Li-Ion Charge Balancing and Cell Voltage Monitoring for Performance and Safety

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Outline / Objectives of this talk

- Basic advantages of Li-Ion Technology
- Challenges of using Li-Ion effectively and safely
- What is required?
  - Individual cell management
  - Charge management
  - How to deal with dead cells in huge battery arrays
- Individual Cell Management approaches
  - Typical topologies
    - Bypass, individual isolated, charge sharing
  - Advantages and disadvantages
- Major investments and the future
  - Aeroflex, Boeing, and other satellite systems have invested millions in charge sharing balancing
  - Others in utility space are investing in ???
- Questions and Answers
**Introduction**

- **Li-Ion batteries are gaining attention as an attractive energy storage mechanism**
  - 2~4 x the volumetric energy density of Lead Acid
  - Longer cycle life and calendar life
  - High energy recovery efficiency
  - Large format cells are becoming available
  - $$$ Research into new chemistries, process, materials
  - Government funded large format cells on the way

- **However Li-Ion has a need for battery management to maintain long life and for safety**
  - Battery management includes cell balancing and cell voltage monitoring

- **What is Balancing / Why balance?**

- **Why monitor?**
What is / Why Balance Cells?

- Balancing is a process to equalize stored charge (voltage) between cells in a battery. It is a differential current applied to individual cells.
- Cells in a battery (a series string) have varying characteristics - leakage & capacity - that causes some cells to increase in voltage, others to reduce in voltage with charge cycling and with time.
- Lithium-ion cells, unlike other types of cells, do not have inherent cell balancing mechanism. For this reason, they are usually balanced by electronic balancing circuits.
- Balancing helps keep cells in their Safe Operating Area:
  - The safe operating area is chemistry dependent
  - Upper voltage is bound by over charge limits
    - Li-Ion chemistry degrades or may have energetic release of stored energy upon over charge
  - Lower voltage bound by permanent damage
- Balancing maximizes the safe energy storage capacity of the battery:
  - Balancing increases useful life
Why Monitor?

- A Cell Monitor allows visibility into the state of charge of all the cells in a battery.
  - Allows proactive maintenance on the battery if cells become too divergent

- Monitoring is a Safety mechanism to take action (terminate charge) if a cell enters an over voltage condition

- Monitoring is a fail safe tool to be used in addition to balancing
  - One does not replace the other.
Some Balancing Approaches
Cell Bypass

- Resistance bypass, fixed or variable threshold
  - A circuit monitors each cell voltage
  - As a cell approaches full charge, turn on a switch to bypass current around the cell.
  - This limits additional charge into the cell allowing other cells to ‘catch up’ in charge
  - Balances at full state of charge, end of charge cycle
  - Commonly employed in IC chip solutions, portable products
  - Relatively simple- low cost and reliable
    - The bypassed cell current is dissipated as heat
  - If few cells are over charged; efficiency is not too bad
    - If few cells are under charged; poor efficiency -most of the charging energy is dissipated as heat!
    - Separate Cell Monitor is required
Individual Charger per Cell

- **Individual Cell Chargers**
  - One isolated charger per cell
    - Constant current bulk charge
    - Constant voltage balance charge
    - High parts count - higher cost
    - High parts count - lower reliability
  - High efficiency
  - Failure Mode Effects needs study
    - E.g. If one of n chargers fail then one cell goes dead or is stressed or take the battery out of service until it is repaired
  - Separate Cell Monitor Required
Charge Sharing Balancer

Transformer Coupled Charge Sharing

- Series Cells are effectively parallel connected through the transformer action by synchronous switching
- In parallel, higher charged cells share their charge with lower charged cells
- Balances autonomously - no decision processes required
- Can balance at any state of charge
  - Continuous balancing is possible
  - Relatively simple - low cost and reliable
  - High efficiency
  - Scalable
  - Failure Mode Effects Analyzed
  - Good Cell voltage monitoring is easily added

US Patent Granted to Boeing March 2005
Charge Sharing Balancer

- Test Results, 13 cell string

2 Ohm Balancing Circuit

Graph showing cell voltage over time.
Cell Voltage Monitoring

- **Differential Measurements**
  - Suffer from common mode issues as cell stack increases

- **Switching Matrix**
  - Complex switching using semiconductors or relays

- **Isolation Amplifiers**
  - Elegant but Costly

- **Transformer Coupled**
  - Easily added as part of Charge Sharing Balancer
  - Transformer isolation is robust, reliable
## Feature Summary

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<tr>
<th>Technology</th>
<th>Cost</th>
<th>Reliability</th>
<th>Efficiency</th>
<th>Failure Mode Effects</th>
<th>Cell Monitor</th>
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<td>Individual Cell Charger</td>
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<td>Sharing Balancer</td>
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Any Questions?

The world's largest battery installation;
13,760 Ni-Cad cells, 5,000V 27MW/15min 46MW/5min