Development of Man Portable Auxiliary Power Unit using Advanced Large Format Lithium-Ion Cells

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ABSTRACT

Power deficiencies have developed and presently continue to exist in numerous remote applications thus limiting mission effectiveness. The warfighter, first responder, personnel stationed in remote location as well as shelters, and command posts have been burdened with exhaustive amounts of electronics and demand for power has increased beyond the capability of supply and re-supply. The only viable solution to this problem is to equip the user with advanced battery technology, specifically high energy lithium-ion batteries, designed for this application. This paper will discuss the development of a man portable auxiliary power unit designed specifically to address these issues.

INTRODUCTION

To meet this growing power and energy need, a 15/30 volt Man Portable Auxiliary Power Unit (APU) is being developed. This APU has an integrated charger that is detachable and a Battery Management System (BMS) with State Of Charge Indicator (SOCI). The unit is capable of accepting charge from 10-36v DC or 110 (dirty) AC. The acceptance of "dirty" power is especially important in remote applications where either an unreliable grid or generators are supplying usable power.

The APU consists of eight 50AH cells, in two four-cell independent series strings. The series strings will be configured in a series or parallel arrangement whereby the battery can provide either 50AH @ 30v or 100AH @ 15v depending upon the application requirements. The current output has been initially set at 15 amperes. Battery weight, including the charger, BMS, case and cells is approximately 70 lbs. The battery weighs 43 lbs and the charger weighs 27 lbs.

This battery is intended to provide the user with a power source to conduct missions in the manner they were intended without limitations due to battery power or an unstable electrical grid. An array of electrical testing to evaluate the soldier portable APU has been conducted and will be presented in this paper. These tests include environmental and safety specific, as well as, performance tests for cycling and storage. The tests have been designed to not only confirm performance of the APU but also provide the required data for a safety release.

EXPERIMENTAL

Initial testing of large format (50 AH) Lithium-Ion cells from International Battery, Inc. (IB) was conducted by CERDEC. This evaluation was conducted to determine the appropriateness of the cells for this application. The cells were subjected to various electrical, and limited preliminary safety testing. These tests were designed to determine if the development of an APU is warranted. Initial testing included capacity and preliminary cycle life and shelf life tests.

In addition to the IB 50 AH cells, IB 200 AH cell tests were conducted during this initial evaluation. The data from the 200 AH cells are appropriate due to the similarities in design and construction and proportional nature of the cell design. The 200 AH cell is being evaluated for an independent application.

The preliminary cycle life test was conducted on 200 AH cells. This test was designed to simulate an in use scenario of charge throughout the day, and discharge over night. The battery was placed in continuous service with a 20 Amp discharge to 2.5 Volts. The charging was performed at 20 Amps to 4.2 volts then 4.2 Volts for 10 hrs or 1.0 Amp.

The preliminary shelf life test was conducted on 50 AH cells. The cells were subjected to three 15-amp charge/ discharge cycles, then were either allowed to remain in the discharge state or were charged to 50% or 100% state-of-charge. After the conditioning the cells were placed in casual storage for 6 months or 1 year.

Due to the promising results of the preliminary tests, the development of the APU, as well as, additional testing was initiated. The expanded tests included: 1) 15 Amp cycling on 50AH cells at 0^{o}C and 40^{o}C, 2) Thermal imaging during a moderate rate (15A charge - 25A discharge on 50 AH cell) charge/discharge cycle, 3) Limited preliminary safety testing, and 4) Tests, conducted on 90 AH cells at the C rate at 25°C, 40°C, and 50°C. The 90 AH cell tests were conducted by a third party commercial entity.

Limited and preliminary safety tests have been conducted on the 50 AH cells. These tests have been adapted from published Navy and SAE/DOE safety test and performance evaluations. These tests are outlined and described in references [2], [3]. Tests conducted included overcharge under constant-current and high temperature exposure.

