The Use of Hybrid-Power Sources for Improved Performance with Pulsed Loads

E. Peter Roth and G. Nagasubramanian
Sandia National Laboratories, P.O. Box 5800 MS0613, Albuquerque, NM 87185-0613

Abstract

Electrical characteristics of hybrid power sources consisting of Li-ion cells and double layer capacitors were studied at 25°C and -20°C. The cells were initially evaluated for pulse performance and then measured in hybrid modes of operation. Cells manufactured by Panasonic delivered pulses up to 3A and cells from A&T delivered 4A at 25°C before cell capacity dropped. Measured cell resistances were 0.15 ohms and 0.12 ohms, respectively. These measurements were repeated at -20°C. Direct coupling of the cells and capacitors ("dumb hybrid") extended the pulse limits to 5.6A using the Panasonic cells and 9A for the A&T cells. Operation in a "smart hybrid" mode using uncoupled cell/capacitor discharge allowed full cell capacity usage at 25°C and showed a factor of 5 improvement in delivered capacity at -20°C.

Introduction

Pulsed current applications of battery systems are becoming more demanding and more common. Communication systems using high power bursts of digitized and compressed voice and data are of special interest to the military. These applications and other similar uses requiring intermittent high - power usage of present batteries can result in significant reduction of available battery capacity when fixed threshold voltage criteria are required for operation.

Only a few results are available for hybrid power sources. [1,2] This paper reports on a hybrid power system combining Li-ion cells and double-layer capacitors to extend the current capabilities of the battery system and allow full usage of the electrochemical capacity. A computerized test apparatus was constructed to allow characterization of the individual cells and parallel cell/capacitor strings. The system also simulates "smart electronic" usage of the individual cell and capacitor components.

Commercially available Li-ion cells were obtained from two sources: Panasonic CGR17500 and A&T LSR17500. These cylindrical "AA" cells are rechargeable Li-ion cells using CoO_2 –based cathodes and intercalating carbon anodes. At full charge, the cell voltage is 4.1V and the cell capacities are approximately 720 mAhr for the A&T cells and 760 mAhr for the Panasonic cells. The cell resistances were initially characterized as a function of current and temperature using a spectrum impedance analyzer (PAR Model398). At 25°C the Panasonic cells showed net resistance of approximately 0.15 ohms while the A&T cells were about 0.12 ohms. The resistances were quite constant at temperatures above –10°C, but increased significantly at lower temperatures, limiting the current pulse amplitudes available from these cells. The cells were stacked in series of three to yield a total stack voltage of 12.3V in the fully charged state.

Double-layer capacitors (18mm OD by 35mm) were obtained from Panasonic (AL series Gold) rated at 2.5V and 10F capacitance. The reported resistance of each capacitor was 0.1 ohms at 1kHz. The capacitors were combined in three parallel strings of five series connected capacitors, yielding an effective capacitance of 6F and an effective resistance of 0.16 ohms.

The experimental plan was to first characterize the pulse performance of the cell stack at room temperature using constant current pulses of 1-5 s. The stack voltage and the individual cell voltages were monitored and the discharge program halted when the stack voltage dropped below 9V or any cell voltage dropped below 3V. These voltage limits were chosen to prevent any degradation of the CoO_2 cathode material. Cell resistances were determined from the measured voltage drop and current level during the individual pulses. The pulse repetition period was limited to about 40 s to provide a constant comparison to the other discharge profiles. After each hybrid discharge run, the cells were recharged using an Arbin test system (Arbin Model BT2042), which allowed accurate determination of the cell capacity prior to each run. After this initial characterization, the cells were retested in a "dumb hybrid" mode where the cells were connected in parallel to the capacitors and discharged as a single unit. Finally, the hybrid system was operated in the "smart hybrid" mode where the cells first charged the capacitors to a 9V level. The cells were then removed

from the capacitors and the capacitors discharged at the constant-current rate. This sequence was repeated until the batteries exceeded the voltage-threshold criteria. A selectable series resistor that also determined the pulse repetition rate limited the current level during capacitor recharge. The computer can be programmed to simulate any "smart" charge/discharge profile desired to determine the optimum usage of the individual cell/capacitor characteristics.

