

High power and high energy lithium-ion batteries for under-water applications

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Abstract

Lithium-ion batteries have demonstrated excellent energy density, reliability, and life in commercial applications. Several new Navy and undersea applications are emerging that need the high energy density and high power capabilities that the lithium-ion technology offers. Such applications have historically utilized silver–zinc technology for their power source. However, life cycle costs, maintenance and logistics issues, and wet-life limitations are true detriments in these applications. Lithium-ion technology has demonstrated the energy and power density of silver–zinc, but with much improved cycle life, shelf life, and low maintenance properties. For these reasons, and others, many under water applications are looking to lithium-ion to provide the performance of the silver–zinc system, but at a greatly reduced life-cycle cost.

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1. Introduction

Lithium-ion technology has demonstrated a wide range of desirable performance parameters, high energy and power density, long cycle and shelf life, high reliability and limited maintenance requirements. These features make the technology very attractive for a wide array of military, aerospace and commercial applications. Increasingly, Naval and other under-water applications are turning to lithium-ion technology to provide unique weight and volume solutions to their high energy and/or high power needs. Historically these applications have relied heavily on silver/zinc technology batteries to provide their power requirements. However, with the limited cycle and wet life, and high maintenance costs of Ag/Zn cells [1,2], many applications are seeking viable alternatives. Lithium-ion batteries offer the high energy and power densities required of many of these applications, with significantly greater cycle and self life, and much less maintenance and logistical costs. Three battery systems are currently in development at Lithion, a corporate sister of Yardney Technical Products, each with unique design and performance requirements. This paper will discuss these three systems

and the application of lithium-ion technology to meet their needs.

2. 10 kWh modular UUV battery

A medium energy, medium power battery is being designed to support an unmanned underwater vehicle (UUV). This battery is designed to deliver 10 kWh at nominally 324 V, discharge rates are moderate with the highest power demands of 10 kW for only short durations, up to 2 m. The lithium-ion battery is being designed to replace an existing Ag–Zn battery currently used for the application. Due to the low energy and power density requirements, and the desire to keep costs to a minimum, a series/parallel array of high-volume production 8 Ah cells was selected to meet the requirements. Battery modules of 90 of these cells in series are assembled to provide the required voltage (Fig. 1). Four of these modules are connected in parallel to meet the capacity requirement. Maintaining the state of charge balance of these cells was seen as critical to the overall battery performance, as the cell to cell voltage divergence would limit the capabilities and life of the battery. Cell monitoring and balancing electronics were designed for this battery to monitor cell voltages and pack temperature and provide cell balancing during charge through resistive bypass circuitry.

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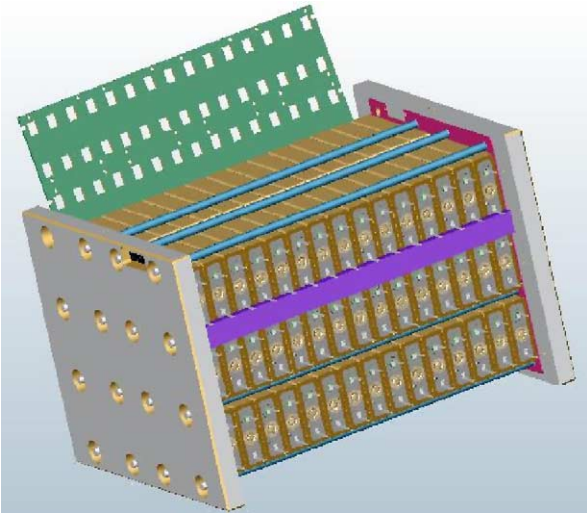


Fig. 1. 90-Cell module for a 10-kWh battery for an unmanned underwater vehicle (UUV).

