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Aalto University
School of Electrical
Engineering

Converter Power Supplies for Electrolyzers

Ushnish Chowdhury

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1. Electrolyzer Characteristics

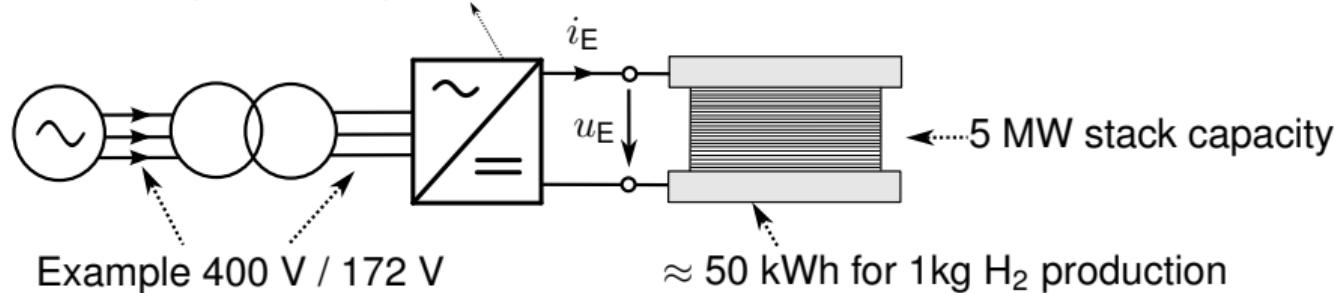
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Characteristics

Current capabilities upto 10 kA



- ▶ Low voltage and high current device; power range in MW¹
- ▶ Current ripple frequency in range < 100 Hz and > 300 Hz have negligible effect on efficiency²
- ▶ Partial-load operation limits; 20% for AEL and 5% for PEMEL of nominal capacity³

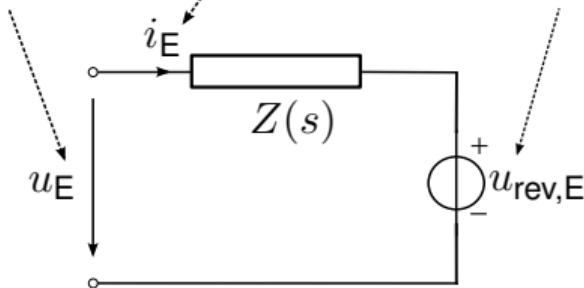
¹A. Abdelhakim, T. Viitanen, and F. Canales, "State-of-the-art power supplies for electrolyzers," *ABB Review*, pp. 60–63, Oct. 2022.

²V. Ruuskanen *et al.*, "Power quality estimation of water electrolyzers based on current and voltage measurements," *Journal of Power Sources*, vol. 450, p. 227 603, Feb. 2020.

³V. Martinez Lopez *et al.*, "Dynamic operation of water electrolyzers," *Renewable and Sustainable Energy Reviews*, vol. 182, p. 113 407, Aug. 2023.

Electrolyzer Model for Converters ⁴

Electrolyzer stack voltage Electrolyzer current Constant reversible voltage



$$\begin{aligned} u_E &= i_E Z(s) + u_{rev} \\ \Rightarrow u_E &= i_E R + u_{rev} \end{aligned}$$

- ▶ Assumes linear operation under constant temperature and pressure
- ▶ Impedance considered to be purely resistive, $Z(s) = R$

