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System-Level Modelling and Experimental Evaluation of a Novel Converterless Hybrid Soluble Lead Flow and Lithium-Ion Battery System

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Global Energy Scenario and Need for Storage

IEA report states that renewable power capacity will rise from about **4,250 GW today to nearly 10,000 GW by 2030**

Renewables and other low-emission sources are expected to generate **more than half of global electricity before 2030**

Global electricity demand is rising quickly, adding the equivalent of **the electricity use of the world's ten largest cities each year**

This creates a storage challenge across multiple timescales:

- seconds to minutes: fast power response
- hours to days: renewable variability
- longer durations: sustained energy support

Key message: Future storage systems must combine fast response with scalable energy capacity

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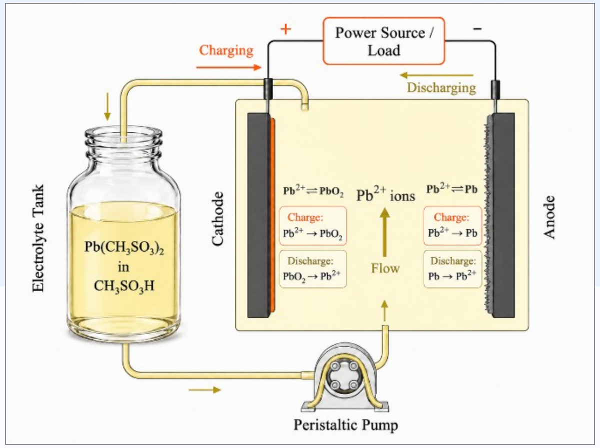
Need for Hybrid

Lithium-Ion Batteries (LIB)

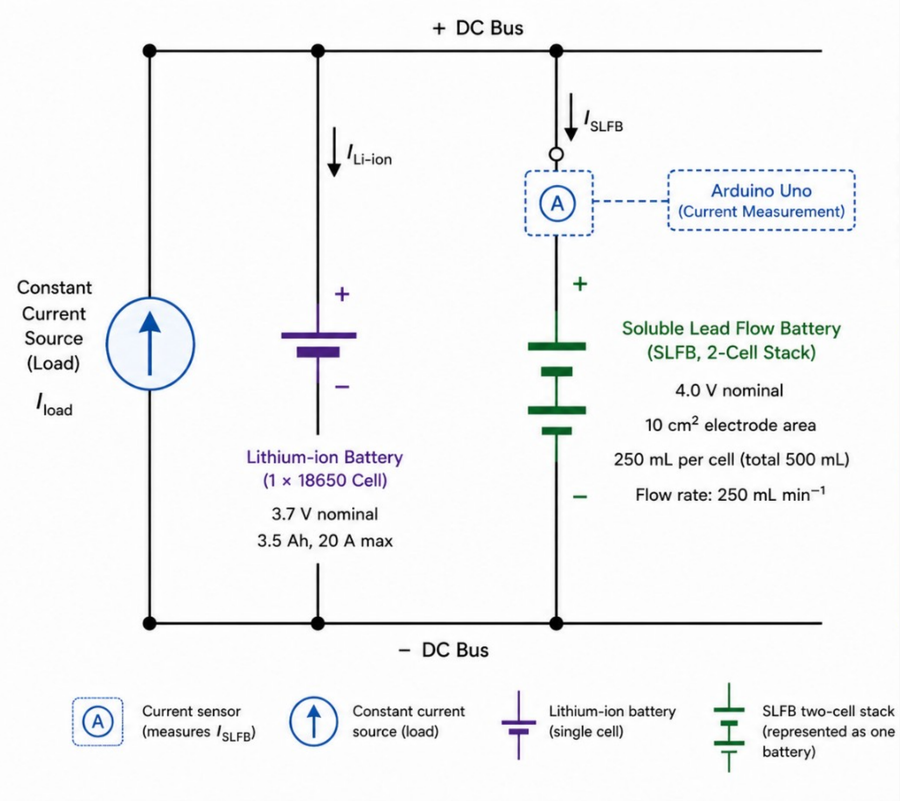
- Excellent energy density and fast dynamic response
- Degrades under high-rate cycling and peak current demands
- High cost for scalability

Soluble Lead Flow Battery (SLFB)

- Flow Batteries have decoupled energy and power densities-scalability can be achieved easily
- Simple architecture, no membrane required
- Uses recycled lead from Lead Acid Batteries
- Aqueous electrolyte, recyclable components, low projected cost
- Emerging technology with strong commercial potential



