Final Long-Term Duty Cycle Report

Primary Frequency Response (PFR) Duty Cycle
Battery Pack: EnerDel, Channel 4 and Battery Module: A123 #5, Channel 1

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Table of Contents

List of Tables

List of Figures

I. Summary of Operations

This test report provides a summary of the complete long-term primary frequency response (PFR) duty cycle testing performed on the EnerDel Pack for two cycling periods and the A123 Module #5 for one cycling period. Prior to the PFR testing discussed herein, both batteries were subjected to automotive duty cycling and over 2 years of stationary storage cycling before long-term primary frequency response cycling began. This pre-PFR long-term stationary cycling degraded the EnerDel Pack to a state at which it retained over 80% of its nameplate capacity and the A123 Module #5 to a state at which it retained about 75% of its nameplate capacity. Due to previous cycling, both batteries displayed approximately 150% of their beginning of life impedance at the start of PFR long-term testing. Subsequent long-term PFR testing included over 120 and over 65 non-consecutive days of PFR cycling on the EnerDel Pack and A123 Module #5, respectively, including both prescribed and real-time cycling.[1] Between each approximate 60-day period, there was a Reference Performance Test (RPT) conducted on the each battery under test.[2] The Reference Performance Test served as an indication of battery degradation under long-term PFR cycling. Table 1 summarizes the testing time of each PFR cycling period under this long-term testing protocol.

Table 1: Overview of PFR Cycling Periods

Period	Battery	Time Range	Elapsed Calendar Days[3]	Cycling Days[4]
Period 1	EnerDel Pack	May 2014-Oct. 2014	175.3	71.9
Period 2	EnerDel Pack	Oct. 2014-Mar. 2015	126.7	49.8
Period 3	A123 Module #5	Oct. 2014-Mar. 2015	158.8	67.6
Total per Battery	EnerDel Pack	May 2014-Mar. 2015	302.0	121.7
	A123 Module #5	Oct. 2014-Mar. 2015	158.8	67.6
Total Overall		May 2014-Mar. 2015	460.8	189.3

[1] Only prescribed PFR cycling was conducted on the A123 Module #5.

[2] After the final RPT, in the third PFR testing period utilizing the A123 Module #5, there was just over two weeks of additional PFR cycling included in the total number of cycling days. It was assumed that an additional two weeks of cycling would not contribute significantly to degradation and, therefore, the capacity and impedance of the battery after this additional two weeks of cycling, if measured, would be very similar to that measured prior to these two additional weeks of cycling.

[3] Elapsed calendar days includes the time for completion of the pre- and post-Reference Performance Tests (RPTs). In the third PFR testing period, there was just over an additional two weeks of PFR cycling run on the A123 Module #5 after the post-RPT. These additional approximate two weeks were included in both the counts for the Elapsed Calendar Days and the Cycling Days in the third period of testing with the A123 Module #5

[4] Cycling days includes only the time for which the battery was under PFR cycling.

I. Results of Reference Performance Tests (RPTs)

The Reference Performance Tests (RPTs) consisted of capacity and DC impedance (or resistance) measurements. Summary results of the RPTs conducted before, after, and during long-term PFR duty cycle testing are presented below. All of the RPT occurrences during this long-term test protocol were performed locally via the Battery Control Software (BCS).

Capacity Tests

Table 2 and Figure 1 summarize the results of the capacity tests performed on the EnerDel Pack and the A123 Module #5 during long-term PFR cycling.

Table 2: Summary of Capacity Tests

	May 2014	Oct. 2014		Mar. 2015	
	EnerDel	EnerDel	A123	EnerDel	A123
Direct Capacity (Ah)[5]	59.44	58.25	42.83	58.91	43.06
Direct Capacity as % of Nameplate	82.56	80.90	75.14	81.82	75.54
Direct Energy (kWh)[6]	19.80	19.39	3.18	19.76	3.19
Direct Energy Efficiency (%)	94.28	92.36	96.33	93.28	96.60
	Period 1	**Period 2**		**Period 3**	
	EnerDel	EnerDel		A123	
PFR Discharge Throughput (kWh)[7]	3,181.5	2,317.2		361.6	
Percent Capacity Change per GWh of PFR Discharge Throughput (%/GWh)[8]	5.195	-3.956[9]		-11.159	

