High Power Performance of $LiFePO_4$-based Batteries for PHEV Application

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Abstract

EIG Ltd. has developed large format lithium-ion batteries that can be suitably used in PHEV applications using $LiFePO_4$ as the cathode material. In order to optimized the balance between power density and energy density, two kinds of cell designs were prepared with different energy to power ratio and their comparative performances investigated. The rate capability and amount of available energy was dependant on the cell design providing the choice of suitable energy systems according to the specification of vehicles. Performance characteristics including long term cycle life and abuse tolerance was also demonstrated for both designs.

Introduction

Lithium-ion batteries are considered the most promising power solution for plug-in hybrid vehicles (PHEVs) due to their high power capability and extremely long calendar life. As PHEVs use the stored electrical energy during EV mode, PHEV batteries should be primarily energy cells. In addition, when the energy is depleted to reach a certain depth-of-discharge (DOD), enough power has to remain as required for HEV mode. In this study, we employed $LiFePO_4$ as the cathode material and investigated the effect of cell design on the battery performance required for the PHEV application.

Experimental

Submicron-sized carbon-coated $LiFePO_4$ was utilized as the cathode material. For the fabrication of positive electrodes, the active material was mixed with carbon black and polyvinylidene fluoride with a ration of 90:5:5 in N-methylpyrrolidinone (NMP) solution. The slurry thus obtained was coated onto Aluminum foil and vacuum dried at 120 ^{o}C overnight. Using the electrode, a laminated type full cell was assembled with a dimension of 8 mm (T) X 130 mm (W) X 216 mm (L). The electrolyte solution was 1M $LiPF_6$ in EC/EMC (1:2 in volume).

Results and Discussion

Table 1 shows the comparative specification of the two batteries which were designed to have different power capability and energy density while maintaining the same dimension. Their power to energy position was illustrated in the Ragone plot of Figure 1.

Table 1: Specification of the batteries designed with different power to energy ratio

Items	Unit	Energy Type	Power Type
Capacity	Ah	14.5	12.0
Nominal Voltage	V	3.2	3.2
Dimension	mm	7	8
	mm	130	130
	mm	216	216
Weight	g	405	410
Internal Resistance	mΩ	<3.0	<2.0
Specific Energy	Wh/kg	115	94
Energy Density	Wh/l	239	193
Specific Power (10sec, DOD50)	W/kg	1430	2120
Power Density (10sec, DOD50)	W/l	2410	3660

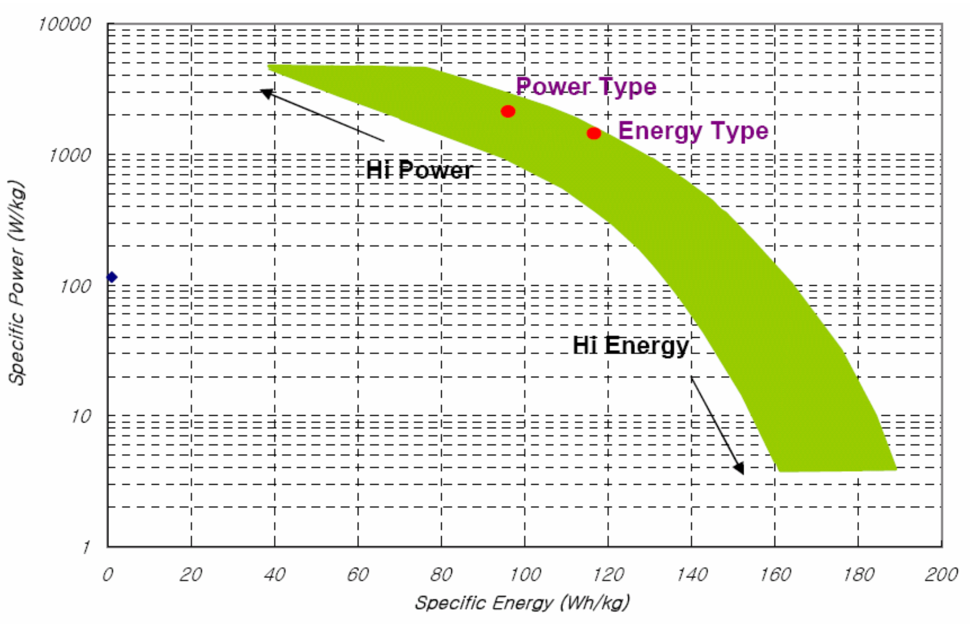

Figure 1. Ragone plot of lithium-ion batteries. The positions of designed cells were indicated in

the figure.

Figure 2 shows the rate capabilities of the two type batteries. Both of them exhibit excellent capacity retention up to 10C discharge, however the voltage drop in the energy type cell is significant with increasing C-rate. Even though the energy type cell experiences the loss of energy at the high rate discharge condition, it still has higher energy density compared to the power type cell as can be seen in Figure 3.

