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288V/8Ah Manganese Type Li-ion Battery System for Hybrid Electric Vehicle

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Abstract

A 288V/8Ah manganese type Li-ion battery system for hybrid electric vehicle was developed. The performances of single-cell and battery system were tested. For the single-cell, the discharge power and regen power are more than 312.5W and 250W at 45-85% DOD, respectively, and the cycle life is more than 2000 cycles. For the battery system, the continuous discharge power is 41kW at 20C rate, and an 80% charge capacity can be achieved in 10 minutes. The values of voltage difference of 80 single-cells are stable with 0.05V, 0.1V and 0.2V at 1C, 10C and 20C rate in the range of 15%-75% DOD in the battery system, respectively. The discharge power and regen power of battery system are more than 25kW and 20kW at 45-85% DOD, respectively, and its available energy is about 1000Wh. The 288V/8Ah battery system with a good discharge rate performance and a fast charging capability could be used in HEV.

Keywords: Li-ion battery, HEV, High power

1. Introduction

Li-ion battery, with its continuous improvement of technology and performance, has become the first choice for electric vehicles in recent years. Nissan, Mitsubishi, GM and other auto companies have launched electric vehicles which is equipped with Li-ion battery.

Hybrid electric vehicle (HEV) requires Li-ion battery with high power, fast charge capability and long life. In the FreedomCAR Energy System Goals, the pulse discharge power (10s) and regen power (10s) are not less than 25kW and 20kW, the available energy is greater than 300Wh, and battery life is more than 15 years [1]. Spinel $LiMn_2O_4$ has been widely used as cathode in high power Li-ion battery. Several studies have been conducted on this type Li-ion battery. Horiba et al. [2] made a manganese base Li-ion battery which output and input power density (50% SOC, 5s) achieves 3000W/kg and 2200W/kg, respectively. Yang et al.

[3] made an 8Ah Li-ion cell with $LiMn_2O_4$ cathode which provided 625W of discharge power and 500W of regen power at 50-70% DOD, and developed a 144V battery system.

In this work, a manganese type Li-ion battery was made and a 288V/8Ah Li-ion battery system for hybrid electric vehicle was developed. For the single-cell, the discharge power and regen power are greater than 312.5W and 250W at 45-85% DOD, respectively, and the cycle life is great than 2000 cycles. For the battery system, the continuous discharge power is 41kW at 20C rate, and an 80% charge capacity can be achieved in 10 minutes. The discharge power and regen power of battery system are greater than 25kW and 20kW at 45-85% DOD, respectively, and its available energy is about 1000Wh. The 288V/8Ah battery system with a good discharge rate performance and a fast charging capability could be used in HEV.

2. Experimental

2.1 Single-Cell Preparation

Modified Li_2MnO_4 (produced by Hunan Reshine New Material Co., Ltd.) and carbonaceous mesophase spheres (CMS, produced by Shanghai Shanshan Tech Group) were used as cathode and anode active materials respectively. The electrolyte consisted of 1.0 M $LiPF_6$ in a 1:1:1(volume ratio) mixture of ethylene carbonate (EC), ethyl methyl carbonate (EMC) and dimethyl carbonate (DMC).

2.2 Battery System

The 288V/8Ah battery system is composed of four parts including battery module, battery management system, cooling system and protection circuit. Figure 1 shows the 288V/8Ah battery system, the inset represents the single-cells. The battery system consists of four modules in series, and each module has 20 single-cells in series. The differences of capacity, voltage and self-discharge rate of single-cell are less than 10%, 50mV and 2mV/day, respectively. The over current protective devices, automatic and manual, exist between the second and third module. The battery management system has the functions of SOC estimation, monitoring current, voltage and temperature of single-cells. The fan will work when the surface temperature of single-cell gets 35^{o}C. The weight of battery system is about 65.3kg.

2.3 Test Equipments and Methods

The high rate discharge performance, rapid charge capability and hybrid pulse power characterization (HPPC) of battery system were tested by a BTS450-300 battery cycler (Digatron Firing Circuits, Germany). The HPPC of single-cell was tested by a BT2000 battery test equipment (Arbin, U.S.). A BS-9366 battery test equipment (Guangzhou Kinte Industrial Co., Ltd) was used for testing the cycle performance of single-cell. All experiments were completed at room temperature (25 ± 5^{o}C).

For cycle life testing, the single-cell was charged at 1C until their voltage reached 4.2 V, followed by constant voltage charging until the current declined to 0.1 C, and then rested 30 min, discharged at 1 C constant current rate to 3.0 V, and again 30 min relaxation. The test profile is repeated.