[5] The Direct Capacity (Ah) is the direct discharge capacity measured during the C/5 capacity test.
[6] The Direct Energy (kWh) is the direct discharge energy measured during the C/5 capacity test.
[7] The PFR Discharge Throughput (kWh) is the absolute value of the kWh Out during PFR cycling days.
[8] The Percent Capacity Change per GWh PFR Discharge Throughput (%/GWh) is the ratio of capacity loss as a percentage of nameplate capacity (72 Ah for the EnerDel Pack and 57 Ah for the A123 Module #5) to the GWh of

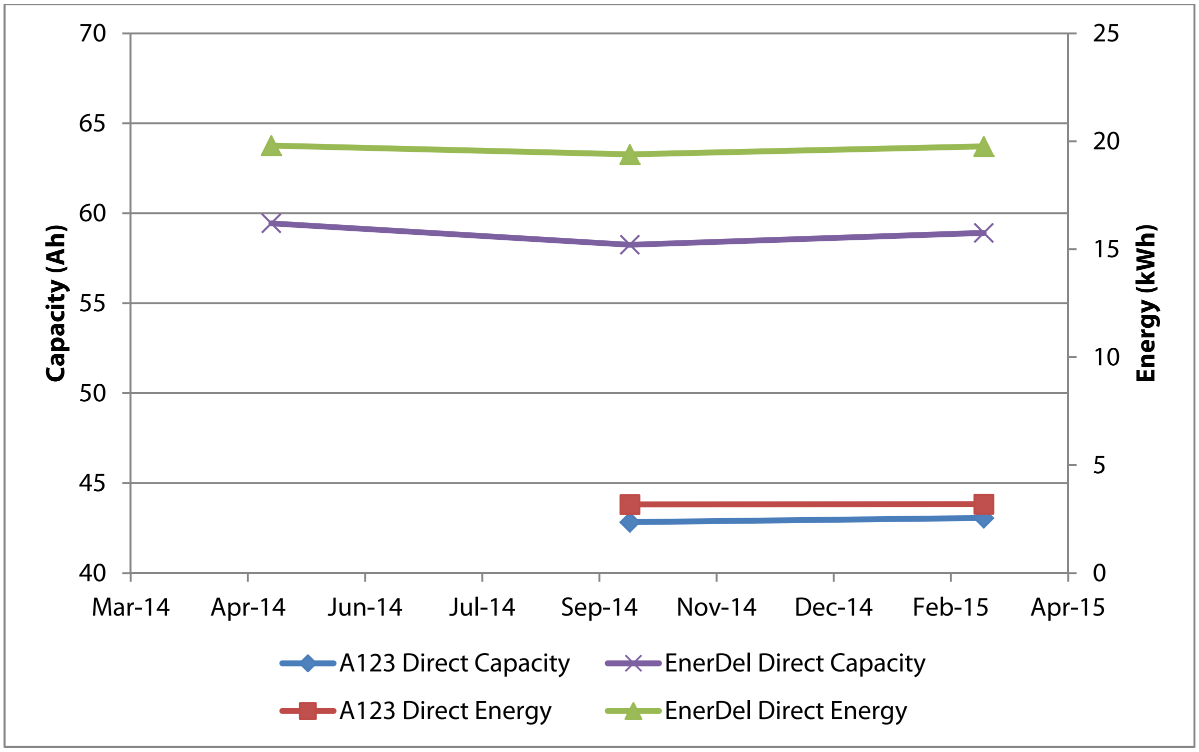

Figure 1: Capacity Degradation of Battery over PFR Cycling

Before each capacity test, the testing protocol called for the battery cells to be fully charged and balanced to 100% state of charge (SOC). The EnerDel Pack is considered fully charged and balanced when the minimum cell voltage is at least 4.08 V and the maximum cell voltage is at least 4.1 V. Likewise, the A123 Module #5 is considered fully charged and balanced when the minimum cell voltage is at least 3.59 V and the maximum cell voltage is at least 3.6 V. This protocol of charging and balancing to 100% SOC was achieved before all capacity tests conducted in this report.

