Power Electronics for Flow Batteries: Single Real-time framework for Flow Battery model with Power Electronics integration

Michael Starke
Principal Investigator
starkemr@ornl.gov

Renata Kimpara
Technical Lead
rezendedacor@ornl.gov

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PROJECT OBJECTIVES

100 % Complete — WFY2024

Develop simulation models of the flow battery technology and the control strategy of the system.

60 % Complete — WFY2025

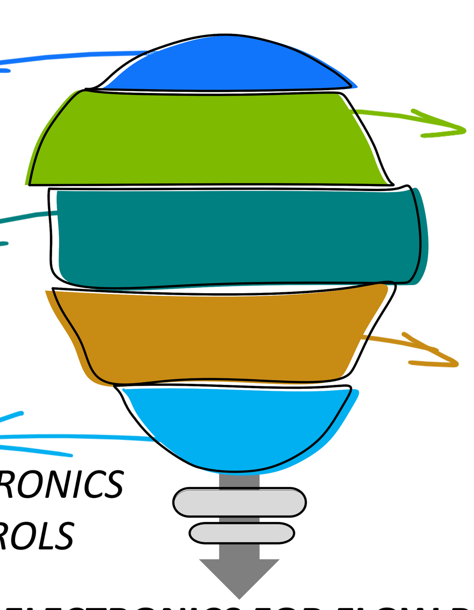
Translate the simulation in real-time platforms and develop a controller hardware in the loop solution.

Not initiated — WFY2026

Constructing the hardware systems and finally performing the control integration and evaluation.