For high rate discharge testing, the battery system was charged at 1C (8A) until the total voltage reached 340V or any single-cell voltage arrived 4.25V, followed by constant voltage charging until the current declined to 0.1 C, then rested 30 min, discharged at 10C and 20C constant current rate to 160V for the total voltage or 2.0V for any single-cell voltage. The discharge cutoff voltage of battery system and single-cell was 240V and 3.0V when discharge current rate was 1C, respectively.

For rapid charge testing, the battery system was discharged at 1C constant current rate to 240V for the total voltage or 3.0V for any single-cell voltage, rested 30 min, then charged with various constant current rate until the total voltage reached 340V or any single-cell voltage arrived 4.25V.

For 60%SOC rapid charge testing, the battery system was discharged at 1C constant current rate to 240V for the total voltage or 3.0V for any single-cell voltage, rested 30 min, then charged with 1C constant current rate until the state of charge reached 60%, rested 30 min again, followed by 6C constant current rate charging until the total voltage reached 340V or any single-cell voltage arrived 4.25V.

For HPPC testing, according to the FreedomCAR HPPC test profile [1], the test profile includes three parts: (1) 10 seconds of pulse discharge at 8C rate, (2) rested for 40 seconds, (3) 10 seconds pulse regeneration at 6C rate. The test profile is repeated, separated by 10% depth of discharge (DOD), from 10% DOD to 90% DOD for the single-cell and from 40% DOD to 70% DOD for the battery system. The desired DOD was arrived by discharging at 1C constant current rate, rested for 1 hour, and then the HPPC test was conducted again.

Figure 1: the picture of the 288V/8Ah battery system, the inset represents the single-cells.

3. Results and Discussion

3.1 The performances of Single-cell

The single-cells' marked capacity is 8Ah, and their continuous discharge power density is 1517 W/kg at 25 C rate (200 A). The weight of one single-cell is about 0.42kg. Herein, the HPPC and cycle life were described. The other specifications are described and interpreted in [4].

Vehicle will be frequent acceleration, deceleration and braking during driving, which require the battery system to power in acceleration, and recover energy in deceleration and braking [5]. This requires the battery has a good performance of pulse charge and discharge. With the number of battery =80, FreedomCar's requirement for the system (25kW/20kW) to 312.5W/250W for one single-cell. Figure 2 shows discharge and regen power versus DOD and energy removed at 1C rate for the single-cell. According to the HPPC test results, the discharge power and regen power of the single-cell are greater than 312.5W and 250W at 45-85% DOD, respectively, and its available energy has exceeded 14Wh.

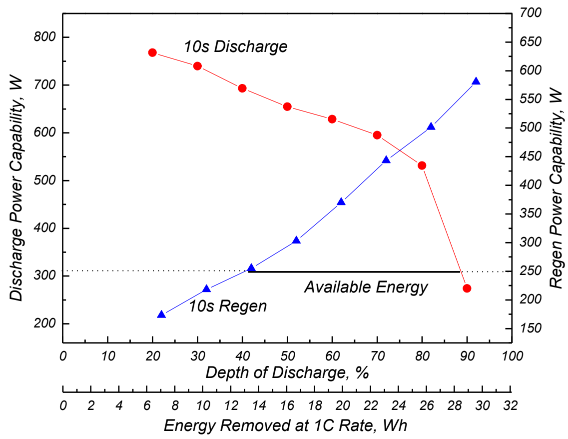

Figure 2: Discharge and regen power versus DOD and Energy removed at 1C rate for the single-cell.

Figure 3 shows the discharge capacity versus cycle number for the single-cell at room temperature. It is shown that the capacity retention with 1000 cycles is greater than 80%. The trend of cycle has a similar trend with other reports [6, 7, 8]. It presents three stage patterns. The discharge capacity decreases rapidly before the 250th cycle, followed by a relatively slow decrease, and resumes a rapid linear decrease after the 1000th cycle. According to this trend, it was forecasted that the capacity retention with 2000 cycles could be greater than 60%.

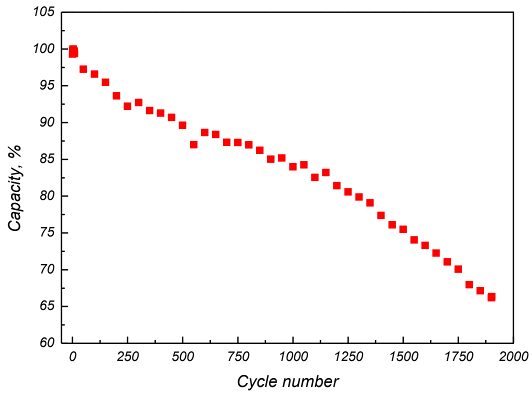

Figure 3: the discharge capacity versus cycle number for the single-cell at room temperature.

