PERFORMANCE TESTING OF COMMERCIAL ULTRACAPACITORS USING PNGV (FreedomCAR) POWER ASSIST TEST PROTOCOLS

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The U.S. Department of Energy sponsored Partnership for a New Generation of Vehicles (PNGV, now referred to as FreedomCAR) Program has expressed renewed interest in the possibility of using ultracapacitors in Hybrid Electric Vehicles (HEVs). This paper will report on the results of performance testing of selected, recent generation commercial ultracapaitors to PNGV test protocols that were originally developed to test batteries in the Power Assist mode of operation for HEVs.

The recent model capacitors tested were two different capacitors from CCR Corporation [Japan] (two capacitors, Model #CCR2011A rated at 2000 F at 2.3 V; two capacitors, Model #CCR3000 rated at 3000 F at 2.3 V); two capacitors from Maxwell Technologies Inc. [USA] (Model #PC2500 rated at 2700 F and 2.7 V); three different capacitors from Panasonic Industrial Company [Japan] (two Model #UP-Cap 1200 rated at 1200 F and 2.3 V; two Model #UP-Cap 2000 rated at 2000 F and 2.3 V), and one Model #UP-Cap 2500 rated at 2500 F and 2.3 V), and two capacitors from SAFT [France] (Model #D.L. SC3500F rated at 3500 F and 2.7 V). This paper will present the test results of testing the ultracapacitors [1] to the PNGV Power Assist Energy Storage Performance Goals (as of February 2001 as given in Reference 2).

The specific tests that the ultracapacitors were subjected to were the Hybrid Pulse Power Characterization Test (HPPC test) and the Cold Cranking Test. From the HPPC tests, the dynamic power capability over the capacitor's useable charge and voltage range can be determined. The low-current-HPPC test [(5C/1) discharge for 18-seconds, then a 32-second rest, followed by a (3.4)(5C/1) regen pulse] over a depth-of-discharge (DOD) range of 0% to 90% at 10% DOD increments at test temperatures of –20°C, 25°C, and 50°C was one of the tests used. Another test that was used was the high-current-HPPC test that was conducted using a (30)(C/1) discharge for 18-seconds, then a 32-second rest, followed by a (3/4)(30C/1) regen pulse over the DOD range of 0% to 90% at 10% DOD increments, and at the three test temperatures. The C/1 rate is the constant-current discharge current that removes 100% of the charge stored in a fully charged capacitor over a period of one-hour. The HPPC test data allows the calculation of a capacitor size factor (CSF) analogous to the battery size factor (BSF), which determines how many capacitors are required to meet the PNGV Power Assist energy and power goals [Reference 2, Table 1]. The PNGV Cold Cranking Test is intended to measure the 2-second power capability at –30°C for three consecutive 2-second pulses, 10-seconds rest between pulses, of a CSF-scaled 5 kW discharge at –30°C [2].

As an example of the test results, below is presented the low-current-HPPC test results for the Maxwell ultracapacitor. The C/1 for this capacitor is calculated using C/1 =(C)(ΔV)/3600 =(2700 F)(2.7 V)/(3600 seconds/hour) = 2.025 Ah, where the rated capacitance (2700 F) and rated voltage range (2.7 V) for the Maxwell capacitor have been used. Figure 1 shows the power in watts as a function of % DOD for a discharge (18-seconds at 5C/1 rate = 10.125 A) and the regen (over the first 2-seconds of a 10-second (3/4)(5C/1) rate =7.594 A regen pulse) for a low-current-HPPC test. A value of Vmin = (0.55)Vmax = (0.55)(2.7 V) = 1.485 V was used to calculate the pulse-power capability as given in the formulas in Reference 2, p.28. As can be seen in Figure 1, the useable power range region is the region below where the curves cross from 0% to ~44% DOD. From these data, a relationship is established between the HPPC power and the C/1 energy as a function of DOD. This results in the pulse power capability as a function of the energy removed at a C/1 rate. From these data, a CSF can be calculated [2] that is the minimum number of cells required to achieve the PNGV Power Assist goals of 25 kW for an 18-second discharge, a 30 kW for 2-second regen, and a total available energy of 300 Wh (at a C/1 rate) with a 30% margin to allow for a decrease in the performance of the device due to aging. The CSF factor for the Maxwell was found to be 262 cells at 25°C. In Figure 2 are shown the Available Energy as a function of Pulse Power Capability for the Maxwell capacitor at 25°C and at –20°C where a CSF of 262 cells has been used for both plots. At –20°C, at CSF of 317 cells was determined in order for the capacitor to meet the goats at this temperature. The major reasons for the large CSF for capacitors is due to their lower C/1 energy and the lower 18-second discharge power compared with, for example, current state-of-the-art Li-ion batteries.

The paper will present the HPPC data and the results of the –30°C Cold Cranking Test for the previously mentioned commercial ultracapacitors.

References

1. Electric Vehicle Capacitor Test Procedures Manual, Revision 0, DOE/ID-10491, October 1994.
2. PNGV Battery Test Manual, Revision 3, DOE/ID-10597, February 2001.

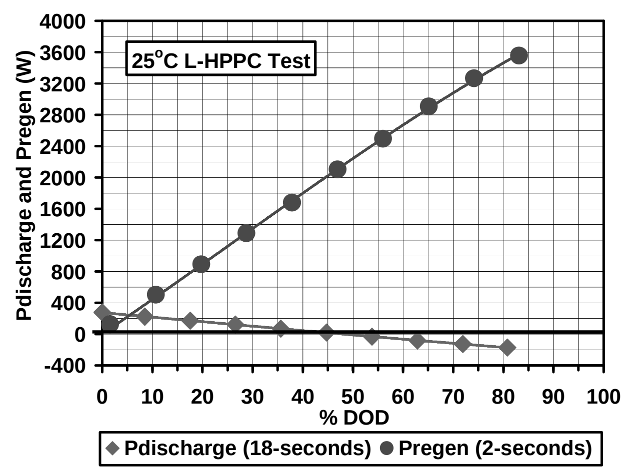

Figure 1. Discharge and regen power as measured from a low-current-HPPC test as function of % DOD for a Maxwell Model #PC-2700 ultracapacitor.

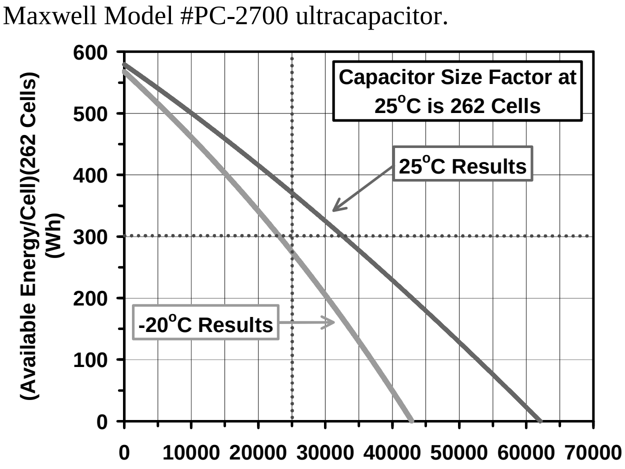

Figure 2. Available energy as a function of pulse power capability at -20°C and 25°C for the Maxwell capacitor.