The EnerDel Pack RPTs in May 2014 and October 2014 show that 1.65% of nameplate capacity was lost over this period. From October 2014 to March 2015, however, 0.92% of nameplate capacity was *regained* due to PFR cycling. For the A123 Module #5, 0.40% of nameplate

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energy discharged out of the battery during PFR cycling. It is important to note that each cycling period did not have the same amount of GWh discharge throughput.

[9] A negative Percent Capacity Change per GWh of PFR Discharge Throughput (%/GWh) indicates that the capacity measured at the end of the cycling period was greater than the capacity measured at the beginning of the cycling period. It appears that there was capacity gain over the course of PFR cycling, but variations in cell temperature and imbalance during the performance of these capacity tests can impact the capacity measured. Controlling for cell temperature and cell imbalance would have provided more accurate results.

capacity was *regained* due to PFR cycling between October 2014 and March 2015. For both the EnerDel Pack and A123 Module #5, it is counterintuitive that measured capacity would increase over time. In order to determine the reason for this apparent capacity increase over time for both the EnerDel Pack and the A123 Module #5, we looked at cell temperature variation and cell imbalance during the October 2014 and March 2015 capacity tests.

The average cell temperature during the discharge portion[10] of the October 2014 C/5 Capacity Test was greater than the average cell temperature during the discharge portion of the March 2015 C/5 Capacity Test for both the EnerDel Pack and A123 Module #5. Lower cell temperatures generally result in capturing a lower capacity measurement of the battery because more resistance is encountered when trying to pull current out of the battery. Additionally, cell imbalance of the A123 Module #5 is fairly constant between October 2014 and March 2015. For the EnerDel Pack, cell imbalance is greater during the March 2015 capacity test than the October 2014 capacity test. Greater cell imbalance generally results in capturing a lower capacity measure of the battery because discharge is considered complete when the first cell hits 2.5 V. Therefore, for both batteries, cell temperature variation and cell imbalance between the two capacity tests cannot explain the apparent capacity increase over time.

The apparent capacity increase of the two batteries between October 2014 and March 2015 is likely due to either measurement error or an actual capacity increase. It is possible that Lithium-ion cells can recover a small amount of capacity over several cycles following a period of inactivity, however, between October 2014 and March 2015 both batteries were continually cycled, aside from periods when the ABC-150 inverters were offline and in between duty cycle test segments. Additionally, the magnitude of capacity increase measured (~0.5%-1.1%) from one capacity test to another for both batteries is within the bounds of test measurement error. Therefore, measurement error is most likely contributing to the apparent increase in capacity over time for both the EnerDel Pack and A123 Module #5.

Pulse Characterization Tests

Table 3 and Figure 2 below summarize the average DC impedance of the EnerDel Pack and A123 Module #5 cells for the charge and discharge pulses of each Pulse Characterization Test (PCT). It is expected that DC impedance will increase over time due to continued cycling. However, while conducting each PCT, we did not control for cell temperatures, which makes it difficult to accurately measure the trend in DC impedance. In general, though, increased cell

[10] Average cell temperature was calculated using cell temperature data from the discharge portion only because the discharge portion of the C/5 Capacity Test is what is used to determine the direct C/5 discharge capacity.

temperatures will result in decreased resistance and decreased cell temperatures will result in increased resistance. Between October 2014 and March 2015, we see this trend of increasing resistance with decreasing average cell temperature for the EnerDel Pack. Similarly, between October 2014 and March 2015, we see this trend with the A123 Module #5. However, in Table 3, as the cell temperature increases slightly, the resistance also increases between May 2014 and October 2014 for the EnerDel Pack. Although, the impedance trend between May 2014 and October 2014 is unexpected, it is difficult to accurately compare impedance without controlling for cell temperature. Therefore, had we wanted to more accurately compare DC impedance degradation over time for both batteries during PFR cycling, we would have needed to control for cell temperatures when performing each PCT. For the EnerDel Pack, comparison of the May 2014 and October 2014 test data, where the cell temperatures were almost the same[11], implies that the resistance of this battery pack has been slightly impacted by PFR cycling, at least for a single cycling period. As for the A123 Module #5, there is not a clear picture on whether the resistance of the cells has been impacted by PFR cycling due to greater variability in average cell temperatures between each PCT.

