Advanced Technology Lithium Polymer Batteries for High Power Applications

Robert L. Myers
Director, Science and Technology
Athena Global Energy Solutions, Inc.
bob.myers@athena1.com
Today’s Li-ion Battery Technology Has Several Limiting Factors

Customer Needs:

Energy
• Manufacturers have come close to the limits on energy density given current technology
• Significant leaps in power output, runtime, etc. are increasingly difficult to achieve with current technology

Safety
• Overheating and explosions have been key issues with current Li-ion technology
• Safety concerns limit design applications/possibilities

Size/Weight
• Customers want longer lasting more powerful devices in a smaller/lighter package
• Battery technology is the limiting factor

Conclusion:
• Most battery development is focused on incremental gains through modification of current technology
• Incremental improvement in current battery technology will not meet growing areas of opportunity
• Disruptive leaps in battery technology and performance are needed to overcome key challenges
Introducing Liberty Energy’s “Solid Structure” Lithium Polymer Batteries

2 A/H

25 A/H

55 A/H
First, Some Definitions......

- Energy Battery: A battery specially configured for high energy density, at the expense of discharge rate. Intended for “long battery life” applications

- Power Battery: A battery configured for high discharge rate at the expense of energy density. Intended for power tools, high torque applications, or distributed energy storage requiring small size and short backup duration

- Nominal Capacity (C): Expression of the amount of charge that can be stored in a battery. Measured in Ampere-hours.

- Discharge Rate (x * C): Expressed as a multiple of Nominal Capacity

- Maximum Discharge Rate: Highest discharge rate a battery can support while still maintaining acceptable performance characteristics (terminal voltage, cycle life, capacity, temperature performance)

- Energy Density (V * C): The amount of energy stored in a battery per unit weight (Specific Energy Density) or unit Volume (Volumetric Energy Density)
Unique Performance Advantages Arising from “Solid Structure” Lithium Polymer Construction

- **Solid Structure Technology: No liquid or gel electrolyte – Safety**
- **Solid Structure Technology: Extremely low internal impedance – Reduced Self Heating**
- **Produced in a sheet from 0.4mm to 10mm thick and up to 36” wide – Form Factor and Packaging Flexibility**
- **Strong shelf life (96+% annual retention rate) - Warehousing and Merge Centers**
- **Up to 50% more energy at similar weight compared to other Lithium technologies – High Specific Energy Density**
- **Up to 100% more energy at similar volume compared to other Lithium technologies – High Volumetric Energy Density**
- **Very consistent production output on commercial production lines – Manufacturability, Reliability & Quality**

Superior Performance in Virtually all Meaningful Performance Categories
Li-FePO₄ vs. “Solid Structure” Li-Poly at High C Discharge

Six 3.3V 2.3Ah battery cells are connected in series to perform the discharge test.

Battery discharge under 10degC

- 14.4V 14C discharge
- 13.78V 15.4C discharge
- 13.85V 17C discharge
- 12.02V 18.8C discharge

Barely 2.6V per cell

Where has all my capacity gone?

Market Available “High Discharge Rate” Li-FePO₄

Liberty Lithium Polymer 20C (28A) Discharge Curves vs. Temperature

1.4Ah Battery 20C Discharge in Different Temperature Characteristic
Currently Available Li-ion Battery Technology Delivers Compromised Performance at High Discharge Rates

Six 3.3V 2.3Ah battery cells are connected in series to perform the discharge test.

Battery discharge under 10degC

Voltage (V)

23

21

19

17

15

13

11

9

7

5

0 25 50 75 100 100

time (s)

14.49V 14C discharge

13.78V 15.4C discharge

13.05V 17C discharge

12.02V 18.8C discharge

Barely 2.6V per cell

Where has all my capacity gone?
LE 20C (28A) Discharge Curves vs. Temperature

1.4Ah Battery 20C Discharge in Different Temperature Characteristic

Battery Specification:
504094-1.4Ah
Charge: 3C-4.2V
Discharge: 20C-3.2V

- 0°C
- 10°C
- 25°C
- 32°C
- 45°C

Capacity (mAh)

Voltage (V)
LE 20C (28Amp) Discharge vs. Temperature
vs. 10°C Li-FePO₄ Characteristics (Normalized) (Superimposed)

Higher and Flatter are characteristics of superior performance!
30C Discharge Curves vs. Temperature

30C Discharging performance for PB504094 at Different Temperature

Battery Specification:
504094-1.4Ah
Charge: 1C-4.2V
Discharge: 30C-3.2V

Voltage (V) vs. Capacity (mAh)

- 10 Degrees C
- 25 Degrees C
- 32 Degrees C
- 45 Degrees C
Preliminary Cycle Results – 20C Discharge

- 8.7% over 350 cycles
Design Example – 1000W, +12V, 2 Minute Backup Requirement, “CFF-Like” Form Factor

For simplicity, assume a single, high efficiency buck converter at 96% eff.