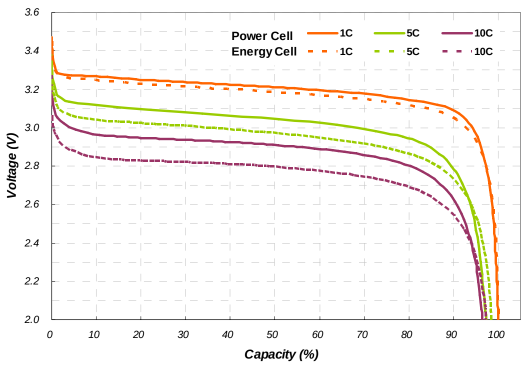

Figure 2. Discharge curves at rates varying from 0.1C to 10C at 25 ℃

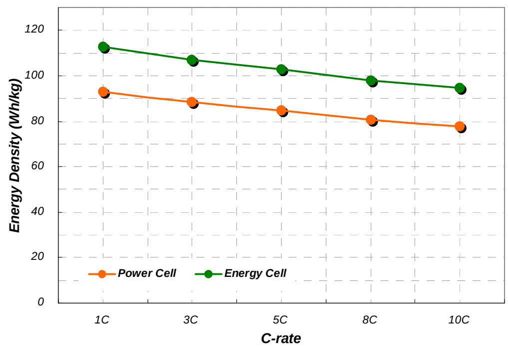

Figure 3. Energy density at various discharge rates

Figure 4 shows the power capability of the batteries at various depth of discharge (DOD). It can be seen that higher power is achievable with the power type cell in the whole region of DOD indicating that it would permit a wider range of DOD to be usable in designing charge depleting mode and charge sustaining mode.

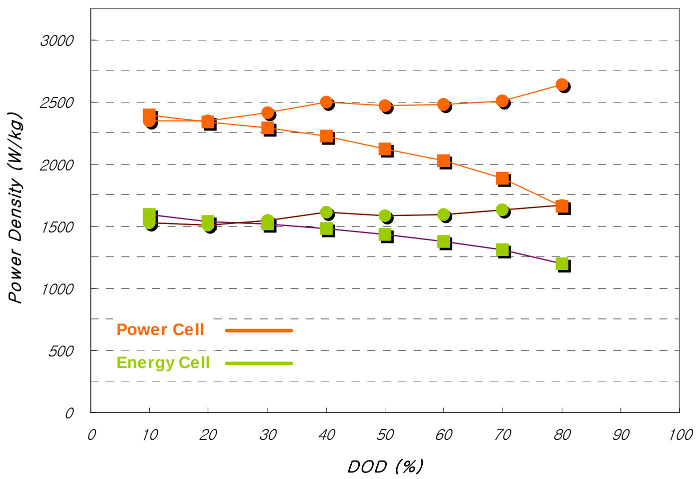

Figure 4. Discharge pulse power capabilities calculated from HPPC test procedure [1].

Figure 5 shows the cycle life measured at 25℃. Both of the batteries showed quite stable cycling capabilities at 25℃ for 100% depth of discharge, which is one of the most important requirements for PHEV batteries. Even at 55℃, it was found that the cycle life extended over 500 times.

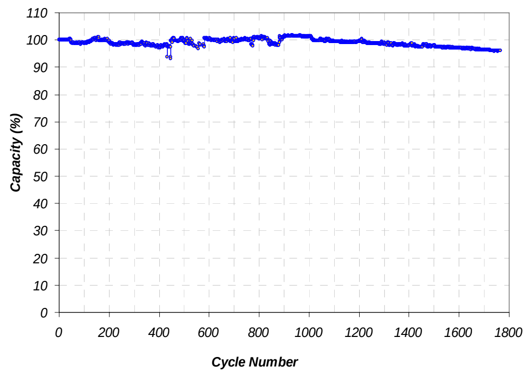

Figure 5. Cycle life at a 1C/1C charge /discharge rate at 25℃ (DOD 100%)

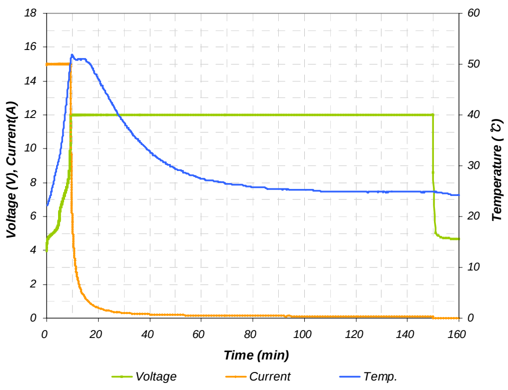

Figure 6. Overcharge profile measured in the condition of 1C/12V for 2.5 hours.

Abuse tolerances at various mechanical, electrical and thermal abuse conditions were investigated for the batteries. Due to the inherent stability of the cathode material, they were found to be safe from thermal run away in the test condition. Fig. 6 shows the overcharge profile measured in the condition of 1C/12V for 2.5 hours. Because there is no excess lithium in the fully charged $LiFePO_4$ material, voltage reached the limit value in 20 minutes and current safely slowed down without abnormal temperature increase as can be see in the graph.

Conclusion

Using $LiFePO_4$ as the cathode material, the cell design was controlled to get optimal power to energy for the PHEV application. It was shown that the adequately designed cell could satisfy the PHEV requirements for long term reliability and abuse tolerance.

Reference

[1] "FreedomCAR Battery Test Manual for Power-Assist Hybrid Electric Vehicles", October 2003.