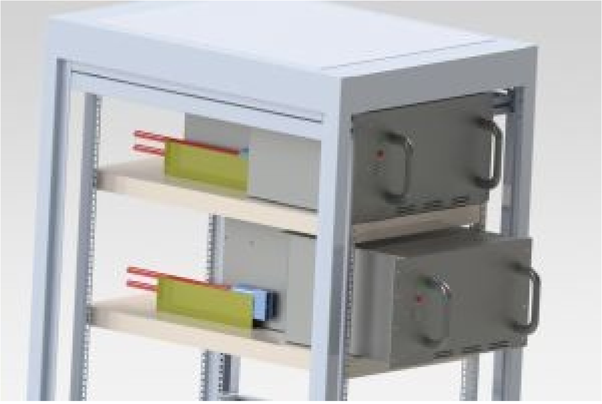
Welcome

Connecting batteries in parallel
Unexpected effects and solutions

Battery Power Conference
Sept. 18 2012
Davide Andrea, Elithion

Elithion

- Lithium-ion BMS for large batteries
- Traction packs
- Battery modules for large arrays



əlithion - Lithium-ion battery packs and BMSs

Overview

- Paralleling at the factory vs. in the field
- Parallel cells, not strings
- Introducing “Short Discharge Time”
- Issues with paralleling batteries in the field
- Some solutions for those issues

Factory vs field

<u>At the factory:</u>

- Parelleled once and for all

<u>Reason</u>

- To get desired capacity

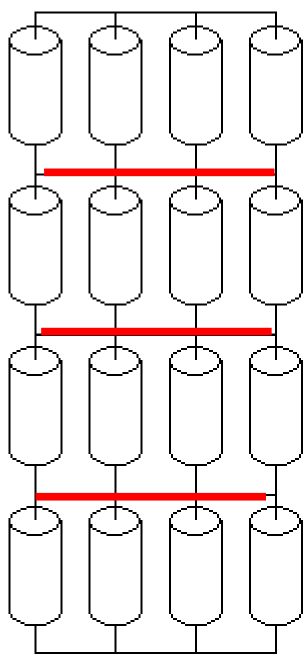
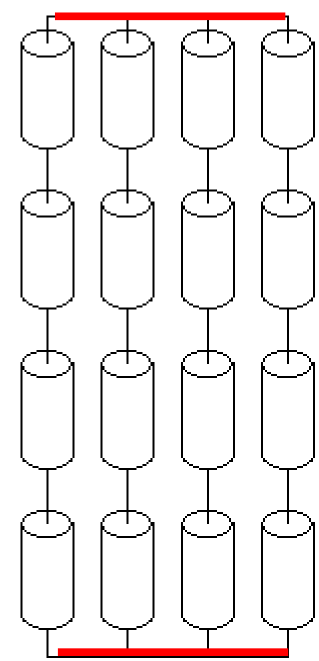
<u>In the field:</u>

- Paralleled at any old time

<u>Reason</u>

- For flexibility

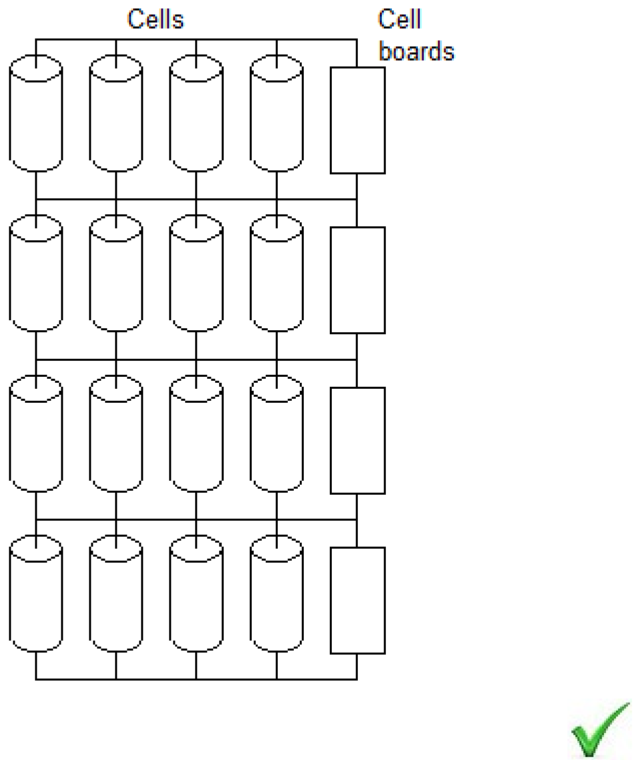
Cell in parallel vs. strings in parallel
(at the factory)