Table 3: Average DC Impedance and Average Temperatures of Battery Cells during each PCT

Pulses	May 2014	Oct. 2014		Mar. 2015	
	EnerDel	EnerDel	A123	EnerDel	A123
Charge (mΩ)	118.8	122.2	26.7	139.3	32.4
Discharge (mΩ)	113.0	115.6	24.4	130.7	30.5
Temperature (°C)[12]	29.0	29.1	25.6	25.5	19.8

[11] The percent difference of the average cell temperature during the PCT in May 2014 versus October 2014 is less than half a percent, which is negligible for purposes of measuring resistance variation.

[12] The average cell temperature is calculated from the cell temperatures beginning with the initial discharge pulse to the end of the recharge after the high-rate pulses.

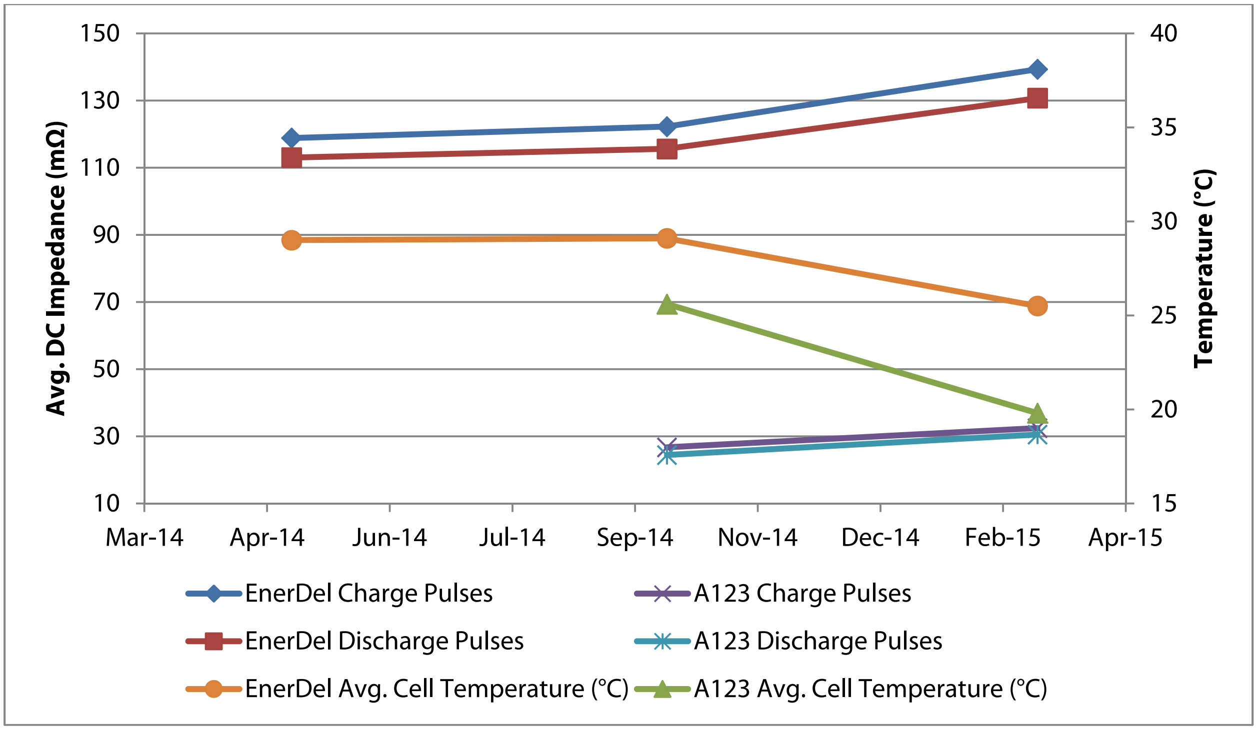

Figure 2: Average DC Impedance and Average Temperatures of Battery Cells during each PCT

II. PFR Cycling

In this long-term testing period, the EnerDel Pack and A123 Module #5 were cycled under a prescribed PFR duty cycle and/or a real-time PFR algorithm. The real-time PFR algorithm was run using Power Analytics Corporation's web-integrated software platform, Paladin. The real-time PFR algorithm incorporated real-time local frequency at the East Campus Utility Plant solar PV array on the University of California, San Diego, campus. Using the frequency data, the PFR algorithm determined an appropriate battery response, either charge or discharge, in order to mitigate any fluctuations in frequency outside of and equal to an acceptable band. A frequency measurement equal to or outside the acceptable band (59.98 Hertz to 60.00 Hertz) triggered the PFR algorithm to issue a charge or discharge command proportionate to the variance of the frequency measured.