3.2 The Performances of the Battery System

3.2.1 High Rate Discharge

Figure 4 shows power versus energy of the battery system at different discharge rates. The battery system has a good characteristic of continuous discharge power. From 1C rate to 20C rate, the energy of battery system reduced only 682Wh. While its power increased up to 40.9kW at 20C rate, which was 16.5 times than that (2.48kW) at 1C rate.

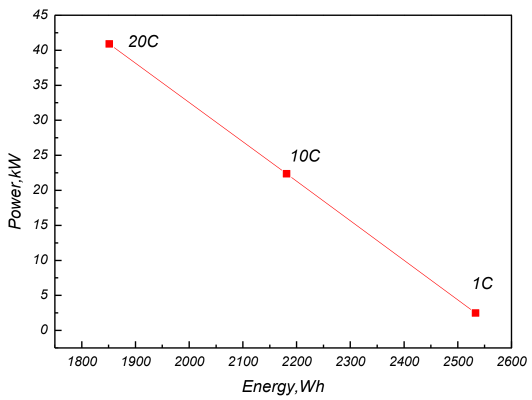

Figure 4: power versus energy of the 288V/8Ah battery system at different discharge rates.

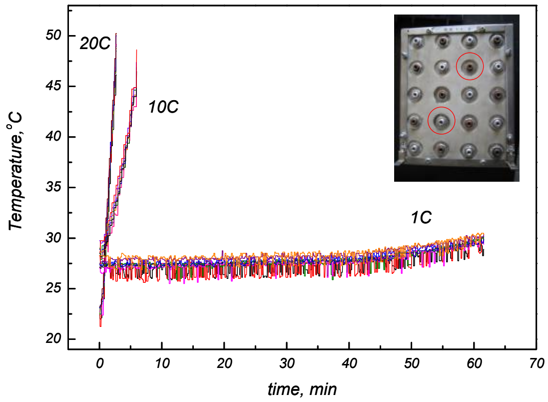

Figure 5: temperature versus time of the 288V/8Ah battery system at different discharge rates, the surface temperature of single-cell marked with red circle is monitored in each module, and the surface temperatures of eight single-cells were detected.

Figure 5 shows temperature versus time of the 288V/8Ah battery system at different discharge rates. The surface temperatures of single-cells marked with red circle are monitored in each module, and the surface temperatures of eight single-cells were detected. According to Figure 3, the temperature curves of four modules coincide at the same discharge current rate. The increasing temperature values of cell surface were 3°C, 20°C and 30°C at 1C, 10C and 20C rates, respectively.

Figure 6 shows the voltage of battery system versus DOD and the voltage difference of 80 single-cells versus DOD at different discharge rates. The value of voltage difference is equal to the maximum voltage minus the minimum voltage of 80 single-cells in the battery system at the same DOD. According to Figure 4, the capacity of the battery system was 8.17Ah at 1C rate, and the capacities with 10C and 20C were 95.5% and 88.7% of the 1C capacity, respectively.

In the application of HEV, available capacity is about 60% of marked capacity, and the state of charge maintained generally 50%-70% [9]. According to Figure 6, the voltage difference of 80 single-cells increased in the early and late discharge, especially in the late discharge, the maximum voltage difference may increase up to 1V. In the range of 15%-75% DOD, the values of voltage difference of 80 single-cells are stable with 0.05V, 0.1V and 0.2V at 1C, 10C and 20C rate, respectively. The smooth voltage ensures that the battery system can output high power when vehicle starts and brakes.

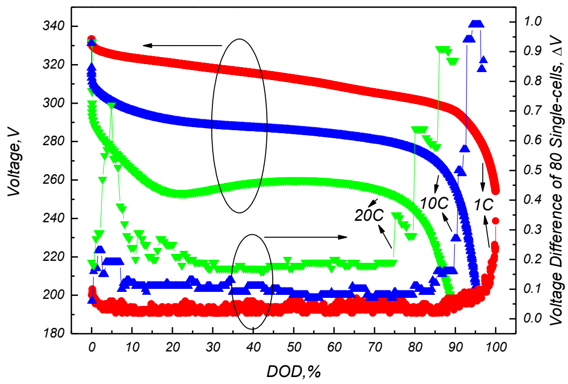

Figure 6: the voltage of battery system versus DOD and the voltage difference of 80 single-cells versus DOD at different discharge rates. The value of voltage difference is equal to the maximum voltage minus the minimum voltage of 80 single-cells in the battery system at the same DOD.