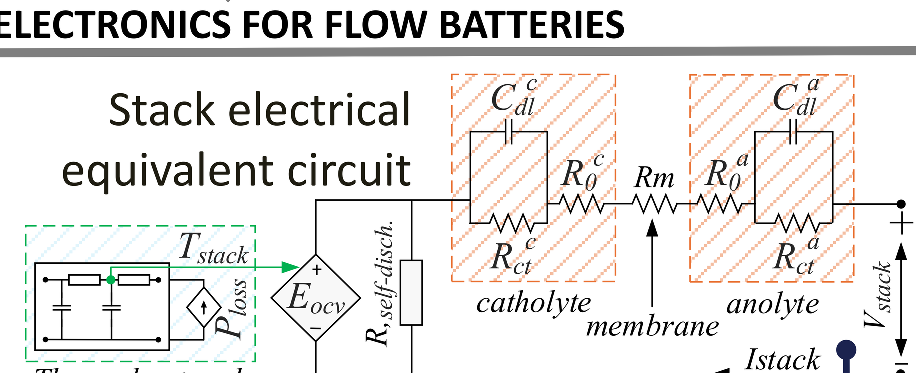
OVERVIEW AND METHODOLOGY

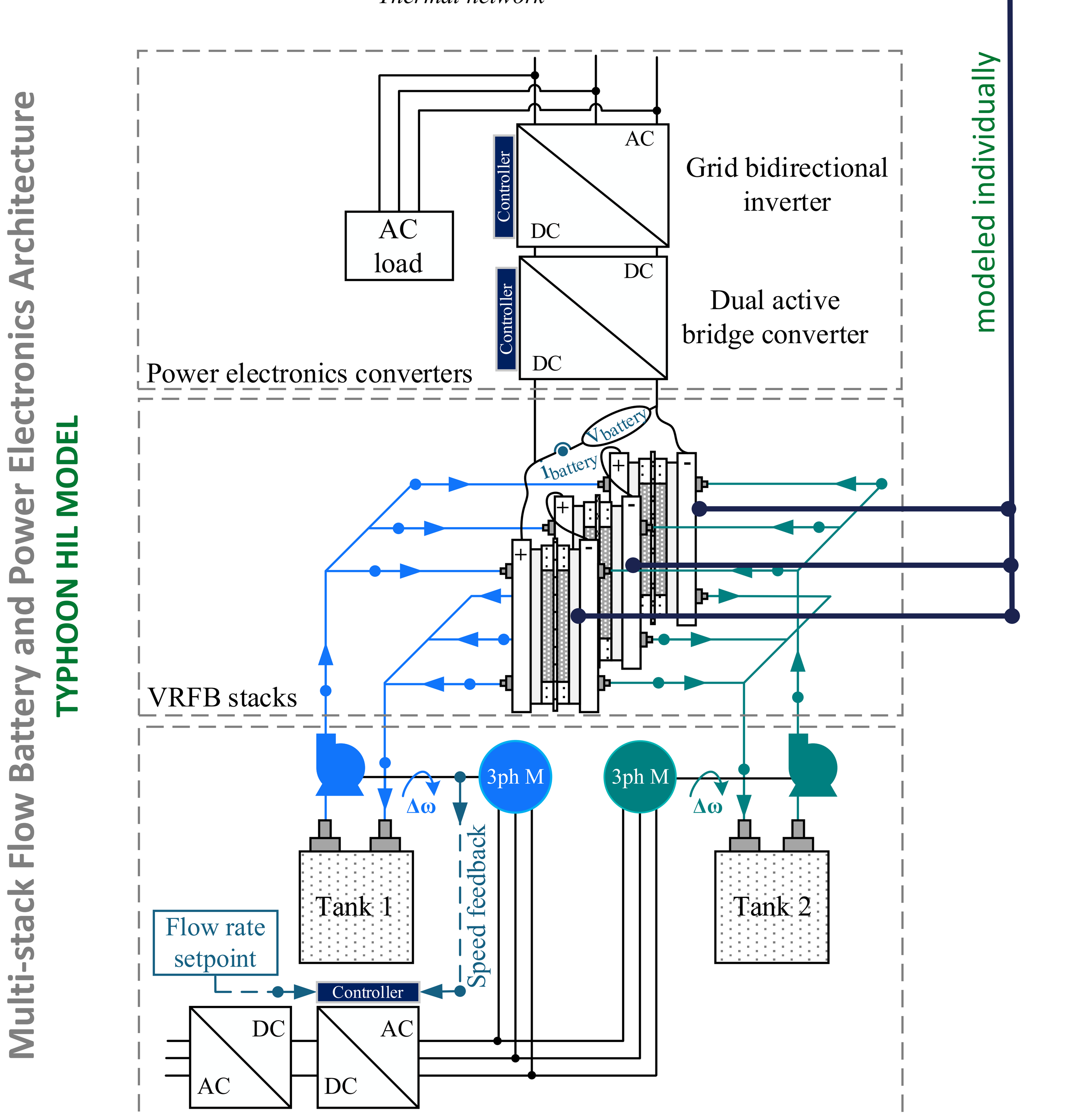
- **Current Practice:** Most flow battery models don't integrate **auxiliary systems** like **pumps and converters**, missing the incorporation of electrical, mechanical, and physics-based behavior.
- **Why ORNL: ORNL** develops **high-fidelity, control-oriented real-time models** with an emphasis on **power electronics and embedded implementation**—critical for advancing integrated energy systems. Besides, ORNL has the hardware implementation and testing capabilities.
- **Innovation:** Integrating the auxiliary systems—including motor drives and power converters—into a **single simulation framework** enables more **accurate control design** and real-time **validation** with safety and **performance** constraints.
- **Impact:** The approach enables modeling and optimization of full-system behavior, **accelerating** development of complete **flow battery solutions** with improved **reliability** and **efficiency**.
- **Alignment:** Supports **innovation in grid-scale energy storage**—key to **modernizing** and increasing **the resiliency of the energy infrastructure** through technologies like **flow batteries**.



