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Linearization of alkaline electrolyzer current-voltage behavior under dynamic operation

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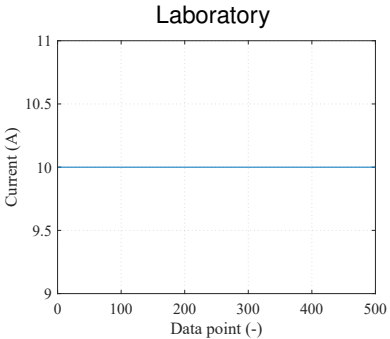
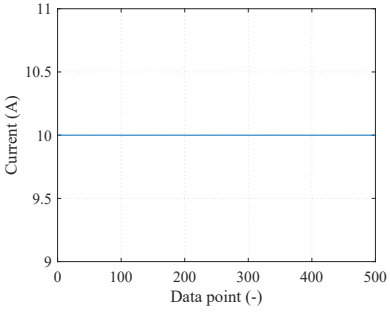
Why is this relevant?



Why is this relevant?

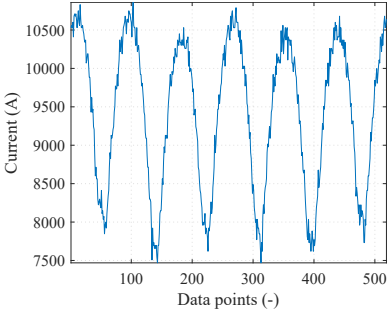
Laboratory



$\longrightarrow$

Industrial scale

Industry



Hydrogen production

- Hydrogen production is determined by the DC current

$$\dot{n}_{\mathrm{H_2}} = \eta_{\mathrm{F}} \frac{jA}{n_{\mathrm{e}} F},$$

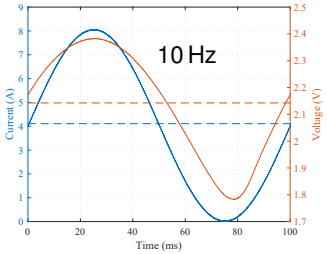
η_{F}: Faraday efficiency
j: Current density
A: Cell area
n_{e}: Transferred electrons
F: Faraday constant

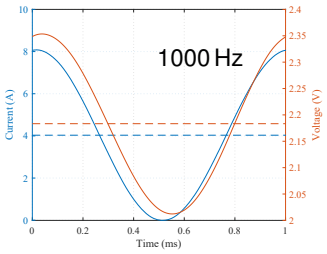
- Only direct current produces hydrogen
- AC current components transform to losses when supplied through the resistive electrolyzer load

Linearization of the electrolyzer behavior

Ripple measurements

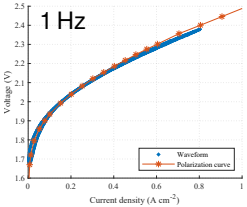
- Supply ripple to the electrolyzer cell
  - Sine waveform
  - 0-100% ripple amplitude
  - 0-1000 Hz ripple frequency
- Power analyzer used to measure current and voltage waveforms





Electrolyzer cell voltage response at varying frequencies

- At low frequencies system mostly follows polarization curve as expected



Electrolyzer cell voltage response at varying frequencies

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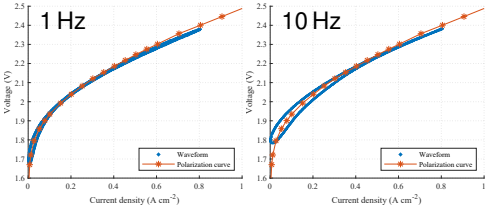
- As frequency increases the waveform starts to linearize



