Evaluation of Supercapacitor – battery hybrid pack for pulse power application

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ABSTRACT

Power sources with high-power and high-energy density are urgently needed for a large number of defence and portable systems. Many of the applications include defence and space communication, missile systems, hybrid electric vehicles, digital cellular phones wherein the loads are not constant but rather span a range of power levels. Setting a Supercapacitor and a battery side by side constitutes an attractive energy storage system with several advantages as it exploits both the high-power density of capacitor and the high-energy density of the battery. In the present paper some of the works conducted on Supercapacitor – battery hybrid pack will be discussed in detail.

Keywords: Supercapacitor (SC), hybrid pack, lithium battery (LB), pulse discharge, low temperature, on-load voltage

1. INTRODUCTION

The hybrid power system involves coupling a source having a high power density with another having a high energy density. Various power source couples of hybrid systems are known namely, a fuel cell and an electrochemical capacitor, battery and an Ultracapacitor to meet the peak power requirement of electronic system.

Supercapacitors (Ultracapacitor or Electrochemical double layer capacitors) are known for their high-energy density (compared to normal capacitors) and high-power density (compared to batteries). Combination of battery – Supercapacitor is mainly used in high-current pulse applications. In hybrid combinations, the advantage of high power density or the ability to deliver large discharge rates by the capacitor is combined with the high energy density of the battery. The performance of hybrid combination yields more than the two components separately, so a good example of synergy.

The ultra-high capacitance capacitor can be used in a new energy backup system for actuator. Typical application having direct commercial significance is using Ultracapacitors as a battery assist for vehicle engine starting. The common SLI lead–acid battery used in automotive systems is designed to meet the power requirements for engine starting. The primary failure operational discriminator is the inability of the battery to initiate an engine under ambient environmental conditions even though the battery has much of its energy storage capacity intact. Since this requirement of power is for short duration, a solution for this problem is the use of an Ultracapacitor in hybrid combination with a battery system.

Advanced battery systems such as Ni-MH, Lithium ion batteries, with very high energy densities are well known, but often have insufficient power densities for high pulse power applications. High power requirements can be met by paralleling more number of batteries but system volume, weight and cost will be increased proportionately. However a hybrid power source i.e., a combination of advanced battery system and Supercapacitor can meet the high power requirement with considerable advantages in weight, volume and cost. Various combinations of hybrid systems are extensively discussed in the literature (1-8). Literature on Supercapacitor cell manufacturers' catalogue (9) can be referred.

In this present work, two packs were assembled, the first pack with Lithium battery alone and second one a hybrid system consisting of Lithium Battery (LB) and Supercapacitor (SC). A Series of experiments were carried out for the high pulse power capability and the experimental results are discussed in this paper.

2. EXPERIMENTAL DETAILS

2.1 Assembly of battery and hybrid packs

Commercially available Lithium ion cells and Supercapacitor cells were used for this study. Both Lithium ion cells and Supercapacitor cells were individually charge / discharged at room temperature to ascertain their initial capacity and capacitance values. Later Lithium ion cells and Supercapacitor with close capacity and capacitance values were grouped together for constructing 12V packs. Two packs were constructed. Pack-1 contains only Lithium ion battery and Pack-2 contains a hybrid pack of Lithium ion Battery and Supercapacitor cells. The details are given in Table 1 and Figure 1.

Table 1. Brief information of individual 12V Packs

Property	value
A. Individual Lithium ion cell	
1. Cylindrical Cell size (mm)	Ø 18 x 65
2. Open Circuit Voltage (OCV) (V)	4.14 – 4.16
3. Nominal Capacity (mAh)	2200
B. Pack – 1	
1. Weight (g)	143.1
2. OCV (V)	12.6
C. Individual Supercapacitor cell	
1. Prismatic Cell size (mm)	23 x 30 x 03
2. Nominal Voltage (V)	2.5
3. Weight of SC pack (5 Cells) (g)	30.7
D. Pack – 2	
1. Weight (g)	177
2. OCV (V)	12.4