Pulse Performance at 25 °C

Direct discharge of the cells at constant-current pulses of 1-5 s resulted in almost full cell capacities being realized up to current levels of about 3A for the Panasonic cells and about 4A for the A&T cells. Above this level, the usable cell capacities quickly dropped. The measured cell capacities for all discharge modes are shown in Figures 1 and 2 for the Panasonic and A&T cells, respectively. The open circuit voltage and the cell resistance determine the usable cell capacity at a given current for a fixed voltage threshold. Figure 3 shows the voltage profiles for the stack and individual cells during discharge. The voltage drop during pulsing was used to calculate the resistance as shown in Figure 4. The cell resistances remained fairly constant over the cell discharge range until the very end of cell life when the cell resistance began to increase.

Pulsing the cells in the "dumb hybrid" mode resulted in extended cell capacity usage for both cell types. Figures 1 and 2 show that the Panasonic cells supported about a 50% increase in pulse current level (3.8A to 5.6A) while the A&T cells obtained about a 100% increase (4.8A to 8.9A). The effective resistance of this cell/capacitor hybrid changes as a function of time, initially showing capacitor-like characteristics and then behaving like the cell at longer times. The resistance can be expressed as:

$$R_{eff} = \frac{R_{batt}\,(R_{cap} + t/C)}{R_{batt} + R_{cap} + t/C}$$

At t = 0 :

$$R_{eff} = \frac{R_{batt}\,R_{cap}}{R_{batt} + R_{cap}}$$

And at long times: $R_{eff} = R_{batt}$

For the A&T cells, the calculated effective single cell resistances at t=0 are:

R_{batt}= 0.16 ohm R_{cap}= 0.056 ohm R_{eff} = 0.04 ohm.

Figure 5 shows the measured resistances during the pulses, which closely match these values.

Operation of the system in the "smart hybrid" mode allows the cells to used in their most efficient, low current mode for capacitor charging while using the capacitors for the high-power pulses. Again looking at Figures 1 and 2 at the "smart hybrid" data, cell capacities over 98% of original charge values were obtained. A selectable series resistor limited the cell currents during the charging period. Peak charging currents of up to 750 mA with an average charging current of 500 mA were typical during these runs as shown if Figure 6. The high measured cell capacities indicate that the resistor did not result in any significant energy loss. Lower charging currents would result in even more efficiency, especially at lower temperatures.

Pulse Performance at -20 °C

At temperatures below -10°C, cell resistance increases rapidly, significantly limiting the available cell capacity. More of the electrochemical capacity of the cell can be accessed if the cells are used in a low-current charging mode as employed by the "smart hybrid" system. As a test of this system under these conditions, the Panasonic cells were cooled to -20°C and connected to the hybrid test system. The capacitors remained at room temperature for these measurements. The cells were initially discharged by direct current pulses and then used in the capacitor recharge mode. Table I below lists the discharge conditions and shows that a factor of five improvement in capacity was obtained. Lower charging currents would result in even more efficient use of the cell capacities.

Table I.

	Pulse(A)	Pulse(s)	Avg.Cell(A)	Capacity(Ahr)
Direct	0.53	4		0.024
Hybrid	4	4	0.34	0.129

Conclusions

A hybrid cell/capacitor tester was used to demonstrate extended performance of Li-ion batteries under pulsed-current conditions. Parallel coupling of the cells and capacitors resulted in a reduction of system resistance, allowing extended discharge periods for cells with fixed discharge voltage criteria.