The prescribed PFR duty cycle was an approximate 2.8-day (67.8-hour) duty cycle run locally through the Battery Control Software (BCS). The prescribed PFR duty cycle power profile for the EnerDel Pack was created by adding statistical error to historical battery commands generated from running the real-time primary frequency algorithm on the same battery pack. Then, the EnerDel Pack PFR power profile was scaled for use on the A123 Module #5. To run prescribed PFR duty cycles on the A123 Module #5 for a period of longer than ~2.8 days, the ~2.8-day power profile was repeatedly strung together such that every ~2.8 days, the prescribed PFR duty cycle started over. This was how the ~14.5-day (~347.2-hour) prescribed PFR duty cycle was created for the A123 Module #5.

During periods 1 and 2 of long-term PFR cycling, the EnerDel Pack was cycled under the prescribed PFR duty cycle for a total of 4.6 days and under the real-time PFR algorithm for a total of 117.1 days, resulting in an overall total of 121.7 days of PFR cycling. During the course of long-term PFR cycling, the prescribed PFR duty cycle was attempted a total of 3 times on the EnerDel Pack. Of those 3 attempts, there was only 1 time in which the battery pack completed the full ~2.8-day (~67.8-hour) cycle. Often times, the duty cycle would be stopped early in order to utilize the battery pack for testing python scripts via Paladin, switching over to running the real-time PFR algorithm, or restarting the BCS.

During period 3 of long-term PFR cycling, the A123 Module #5 was cycled under the prescribed PFR duty cycle for a total of 67.6 days. The A123 Module #5 did not cycle under the real-time PFR algorithm in this long-term test protocol. Therefore, the overall total number of PFR cycling days for the A123 Module #5 is equal to the number of days the module was cycled under the prescribed PFR duty cycle. During the course of long-term PFR cycling, the prescribed PFR duty cycle was attempted a total of 23 times on the A123 Module #5. Of those 23 attempts, there were 16 times in which the battery module completed either the full ~2.8-

day (~67.8-hour) cycle or the full ~14.5-day (~347.2-hour) cycle. Often times, the duty cycle would be stopped early due to a variety of reasons, including ABC-1 going offline, restarting of the BCS, or the battery going out of REM mode in the BCS.

a. Prescribed PFR

i. EnerDel Pack

Figure 3 below showcases a sample ~2.8-day PFR duty cycle occurrence (August 15-18, 2014) run on the EnerDel Pack during PFR cycling period 1. We can see that the battery pack is continually cycled in this duty cycle and often very close to the programmed BCS inverter channel limits of (+) and (–) 30 kW. Because of these frequent swings in power that push the battery very close to or over (i.e. a 2.62 minimum voltage was achieved) its minimum cell voltage limit of 2.5 V, the cell temperature on the battery pack rose significantly at lower states of charge (SOCs) and almost reached the Battery Control Software (BCS) limit of 45 °C as seen in Figure 4. Monitoring cell temperature of the battery pack was important to maintaining the health and safety of the battery during the primary frequency response application cycling. The EnerDel Pack's SOC was maintained between about 10% and 90% SOC in this particular occurrence. As long as the EnerDel Pack's cell temperatures don't exceed the BCS limit of 45 °C, it is safe to continue operating the battery under PFR, although, it should be noted that increased cell temperatures can contribute to faster battery degradation.

