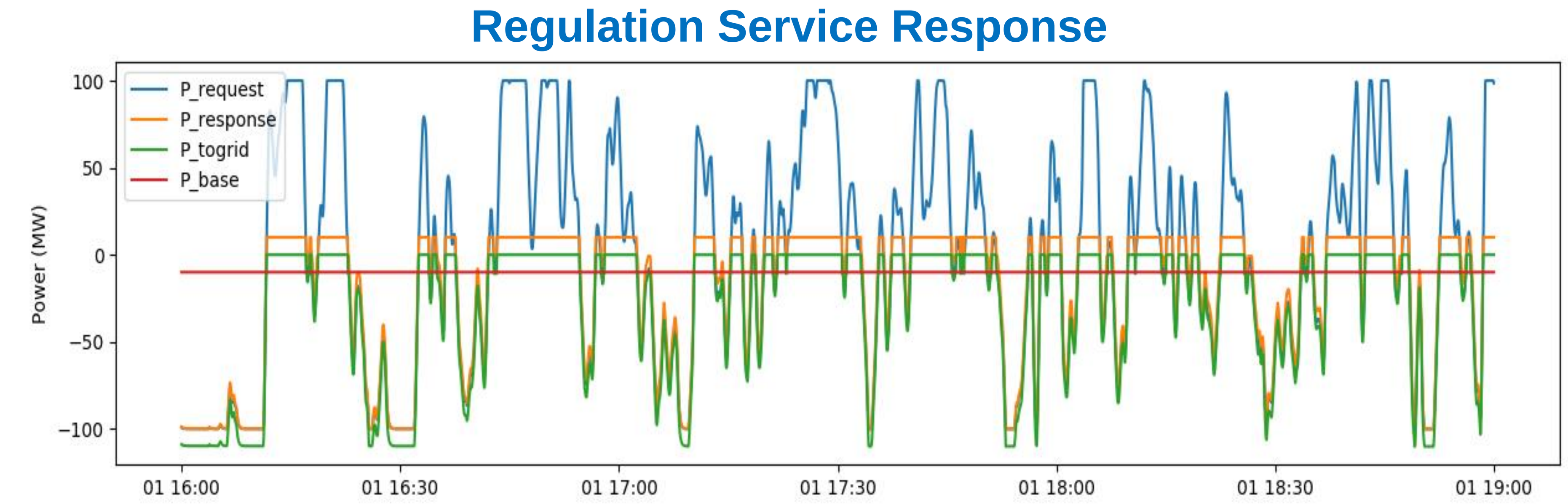








Regulation Service Response



References

[1] Manfred Waidhas (Siemens), "Electrolyzer technology – the Siemens view", 2016.
[2] Alan Kneisz (Hydrogenics), "Hydrogen – Most Versatile Energy Storage; Australia Energy Storage - Adelaide".

Acknowledgement

[1] GMLC 1.4.01: "Standards and Test Procedures for Interconnection and Interoperability"
(Link: https://gmlc.doe.gov/projects/1.4.01)
[2] GMLC 1.4.02: "Definitions Standards and Test Procedures for Grid Services"
(Link: https://gridmod.labworks.org/projects/1.4.02)

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