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14. ABSTRACT
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RESULTS

Figures 1 – 3 show the capacity versus cycle for the 200 AH cell cycled at 20 Amps at 20°C and 50 AH cells cycled at 40°C and 0°C, respectively.

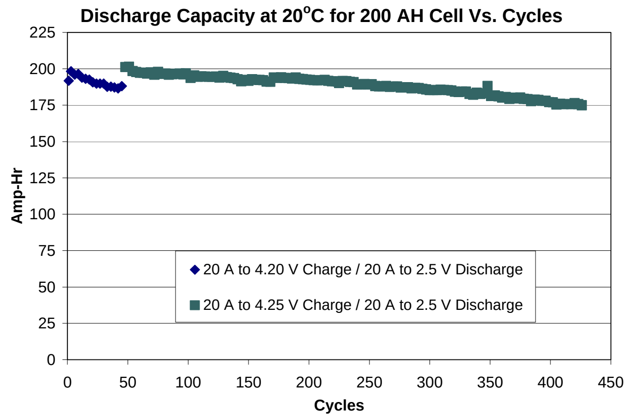


Figure 1. Capacity Vs. Cycle for a 200 AH. Cell cycled at 20 Amps at 20°C. Charge limit changed from 4.2 V to 4.25 V after 50 cycles, discharge cut off 2.5 V.

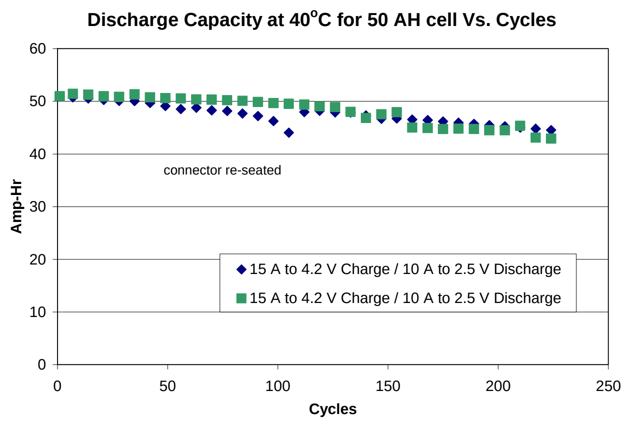


Figure 2. Capacity Vs. Cycle for a 50 AH. Cell cycled at 40°C. Charge limit 15 Amps to 4.2 V discharge 10 Amps to 2.5 V.

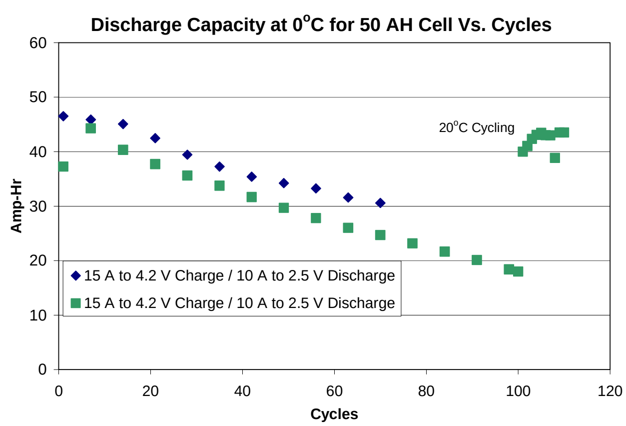


Figure 3. Capacity Vs. Cycle for a 50 AH. Cell cycled at 0°C. Charge limit 15 Amps to 4.2 V discharge 10 Amps to 2.5 V. Cell 1 still under test, Cell 2 cycling continued at 20°C after 100 cycles.