⁴Applicable for both alkaline and proton membrane exchange electrolyzers

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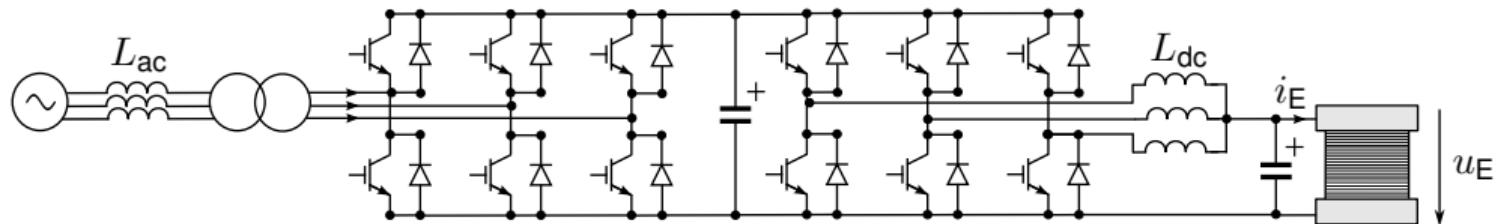
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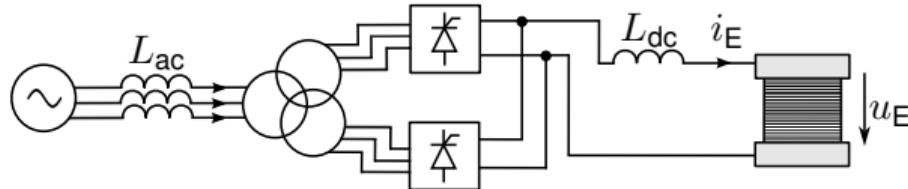
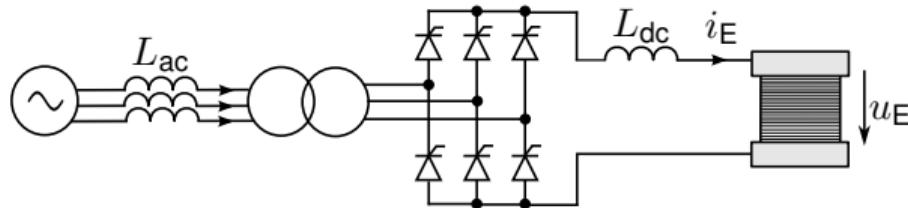
Voltage-Source Rectifiers

- Grid currents almost sinusoidal
- Higher losses at high current operation
- Parallelizing required to meet high current demands, increased number of components increase cost and carbon footprint of the system

