Energy Storage for Smart Grid Applications

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Today’s Grid with Renewables Mix

What Is Energy Storage?

- Store electrical energy for use at a later time

Off-grid
Not connected to main electrical grid

On-grid
Connected to main electrical grid
What Would It Do?

Energy Shifting: The Duck Curve

Frequency Regulation

Back Up Power

Renewable Smoothing

Source: California ISO

Source: EB&I Consulting
Energy Storage for Demand Shave/Shift

- Peak demand is expensive (3-5x off-peak price)
- Inefficient and higher emissions
- Requires expensive new power generation capacity
- Requires inefficient and underutilized Peaker plants (<5% annual use)
How Is Energy Storage Used?

What Technologies Are Options?

**Deployed**
- Pumped hydro
- Compressed Air Energy Storage (CAES)
- Batteries (NaS, Li-ion, Pb-Acid)
- Flywheels

**Demonstration**
- Advanced Pb-acid and Flow batteries
- Superconducting Magnetic Energy Storage (SMES)
- Electrochemical Capacitors

**Some early stage technologies**
- Adiabatic CAES
- Hydrogen
- Synthetic Natural Gas

How Do Technologies Compare?

Figure 2-11 | Maturity and state of the art of storage systems for electrical energy (Fraunhofer ISE)
Li-ion Battery Terminology

- **Anode** – Electrode of cell that is being oxidized
- **In discharge**, the negative material is the anode
- **In charge**, the positive material is anode
- **Cathode** – Electrode of cell that is being reduced
- **In discharge**, the positive material is cathode
- **In charge**, the negative material is the cathode
- **Separator** - Porous film electrically isolating anode and cathode, ionically conductive

**SoC** – State of charge, amount of energy available in the battery (also see depth of discharge, DoD = 1 - SoC)

*Goodenough, Park, JACS 2014*
Why Is Li-ion Energy Storage Becoming Popular?

Solar and energy storage are complementary and both are dropping in cost

Source: Bloomberg
# Example Lithium-Ion Systems

<table>
<thead>
<tr>
<th>System</th>
<th>30 kW</th>
<th>100 kW</th>
<th>250 kW</th>
<th>500 kW – LV</th>
<th>500 kW – HV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (kWh)</td>
<td>20</td>
<td>81</td>
<td>182</td>
<td>325</td>
<td>325</td>
</tr>
<tr>
<td>Max Power (kW)</td>
<td>30</td>
<td>100</td>
<td>250</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Max Current (A)</td>
<td>95</td>
<td>250</td>
<td>550</td>
<td>770</td>
<td>625</td>
</tr>
<tr>
<td>Nominal Voltage (V)</td>
<td>357</td>
<td>525</td>
<td>525</td>
<td>840</td>
<td>927</td>
</tr>
<tr>
<td># Cabinets</td>
<td>1 - small</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

**Integrated BMS Features**

- Overdischarge Reporting
- Short Circuit Protection
- Galvanostatic Isolation
- Pre-charge circuit
- Overcharge Reporting

- CAN Communication
- Overcurrent Protection
- Cell Balancing
- Current Measurement
- SoC Monitoring
- Isolation and Ground Fault Detection
- CAN bus port with GUI
- High Temperature Cutoff
- Compact | Lightweight | Long Lasting

Confidential
What’s In the Cabinets?
Batteries Must Be Combined With Power Conversion Equipment

• AC systems: Battery + Inverter + Transformer + Controller
• DC systems: Battery + DC/DC converter + Controller
Konterra Microgrid Project

- 300 kWh/500 kW battery with solar at commercial building
  - Primarily for back up power
  - Allows solar to keep operating when grid is down
  - Generates revenue 24/7 in frequency regulation market
  - EV charging stations built-in

Installed: 2013
Location: Maryland
Customer: Solar Grid Storage/SunEdison
Franklin Township Project

- 222 kWh/500 kW battery with solar at school
  - Allows solar to keep operating when grid is down
  - Generates revenue 24/7 in frequency regulation market

Installed: 2015
Location: New Jersey
Customer: Solar Grid Storage/SunEdison
Cuisinart Resort Project

- 125 kWh/250 kW battery with solar at school
  - Stabilizes microgrid during solar fluctuations
  - Powers desalination plant

Installed: 2014
Location: Anguilla
Customer: Dynapower
Off-Grid EV Charging

- Demonstration project in Amman, Jordan
  - 25 kWh battery @ 24V
  - 3 kW solar array
  - Level II EV charging station