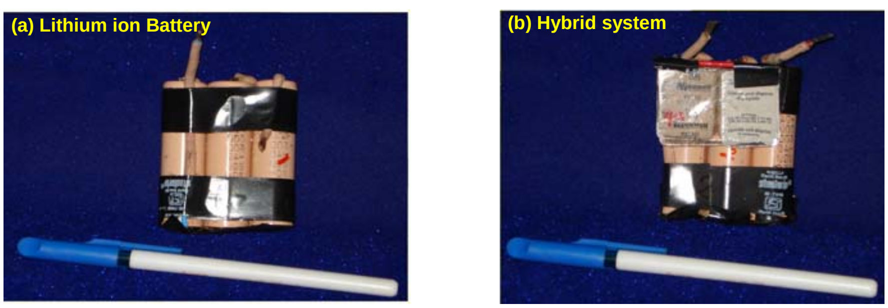

Fig. 1. Assembly details of (a) Pack – 1 (containing only Lithium ion cells) and (b) Hybrid pack (containing Lithium ion cells and Supercapacitor Cells connected in parallel).

2.2 Evaluation of electrical performance of LB battery and hybrid packs

Both Lithium ion Battery (LB) and hybrid packs were charged simultaneously at room temperature with the same condition using computerized charge / discharge setup. After completion of charging sufficient rest period (varying 1 – 2 hrs) was allowed before proceeding to pulse power test. Both systems were discharged for high pulse loads as indicated in the Figure 2.

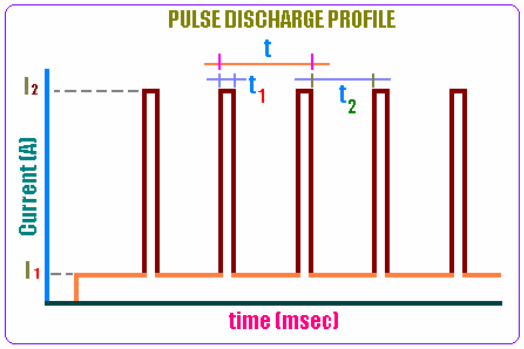

Fig. 2. Pulse test profile where, I_1 = 0.05A, I_2 = 7A, t_1 = 0.2s and t_2 = 0.8s.

2.3 Effect of storage temperature on LB battery and hybrid packs

To understand the effect of extreme ambient temperature on these packs, both low and high temperature soaking studies were conducted. Prior to carrying out of this experiment, both LB and hybrid packs were charged. After completing the charging process both of them were stored at -30±2ºC for 4hours. They were subjected to the same load profile. Similarly both packs were stored at +55±2ºC for 4hours and evaluated for their pulse power capability.

3. RESULTS AND DISCUSSION

3.1 Evaluation of Supercapacitor cell

The charge – discharge behavior of Supercapacitor cells was studied at constant current mode. Typical charge-discharge profile is shown in Figure 3. From the graph it is observed perfect symmetry pattern during charge – discharge process. Charge efficiency is more than 98 per cent. Observed capacitance value is 8.4F. All Supercapacitor cells were charge / discharged before assembling them into Hybrid packs.

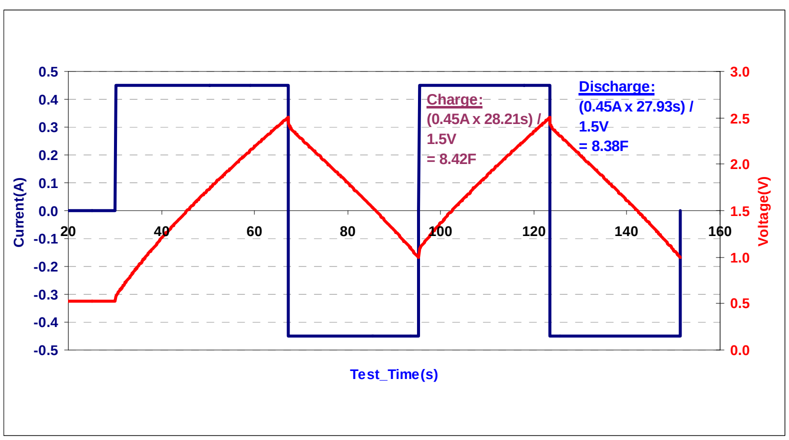

Fig. 3. Typical charge / discharge data of individual Supercapacitor cell.