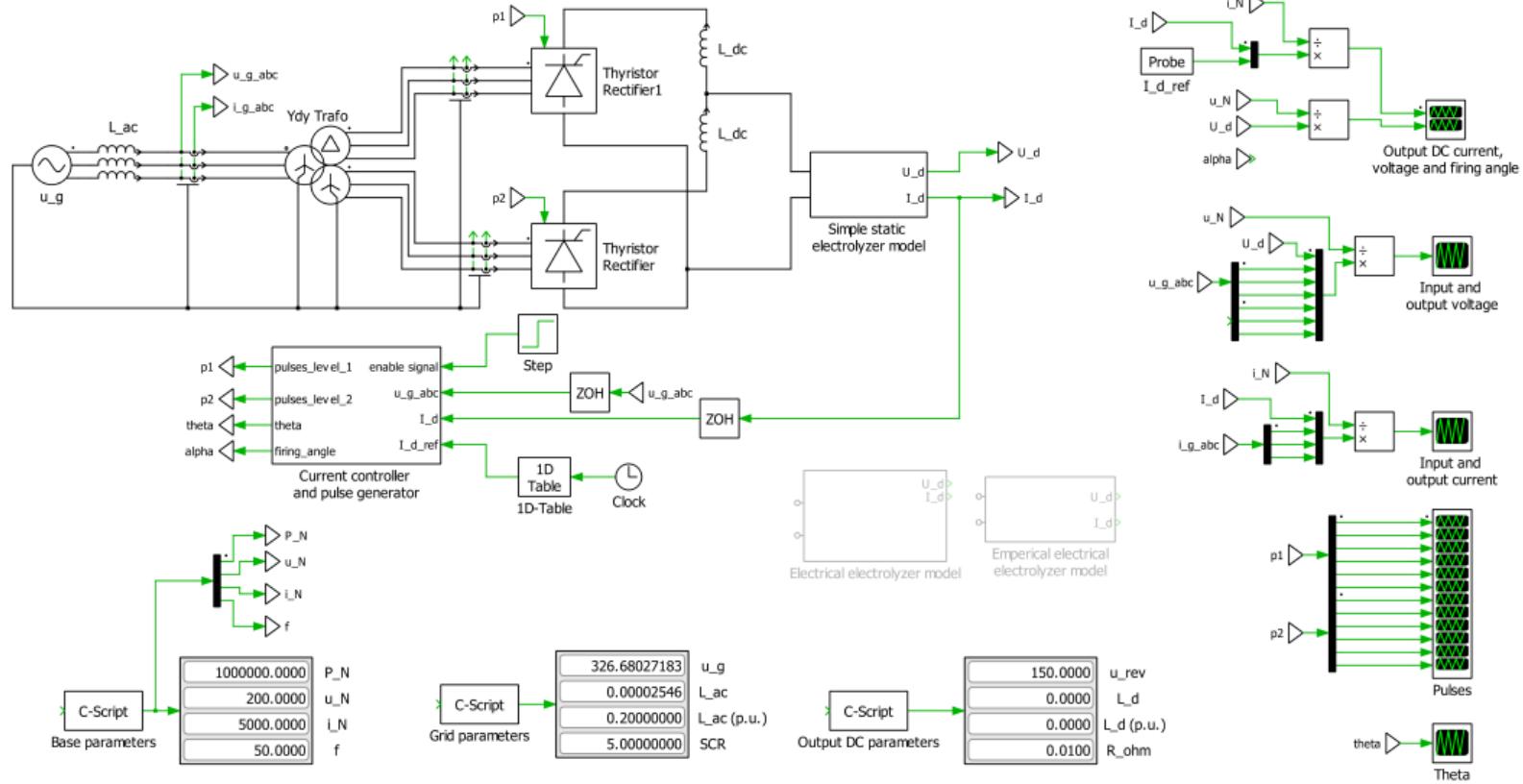


Thyristor Rectifiers

- ▶ Simple, reliable with low device losses, cheap
- ▶ Semi-controllable, PI controller to determine firing angle
- ▶ High dc current ripple, high harmonic content on the ac side
- ▶ 12-pulse configuration used to reduce harmonics

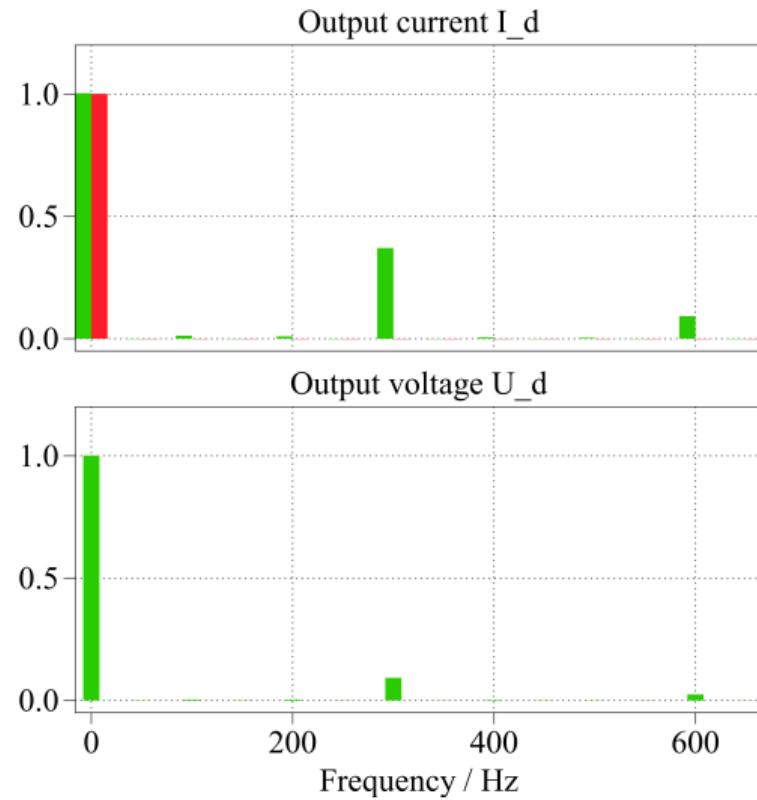
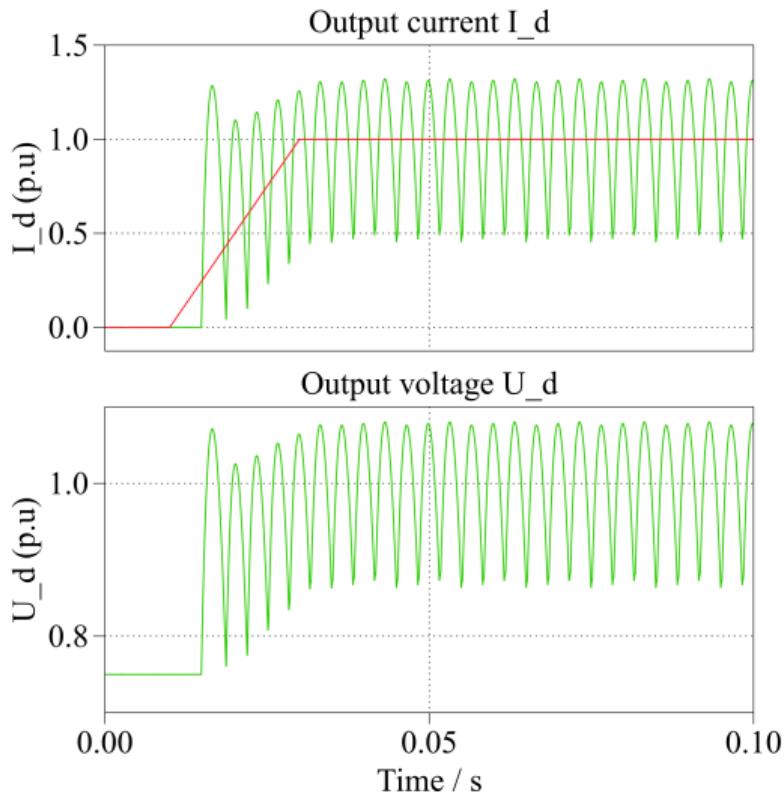