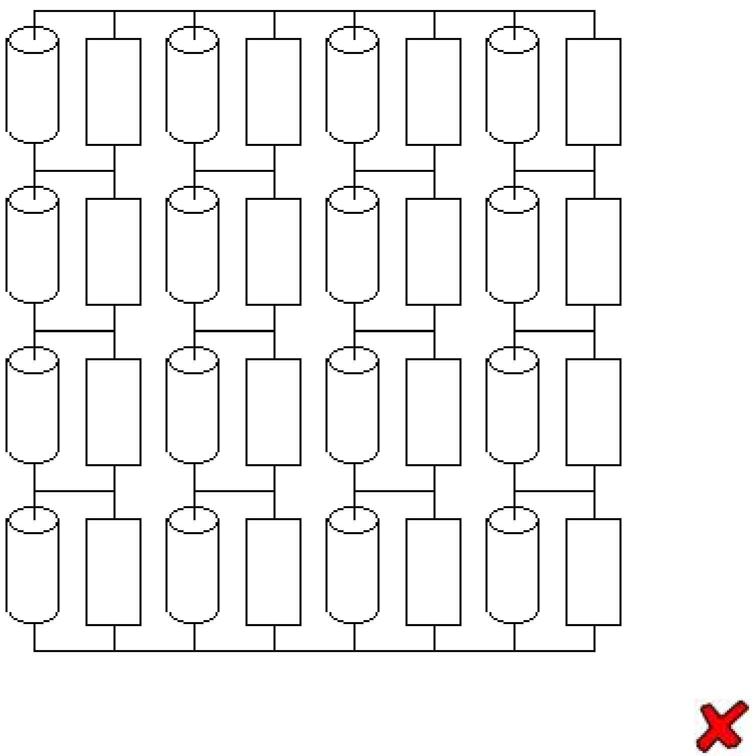
Cells in parallel	Strings in parallel
Cellis in parallel, then sets in series (lattice network) 	Cells in series, then strings in parallel 

Cell in parallel vs. strings in parallel

BMS cell boards or tap points

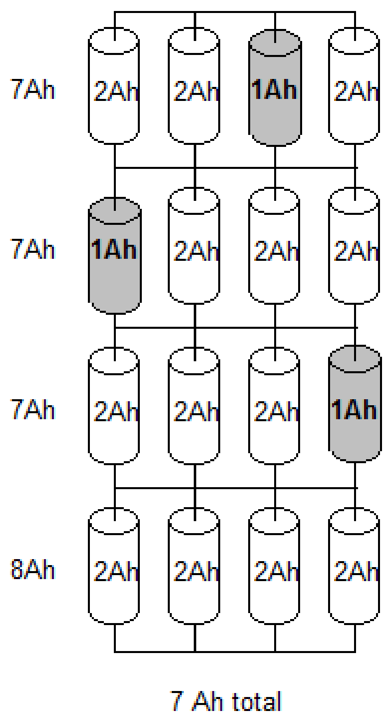
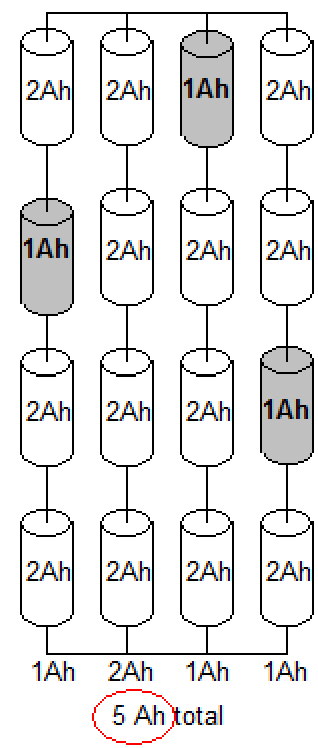
Cells in parallel	Strings in parallel
4 cell boards, or 5 tap points	16 cell boards, or 14 tap points