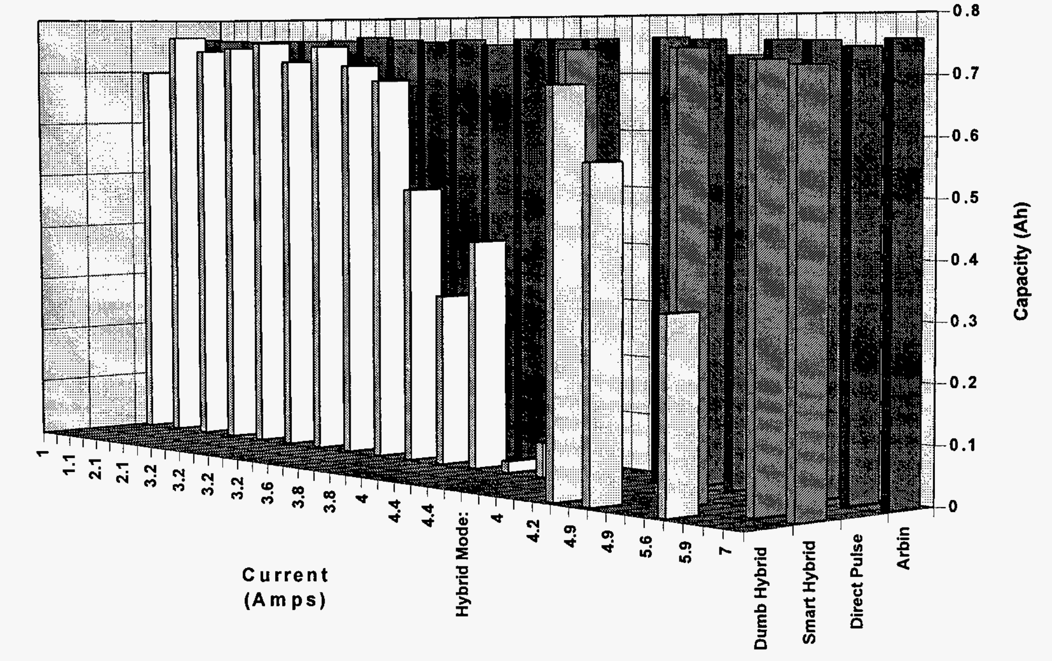

Figure 1. Load capacity of Panasonic Cells under direct and hybrid pulse conditions.

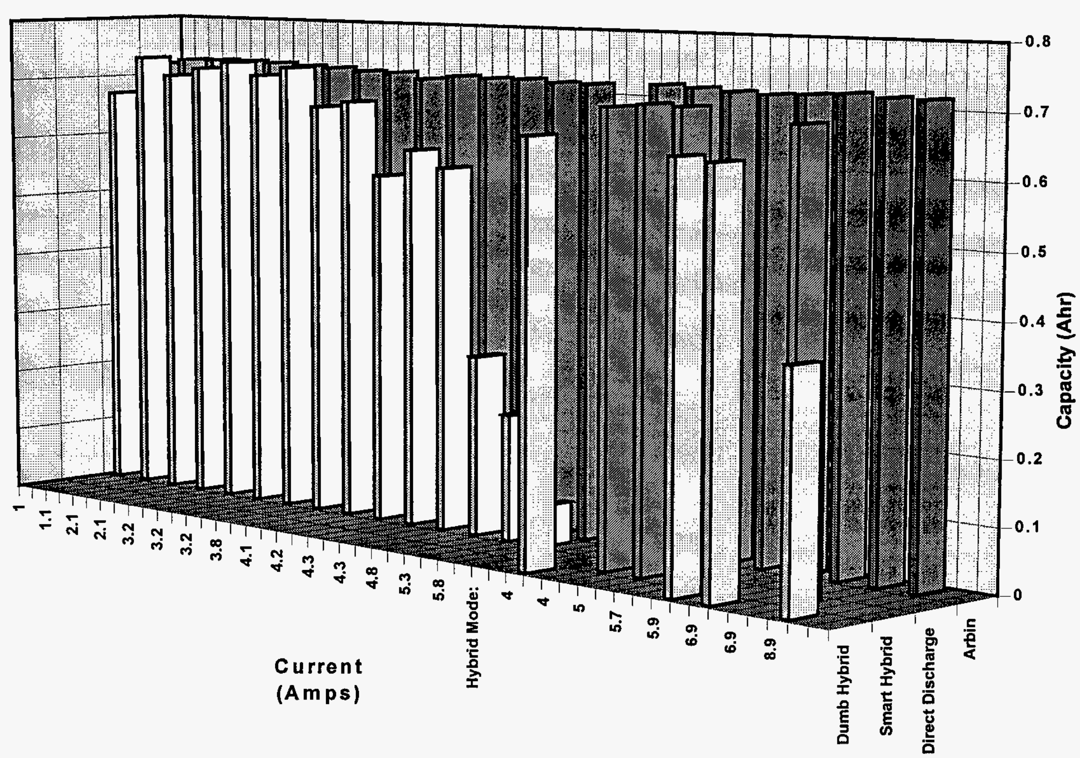

Figure 2. Load capacity of A&T Cells under direct and hybrid pulse conditions.