PLECS Model⁵

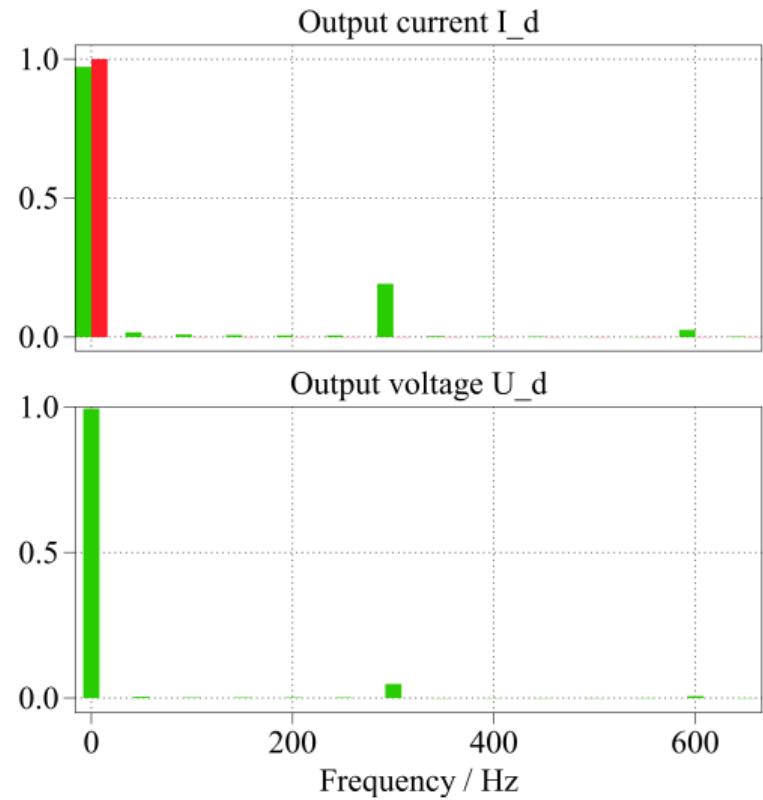
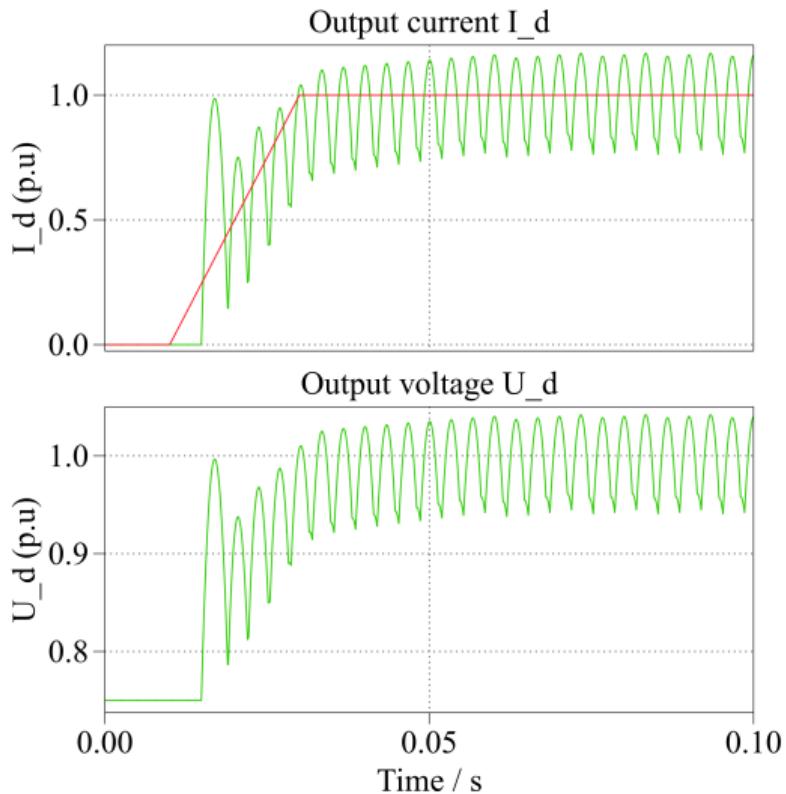