APPROACH

20 kW Vanadium Redox Flow Battery (VRFB)





COMPUTATIONAL COST AND MODEL ACCURACY + CO-SIMULATED THERMAL NETWORK + PUMP SYSTEM FULLY INTEGRATED IN A SINGLE RT FRAMEWORK + INCREASED LEVEL OF FIDELITY

COMPLETE CONTROL SOLUTION FOR FLOW BATTERIES

VRFB MODEL & POWER ELECTRONICS INTEGRATION RESULTS

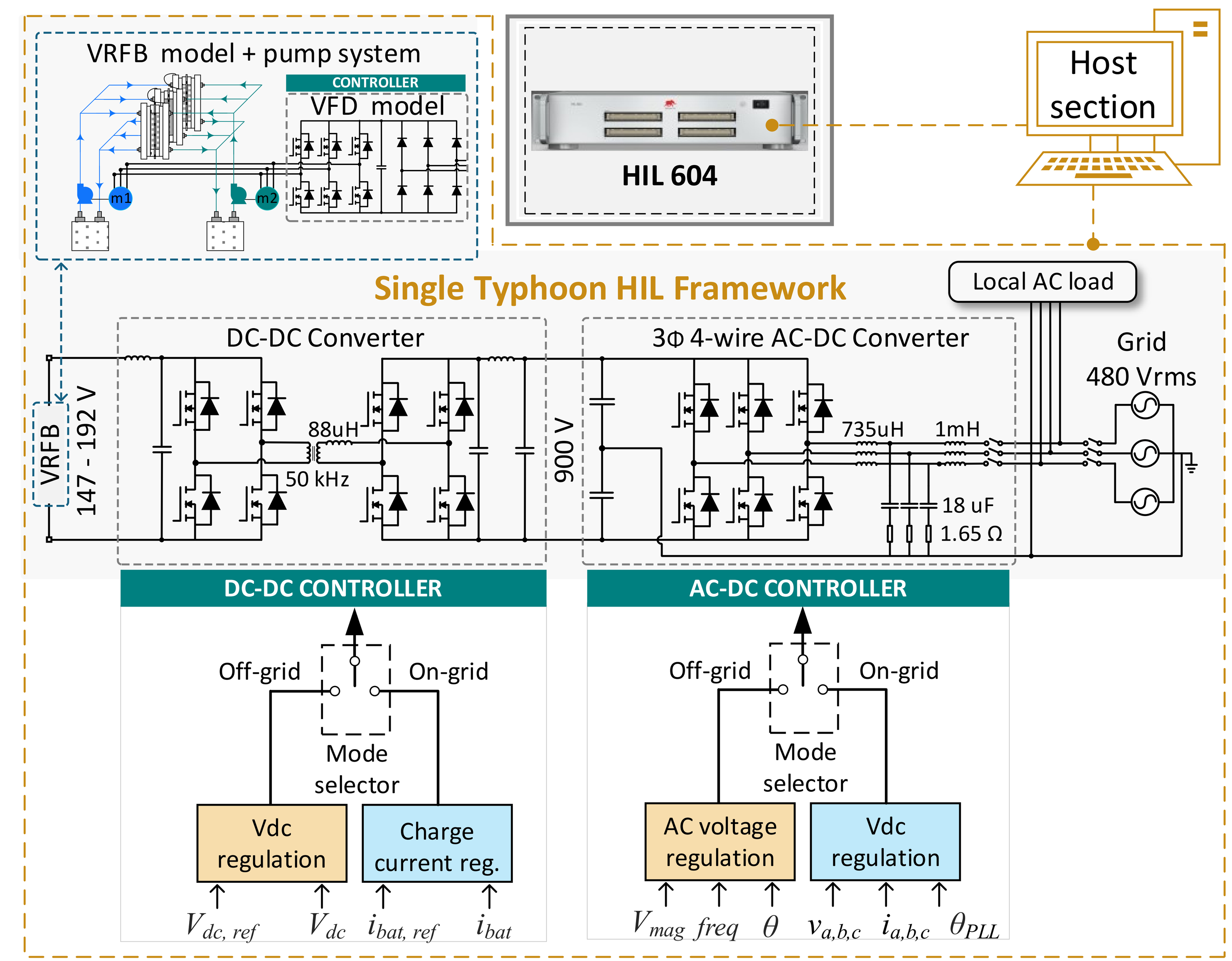


Fig. 1 Real-time simulation framework, converter topologies and controls.