- Project goals:
  - Illustrate viability of off-grid solar charging
  - Prove durability/performance in a hot environment
  - Develop working prototype for large-scale deployment
    - Modular and scalable
    - Easy to install and operate
Safety and Thermal Management of Li-ion Batteries
Integrated PCC + iBTM Solution

Power Grid → Renewable Energy → ESS Buffering → Charging Station

PCC+iBTM Battery Enabled Energy Storage System

E-Aircraft
Material Handling
Robots

ESS Buffering

Optimal Charging/Dis-Charging Current Command

Thermal SoC

Cell Balancing

Monitoring Sensors

Thermal Control

ESS Buffering

Renewable Energy

AllCell Phase change composite

Battery Pack with PCC

Melting Point

Temperature Remains Constant During Melting

Temperature with No PCC

Temperature with PCC

Time

PCC Material
Li-ion Cells

Compact | Lightweight | Long Lasting

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Thermal Runaway Characteristics

- Cell Thermal Runaway (TR) is defined as uncontrollable heating > 10 °C/min
- ARC shows trigger temperatures and rate of energy release dependent on cell capacity
- TR has been observed to occur at temperatures as low as 100 °C in fully charged 18650 cells

A Conceptual Roadmap To Thermal Runaway in Li-ion Cells

- **High Rate Abusive Conditions Internal Shorts**
  - **T > 85°C**
    - Anode SEI/Elect. $\Delta H = 350$ J/g
  - **T > 140°C**
    - Solvent/Salt $\Delta H = 200$ J/g
    - Cathode SEI/Elect. $\Delta H = 300$ J/g
  - **T > 180°C**
    - LiNi$_{0.8}$Co$_{0.2}$O$_2$/Elect. $\Delta H = 500$ J/g
  - **O$_2$ Evolution**
  - **T > 240°C**
    - Li$_x$C$_6$/PVDF/O$_2$/Elect. $\Delta H = 1500$ J/g
  - **Fire**
  - **T > 660°C**
    - Aluminum Meltdown $\Delta H = -395$ J/g

Initiates PTC
Separator Fusion
Pressure Disconnect
Li-Ion Thermal Runaway: Pack Level Nail Penetration

No PCC Pack

PCC Pack
Need For Fast-Charging Solutions

- Range anxiety and expensive EV charging downtime
- **Complex problem:** Elevated temperatures favor fast charging but reduce discharge performance
- Current energy storage technologies have major limitations

**Capacity fade & resistance increase throughout 1C/1C cycling of NMC Li-Ion cells**
Li Plating and Thermal Effects

- Li\(^{+}\) ions plate on the surface of the anode instead of intercalating into it
  \[x\text{Li}^{+} + \text{Li}_6\text{C}_6 + x\text{e}^{-} \rightarrow \text{Li}_{6+x}\text{C}_6\]
  \[(1 - x)\text{Li}^{+} + (1 - x)\text{e}^{-} \rightarrow (1 - x)\text{Li}^{0}\]

- Li metal forms dendrites  \(\Rightarrow\) Poor Battery Performance
  - Internal Short-circuit
  - Rapid Heating
  - SEI formation
  - Electrolyte Drying
  - Dissolution of positive electrode

- Heat generation occurs as a result of both, reversible and irreversible processes:
  \[Q_{\text{irr}} = (V_{\text{bat}} - U)I\]
  \[Q_{\text{joule}} = I^2R\]
  \[Q_{\text{rev}} = I \frac{T \Delta S}{nF}\]

In situ detection of lithium metal plating on graphite in experimental cells, Journal of Power Sources 279 (2015) 428-438

Lithium-ion battery fast charging: A review, eTransportation 1 (2019) 100011
Passive Thermal Management: PCC + iBTM

- Elevated temperatures maintained by PCC during fast charge improves intercalation kinetics & mass transport resulting in improved performance.

AllCell’s Work: Voltage profiles during cycling at a) 1C CH, C/3 DCH, 25 °C b) 3C CH, C/3 DCH, 25 °C c) 1C CH, C/3 DCH, 35 °C d) 3C CH, C/3 DCH, 35 °C

Source: Asymmetric Temperature Modulation for Extreme Fast Charging of Lithium-Ion Batteries, Joule 3, 1–18, December 18, 2019
Final Comments

- Energy storage is necessary for maintaining growth of renewable energy.
- Energy storage applications are different and require various technologies.
- Li-ion batteries are currently leading the pack but other low tech solutions are still viable.
- Need of energy storage is high for grid and off-grid applications.
Thank you

Said Al-Hallaj

salhallaj@allcelltech.com