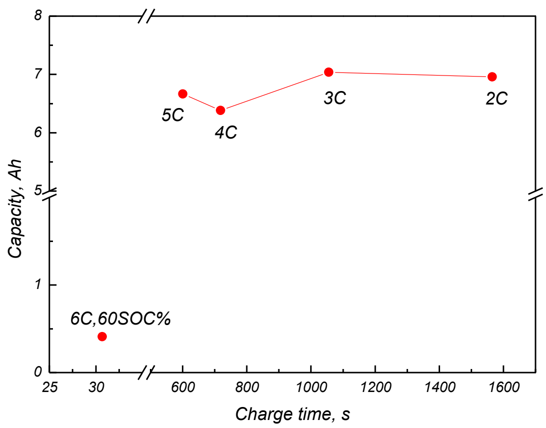

Figure 7: the capacity of constant current charge versus time at different rates.

3.2.2 Rapid Charge

Figure 7 shows the capacity of constant current charge versus time at different rates. According to figure 5, the rapid charge performance of battery system is good. The charge capacities from 2C rate to 5C rate are not significant difference. The battery system can be charged up to 80% of marked capacity in ten minutes at 5C rate. The energy efficiencies at various rates are all more than 90%. The charge time is 30.7 seconds at 60% SOC at 6C rate.

3.2.3 HPPC

Figure 8 shows discharge and regen power versus DOD and energy removed at 1C rate for the battery system. The values of discharge power capability at the 80% and 90% DOD are equal to the values of discharge power capability of single-cell at the 80% and 90% DOD time the average value of the ratios of discharge power (battery system and single-cell) at the 40%, 50%, 60% and 70% DOD, respectively.

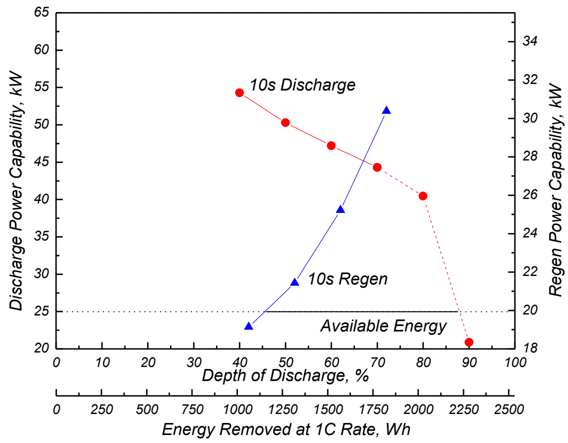

Figure 8: Discharge and regen power versus DOD and energy removed at 1C rate for the battery system. The values of discharge power capability at the 80% and 90% DOD are equal to the values of discharge power capability of single-cell at the 80% and 90% DOD time the average value of the ratios of discharge power capability (battery system and single-cell) at the 40%, 50%, 60% and 70% DOD, respectively.

According to the HPPC test results, the discharge power and regen power of battery system are greater than 25kW and 20kW at the 45-85% DOD, respectively, and its available energy has exceeded 1000Wh at the 45%-85% DOD.

Compared with the cell, the discharge and regen power density of the battery system decreased by about half. This is due to the weight of the cell is only 51.5% of the battery system weight. About half weight is the weight of other components. The power density of the battery system needs to be improved.

4. Conclusion

For the single-cell, the continuous discharge power density is 1517 W/kg at 25 C rate (200 A). The discharge power and regen power are greater than 312.5W and 250W at 45-85% DOD, and its available energy has exceeded 14Wh. The cycle life is great than 2000 cycles.

The 288V/8Ah Li-ion battery system has a good discharge rate performance and a fast charging capability. The continuous discharge power of battery system is 41kW at 20C rate, and an 80% charge capacity can be achieved in 10 minutes. The values of voltage difference of 80 single-cells are volatile in the early and late discharge, and are stable with 0.05V, 0.1V and 0.2V at 1C, 10C and 20C rate in the range of 15%-75% DOD, respectively. The discharge power and regen power of battery system are greater than 25kW and 20kW at 45-85%DOD, respectively, and its available energy is about 1000Wh. The 288V/8Ah Li-ion battery system could be used in HEV.

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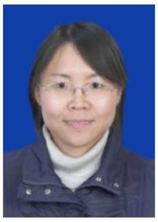

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