Electrolyzer cell voltage response at varying frequencies

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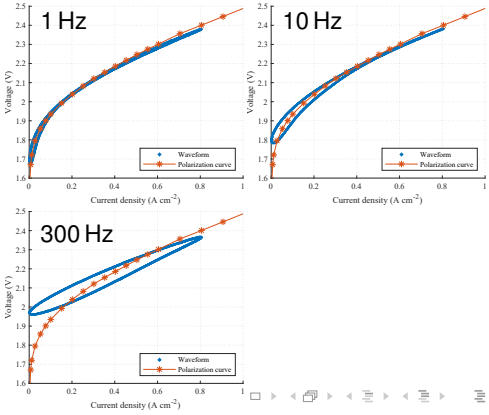

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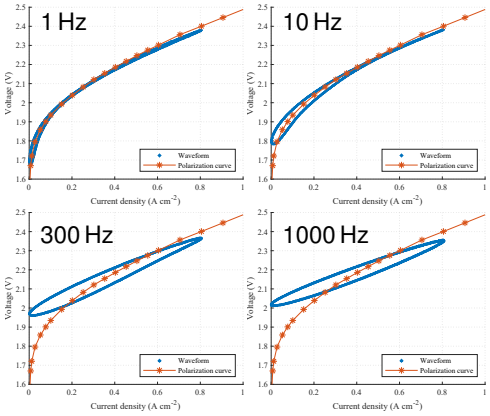
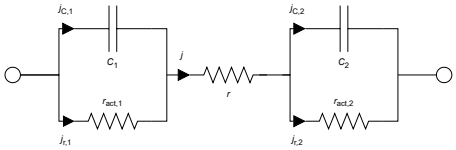


Why the linearization happens



- Cell capacitances at the electrodes provide low impedance path for high frequency AC currents
- Amplitude of the AC current through the activation is reduced

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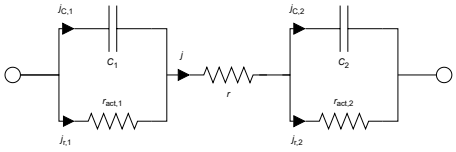

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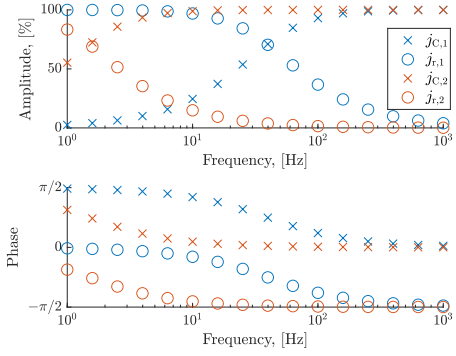
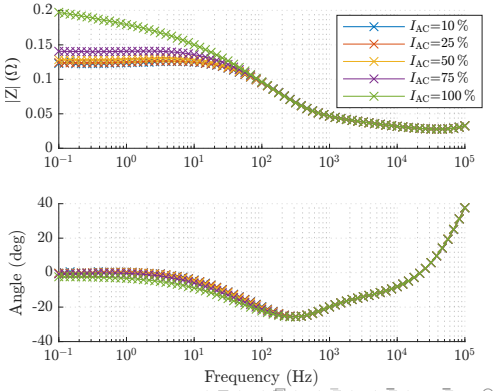


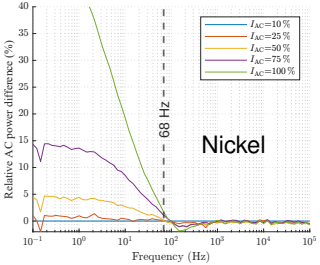
Defining the linearization frequency

- Nonlinear electrochemical impedance spectroscopy
  - Measurements done with a potentiostat
- Ripple amplitudes between 10-100% were used
- Convergence of the measurements indicates linearization



Finding the frequency limit for linearization

- Two electrode sets tested
  - Nickel foam
  - Advanced materials (DTU)
- System considered linear when relative AC power difference $< 2\%$ between all measurements