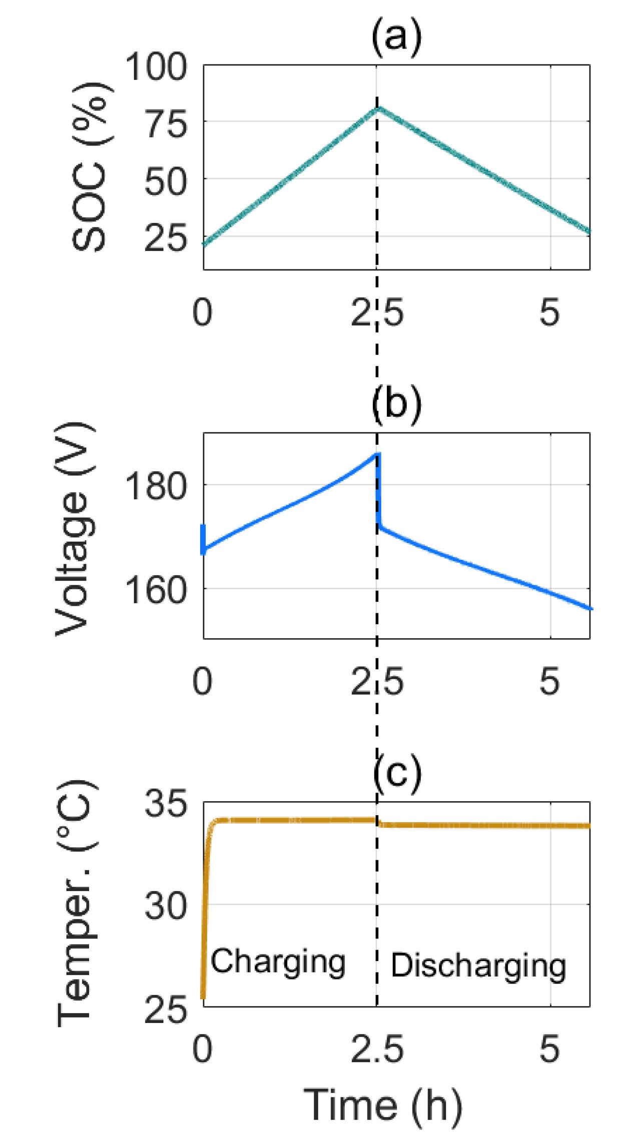


Fig. 2 Battery results: (a) SOC, (b) Terminal voltage, (c) Stack temperature.

