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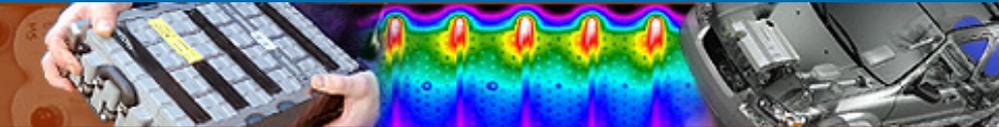
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Fail Safe Design for Large Capacity Lithium-ion Batteries

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Energy Storage



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Challenges for Large LIB Systems

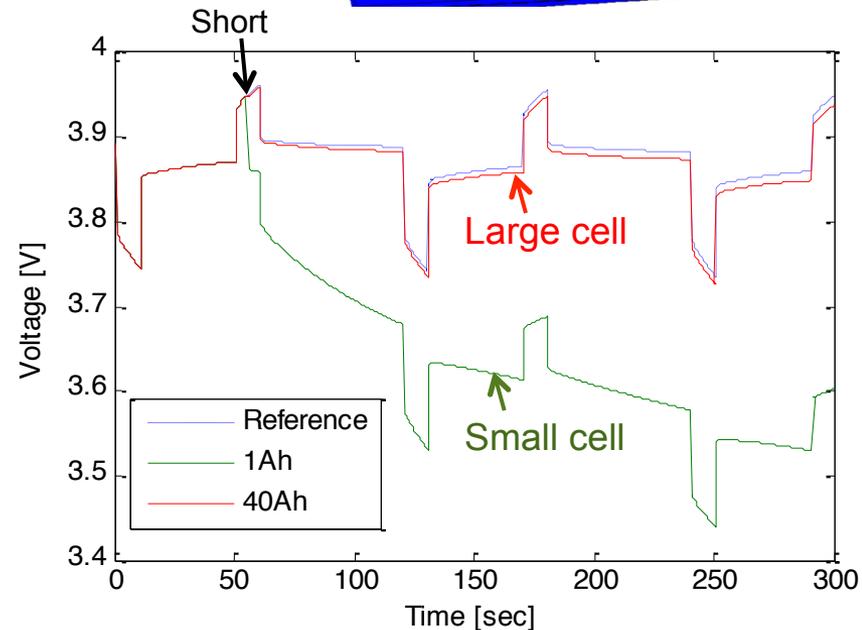
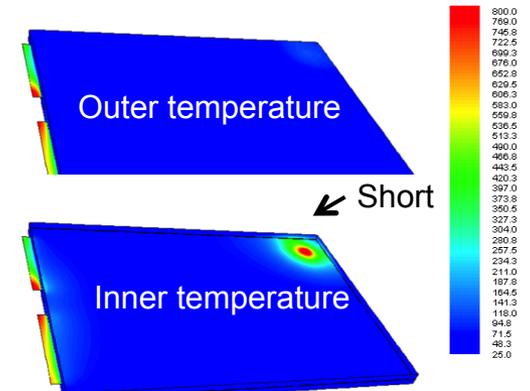
- Li-ion batteries are flammable, require expensive manufacturing to reduce defects
- Small-cell protection devices do not work for large systems
- Difficult to detect faults in large cells before catastrophe



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Barriers for Safe Large LIB Systems

1) Early Fault Detection

- The faults leading to a field accident are believed to grow from a latent defect over time
- Signals of an early-stage-fault are difficult to detect in large capacity LIB systems

2) Electrical Isolation of Fault

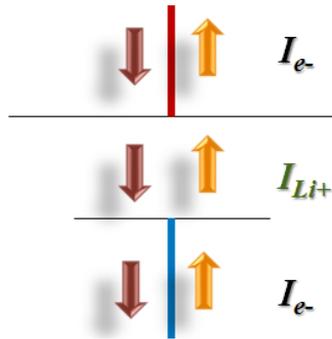
- To limit further electric current feed energizing the fault
- Neither active nor passive circuit breaker is directly applicable in large capacity LIB systems