Cell in parallel vs. strings in parallel

Low cell capacity limitation

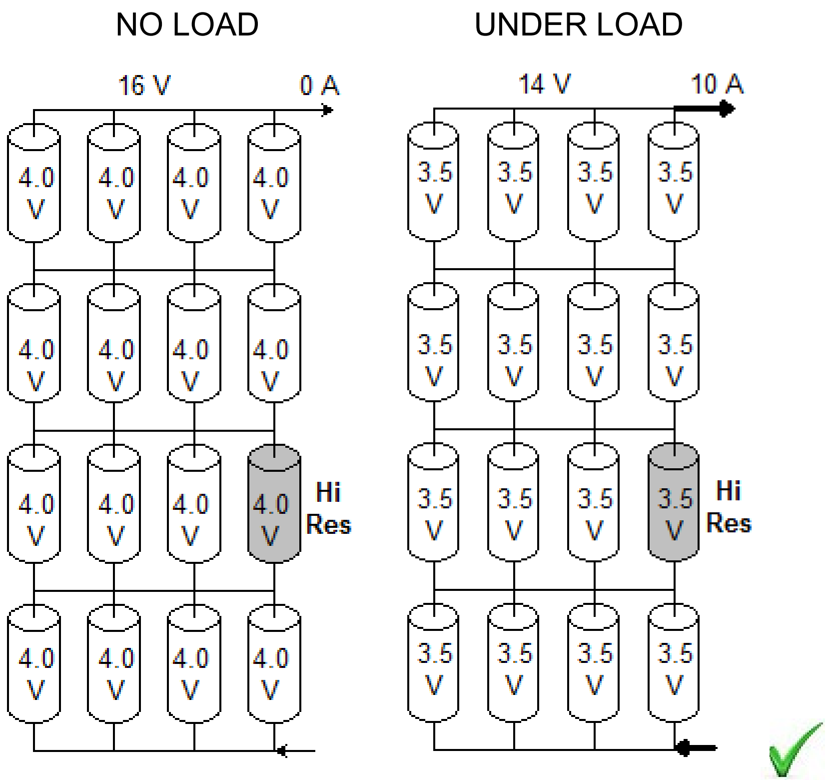
Cells in parallel	Strings in parallel
	

Cell in parallel vs. strings in parallel

Hi cell resistance limitation

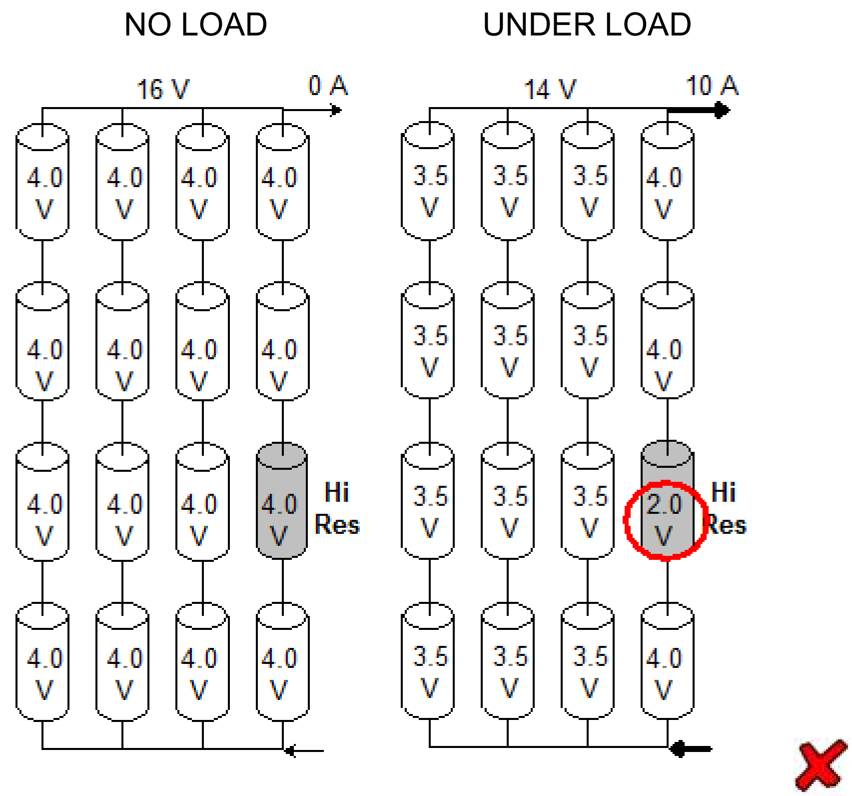
Cells in parallel

Bad cell reduces capacity

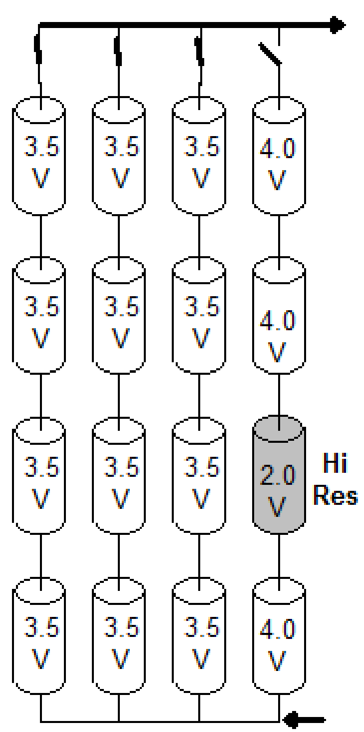
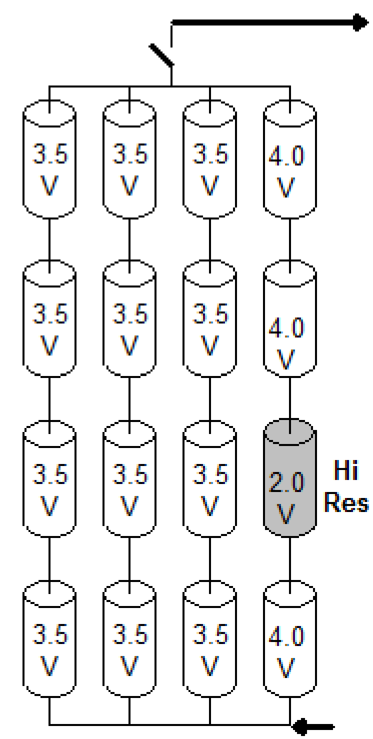


Strings in parallel

Bad cell shuts down battery



Strings in parallel
One switch vs many switches

One switch per string	String directly in parallel
Bad string can be isolated 	Bad cell shuts down battery 

Parallel connection in the field

Reasons:

- To carry only required capacity
- To add to depleted battery
- To service a battery
- To add redundancy

Issues:

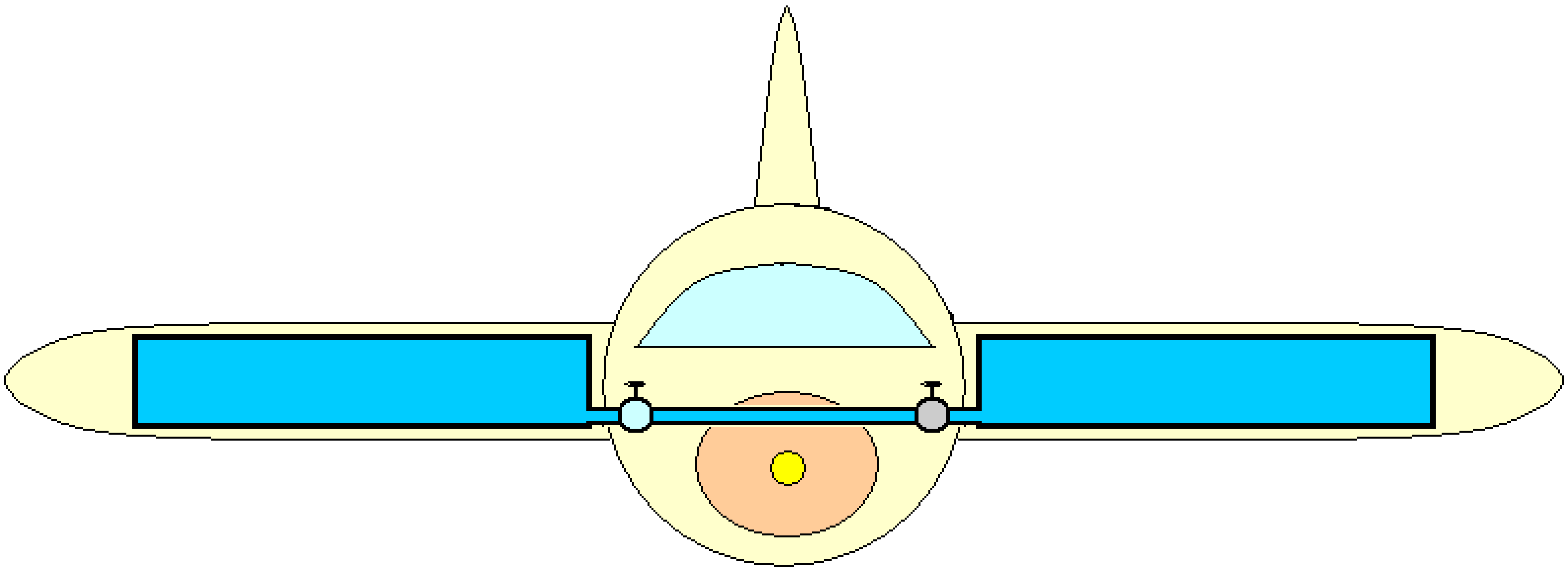
- Inrush current with differing SOC
- Keeping track of SOC, capacity

Parallel connection in the field

The fuel tank mindset: you can always add fuel tanks to increase range.

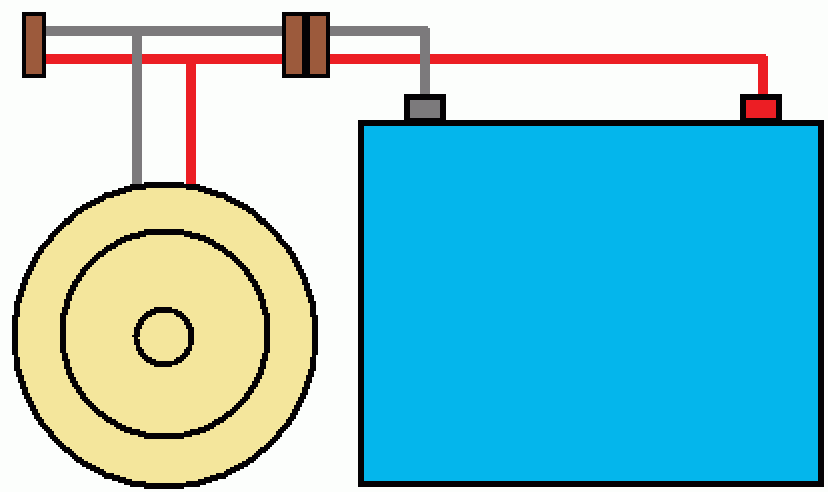
This is not applicable to batteries.

The fuel tank analogy
One tank at a time



Bad analogy to batteries in parallel

Adding a full battery
when the first battery is empty

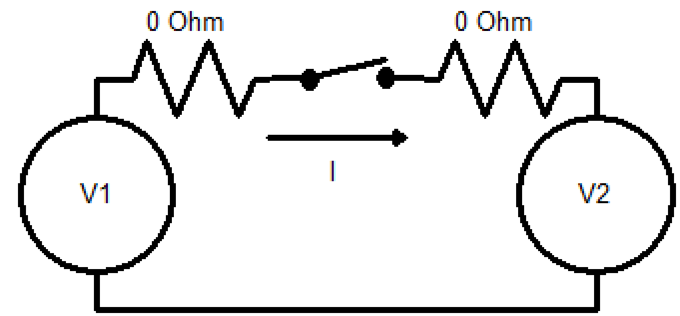


Charge rushes into the empty battery: heat!

Initial connection (in field)

Batteries as voltage sources

- Batteries are voltage sources:
  - Series: easy
  - Parallel: problematic
- If ideal voltage sources...