System Architecture: Passive Coupling



LIB and SLFB are directly connected on same DC Bus: Passively Connected

Current sharing is governed passively by:

- terminal voltage
- state of charge
- internal impedance
- electrochemical response

- ~4.0 V nominal, 10 cm² electrode
- 0.7 M Pb^{2+} / 1.0 M MSA electrolyte (Sodium Acetate and HDTMA additives)

LIB role: fast transient response

SLFB role: sustained current support

Key novelty: Passive current sharing without intermediate power electronics between the Li ion and Flow Battery System

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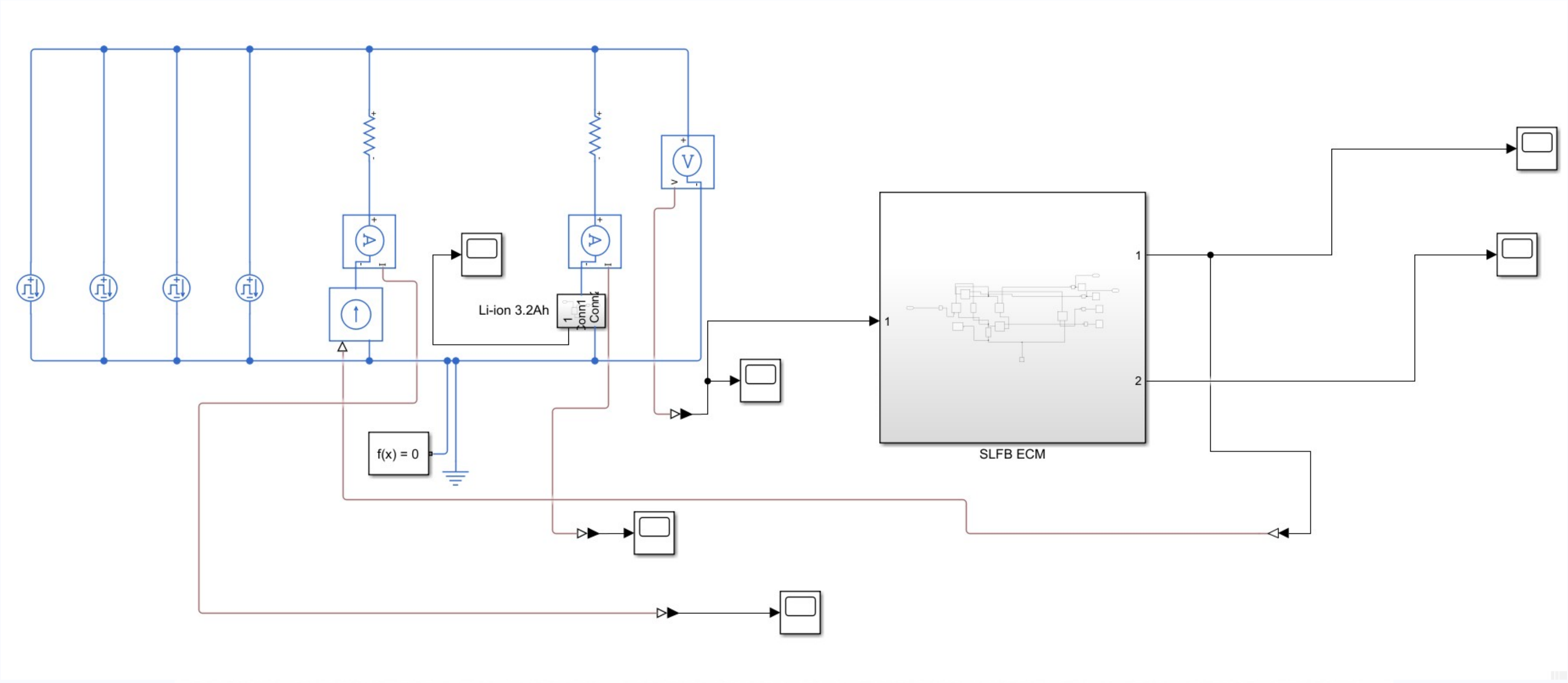
Modelling Approach



System Coupling : LIB and SLFB models directly paralleled in Simulink
Controlled current source emulates load • Evaluated at constant current up to 3 A • Mirrors real hardware architecture

Experimental Evaluation

LIB Characterisation

• EIS: impedance spectra, internal resistance
• GCD cycling: voltage-capacity data
• Data used to parameterise Simscape model