3) Suppression of Fault preventing Propagation

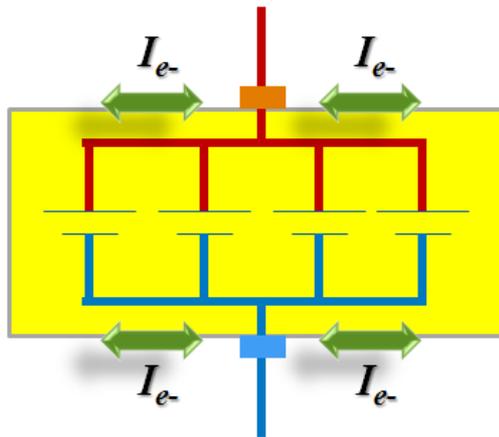
- Pack fault response depends on pack integration characteristics as well as individual cell safety characteristics
- Using safe cells does not guarantee the safety of a pack consisting of them

Electrical Current Paths in LIBs

1) Battery Electric Power Delivery: Charging/Discharging

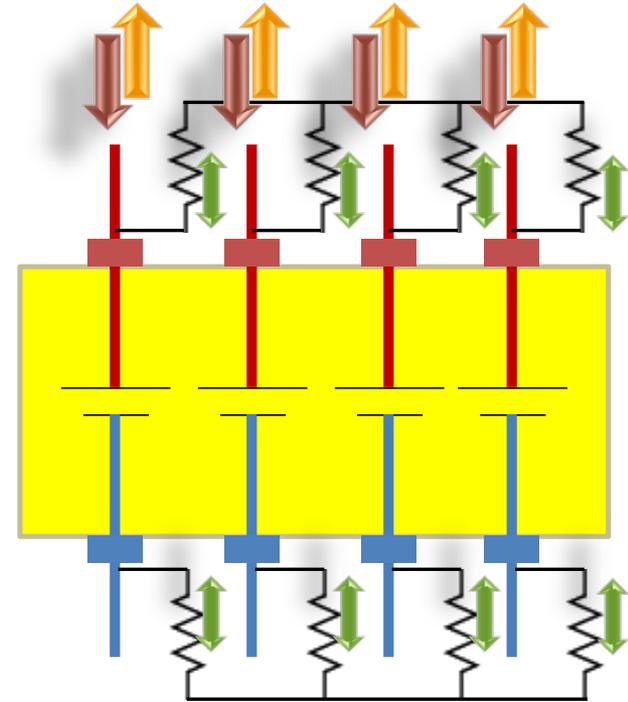


2) Balancing: Material Utilization



“Fail-safe” concept differentiates:

- **Power line** (to be as *conductive as possible*) and
- **Balancing line** (to be *relatively resistive*);



The proposed architecture facilitates early fault detection and isolation features...