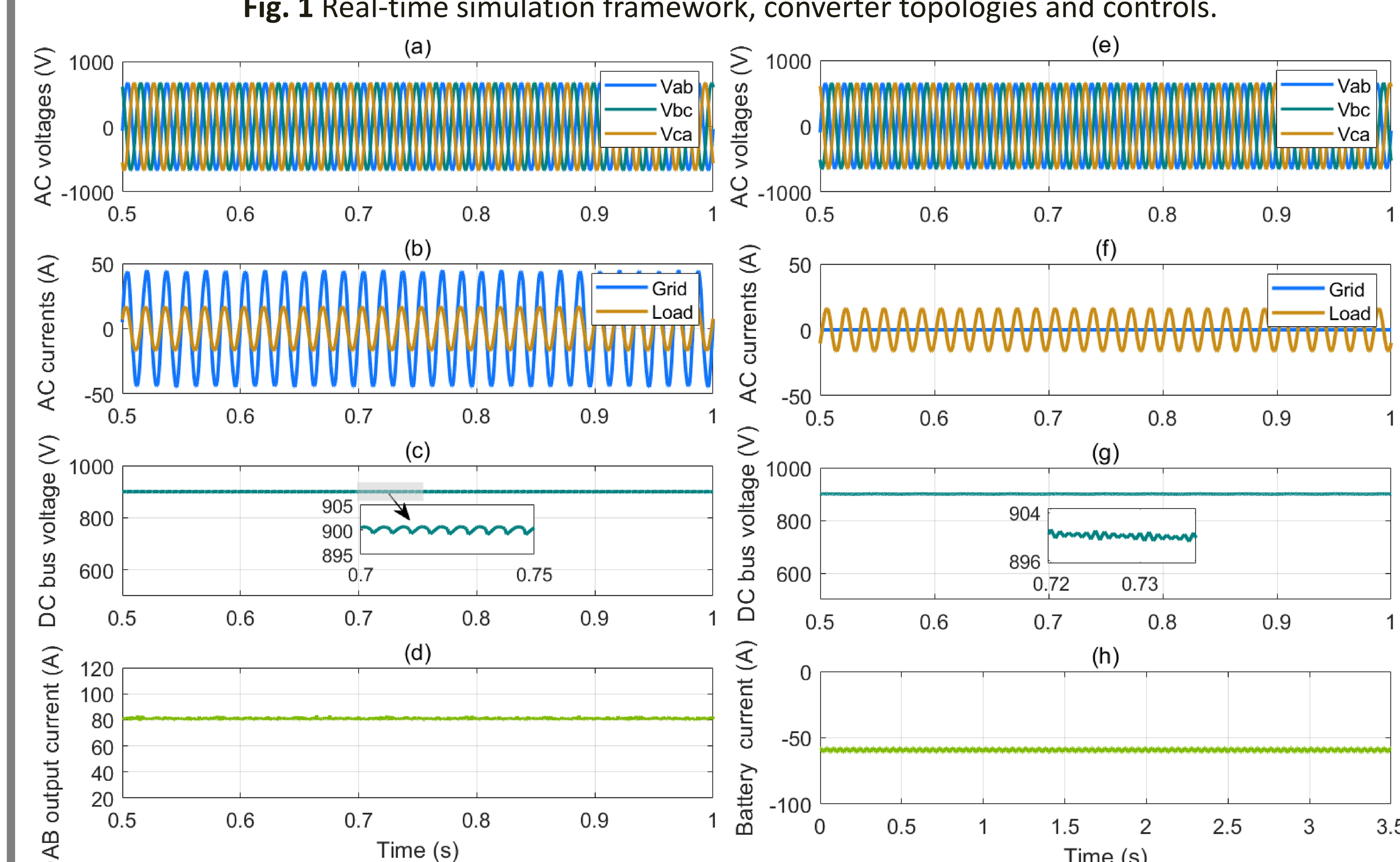


Fig. 3 *On-grid mode*. (a) Grid voltages, (b) Load and Grid currents, (c) DC bus voltage regulation by the AC-DC converter, (d) DC-DC converter controlling the charging current.

Fig. 3 *Off-grid mode*. (e) Voltages generated by the inverter, (f) Load and Grid currents, (g) DC bus voltage regulation by DAB, (h) Battery current

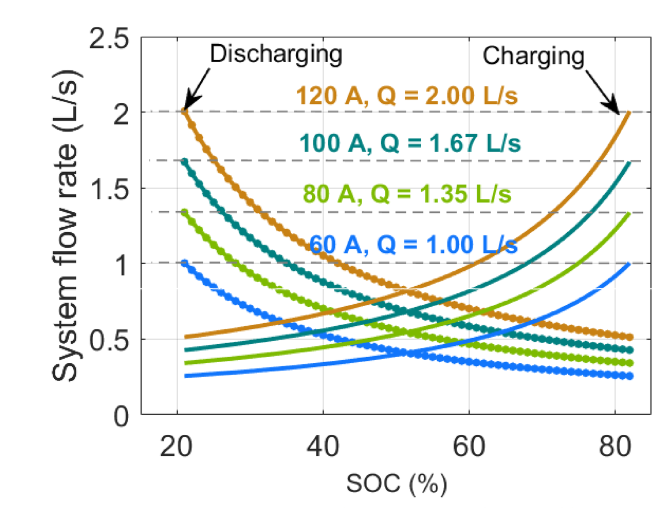


Fig. 4 Required flow-rate for different stack currents and SOC levels.