⁵J. Koponen *et al.*, "Effect of converter topology on the specific energy consumption of alkaline water electrolyzers," *IEEE Transactions on Power Electronics*, vol. 34, no. 7, pp. 6171–6182, 2019.

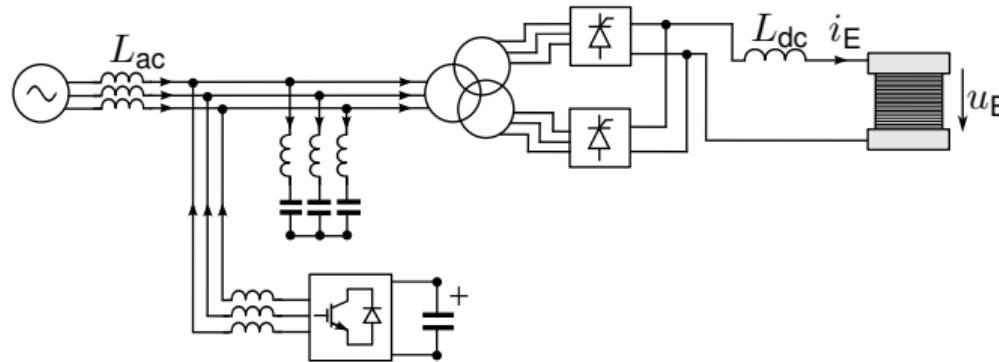
Simulation Results ($L_{ac} = 0.01$ p.u.)



Simulation Results ($L_{ac} = 0.20$ p.u.)



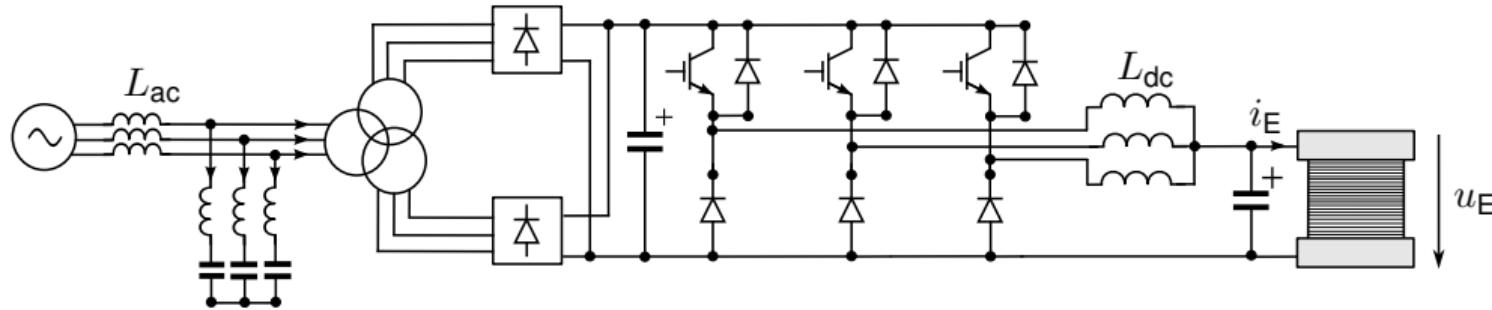
Thyristor Rectifiers with Hybrid Filter⁶



- ▶ Hybrid filter to provide both harmonic and reactive power compensation
- ▶ APF connection to the primary side can increase transformer losses due to current harmonics produced by electrolyzer
- ▶ Multilevel configuration or additional coupling transformer required, increasing system cost and complexity

⁶L. Sánchez *et al.*, "Comparative analysis of power converter topologies for hydrogen electrolyzers," *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 12, no. 5, pp. 4325–4341, 2024.