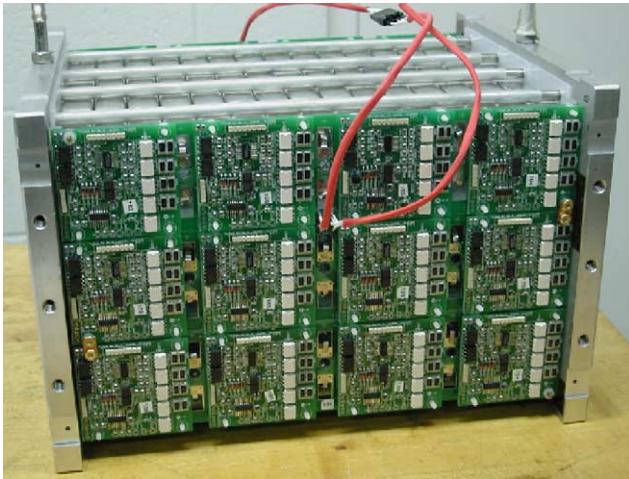


Fig. 2. Monitor/equalizer boards attached to UUV battery.

Monitor/equalizer cards (Fig. 2) that can monitor and balance up to four cells have been developed. These cards are interconnected via an optically isolated Micro-LAN to each other and to a Master Control Board (MCB) that resides in the supplied battery charger. These cards are modular and up to 44 cards can be connected to a single MCB. Each card contains a One-wire™ addressable device that allows for simple communications to all cards, and complete telemetry on the voltage and location of any individual cell.

3. High power lithium-ion battery

To support the power requirements of an all electric torpedo, a high-power lithium-ion battery has been developed. This battery (Fig. 3) provides up to 250 A continuous at a nominal 300 V. One hundred, specially designed high-power 25 A h lithium-ion cells are connected in series to meet these requirements. With an estimated battery weight of 115 kg,

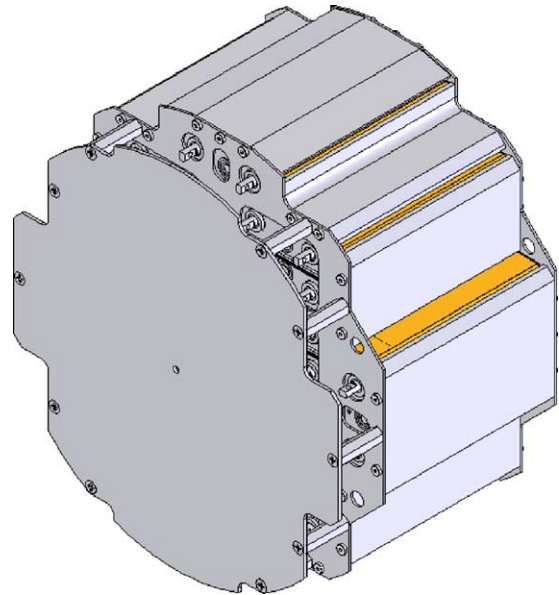


Fig. 3. One 20-cell module for high-power battery for an electric torpedo.

this battery provides a specific power of over 650 W/kg at the battery level. To save on development time, a standard prismatic cell design was utilized for this application, however, the battery design still required packaging these cells to fit within the cylindrical volume of the torpedo (Fig. 4).

The high rate chemistry selected for these cells was the result of several development programs focusing on rate capability improvements and is very similar to the chemistry utilized for the lithium-ion batteries being supplied to support a battery upgrade on the B2 Bomber. Once again cell monitoring and balancing electronics are provided to minimize state of charge divergence between the cells. The same modular monitor/equalizer boards are used for this application with only slight modifications. To provide telemetry and safety warnings during discharge, the Master Control Board for this application has been located within the vehicle.

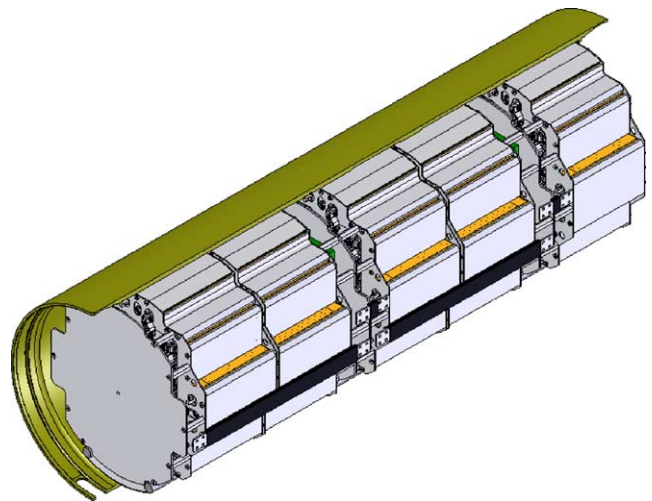


Fig. 4. High power, 75 kW, battery configuration for an electric torpedo application.