3.2 Evaluation of Lithium Battery and Hybrid Pack at Room Temperature

Both LB and Hybrid packs were fully charged simultaneously and at room temperature. Later pulse discharge test was carried out as per the load profile indicated in the Figure 2. Pulse discharge study was conducted (about 1900 pulses) as shown in Figure 4 (A). Drop in on-load voltage of Lithium battery alone system is much higher when compared to that of the Hybrid system. See Figure 4 (B). Similarly, voltage variation in hybrid system is less over the entire period of pulse discharge test. Whereas LB alone system the variation is substantially high and especially at the beginning of the operation. In the case of hybrid system, pulse load is shared between both battery and Supercapacitor and thereby the voltage fluctuation and drop in voltage is minimized.

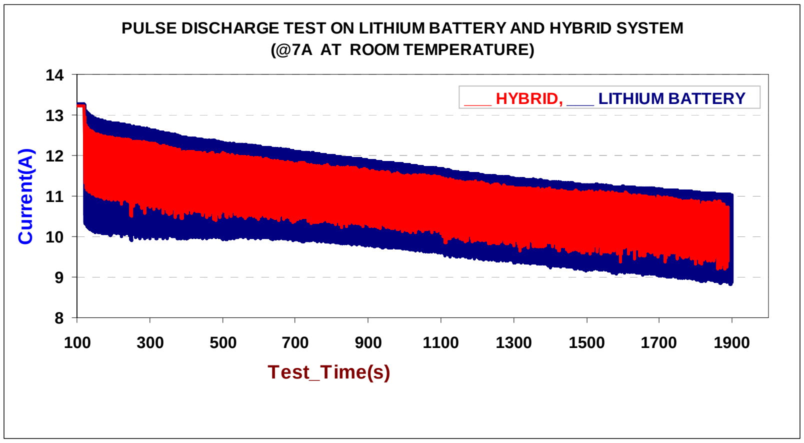

Fig. 4 (A). Lithium battery and hybrid packs are pulse discharged at room temperature. Pulse current and durations are 7A and 0.2sec.

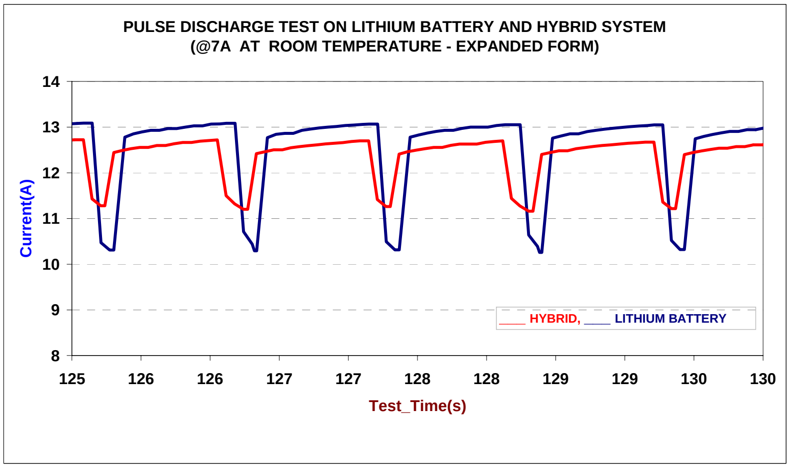

Fig. 4 (B). Lithium battery and hybrid packs are pulse discharged at room temperature (Expanded form).

3.3 Evaluation of Lithium Battery and Hybrid Pack at -30ºC

Both LB and Hybrid packs were fully charged simultaneously and at room temperature condition. After charging they were loaded into a cold chamber and soaked at -30±2ºC for 4 hours. Then the packs were removed from the chamber and kept in an insulated box. Packs were connected to a computerized charge/discharge set up and subjected to pulse discharge test. Same pulse load profile as shown in Figure 2 is used. At the beginning of the test, only Hybrid system is able to give a few pulses while no pulse power is delivered by LB alone system Figure 5(A). The test was repeated immediately applying the same pulse profile. There is improvement in the number of pulses being delivered by hybrid system which was not observed in case of LB alone system Figure 5(B). Similar trials were continued. Gradually, hybrid system was able to give more number of pulses and after a few trials, hybrid system is able to deliver pulse discharge continuously Figure 5(C). Finally after about 15 minutes of rest, LB alone system started delivering the pulse power Figure 5(D).