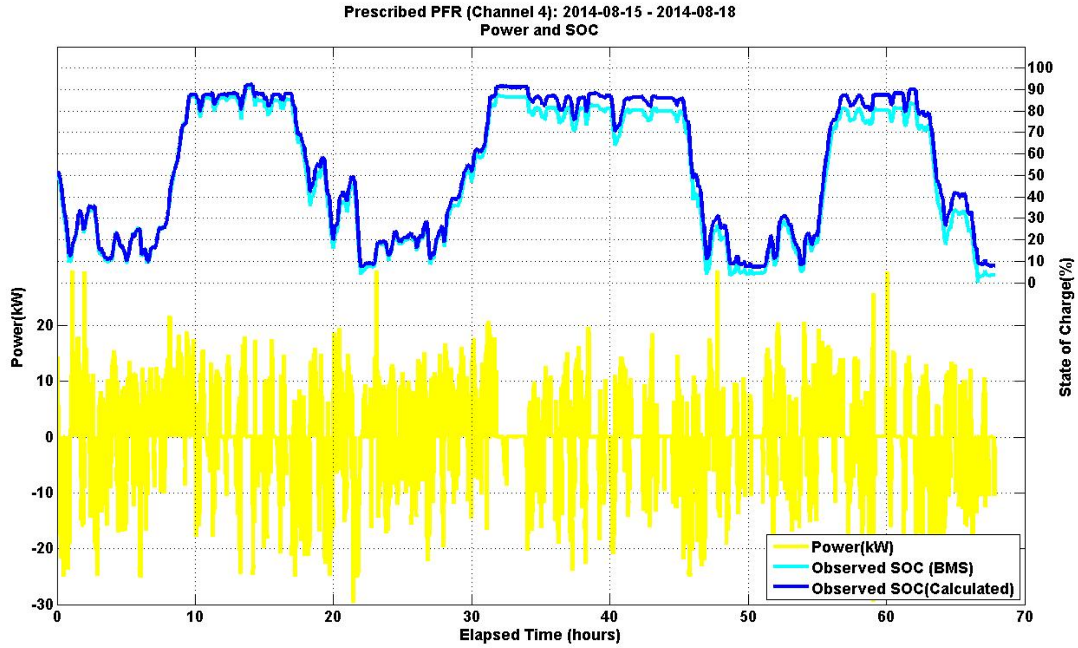

Figure 3: Power and SOC Trends for ~2.8-Day PFR Duty Cycle (08-15-2014 to 08-18-2014) on EnerDel Pack

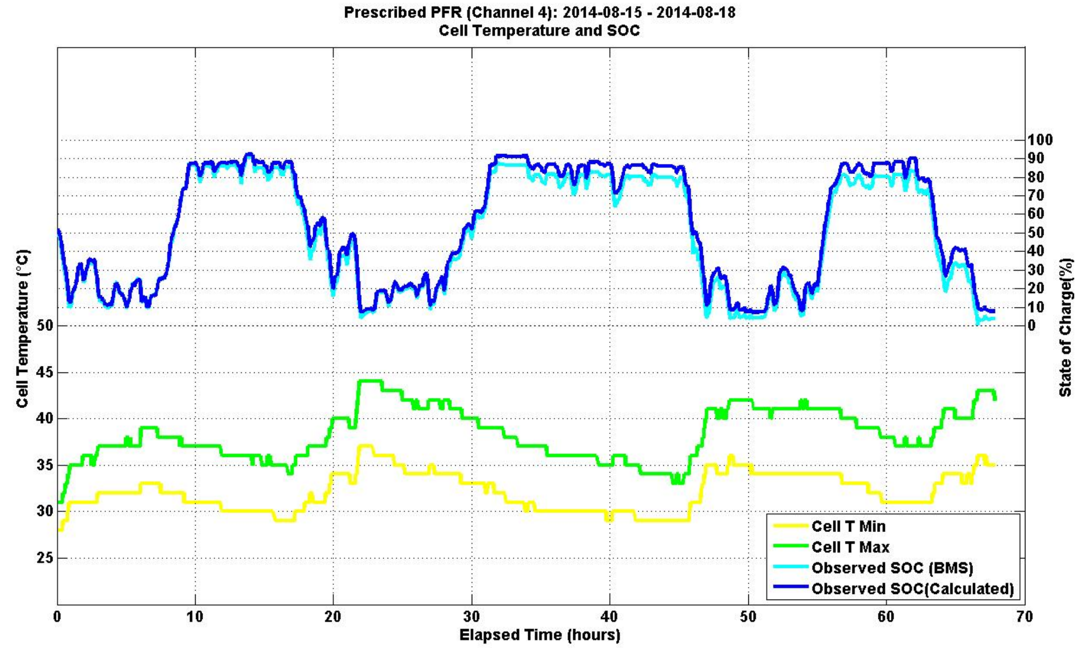

Figure 4: Cell Temperature and SOC Trends for ~2.8-Day PFR Duty Cycle (08-15-2014 to 08-18-2014) on EnerDel Pack