Table 1 shows the reduced data for 50 AH cells preconditioned and stored for 6 months and 1 year at 0%, 50%, and 100% state-of-charge. Figure 4 shows the thermal image at the hottest point during 15A charge - 25A discharge cycle. The highest temperature occurred as expected at the end of discharge. It is interesting to note that the cell temperature rose and fell with cycling, and remained consistent for successive charge discharge cycles. For example the cell temperature at end of discharge was 40°C for the first and third cycle.

Table 1. Capacity Retained and Recovered for 50 AH cells Casually Stored at 0%, 50% and 100% States-of-charge

Conditioned SOC and Storage Time	Initial Capacity (Amp-Hr)	Retained Capacity (Amp-Hr)	Recovered Capacity (Amp-Hr)
100%, 6 Mo.	51.3	37.1	47.2
100%, 6 Mo.	50.6	35.7	44.8
50%, 6 Mo.	50.9	15.8	47.6
50%, 6 Mo.	50.5	13.9	46.8
0%, 6 Mo.	51.1	~0	47.5
0%, 6 Mo.	49.8	~0	42.2
100%, 1 Yr.	50.4	26.4	46.2
100%, 1 Yr.	50.5	24.1	45.6
50%, 1 Yr.	51.1	10.7	48.0
50%, 1 Yr.	49.1	9.9	47.4
0%, 1 Yr.	51.2	~0	46.6
0%, 1 Yr.	49.6	~0	45.4

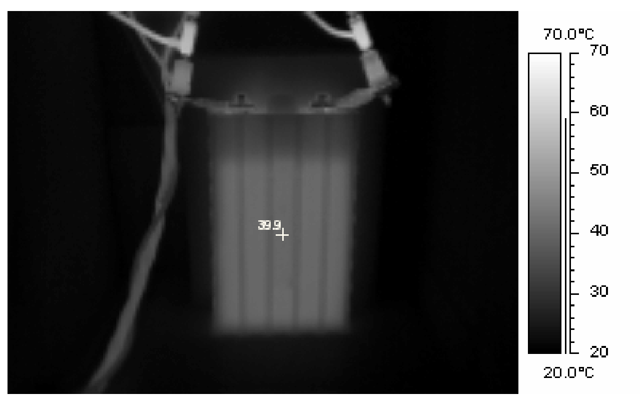
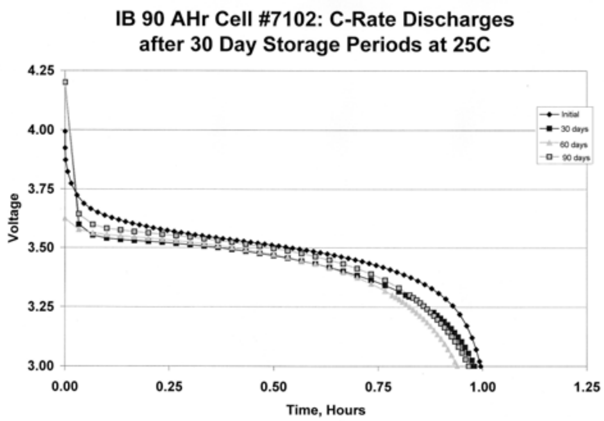
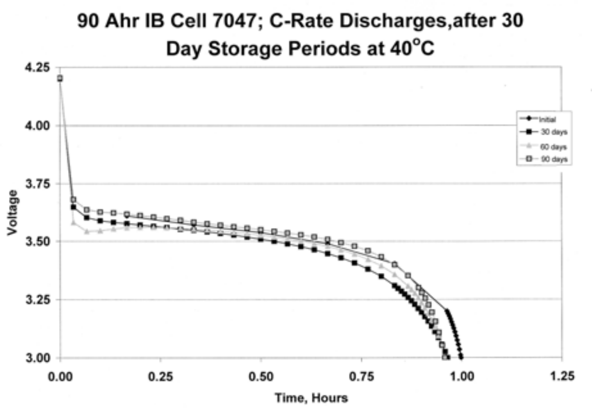


Figure 4. Thermal image at end of life of 50 AH cell discharged at 25 Amps to 2.5 Volts. Cell Temperature is uniform at 40°C.