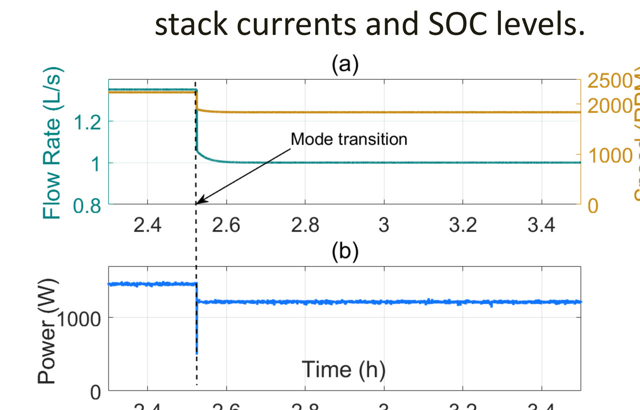


Fig. 5 Pump system. (a) flow rate and speed (b) Power consumption.

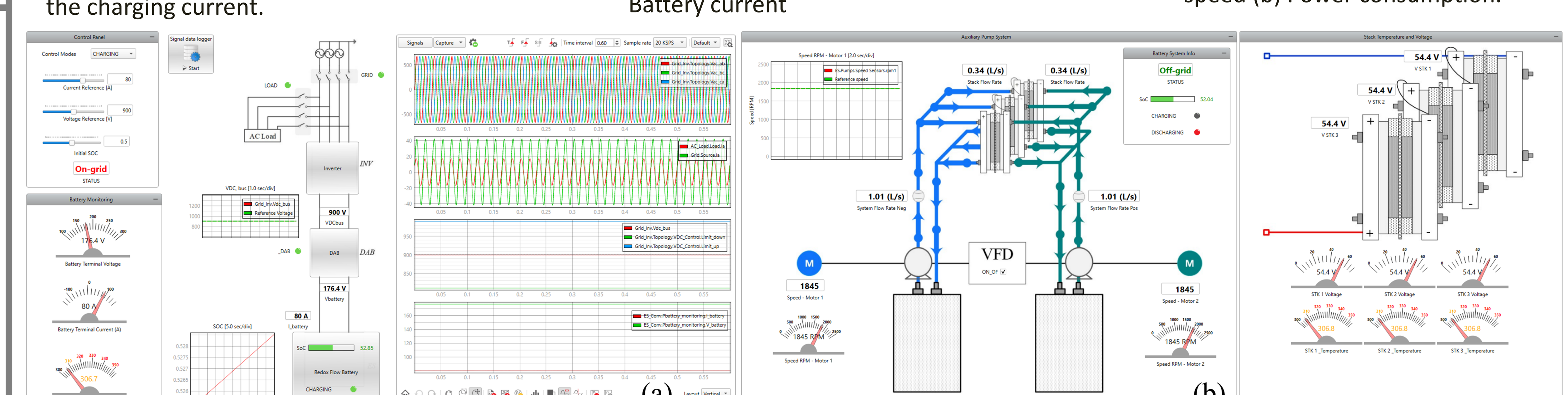
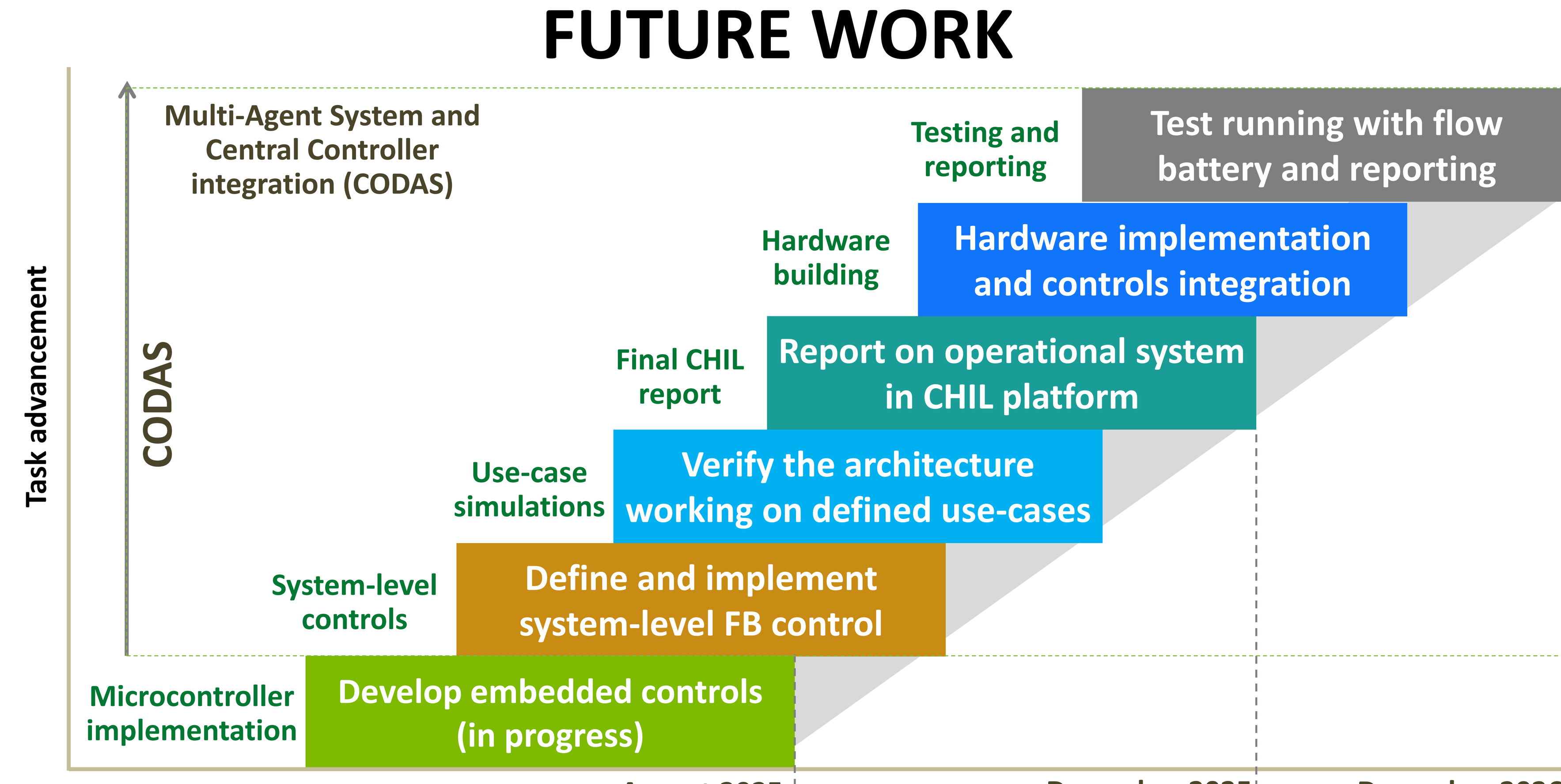


Fig. 6 SCADA panel. (a) Battery charging. (b) Battery discharging.

FUTURE WORK



- Central controller and multi-agent system – CODAS integration.
- Architecture control, including flow rate setpoints, temperature monitoring, control mode of power electronics converters, relays commands and optimization (energy dispatch, price signals).
- Grid services and Microgrid capabilities use-cases, local load.
- Hardware building and controls integration for real test using flow battery.

PROJECT OUTPUTS

- 2 peer-reviewed papers (IEEE conferences: EESAT and ECCE)
- 2 Flow Battery Models (non-real time and real-time)
- Power Electronics converters design and controls integration for Flow Batteries