Equations for Frequency component I:

$$|Z_I| = \frac{U_I}{I_I} \qquad P_{AC,I} = \frac{|Z_I| I_I^2}{2} \cos\theta_I$$

$$\theta_I = \phi_{u,I} - \phi_{i,I}$$

Z: Impedance U: Voltage
I: Current θ: Phase

Finding the frequency limit for linearization

- Two electrode sets tested
  - Nickel foam
  - Advanced materials (DTU)
- System considered linear when relative AC power difference $< 2\%$ between all measurements
- Advanced electrodes have higher surface area
  $\rightarrow$ higher capacitance
  $\rightarrow$ Lower linearization frequency

Equations for Frequency component *I*:

$$|Z_I| = \frac{U_I}{I_I} \qquad P_{\mathrm{AC},I} = \frac{|Z_I| I_I^2}{2} \cos\theta_I$$

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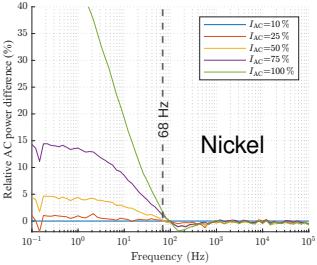
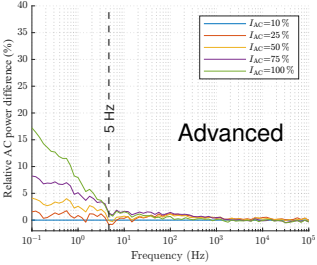
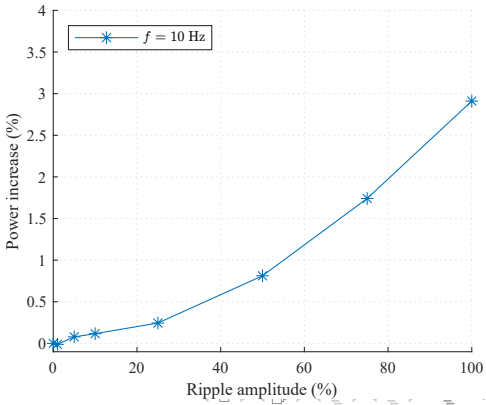




Performance impacts of the dynamic operation

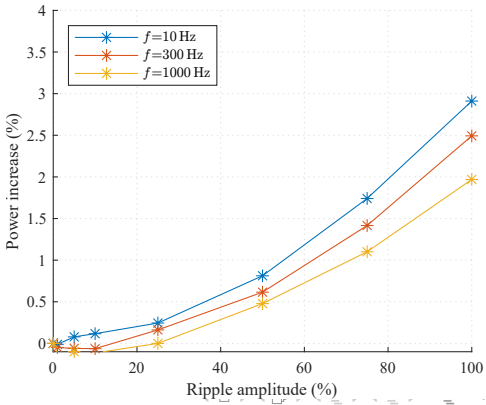
Additional power consumption

- Ripple amplitude increases the losses



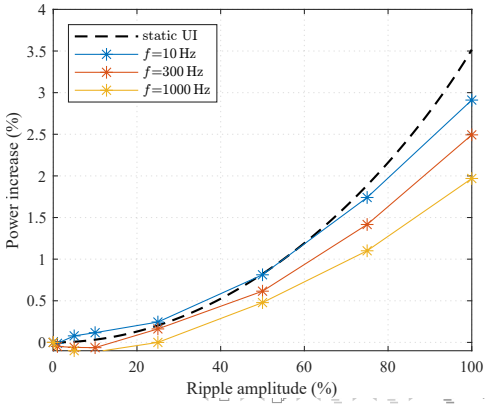
Additional power consumption

- Ripple amplitude increases the losses
- Ripple frequency counteracts the losses



Additional power consumption

- Ripple amplitude increases the losses
- Ripple frequency counteracts the losses
- As frequency is reduced losses approach the case where ripple follows the static UI curve
- Ripple following the static UI curve should present the maximum loss



Thank you