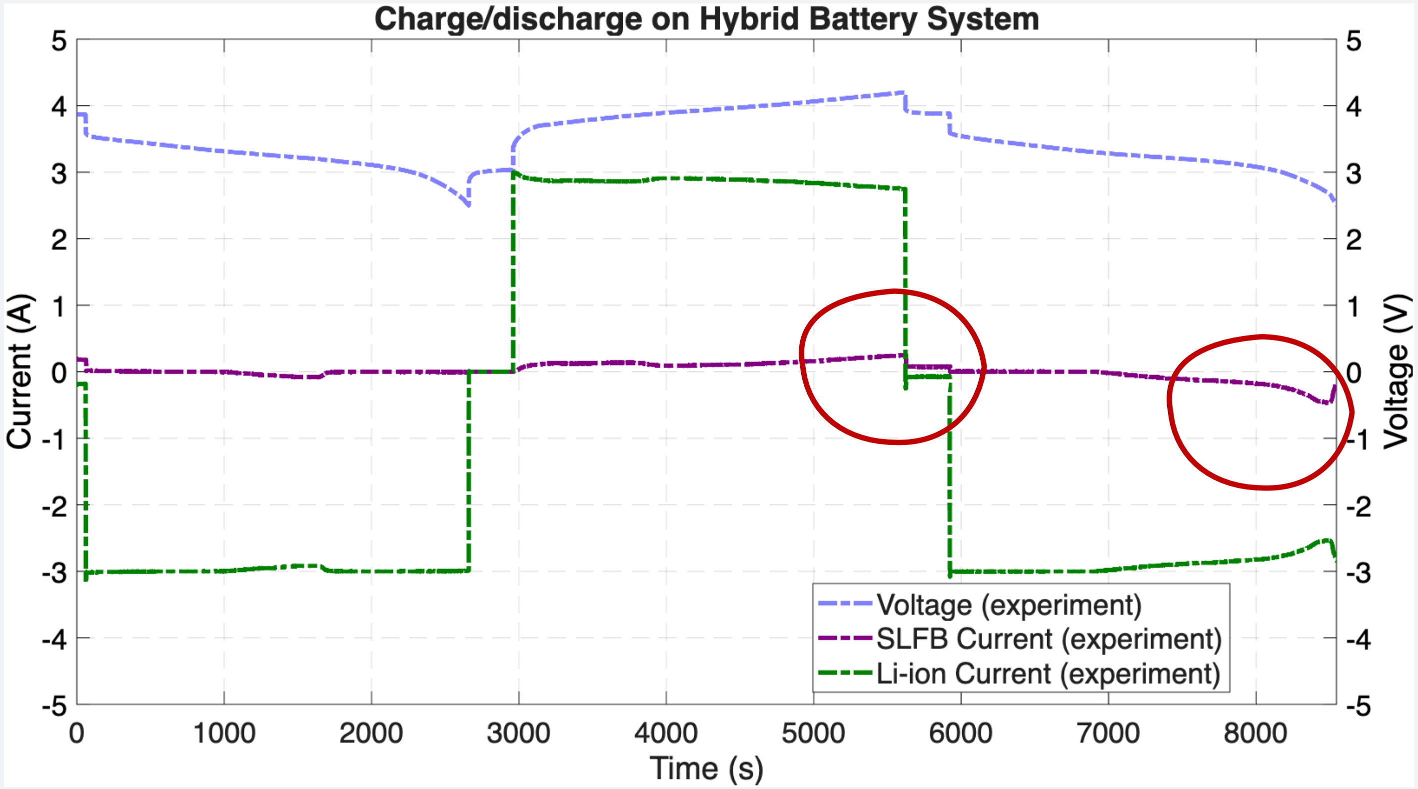
SLFB Assembly & Test

• 2-cell stack assembled in lab
• 0.7 M Pb^{2+}, 1.0 M MSA, Na Acetate + HDTMA
• 250 mL per cell at 250 mL min^{-1} flow rate
• Tested under current-controlled conditions

Hybrid System Test

• LIB and SLFB directly connected in parallel
• Arduino-based current monitoring (SLFB branch)
• Constant current load applied (charge and discharge)
• Model vs experiment overlaid

Experimental Results: Current Sharing



Key Results

~0.47 A

SLFB discharge contribution (~8,500 s)