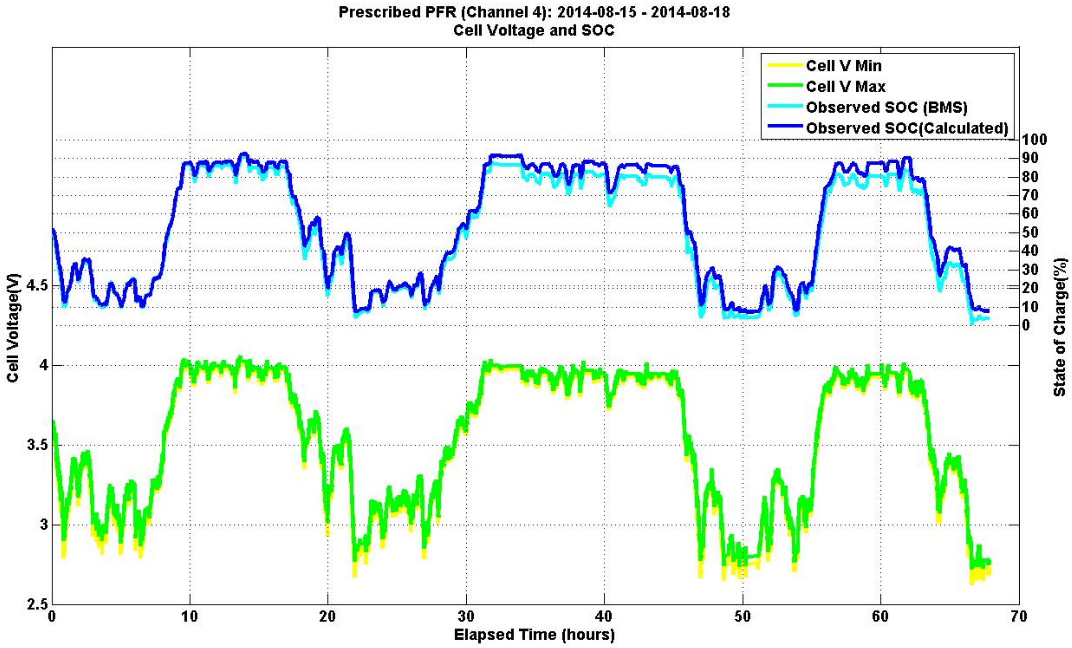

Figure 5: Cell Voltage and SOC Trends for ~2.8-Day PFR Duty Cycle (08-15-2014 to 08-18-2014) on EnerDel Pack

ii. A123 Module #5

Figure 6 below showcases a sample ~2.8-day PFR duty cycle occurrence (January 5-7, 2015) run on the A123 Module #5 during PFR cycling period 3. We can see that the battery module is continually cycled, switching frequently between charging and discharging. During this occurrence, the minimum power achieved by the module was -3.66 kW and the maximum power achieved was 3.61 kW. Frequent swings in power generally cause cell temperatures to rise, but because we did not bump up against the module's 10-second charge and discharge power limits of 25.0 kW and 40.4 kW, respectively, nor the module's continuous charge and discharge power limits of 4.6 kW and 13.2 kW, respectively, nor the module's minimum and maximum cell voltage limits of 2.5 V and 3.6 V, respectively, cell temperatures remained relatively constant throughout the day, with a minimum and maximum cell temperature overall of 16.5°C and 23.5°C, respectively, as seen in Figure 7.

