Robert Strong P.E.
Li-ion Battery Technology vs. VRLA

- 60% Less Footprint
- 70% Less Weight
- 4X Expected Life
- Only 2X Initial CAPEX
- 10X # of Cycles
- AND 50% TCO Savings over 12 years
Large data centers - and other critical sites - are striving to improve their competitiveness...

...improvements in backup storage technology are a key enabler.

What can be improved from the current VRLA battery solution?

- Reduce footprint
- Improve battery lifetime/reduce maintenance
- Improve backup storage predictability and manageability
- Reduce cooling constraints
- Reduce weight
- Reduce TCO
Collaboration History between Samsung and Schneider

2011

• Starting joint work for LIB for UPS
  + Technical supports for developing battery system

2012

• First Deployment in Internet Data Centers
  + Matched Galaxy 7000 with Samsung LIB (SE R&D @ Grenoble (FR) & Kolding (DE))
  + Installed to Shinhan Bank DataCenter (Galaxy 7000, 500kVA x 34, 15 minutes)

2013

• MOU for Energy Business
  + Synergy from leadership of each companies
  + Samsung : lithium battery & SE : Energy Solution → US, France and Africa

2014

• Expanding business in Korea
  + Samsung SDS Datacenter (Symmetra MW 1600kVA x 12, 15 minutes)
  + Financial and Industrial (Display & Semiconductors) Sector

2015

• Deployments in Utility Sector
  + Korea Electric Power Company (Symmetra MW 600kVA x 2, 15 minutes)

• Official Test Program in Schneider facility
  + Battery test to be carried in November ’15 at Kolding, Denmark facility
Customer needs/pain points of lead-acid batteries (esp. large data centers & semiconductor fabs)

**Customer Needs:**
- Footprint (m²)
- Life time (year)
- Operating temp. (°C)
- Reliability/predictability
- Maintenance
- Weight (kg)
- High # of cycles (>3,000)
- Fast recharge time
- Extremely high # of cycles (>50,000)

- CAPEX ($)
- TCO (10-year) ($) (***)

**Example:** « need 2min » 600KW

<table>
<thead>
<tr>
<th>VRLA (EMEA) (5 min)</th>
<th>Li-ion (7 min)</th>
<th>Flywheel (20s) (2min)</th>
<th>Ultracaps (20s) (2min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.3</td>
<td>1.6</td>
<td>2.3</td>
<td>8.1</td>
</tr>
<tr>
<td>5</td>
<td>12</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>20-25 °C</td>
<td>0-35 °C</td>
<td>-20-40 °C</td>
<td>-40-40 °C</td>
</tr>
<tr>
<td>Medium</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>10,500</td>
<td>1,920</td>
<td>3,400</td>
<td>11,900</td>
</tr>
<tr>
<td>500</td>
<td>&gt;5,000</td>
<td>&gt;30,000</td>
<td>&gt;100,000</td>
</tr>
<tr>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>500</td>
<td>&gt;5,000</td>
<td>&gt;30,000</td>
<td>&gt;100,000</td>
</tr>
<tr>
<td>1X</td>
<td>1.9X</td>
<td>8.5X</td>
<td>29.6X</td>
</tr>
<tr>
<td>1X</td>
<td>0.75X</td>
<td>3.1X</td>
<td>10.0X</td>
</tr>
</tbody>
</table>

Life is ON
# Key Difference between Li-ion Battery Technologies

<table>
<thead>
<tr>
<th></th>
<th>Cell phone</th>
<th>Industrial (ours)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chemistry</strong></td>
<td>LCO</td>
<td>LMO/NMC</td>
</tr>
<tr>
<td><strong>Form factor</strong></td>
<td>Pouch cell</td>
<td>Prismatic cells (sealed aluminum can)</td>
</tr>
<tr>
<td><strong>Number of battery</strong></td>
<td>1</td>
<td>Over 100 (104 or 136) per cabinet</td>
</tr>
<tr>
<td><strong>BMS system</strong></td>
<td>Very simple</td>
<td>Three layers of sophisticated BMS system (module, rack, system level)</td>
</tr>
<tr>
<td><strong>R&amp;D Period</strong></td>
<td>3-6 months</td>
<td>2-3 years</td>
</tr>
<tr>
<td><strong>Design Priority</strong></td>
<td>High energy density</td>
<td>Safety (considering car accidents)</td>
</tr>
<tr>
<td><strong>Experience</strong></td>
<td>Industry average</td>
<td>Long time leader</td>
</tr>
</tbody>
</table>
Safety – Cell Design