16%

Reduction in LIB discharge current

~0.25 A

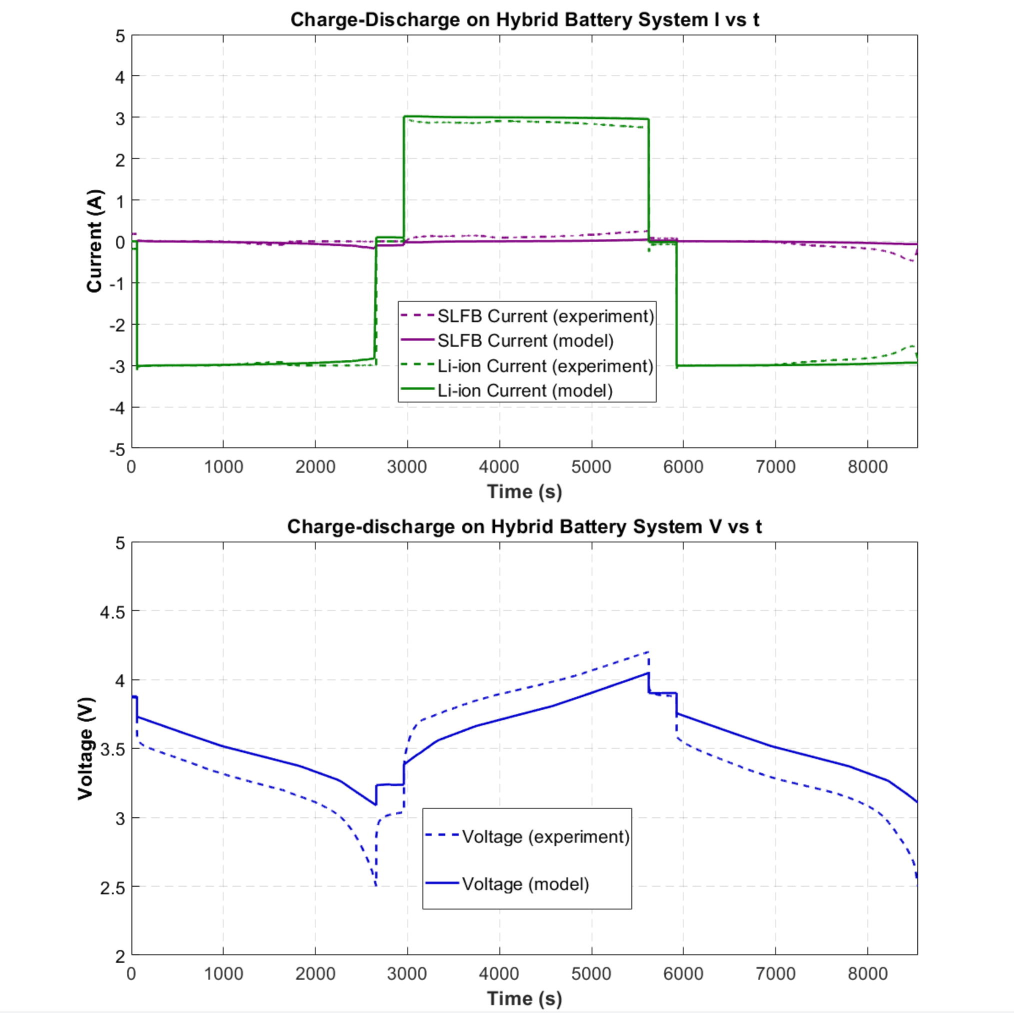
SLFB charge absorption (~5,500 s)

8%

Reduction in LIB charge current

Passive sharing — no active control required

Model Validation



Model Gets Right

- Current redistribution trends
- Direction of SLFB contribution
- Terminal voltage evolution profile

Known Deviations

- The extent of SLFB contribution isn't captured
- Cause: uncertainty in SLFB system level parametrisation

Conclusions & Future Work

Conclusions

1. Passive current sharing between LIB and SLFB on a shared DC bus is experimentally demonstrated

2. SLFB reduces peak LIB current by up to 16% (discharge) and ~8% (charging)

3. Model qualitatively captures the behaviour but needs further optimisation to capture the contribution of each subsystem quantifiably

Future Work

- Improved SLFB SoC initialisation, parametrisation and state estimation in the model

1

- Dynamic and variable load profiles

2

- Degradation and ageing under prolonged hybrid cycling

3

- System scalability (Laboratory W scale → KW scale)

4

- Renewable integration (solar, wind profiles)

YOUR QUESTIONS