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Large Format High Power Lithium Ion Battery Systems

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Abstract

Saft America, inc. Space and Defense Division, located in Cockeysville, Maryland, is the world leader in providing state of the art lithium ion systems for the demanding defense and space markets. Saft has been manufacturing batteries at its facility in Cockeysville for over 26 years. Our products have evolved to match the requirements of all branches of the military. One major focus of the facility is large format high power Lithium Ion cells and battery systems for defense applications. Recent effort has focused on the industrialization of the technology for use in military hybrid vehicles. This effort is focused under the ManTech program with TARDEC. Overall goals of the program are aimed at improving the technology readiness to support the production of military hybrid vehicles, with areas of focus on improved performance, reliability, manufacturability, and overall cost.

Saft SDD has developed a standard series of batteries designed specifically for use in military hybrid vehicles. The 'HEMV' battery pack design is scalable by adding additional modules to match the system voltage of the application. This battery system solution provides an ideal balance between power and energy to support the varying military hybrid vehicle modes, including drive assist, regenerative braking, silent watch, and limited battery only motive power.

Keywords: Battery, Lithium Battery, Energy Storage

1 Introduction

Saft SDD is a fully integrated facility complete with research, development and manufacturing capabilities. Saft SDD produces complete energy storage systems, including electrode manufacturing and locally made hardware to assemble the cells, modules, and system. Saft SDD also performs all of the electrical tests for both the cells and the batteries in house.

One major focus of the facility is large format high power Lithium Ion cells and battery systems for defense applications. Recent effort has focused on the industrialization of the technology for use in military hybrid vehicles. This effort is funded by programs with TARDEC for demonstrating and maturing the technology. Overall goals are aimed at improving the technology readiness to support the production of military hybrid vehicles, with areas of focus on improved performance, reliability, manufacturability, and overall cost. All of the improvement efforts utilize design for manufacturing techniques and results are carried across the entire product range at Saft SDD to develop a standard product line.

The Saft SDD HEMV standard series of batteries is designed specifically for use in military hybrid vehicles. The HEMV scalable design can be configured with 4 to 8 standard modules, for a nominal system voltage range from 175V to 350V. The HEMV pack design is based around the VL34P cell design, a cell within Saft SDD's P Series (High power) cell line.

The usable performance of the cells within the battery pack is typically limited by actual usage of the system. Typical design constraints are system voltage, peak charge and discharge current, and heat generation. The battery pack is equipped with monitoring and control electronics that are designed to integrate within the vehicle to allow for communication and management of the battery usage by the vehicle controller. The total system approach provides what is required in one package.

2 High Power Cell Technology

Saft has been developing high power battery systems for military and automotive applications for the past 12 years. This high power battery technology has been steadily improving as advances in electrochemistry are proven and implemented. The VL34P cell was developed to provide the ideal dual performance of power and energy suited for military vehicle applications. This cell has been used in series hybrid applications to support battery only operation, silent watch and drive assist. The performance characteristics of the cell make it an ideal candidate for integration into battery systems for hybrid electric drive vehicles.

The cell incorporates improvements in many aspects of the cell design. The electrochemical design has been updated to improve the performance of the cell for high rates and low temperatures. It has been repackaged to improve the volumetric and gravimetric power and energy densities, while moving to lower cost components and processes. Improved packaging and assembly methods have also allowed for a significant reduction in the internal resistance of the cell, resulting in increased power, improved energy, and lower heat generation. This allows for a uniform temperature distribution within the cell and a means of effectively removing heat from the cell to improve cell life. The following table is a summary of the performance characteristics of the VL34P Li-Ion cell.

Table I – VL34P Performance Characteristics

	Units	Value
Mass	kg	0.94
Volume	L	0.41
Charge Voltage	V	4.1
Nominal Capacity	Ah	33
Specific Energy	Wh/kg	120
Energy Density	Wh/dm3	280
Terminal-to-Terminal Length	mm	184
Max Discharge Current @ 25°C - Continuous	A	500
Max Discharge Current @ 25°C – 2 sec pulse	A	1900
1kHz AC Impedance	mΩ	0.4

The VL34P cell exhibits a uniform low resistance over the SOC range is ideal for hybrid vehicle type applications that operate in the 30-70% SOC range.

2.1 VL34P Rate Performance

The VL34P cell was discharged at various rates while at 25°C and -30°C in order to characterize its performance. The results confirm the excellent rate capability of the cell. The cell can support a 510A (15C rate) constant current discharge and still deliver its full capacity. Figure 1 shows the results of the testing.

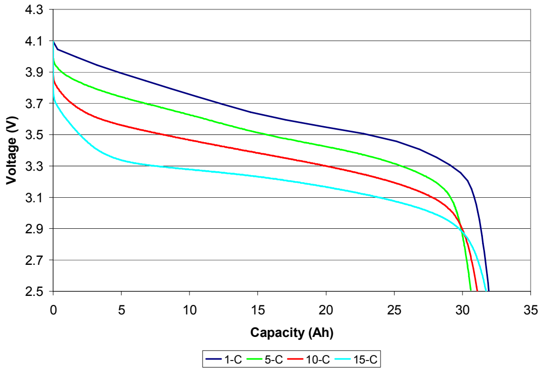

Figure 1 – VL34P Constant Current Rate Capability @ Room Temperature

Figure 2 shows a similar series of constant current discharge tests at -30°C. The excellent cold temperature performance of the cell is shown with 85% of the cell capacity delivered at C rate discharges at -30°C.