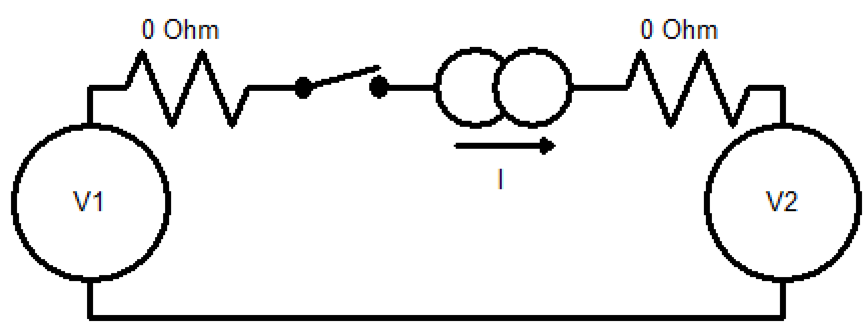


$$\frac{V1 - V2}{0\ \Omega} = \infty A$$

- Parallel ideal voltage sources = infinite current

Initial connection (in field)
Way to parallel voltage sources

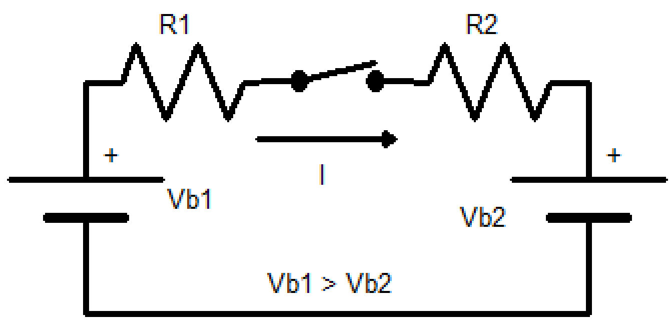
- Ideally, voltage sources are connected through current sources



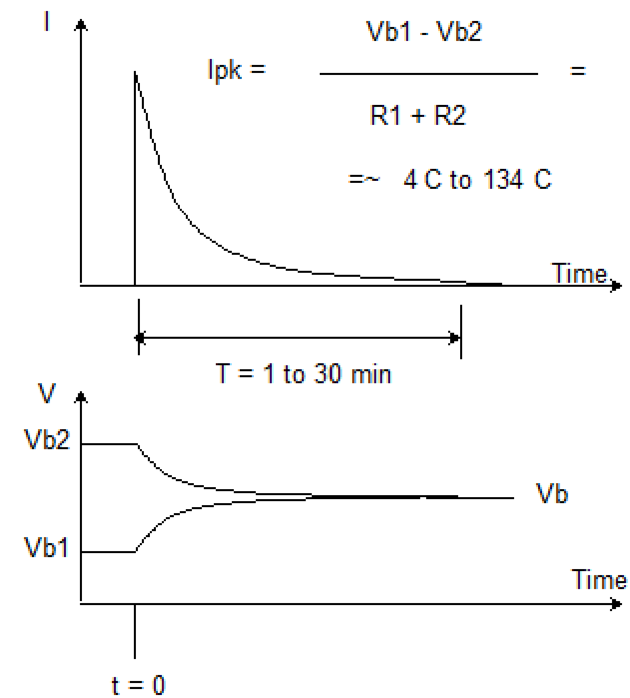
- Or, at least, through resistors
- Never directly

Initial connection (in field)
Real world batteries

- Resistance is non-0
- Voltage changes with SOC

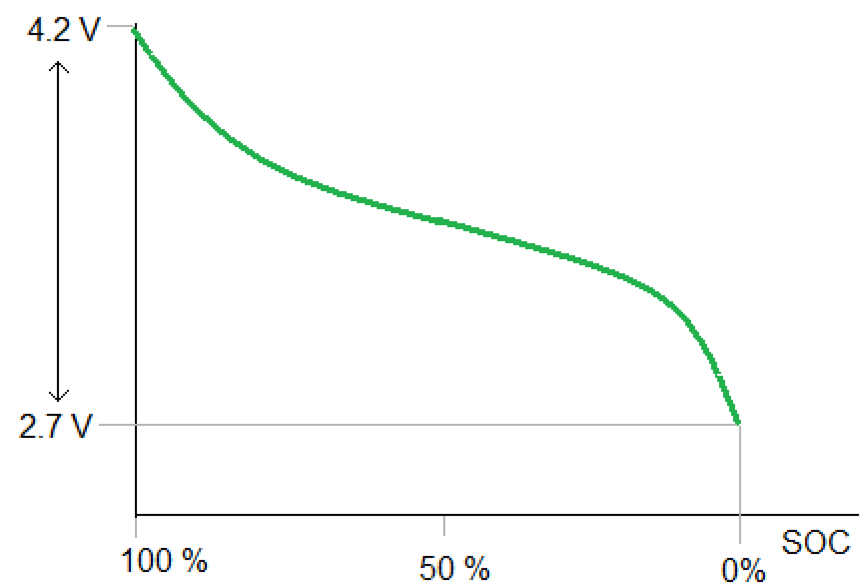


$$i(t) = \frac{Vb1 - Vb2}{R1 + R2}$$



Initial connection (in field)
Damage from inrush current

- Damage to interconnects
- Damage to cells? Possible if:
  - High dV/dSOC (standard Li-ion)
  - Low Rseries