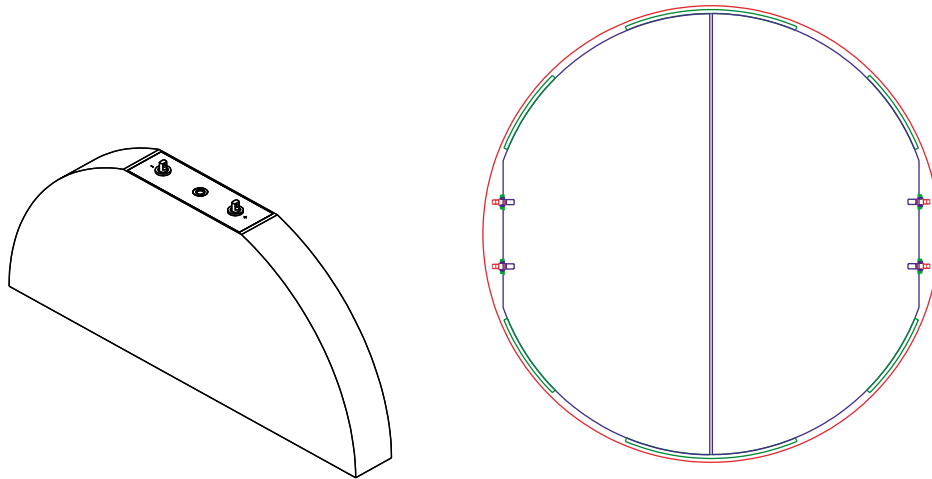


Fig. 5. One of several cell designs for a high energy application utilizing all of the cylindrical space available.

Communications back to the charger system still provide for full charge control and cell balancing, and a user interface is provided to display status and battery condition. During discharge, the MCB collects the high and low cell voltages and high pack temperature data from the monitor/equalizer cards and provides that information to the on-board computers. Safety signals are provided to indicate when one cell is dropping below a predefined threshold, or when the battery temperature exceeds acceptable limits. Again, the addressable nature of the electronics provides not only the actual voltage and temperature values, but also the location of the cells reporting them. This aids in troubleshooting and optimization of the battery design and performance.

4. High-energy battery

The Advanced SEAL Delivery System (ASDS) is a mini-sub-type vehicle with high energy requirements. To minimize the weight of the system, battery-level energy densities of $>165 \text{ Wh/kg}$ are required. Very large batteries, totaling over 1.2 MWh , power the system used for insertion and extraction of Navy SEALs. Large lithium-ion cells typically offer $170\text{--}200 \text{ Wh/kg}$, and are thus ideal for this application. In this case, the flexible form factor of true parallel plate prismatic lithium-ion cells provides an advantage in utilizing as much of the available volume (Fig. 5).

In fact, proposed cell designs had to be scrapped as they completely filled the available volume, but put the battery overweight. High-energy chemistry designs are being developed to optimize the performance for this low rate application. Much of the lessons learned in developing very high power chemistries for aircraft and other applications are being applied in reverse to optimize the capacity of the system. Larger particle sizes for the active materials, and heavier electrode weight loadings are being investigated.

5. Conclusions

Lithium-ion technology has proven its capabilities and adaptability to make it attractive for a wide range of uses. In the cases highlighted here, three different battery designs with different performance requirements have been developed for three different underwater vehicles. The range from very high power ($>650 \text{ W/kg}$) to very high energy ($>165 \text{ Wh/kg}$) demonstrates the flexibility of the technology.

Cycle life, maintenance and logistics costs can be minimized by utilizing lithium-ion batteries in place of some traditional chemistries. And the manufacturing costs of high-energy batteries can be reduced through utilization of high-volume production capabilities. Lithium-ion technology is proving its utility in a broad range of applications, and offers a unique power supply solution to many of them.

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