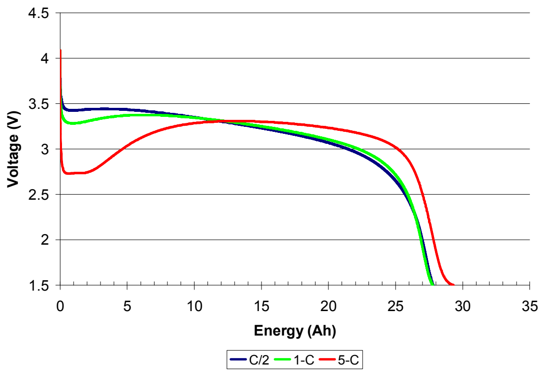

Figure 2 – VL34P Rate Capability @ -30°C

Because of the low internal resistance, the cell is able to handle large continuous currents and still maintain an internal temperature that is acceptable. A continuous constant power discharge at 15C shows that the cell can sustain a draw of 1.6 kW for over 3.5 minutes before reaching end of discharge voltage, while delivering 29.7 Ah capacity.

2.2 Cold Temperature Performance

Even at cold temperature, over 80% of the capacity can be removed from the cells, at current up to 10C (340A). The effect of the self heating of the cells at cold temperature is seen for the higher current draws at 5C and 10C (170A to 340A). Observe the dip in voltage in the discharge curves and subsequent rise, especially pronounced at higher rates. This self heating is due to higher internal resistance at cold temperature which allows the cell to self heat, which in turn reduces internal resistance allowing for more power and energy usage. The cell has also been shown to deliver current at C/10 and C/3 rates at temperatures as low as -60°C.

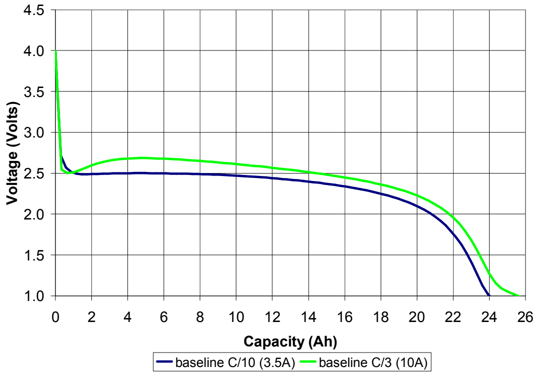

Figure 3 – VL34P Rate Capability @ -60°C

It is shown that the design of the cell allows for removal of over 70% of the capacity of the cell at extreme cold conditions of -60°C.

2.3 VL34P Pulse Discharge Power

Pulse testing was performed on the VL34P. 4.7 kW constant power pulses were applied to the cell for 2 seconds, followed by 30 second rests. Twenty six (26) pulses were completed, with the twenty seventh pulse lasted 1.8 seconds before hitting the lower voltage limit. The average discharge current during the pulse chain was 1,350 A, with the minimum current 1,150 A, and a peak current of 1,850 A. Over 23 Ah of energy was discharged from the cell during the pulse series, again confirming the high rate capability of this cell. The results are shown in Figure 4 below.

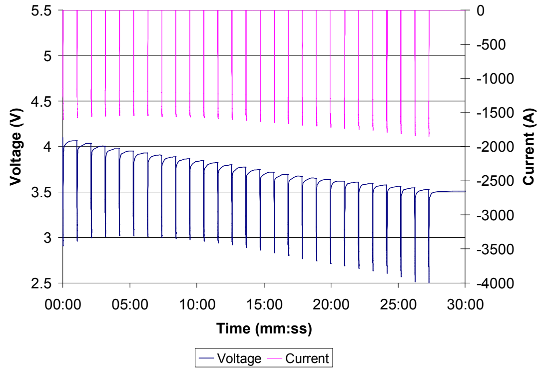

Figure 4 - VL34P 4.7kW 2 sec Pulse Discharge Power

3 VL34P Module Testing

In order to fully evaluate the VL34P cell, testing was done at the module level to quantify the heat generation during cycling. Testing was done in ambient air at 28°C with no forced air cooling, only natural convection. Various tests were run on the VL34P modules. Thermocouples were attached to the cells in the modules to fully evaluate the cell temperatures at various locations. Figure 5 shows results from cycling the VL34P module. The initial testing was run at a constant current cycle of 50A for 3 hours. The cycling was performed around 50% SOC with a 30sec charge and 30 sec discharge. The temperature for the cycling at 50A stabilized at 37°C. This testing was immediately followed by cycling at 100A for three hours under the same conditions. The temperature for the cycling at 100A stabilized at 45°C.