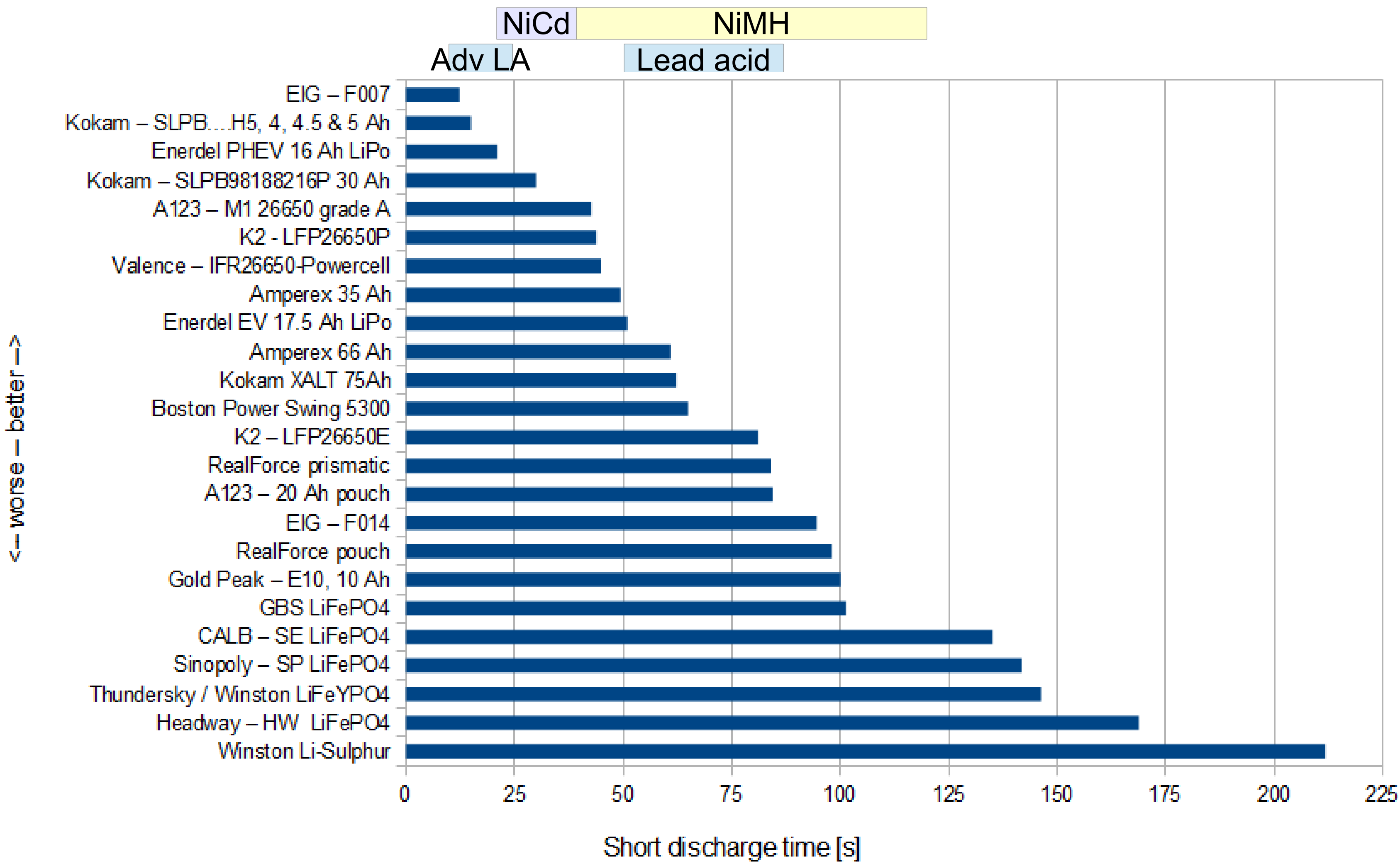


Short discharge time

Definition

- Theoretical discharge time across a short circuit
- Constant, characteristic of each cell technology, regardless of capacity or voltage
- Easy calculation of resistance
  - $R = T_{ShortDisch} * Voltage / Capacity$
- Easy calculation of efficiency
  - $E_{heat} = E_{out} * T_{ShortDisch} / T_{ActualDisch}$
- Ranges from ~10 s to ~250 s