Figures 5A-5C depict the C rate discharge performance of 90 AH cells after three months of storage at 25°C, 40°C, and 50°C as compared to initial. As can be seen, the cells stand up well to extended high temperature environments and show little degradation after three months. These tests were run by an independent commercial entity.



5A



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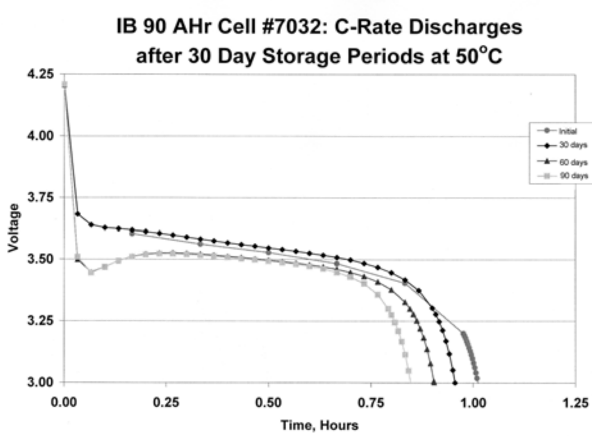

5C

Figure 5 discharge performance of 90 AH cells after three months of storage at A) 25°C, B) 40°C, and C) 50°C. Graphs display initial 30 day, 60 day and 3 Month storage periods.

Results of Preliminary Limited Safety Tests

The battery cells in response to severe constant current overcharge at a C/3 rate and thermal abuse resulted in immolation of the cell under test. The 50 AH cells, although "burning" with a noticeable volume, did not produce a pressure event, nor eject debris away from the cells under test. Post test inspections reviewed the cell plate stack to be essentially intact in a tight bundle evidenced with severe thermal damage but no indication of mechanical instability during the combustion. This was a very stationary event. This is in contrast to smaller cells (25 AH) that produced substantial pressure releases as the vent mechanisms were overcome by the volume of gassing products from the cells. The plastic case material of IB cells contributes to both the volume of material released, as well as, the relative mechanical safety under extreme abuse and combustion.

DISCUSSION

As a result of the promising preliminary cell tests, an APU was designed. This design incorporated input from potential users and lessons learned from previous development efforts. From concept to first fully functional and submersible prototype, the development process took less than 6 months. This was due to the cooperation of the major players, CERDEC, International Battery, Inc., and Bren-Tronics, Inc working toward a common goal. Figure 6 shows the resultant Man Portable Auxiliary Power system and its separate charger and battery components. The fully assembled unit has the dimensions of 12 inches in length, 9.5 inches in width and 16 inches in height.

User feedback indicates that a high capacity, high energy battery (1.5 – 2.7 KWHs) is necessary to power devices in many remote applications. To meet the growing power and energy needs, users are reporting that they have tried to use smaller capacity batteries in parallel. This practice is burdensome and has safety and service life implications, especially when the batteries are not properly maintained. . Additional concern arises from temporary good set-up using portable generators in remote applications. Under these conditions, the power is often “dirty” and disrupts the operation of advanced electronics being used.

The Man Portable Auxiliary Power Unit is being developed to meet the ever growing power and energy needs of today’s soldiers. This unit also has an integrated charger that can be detached from the battery, thereby minimizing the weight into the field if necessary or desired. The battery itself contains a Battery Management System (BMS) with State of Charge Indicator (SOCI) displaying state of charge on the container surface. The unit is capable of accepting charge from 10-36v DC or (dirty) 110 AC. The output is currently delivered through two independent 15 volt taps that can be placed in parallel or series to obtain 100 Ah @ 15V or 50 AH @ 30V.

Figure 6. Man Portable Auxiliary Power Unit. Configured as a complete system (A) and the two components: battery unit (B) and charger unit (C).