First set the battery string size based on End-of-Discharge voltage:

Full Charge Voltage: 3.6V
Plateau Voltage: 2.6V
EOD Cutoff: 2.1V
Max Discharge Rate (C): 15C
EOL Capacity (%): 80%
Capacity Derate for High C (%): 45%

7 Cell Series String:
Vmax = 7 * 3.6V = 25.2V
Vplateau = 7 * 2.6V = 18.2V
Vmin = 7 * 2.1V = 14.7V

Full Charge Voltage: 4.2V
Plateau Voltage: 3.6V
EOD Cutoff: 3.2V
Max Discharge Rate (C): 25C
EOL Capacity (%): 80%
Capacity Derate for High C (%): 94%

5 Cell Series String:
Vmax = 5 * 4.2V = 21.0V
Vplateau = 5 * 3.6V = 18.0V
Vmin = 5 * 3.2V = 16.0V
Design Example – 1000W, +12V, 2 Minute Backup Requirement, “CFF-Like” Form Factor

Determine the Max Power Delivery requirement, Output Current at Maximum Allowable Discharge Rate, and apply Derating Factors:

\[
\begin{align*}
P_{\text{max}} &= \frac{1000\text{W}}{.96} = 1041.7\text{W} \\
\text{Max Discharge Rate} &= 15C \\
1041.7\text{W} / (V_{\text{plateau}}) &= 57.2\text{A} \\
57.2\text{A} / 15C &= 3.8\text{Ah}
\end{align*}
\]

Verify Runtime at EOL:
\[
\begin{align*}
60\text{min}/15C &= 4\text{ min} \\
4\text{min} \times .45 \times .80 &= 1.44\text{ minutes} - \text{Need to scale up by 2mins/1.44mins}
\end{align*}
\]

5.3 Ah/cell Nominal Capacity

\[
\begin{align*}
P_{\text{max}} &= \frac{1000\text{W}}{.96} = 1041.7\text{W} \\
\text{Max Discharge Rate} &= 25C \\
1041.7\text{W} / (V_{\text{plateau}}) &= 57.9\text{A} \\
57.9\text{A} / 25C &= 2.3\text{Ah}
\end{align*}
\]

Verify Runtime at EOL:
\[
\begin{align*}
60\text{min}/25C &= 2.4\text{ min} \\
2.4\text{min} \times .94 \times .80 &= 1.80\text{ minutes} - \text{Need to scale up by 2mins/1.80 mins}
\end{align*}
\]

2.6 Ah/cell Nominal Capacity
Design Example – 1000W, +12V, 2 Minute Backup Requirement, “CFF-Like” Form Factor

Determine number of series strings needed to achieve the required capacity and estimate the physical space needed for the battery cells:

5.3Ah / 2.6 Ah = 2.03 (round down to 2)

Two series strings of seven 2.6Ah cells in parallel

Physical space required:
14 * 1.8 * π * 6.5 = 514.6 cm³

Physical space available:
3.8 * 19.5 * 7.8 = 578 cm³

Because the prismatic cells are customizable for shape, a 2.6AH package is easily achieved

Single string of five 2.6Ah Cells

Physical space required:
5 * 4.0 * 9.4 * 0.7 = 131.6 cm³

Physical space available:
3.8 * 19.5 * 7.8 = 578 cm³

Batteries alone consume 90% of the available space within the CFF mechanical envelope, before considering battery any management, charging or power conversion circuits

Batteries consume only 20% of the available space within the CFF mechanical envelope
Conclusions

- **High Discharge rates dramatically reduce the physical size of batteries for high power applications**

- **Solid structure batteries exhibit enhanced performance at high discharge rates in terminal voltage and delivered capacity over a wide temperature range**

- **Prismatic solid structure construction makes form factors extremely flexible and mechanical packages easy to customize, while significantly enhancing safety**
Call to Action

- **Have Fun:** There is no greater fun to be had than designing with high-power batteries!

- **Help us define cycling test protocols that are meaningful to your applications**