Short discharge time
for various cell families

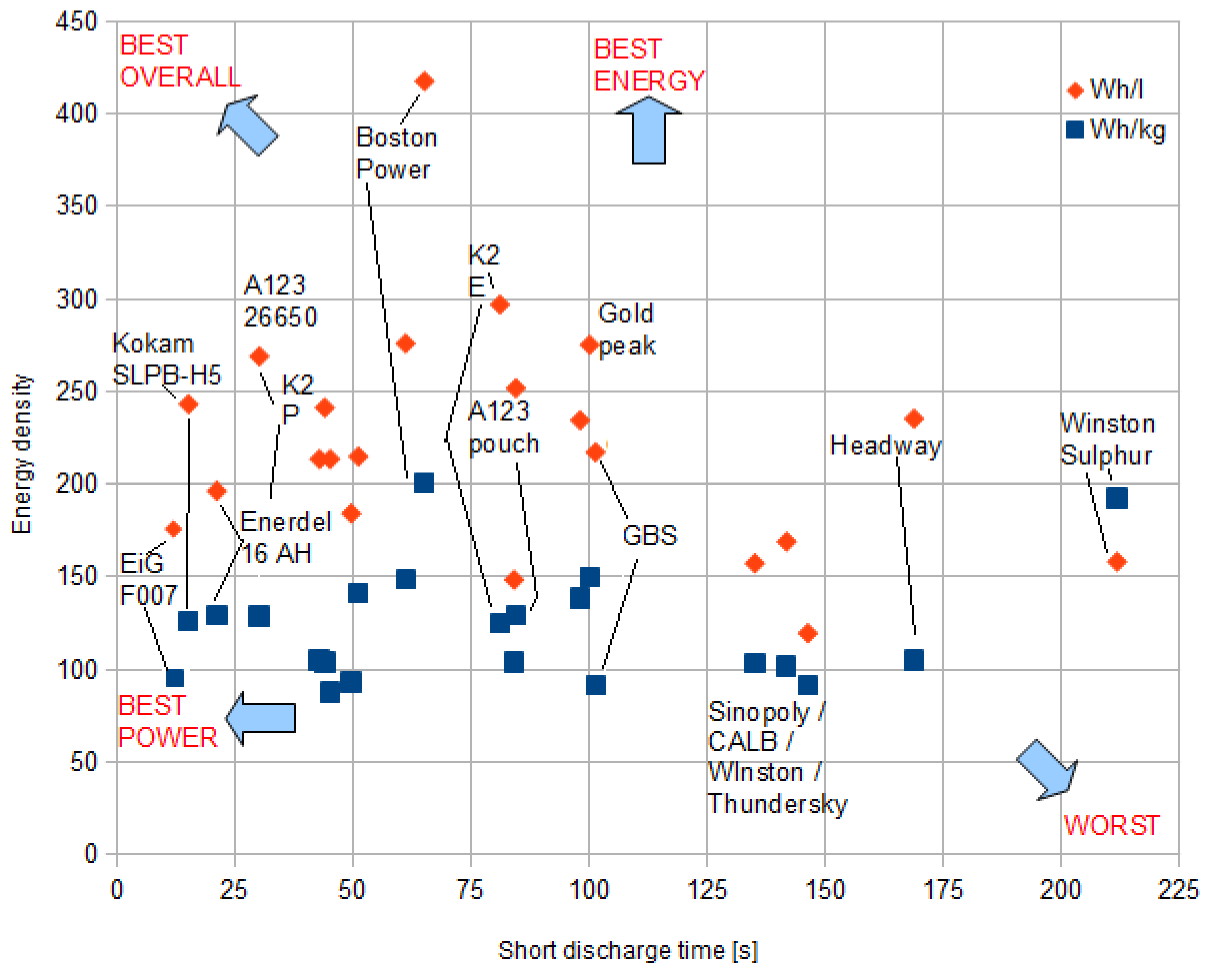


Specific Power vs. Short discharge time

Specific power	Short discharge time
•Marketing more than engineering? •Achievable in reality	•Mathematically precise •Not achievable in reality

