Ripple current effects and its implications on the battery management system for vanadium redox-flow-battery

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What is a ripple current and what makes them problematic?

Definiton :

The alternating voltage/current component of the voltage/current on the DC side of a converter [1]

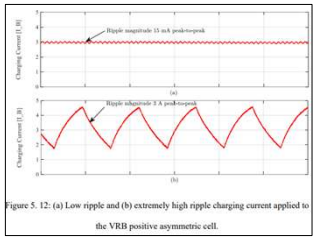


Figure 1 example of ripple charging currents [2]

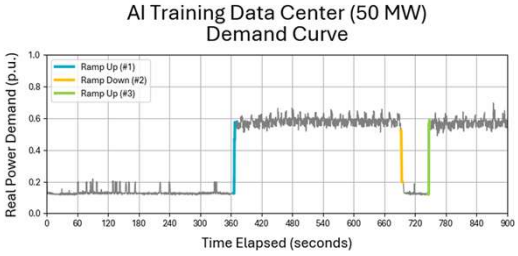


Figure 2 loard profile of an AI traning center [3]

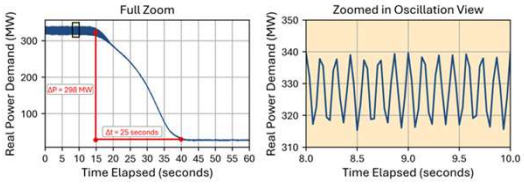


Figure 3 Power demand from a grid occurance because of a sudden decrease in demanded power and the resulting oscillation (ripple) [3]

Ripple currents accelerate Li-ion battery aging: increasing ripple amplitude shortens cycle life, while higher AC frequency increases capacity fade, impedance rise, and cell-to-cell variability. [4]

Ripple currents degrade PEM electrolyzer performance: increasing ripple amplitude raises energy consumption and reduces efficiency, [5,6]

Ripple currents degrade Redox-Flow-Batteries?

→ Not enough studies performed to confidently tell, especially long-term

Results in:

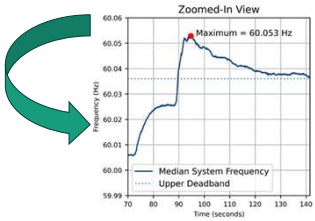
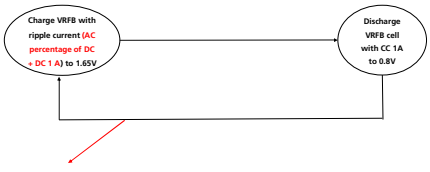


Figure 4 Effect on the grid frequency/stability [3]

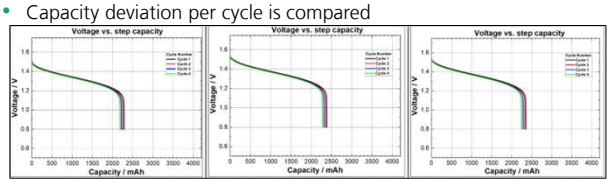
Ripple current effects

- **Cell tests on 40 cm² ICT in-house developed cells,**
- **Potentiostat: Biologic 300-SP**

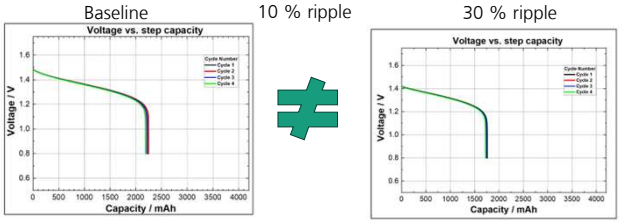


Test was done for 4 cycles.

- Capacity deviation per cycle is compared



Baseline | 10 % ripple | 30 % ripple



100 % ripple ≠ 250 % ripple

Figure 5 Comparison of capacity change with different applied ripple current amplitudes (0, 10, 30, 100, 250 %)

Why the difference between 100 and 250 % ripple?

Biologic detected 1.65 V prematurely

→ Cycle is terminated

This could be problem for measurements in big system which are far less precise

→ First tests show that with an OCV cell these problems can be bypassed

Conclusion, Subsequent steps and implications for BMS

Conclusion

- Due to loads like data centers/electrolyzers introduced into the grid, ripple become an increasing problem for frequency stability, as well as for electrochemical systems such as electrolyzers & li-ion batteries
- RFB a good solution as experiments do not show any effects of ripple currents on the electrolyte capacity

Subsequent steps

- Finish preliminary tests
- Include Mass spectrometry & ESR
- Translate methodology into a kW class setup
- Long term tests (<1000 cycles)

Implication for the BMS

- Ripple currents have probably no effects on the OCV cell
- Impact of voltage overshoots on hydrogen evolution reaction must be studied
- Long-term behavior is crucial for ripple currents, the BMS must take it into account

[1] International Electrotechnical Commission (IEC). *International Electrotechnical Vocabulary (IEV), entry 551-17-27: ripple voltage (on the DC side).* Available at: https://www.electropedia.org/iev/iev.nsf/display?openform&ievref=551-17-27
[2] Akter, M. P. *Optimal Charging and Converter Design for Vanadium Redox Flow Batteries.* PhD thesis, University of New South Wales (2021). https://doi.org/10.26190/unsworks/24584
[3] North American Electric Reliability Corporation (NERC). *Characteristics and Risks of Emerging Large Loads.* Large Loads Task Force White Paper (2025).
[4] Muñoz-Torrero, D. *et al.* On the degradation of lithium-ion batteries over a current ripple effect. Electrochim. Acta *530*, 146326 (2025).
[5] Buitendach, H. P. C., Gouws, R., Martinson, C. A., Minnaar, C. & Bessarabov, D. Effect of a ripple current on the efficiency of a PEM electrolyser. Results Eng. *10*, 100216 (2021).
[6] Parache, F. *et al.* Impact of power converter current ripple on the degradation of PEM electrolyzer performances. Membranes *12*, 109 (2022)

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