Diode Rectifiers with DC Chopper⁷



- ▶ Better efficiency for medium to low electrolyzer applications compared to thyristor topology with hybrid filter
- ▶ Smaller output filter requirements due to chopper section; capacitor filter required after rectifier stage; larger inductors on both AC and DC side
- ▶ System still bulky, passive component cost higher

⁷J. Solanki *et al.*, "Comparison of thyristor-rectifier with hybrid filter and chopper-rectifier for high-power , high-current application.", 2013. [Online]. Available: <https://api.semanticscholar.org/CorpusID:53310787>.

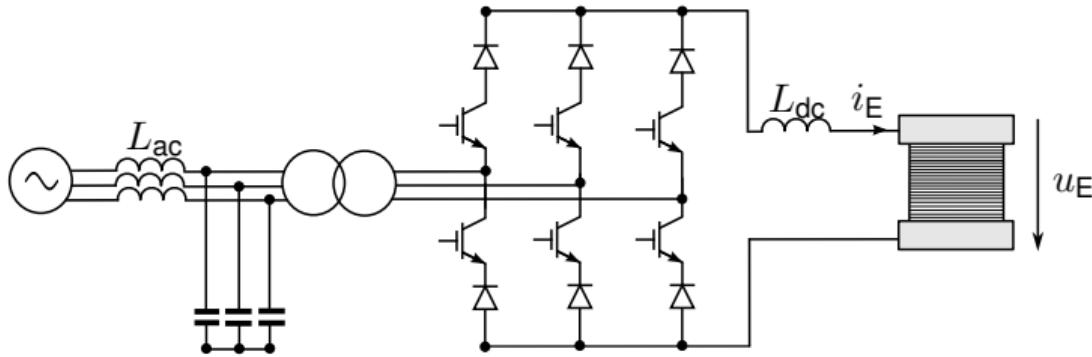
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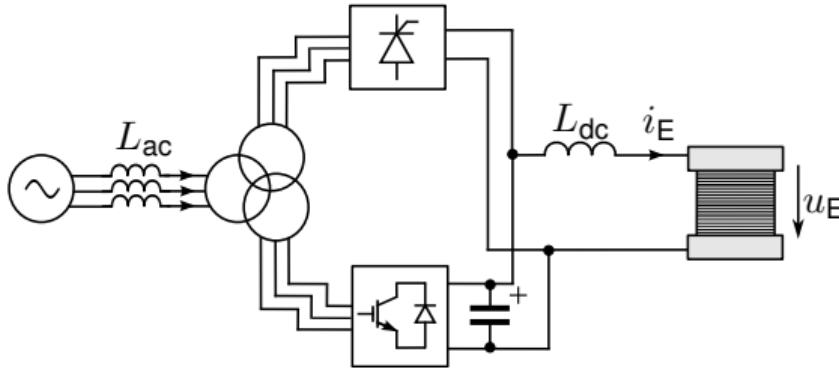
Current-Source Rectifiers⁸



- ▶ Controllable step down rectifier; low current THD
- ▶ DC side inductor to reduce output current ripple; capacitors to filter input current; DC-DC converter not required
- ▶ Not as matured as voltage-source rectifiers

⁸J. Solanki *et al.*, "High-current variable-voltage rectifiers," *IET Power Electronics*, vol. 8, no. 6, pp. 1068–1080, Jun. 2015.

Parallel Rectifiers with Thyristor and Active Front End⁹



- ▶ Thyristor rectifier will deliver main part of output current (> 80 %); AFE for smoothening current
- ▶ Reduced number of passive components
- ▶ Technology not matured, needs further investigation

⁹S. Bintz, M. Fischer, and J. Roth-Stielow, "Parallel rectifier for regenerative hydrogen production utilizing a combination of thyristor and pwm-based topologies," in *2018 20th European Conference on Power Electronics and Applications (EPE'18 ECCE Europe)*, 2018, P.1–P.10; S. Schumann *et al.*, "Water electrolysis power supply," in *Components of Power Electronics and their Applications 2023: ETG Symposium*, 2023, pp. 122–128.

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Summary

- ▶ Electrolyzer is a high current, multi-MW device, requiring dc current for operation
- ▶ Power intermittency have significant effect on efficiency compared to high frequency current ripple
- ▶ From a converter prospective, electrolyzer can be modeled as a resistive voltage source
- ▶ Pros and cons of state-of-the-art power converters used in the industry have been discussed
- ▶ Some potential topologies suggested in literature have been showcased
- ▶ Future focus should be on compact, cost-effective, compatible converter topologies; control methods and semiconductor materials also to be considered