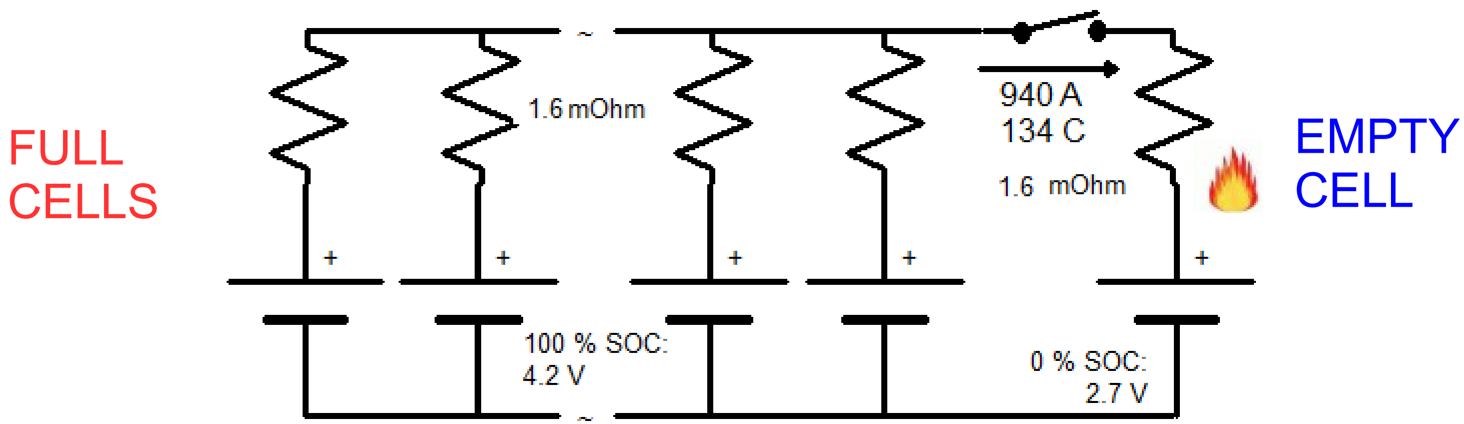
Short discharge time

Short discharge time vs energy density



Initial connection (in field)
Worst case

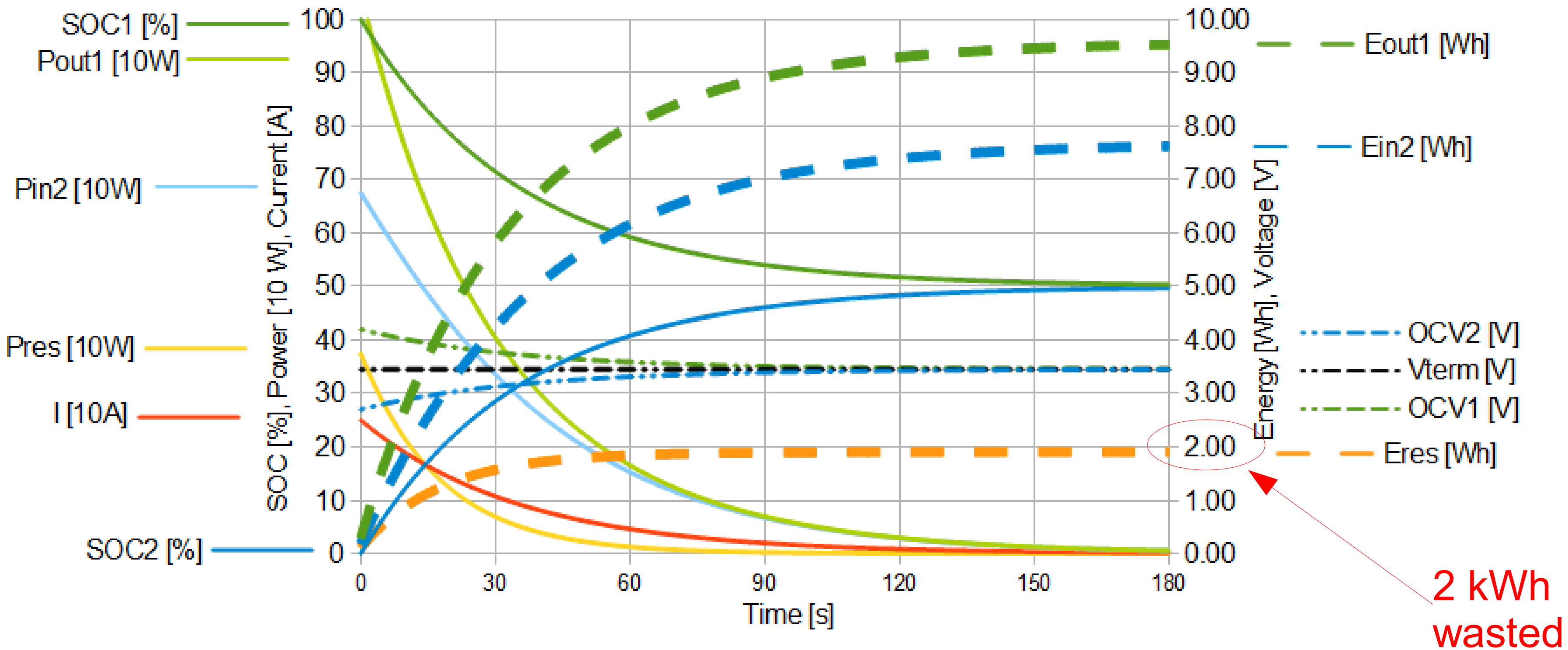
- EIG F007 cells (LiPo, 7 Ah, 1.6 mΩ)
  - Lowest resistance, high dV/dSOC
- N-1 cells 100 % SOC + 1 cell 0 % SOC



- (4.2 V – 2.7 V) / 1.6 mΩ = 940 A-pk = 134 C-pk
  - In general 4 ~ 134 C peak

Initial connection (in field)
2 cells

- KOKAM SLPB....H5 cells (LiPo, 5 Ah, 3 mΩ)
- 1 cell 100 % SOC + 1 cell 0 % SOC2



Initial connection (in field)

Energy and charge loss

Charge loss	Energy loss
No charge is lost: Just as many electrons flow out of the most charged battery as flow into the least charged one.	A bit of energy is lost: The current through the connecting resistance produces heat. The energy loss is: •~12 % for std Li-ion •~8 % for LiFePO4 •Less for delta SOC < 100 % •Independent of resistance

Paralleling batteries
Factory vs. field

- Paralleling at the factory: OK
  - Cells all have same SOC

- Paralleling in the field: not ideal
  - Possible damage with low resistance cells
  - BMS's SOC value may become invalid
    BMS may be off, or current could exceed BMS's range
  - Energy loss ~10 % @ ΔSOC = 100 %

Paralleling techniques (in field)

To minimize inrush

- Wait for equal voltages, or
- Charge lowest battery, or
- Discharge highest battery, or
- Transfer energy between batteries (DC-DC)

THEN you can connect in parallel

Paralleling techniques (in field)
SOC and capacity evaluation

- Each battery requires its own BMS (& SOC)
- SOC after connection:
  - High inrush: each BMS estimates SOC from OCV
  - Low inrush: each BMS calcs SOC from current
- Master BMS computes SOC and capacity of entire pack from individual battery SOCs

Conclusions
At the factory

- Paralleling at the factory is OK
  - Parallel cells directly (not strings)

Conclusions
In the field

- Paralleling in the field can be a problem
  - Avoid if possible:
    - Damage, loss of energy, complex calculations
  - But, if you must:
    - Use 1 BMS & 1 switch / string
    - Prevent high inrush at connection by equalizing voltages before connecting
    - Calculate capacity and pack SOC from each battery's capacity and SOC

Thank you

Questions?