**Guaranteed cell-level safety: Physical protection mechanism**

- **Fuse**
  - Internal fuse to prevent external short circuit / overcharge (Non-arching at high potential)

- **Anode Design**
  - Safety Functional Layer to prevent Electrical Short

- **Separator Design**
  - Multi-layered Separator

- **Vent**
  - Vent at internal pressure of 0.85 ± 0.1 Pa

- **OSD (Overcharge Safety Device)**
  - Cut-off current and prevent arc at overpotential

- **Retainer**
  - Prevent Internal Short on Crush

- **Cathode Material**: LMO/NCM based
  - Thermally Stable Materials
Same Battery as BMW i8 & i3
Solution Overview

Schneider Electric UPS & Samsung SDI LIB

Galaxy 7000 and Symmetra MW  Galaxy VM  Galaxy VX

H1  H2  2016

Lithium-ion battery racks
Ambient Temperature vs. Calendar Life

1. Temperature: 25°C
   - Remaining capacity (%)
   - Year
   - Graph showing the remaining capacity over years for a temperature of 25°C.

2. Temperature: 30°C
   - Remaining capacity (%)
   - Year
   - Graph showing the remaining capacity over years for a temperature of 30°C.

3. Temperature: 35°C
   - Remaining capacity (%)
   - Year
   - Graph showing the remaining capacity over years for a temperature of 35°C.

4. Temperature: 40°C
   - Remaining capacity (%)
   - Year
   - Graph showing the remaining capacity over years for a temperature of 40°C.
Major UPS Projects with Samsung

**Shinhan Bank (Galaxy 7000)**

World's First LIB-UPS for Internet Data Center

- Installed at Korea’s Shinhan bank in 2012
- Capacity: 4MWh (500kVA * 34Set, 15mins)

![Shinhan Data Center](image1)

**SDS (Symmetra MW)**

Adoption of LIB-UPS for Data Center at Samsung SDS

- Installed at SDS data center in 2015.06
- Capacity: 5.54MWh (1600kVA * 12Set, 15mins)

![Samsung SDS Data Center](image2)
# System Component Specs.

<table>
<thead>
<tr>
<th>System Component</th>
<th>Cell</th>
<th>Module</th>
<th>Rack</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configuration</td>
<td>1S1P</td>
<td>8S1P</td>
<td>136S1P</td>
</tr>
<tr>
<td>Dimension (mm)</td>
<td>125.7x173.9x45.6</td>
<td>414x216x163</td>
<td>650Wx600Dx2055H</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>1.88 kg</td>
<td>17 kg</td>
<td>550 kg</td>
</tr>
<tr>
<td>Nominal Voltage (V)</td>
<td>3.8V</td>
<td>30.4V</td>
<td>517V</td>
</tr>
<tr>
<td>Nominal Current (A)</td>
<td></td>
<td>460 A</td>
<td></td>
</tr>
<tr>
<td>Operating Range (V)</td>
<td>2.7V – 4.2V</td>
<td>24.0V – 33.6V</td>
<td>408V – 571V</td>
</tr>
<tr>
<td>Capacity (Ah)</td>
<td></td>
<td></td>
<td>67 Ah</td>
</tr>
<tr>
<td>Capacity (kWh)</td>
<td>0.254 kWh</td>
<td>2.04 kWh</td>
<td>34.6 kWh</td>
</tr>
<tr>
<td>Nominal Power (kW)</td>
<td>1.7 kW</td>
<td>13.6 kW</td>
<td>231 kW</td>
</tr>
</tbody>
</table>
LIB Requirements for UPS application

- Top safety technology
- High energy and power density: 35kWh and up to 230kW per rack
- Backup time from 5/6min to 30+min
- 15-years design life
- Competitive CapEx (~2X VRLA)
- Breakthrough TCO (-10-40%)
- Partnership with leading li-ion manufacturer

Schneider Electric’s LIB Solution

A modular solution accommodating a wider range of needs

- LIB Rack (W600xD650xH2100mm)
- 1 Gateway (System BMS) per system (1U, fit in one of the LIB racks)

- Switch Gear & Rack BMS
- SMPS & System BMS
- Module (8 cells)
- Cell

Switch Gear & Rack BMS
SMPS & System BMS
Module (8 cells)
Cell

LIB Rack (W600xD650xH2100mm)

1 Gateway (System BMS) per system (1U, fit in one of the LIB racks)
Actual 750kW Application in Colorado

• **VRLA Batteries:**
  - H:=77.00in. W:=160.00in. D:=34.00in.
  - Weight:=20,800.00Lbs.