Fail-Safe Design

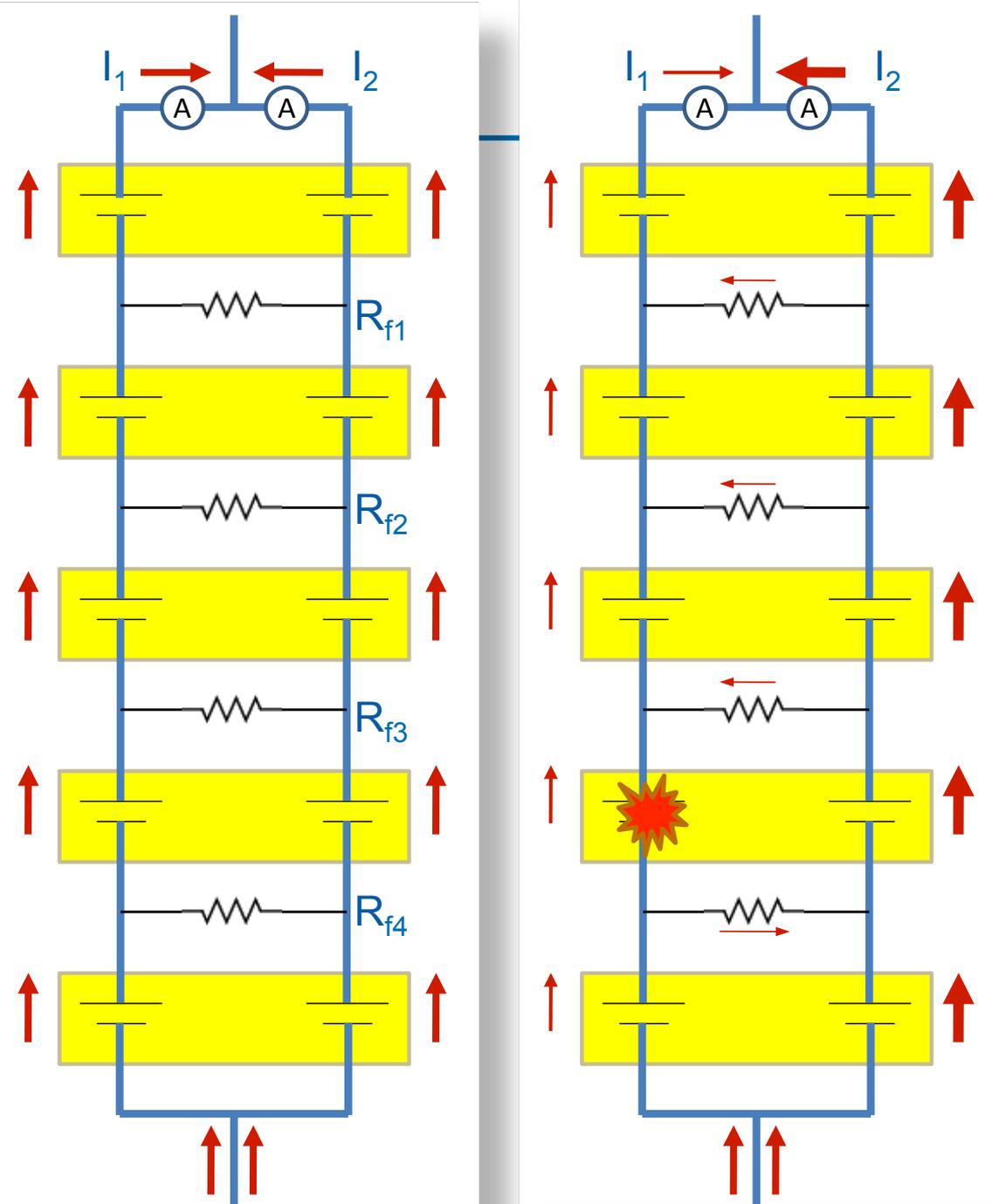
Fault Detection

$$I_2 - I_1$$

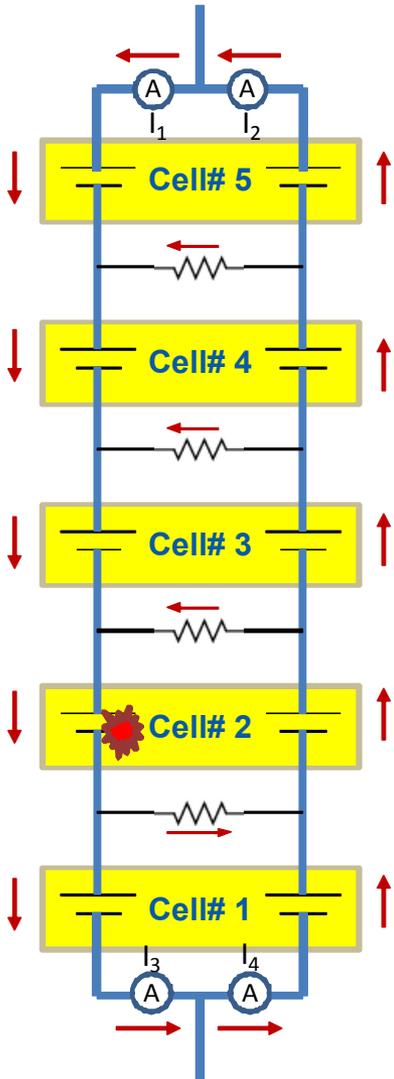
- $|Signal| \gg |Noise|$
- Known reference; $(I_2 - I_1)_{ref} = 0$
- Single measure per module

Viability of the proposed concept has been investigated against various design parameters and operation conditions