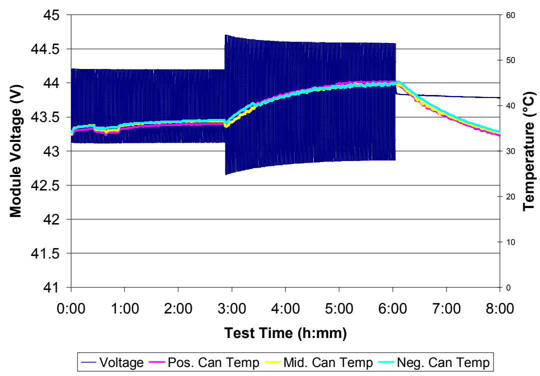

Figure 5 - VL34P Module Cycling: 50A Cycling followed by 100A Cycling

The cycling performance shows that the lower cell internal resistance results in less heat generation rates that can be easily managed with simple cooling methods.

4 Heat Generation and Thermal Management

A distinct advantage with the cells developed by Saft SDD is the low internal resistance and resulting low heat generation. In a HEMV-7 system with a typical duty cycle that results in a 150A RMS average current in and out of the battery pack, the resulting steady state heat generation is <10W per cell, or 0.8kW of heat at the pack level. At this current the charge power is 46.6kW and the discharge power is 45.0kW, for a power efficiency of 96.5%. For a typical duty cycle that results in a 200A RMS average current in and out of the battery pack, the resulting heat generation is <18W per cell, or 1.5kW of heat at the pack level. At this current the charge power is 62.9kW and the discharge power is 60.0kW, for a power efficiency of 95.3%. This shows a very efficient design with minimal losses due to electrochemical inefficiencies internal resistance in the system.

The 0.8kW of heat generated with 45kW cycling of the pack requires the same heat rejection rate as a crew compartment occupied by 8 idle people. The cell and module within the pack are specially designed to allow for easy heat rejection from the components that generate the heat. The battery pack design is flexible and can be equipped with liquid cooling or air cooling, while still maintaining the sealed box design. Saft SDD has developed several system designs to support liquid or air cooling, depending upon the available liquid or conditions of ambient air available within the vehicle.

5 HEMV Performance Specs

The first HEMV design was for a 220V nominal pack that was used in a demonstrator vehicle. The HEMV battery pack design is scalable by adding additional modules to match the system voltage of the application. Saft SDD has designed the battery so that it can be configured with 5 to 8 standard modules, for a nominal system voltage range from 220V to 350V. The HEMV pack design is based around the VL34P cell design.

The following table shows the typical performance specification for the 7 module variant of the HEMV battery pack, based upon a standard high voltage control unit and cooling method.

Table II - HEMV-7 Battery Performance Specs

Weight (kg)	151
Volume (L)	87
Energy (kWh)	9.3
Nominal Voltage	308
Min Voltage	210
Max Voltage	344
2 Sec Peak Power – Discharge (kW)	142
- Charge (kW)	81
Continuous Power – Discharge (kW)	74
- Charge (kW)	39

The ratings shown in the above table are restricted by the fuse and contactor selection, and the cooling method. The cells are capable of delivering much high power with higher rated electronics and alternate cooling sources. Such improvements have been demonstrated on other Saft SDD battery designs, but not yet required by any customer of the HEMV battery systems. The pack design shows an excellent power efficiency of over 95%, with heat generation of only 1.5kW at 150A continuous cycling. The scalable design allows for implementation of various size battery packs to meet specific system requirements of the customer.

The most common pack design used in many of the demonstration hybrid vehicles has been a battery configuration with seven modules in series, the HEMV-7. The module design is based upon a Saft SDD standard 12 cell module, with a voltage <50V at full SOC. The battery itself is a sealed case design. It includes a breather valve and a vent disc to maintain a pressure balance during altitude or temperature changes and provide a means of controlling an overpressure. It also includes a service disconnect to ensure that the power circuit is open when handling the battery pack. Besides the monitoring feature of the control electronics, the integrated controller includes such items as precharge, cell balancing, and contactors in one plug and play package for integration into a vehicle. In addition, the system also reports battery status and provides feedback control of allowable charge and discharge currents based upon, temperature, SOC, and prior usage conditions.

Saft has gained valuable experience with implementation of battery systems in a number of vehicle applications. Saft has delivered several systems with fully integrated control electronics. Such battery controllers are used to monitor the individual cells and maintain the battery in a usable operating window.

6 Conclusions

Saft's VL34P cell has been shown to be well suited for use in military vehicle applications. The high power of the cell is able to support the charge and discharge power profiles of hybrid vehicles. The low cell resistance allows for simple cooling methodologies for the modules and batteries and Saft's implementation of controls in the battery systems for vehicles provide an excellent means of effectively monitoring and integrating the battery within the vehicle controller. This technology has been proven as a solution for load leveling in a hybrid vehicle application, but also could be used in other load leveling applications for power systems.

Acknowledgments

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