• **TPPL Batteries:**
  - H:=82.00in. W:=135.00in. D:=30.00in.
  - Weight:=16,080.00Lbs.

• **Lithium Ion Batteries:**
  - Weight:=3638.00Lbs.
## BMS (Battery Management System)

Main Function: Measure, Calculation, Control, Communication

<table>
<thead>
<tr>
<th>Function</th>
<th>System BMS</th>
<th>Rack BMS</th>
<th>Module BMS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Measurement</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rack Voltage / Current</td>
<td>-</td>
<td>o</td>
<td>-</td>
</tr>
<tr>
<td>Cell Voltage / Temp</td>
<td>-</td>
<td>-</td>
<td>o</td>
</tr>
<tr>
<td><strong>Calculation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOC Estimation</td>
<td>-</td>
<td>o</td>
<td>-</td>
</tr>
<tr>
<td>SOH Estimation</td>
<td>-</td>
<td>o</td>
<td>-</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switching Control</td>
<td>-</td>
<td>o</td>
<td>-</td>
</tr>
<tr>
<td>Cell Balancing</td>
<td>-</td>
<td>o</td>
<td>o</td>
</tr>
<tr>
<td><strong>Communication</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UART</td>
<td>-</td>
<td>o</td>
<td>o</td>
</tr>
<tr>
<td>CAN</td>
<td>-</td>
<td>o</td>
<td>-</td>
</tr>
<tr>
<td>RS-485 or MODbus-TCP/IP</td>
<td>o</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Dry Contact</td>
<td>o</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
BMS Software Cont.
<table>
<thead>
<tr>
<th>#</th>
<th>Protection Level</th>
<th>Description</th>
<th>Li-Ion</th>
<th>VRLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>System Level</td>
<td>System BMS (SOC, SOH)</td>
<td>✔️</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Rack Level</td>
<td>MCCB with UVR</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fuse</td>
<td>✔️</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rack Level BMS (Vol/Current/temp)</td>
<td>✔️</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(134 Voltage/51 Temp Points/Rack Current Monitoring)</td>
<td>✔️</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Module Level</td>
<td>Module BMS (Voltage/Temp)</td>
<td>✔️</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(8 Voltage/3 Temp Points Monitoring)</td>
<td>✔️</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Cell Level</td>
<td>Fuse, OSD, Multilayer Separator, Vent, Safety Functional Layer</td>
<td>✔️</td>
<td></td>
</tr>
</tbody>
</table>
Safety – Rack Design

Guaranteed rack-level safety: MCCB & Fuses

Switch Gear

Rack

Main Fuse

MCCB

Module Fuse
## Maximized Safety

Potential safety risks in UPS batteries: **Over-potential / Short-circuit**

<table>
<thead>
<tr>
<th>Risk of Over-Potential</th>
<th>Risk of Short-Circuit</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Main cause: Abnormal battery charger operation</td>
<td>- Main cause: Decrepit equipment/cable, human fault</td>
</tr>
<tr>
<td>- Protection: Disconnect battery → Cell protection</td>
<td>- Protection: Disconnect battery → Fuse → Cell protection</td>
</tr>
</tbody>
</table>

### 1<sup>st</sup> level protection
- Current path disconnection by BMS

### 2<sup>nd</sup> level protection
- Passive protection

### 3<sup>rd</sup> level protection
- Cell protection

### Overpotential: OSD
- Overcurrent: Cell-fuse
- (And safety devices)

<table>
<thead>
<tr>
<th>Lithium-Ion Battery System</th>
<th>VRLA Battery System</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCCB</td>
<td>MCCB</td>
</tr>
<tr>
<td>Fuse (Main → module fuse)</td>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Basics of Batteries – Charge and Discharge Mechanism

**Lead Acid**

Gas emission during normal charge and discharge
- Sulfurous acid gas, Hydrogen gas, Oxygen

**Charging**

\[ 2\text{PbSO}_4 + 2\text{H}_2\text{O} \rightarrow \text{Pb} + \text{PbO}_2 + 2\text{SO}_4^{2-} + 4\text{H}^+ \]

**Discharging**

\[ \text{Pb} + \text{PbO}_2 + 2\text{SO}_4^{2-} + 4\text{H}^+ \rightarrow 2\text{PbSO}_4 + 2\text{H}_2\text{O} \]

**Lithium Ion Battery**

No gas emission during normal charge and discharge

LiMn2O4 + C6 ⇌ Li1-xMn2O4 + LixC6

LIB is based on Li-ion transfer from negative to positive electrodes

No chemical reactions btw electrolyte and electrodes during charging/discharging