- Simulation model
- Initial testing



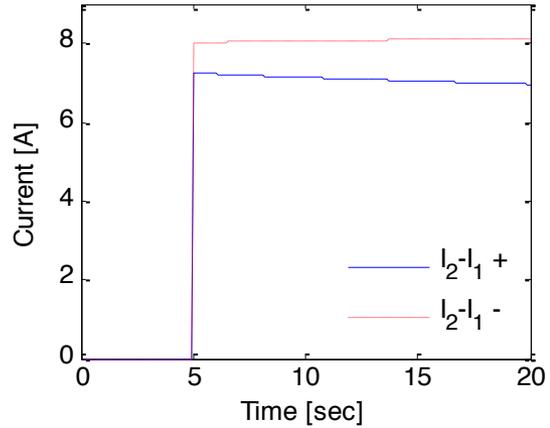
Impact of ISC Resistance on Signal



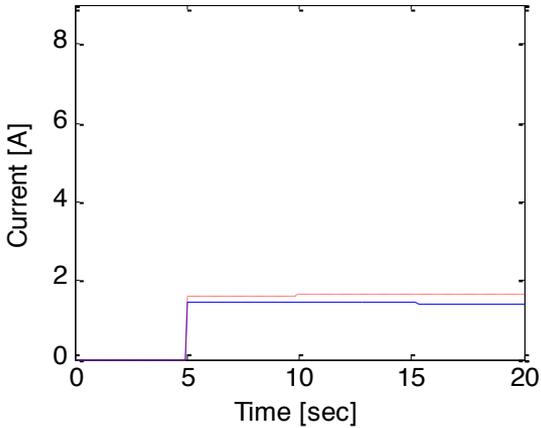
Magnitude of signal varies with ISC resistance

40Ah (20Ah+20Ah)
 $R_f = 100 \text{ m}\Omega$
 Module current : 0 A
 N in series : 5
 Shorted Cell # : 2
 R_s : 100 m Ω / 500 m Ω /2 Ω

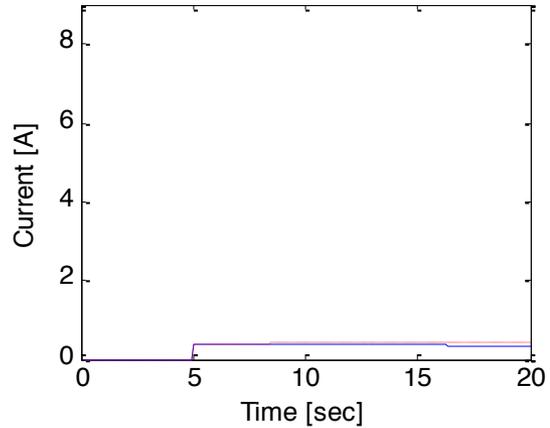
$R_s = 100 \text{ m}\Omega$



$R_s = 500 \text{ m}\Omega$



$R_s = 2 \Omega$



Experiments Confirmed Model Predictions

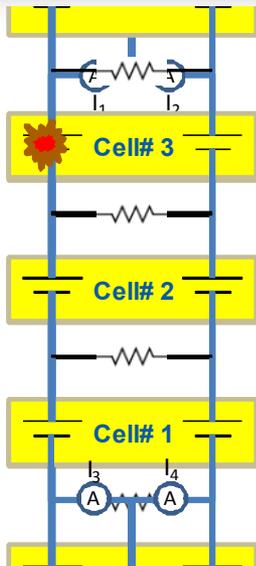
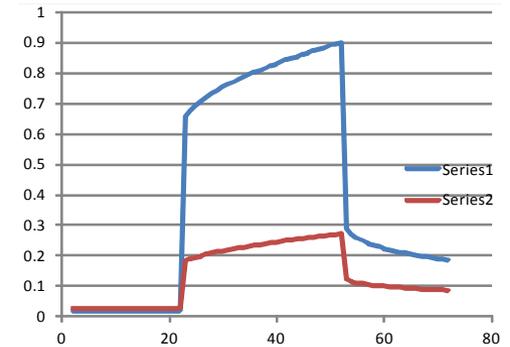
Fault Detection

Experimental implementation reproduces the results

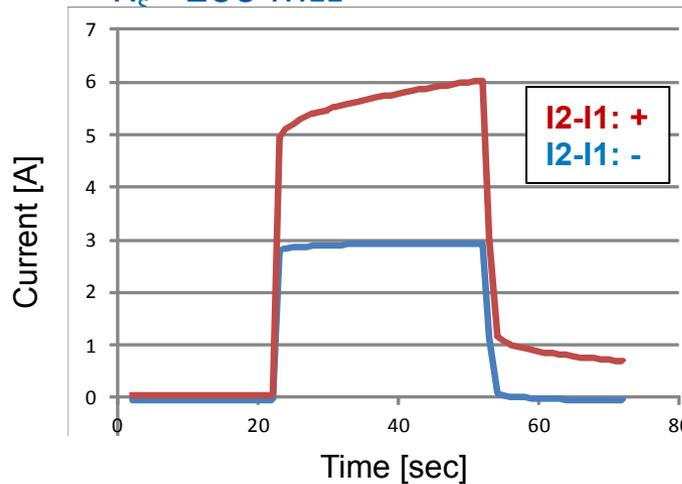
16Ah (8Ah+8Ah)
 $R_f = 180 \text{ m}\Omega$
 Module current : 0 A
 N in series : 3
 Shorted Cell # : 3