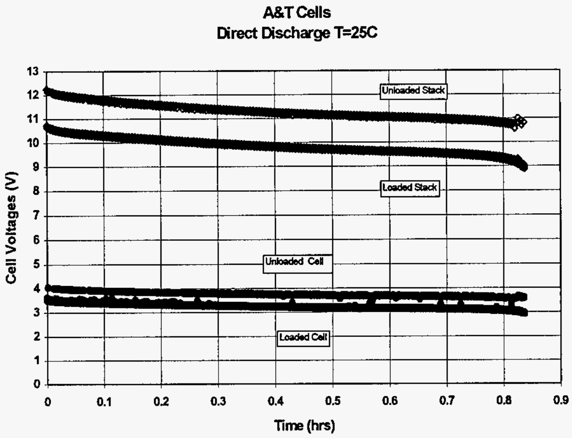

Figure 3. Direct discharge voltage profiles for pulsed A&T cells.

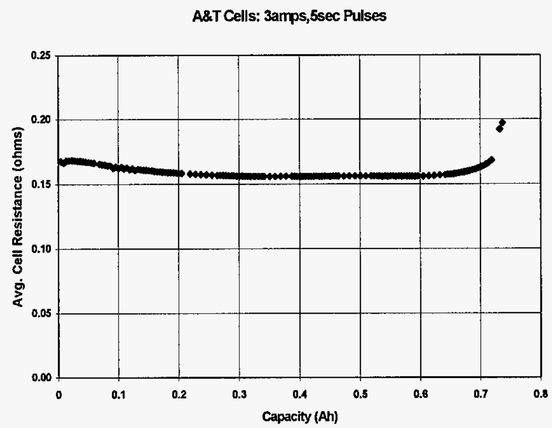

Figure 4. Measured cell resistance during direct pulsing of A&T cells.

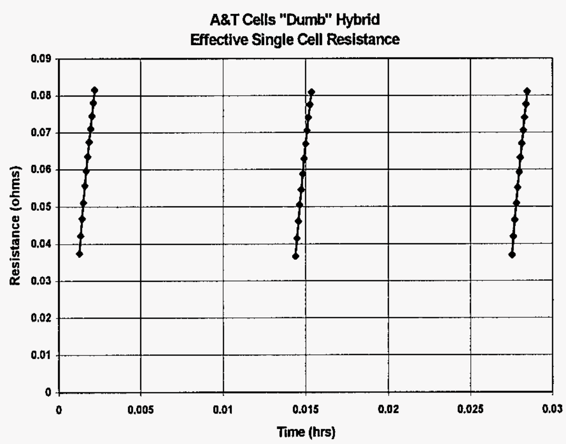

Figure 5. Measured effective resistance of "dumb hybrid" system during pulsing using A&T cells.

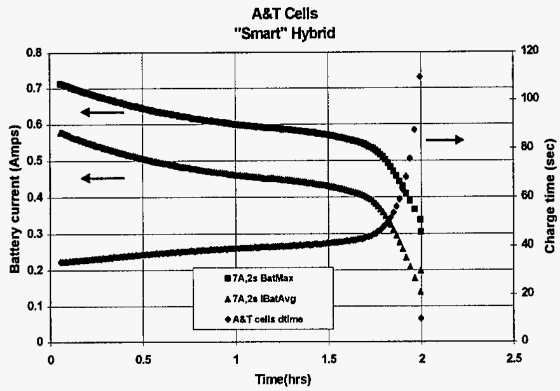

Figure 6. Peak and average charging currents with associated charging time during capacitor recharge for "smart hybrid" system.

Direct coupling of the cells and capacitors in a "dumb hybrid" mode resulted in a 50% - 100% improvement of available capacity at room temperature. Using a computer controlled tester to simulate smart control electronics, the full capacity of the cells was obtainable to recharge the capacitors for high current pulses. The output current pulses were determined strictly by the properties and number of the capacitors used. Use of the "smart hybrid" system resulted in a factor of five improvement in available cell capacity at -20°C where high cell resistance severely limits performance. Even higher efficiencies are obtainable for applications with lower charge currents and longer charge times.

Acknowledgements

Sandia National Laboratories is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

References

1. T. Atwater and P.Cygan, Proceeding of the 37th Power Sources Conference (June 17-20, 1996).

2. M.Juzkow and M. Isaacson, Power'96, Santa Clara, CA (Oct. 13-16, 1996).

M98004744

Report Number (14) SAND--98-0941C

CONF-980644--

Publ. Date (11) 199804

Sponsor Code (18) DOE/CR, XF

UC Category (19) UC-900, DOE/ER

DOE