The initial design consisted of eight 50AH cells, in two four cell independent series strings. Lessons learned during development enabled design of the same case to accept 90 AH cells for applications that might require an increased run time off the grid. By using the 90 AH cells, the battery will provide 180 AH @ 15V 0r 90 AH @ 30V. The current output has been initially set at 15 amperes. Battery weight, including the charger, BMS, case and cells is approximately 70 lbs. The battery weighs 43 lbs and the charger 27 lbs. . As designed, the unit is capable of full immersion.

We have been testing four units with no anomalies and look forward to completing full qualification testing.

Figure 7 shows the APU block schematic. The schematic shows the layers of protection incorporated in the system. In order to address the various input options, a two-layer charge system has been incorporated in the APU. This is also shown in the schematics.

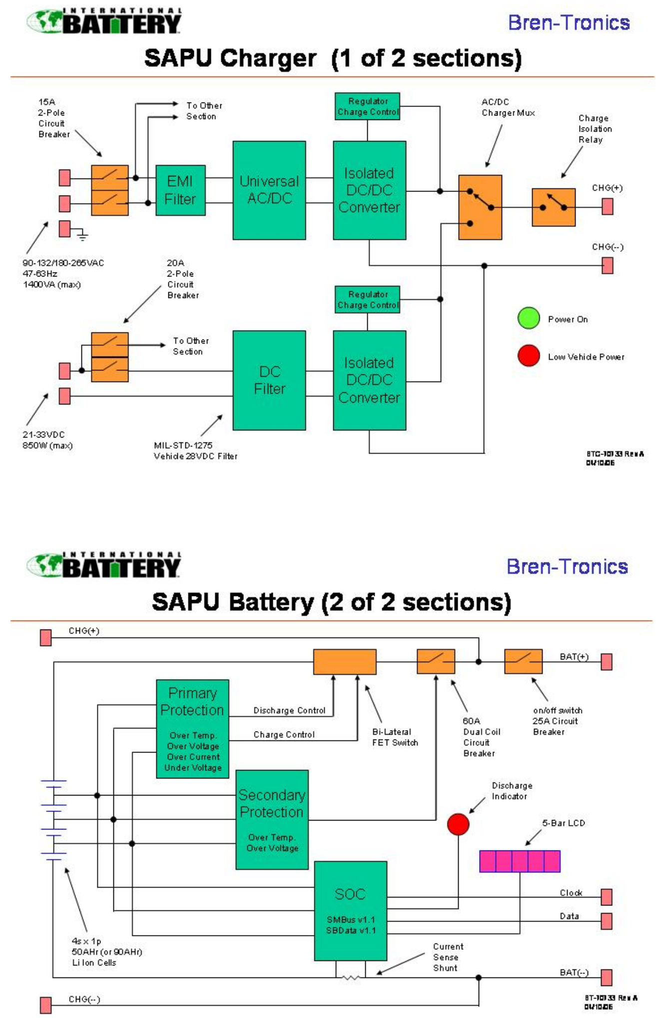

Figure 7. Auxiliary Power Unit Schematic
1) Charger Section 2) Battery Section

The APU offers the user a complete auxiliary power unit that is portable and can be powered (recharged) by either AC (96-264v) or DC (28v) supplies. The APU is packaged as one portable compact unit. The charger and battery can be separated and used independently. This is of special importance if weight is an issue. The APU offers the user the opportunity to easily provide power in remote locations where the use of multiple batteries is not efficient.

REFERENCES

1) www.internationalbatteryllc.com
2) **NAVSEA Technical Manual**, S9310-AQ-SAF-010, 19 Aug 04
3) SAND 2005-3123 FreedomCAR Electroical Energy Storage System Abuse Test Manual for Electric and Hybrid Electric Vehicle Applications, June 2005 also listed under SAE J2464 “Electric Vehicle Battery Abuse Teating”