From this it is obvious that for the initial pulses, Supercapacitor has assisted in delivering the requisite power. Even in the continuous pulse discharge profile, it is observed the voltage fluctuation is more in the case of the LB alone system than the hybrid system. Thus for critical pulse discharge at low temperature condition LB-Supercapacitor pack is more suited than the stand alone LB system.

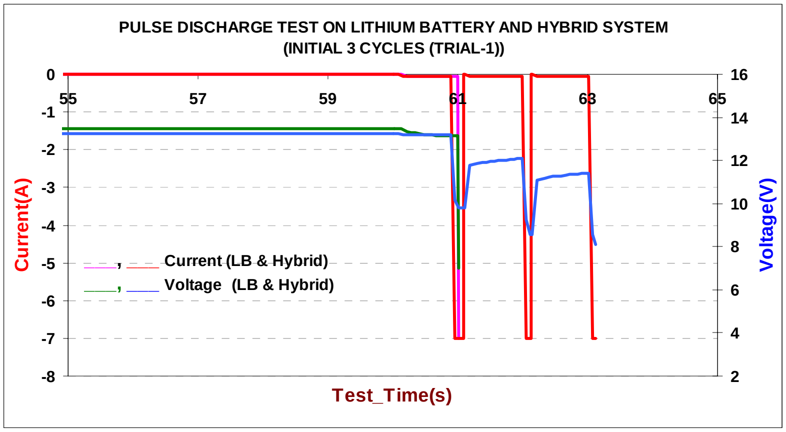

Fig.5 (A). Both Lithium battery and Hybrid packs were pulse discharged after soaking them at -30±2ºC for 4 hrs.

Initial pulse discharges are shown above.

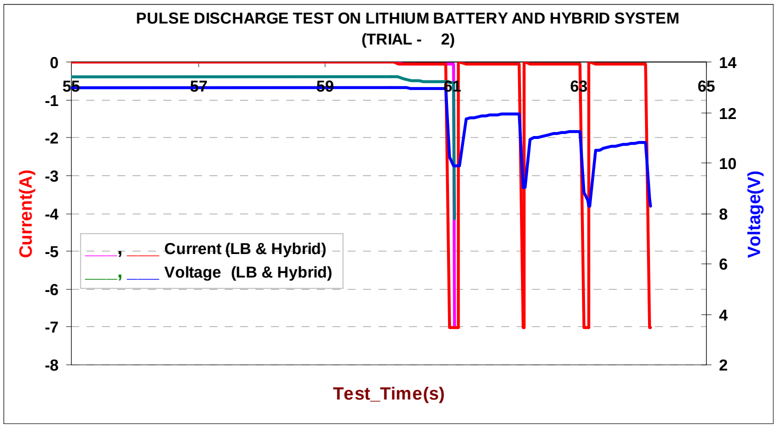

Fig.5 (B). Subsequent pulse discharge trials on Lithium battery and Hybrid system.

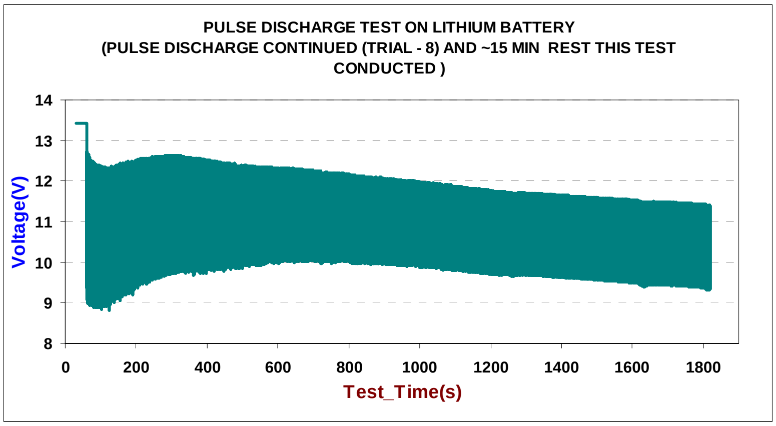

Fig. 5(C). Pulse discharge test on Lithium battery after 15 minutes rest at room temperature.