$R_s : 200 \text{ m}\Omega / 1 \Omega$

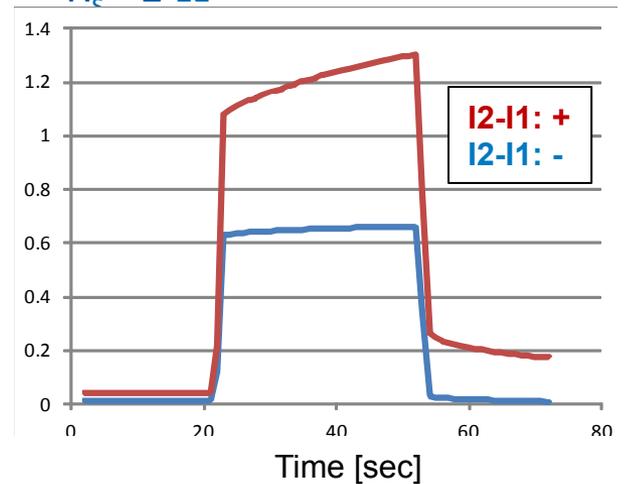
Current through parallel junctions



$R_c = 200 \text{ m}\Omega$



$R_c = 1 \Omega$



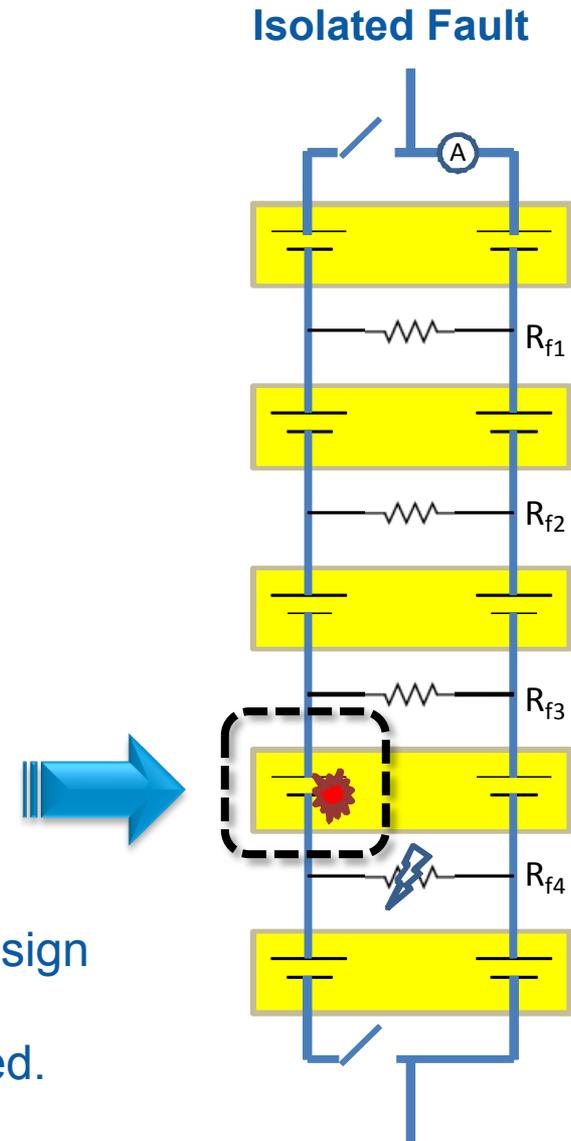
Isolating the Fault

Reviving “Mitigation technologies valid with small capacity batteries”

Once the faulted electrode is electrically isolated, the subsequent behavior of the faulted electrode depends on the characteristics of individual unit, and not on the pack or module assembly characteristics.

Therefore, designing safe packs can possibly be reduced to designing safe unit cells.

Multi-series-branch configuration of the proposed design still allows partial power delivery from the pack even after the local-shut down for fault isolation is executed.



Summary & Next Steps

- Proposed “**Fail-safe design for large capacity LIB system**” is promising to address the barriers identified: Early fault detection, Electrical isolation, Fault suppression.
- Simulation models have demonstrated the viability of the proposed concept against various battery design parameters and operation conditions
- Collaborate with **others** for further evaluation, development and embodiment of the design and the methodologies proposed
 - *Develop/refine computational tools for specific designs*
 - *Build prototypes and test*
 - *Demonstrate safety improvement of the proposed design against various failure modes of vehicle battery systems*

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Thank you for your attention!