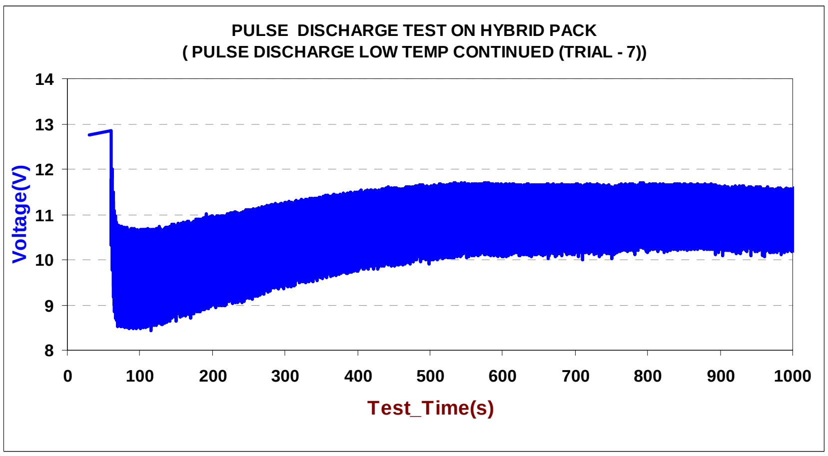

Fig. 5 (D). Pulse discharge test on Hybrid pack after initial trials.

3.4 Evaluation of Lithium Battery and Hybrid Pack at +55±2ºC

LB and Hybrid packs were fully charged simultaneously and at room temperature. After charging both packs were loaded in an oven at +55±2ºC and soaked for 4 hours. Then the packs were removed from the oven and connected to a computerized charge/discharge unit for pulse discharge test. Same pulse load profile as shown in Figure 2 is used. Pulse discharge study was conducted (about 1900 pulses) and the result is shown in Figure 6. The performance of the hybrid system is much better than that of LB system. Both systems do not show any degradation in pulse discharge at this high temperature test.

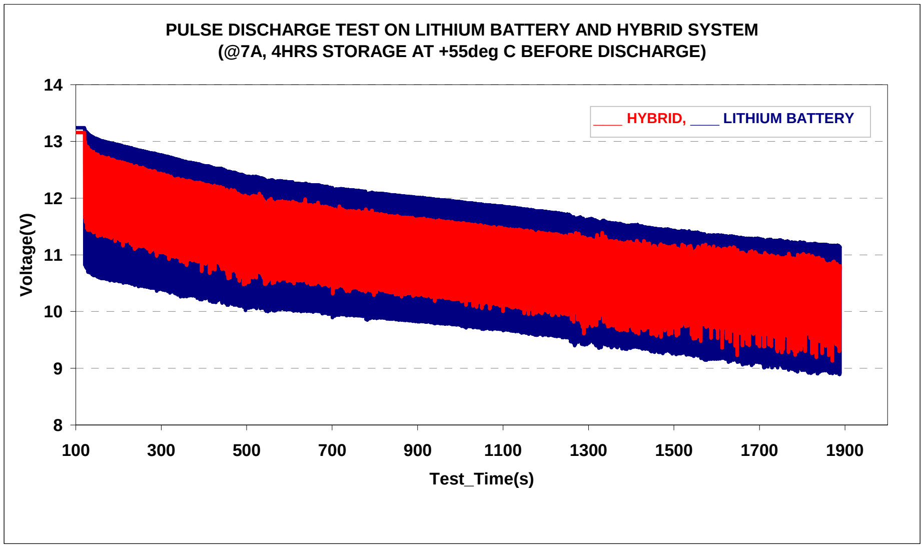

Fig. 6. Both Lithium battery and Hybrid packs were pulse discharged after soaking them at +55±2ºC for 4 hrs.

4. CONCLUSION

In this paper, we have demonstrated a LB – Supercapacitor parallel combination as an effective system for pulse power application. Especially the hybrid system performed much better at -30±2ºC compared to LB alone system. The power delivered at this temperature is mainly contributed from the charge stored in Supercapacitor. Time taken for charge and readiness for subsequent trials is less in the case of hybrid system. Voltage variation is also minimal in case hybrid system when compared to the LB system.

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