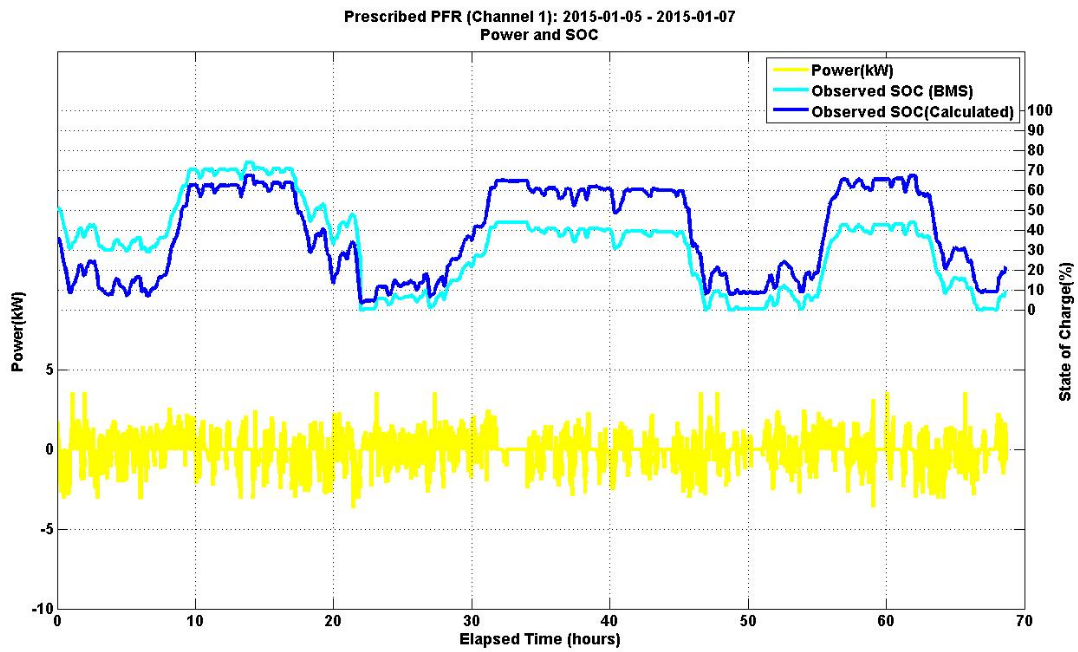

Figure 6: Power and SOC Trends for ~2.8-Day PFR Duty Cycle (01-05-2015 to 01-07-2015) on A123 Module #5

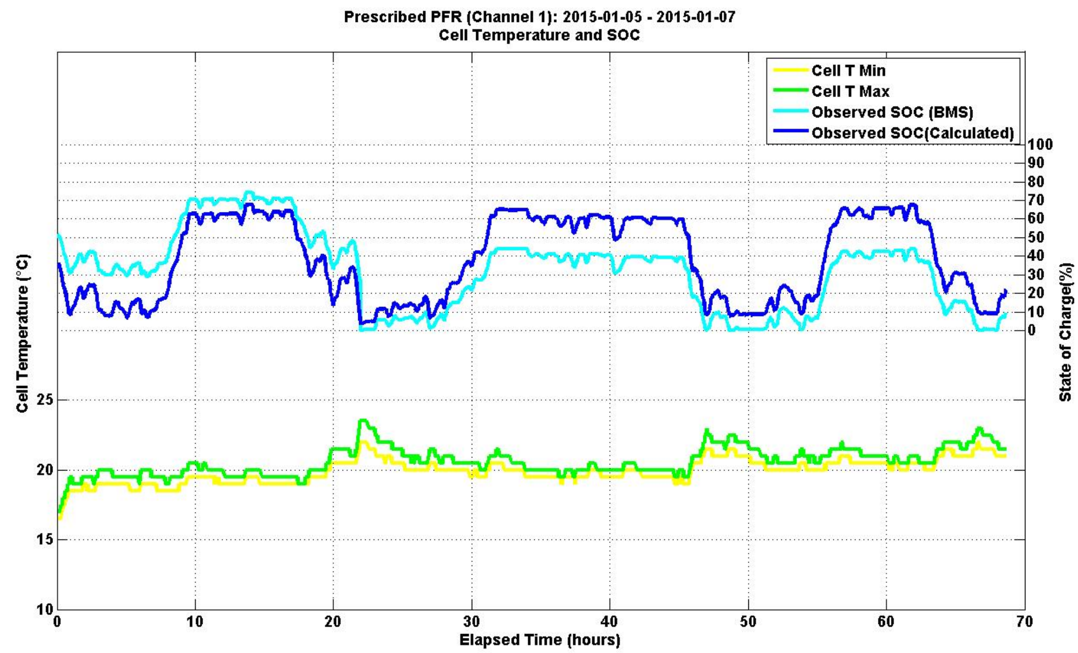

Figure 7: Cell Temperature and SOC Trends for ~2.8-Day PFR Duty Cycle (01-05-2015 to 01-07-2015) on A123 Module #5

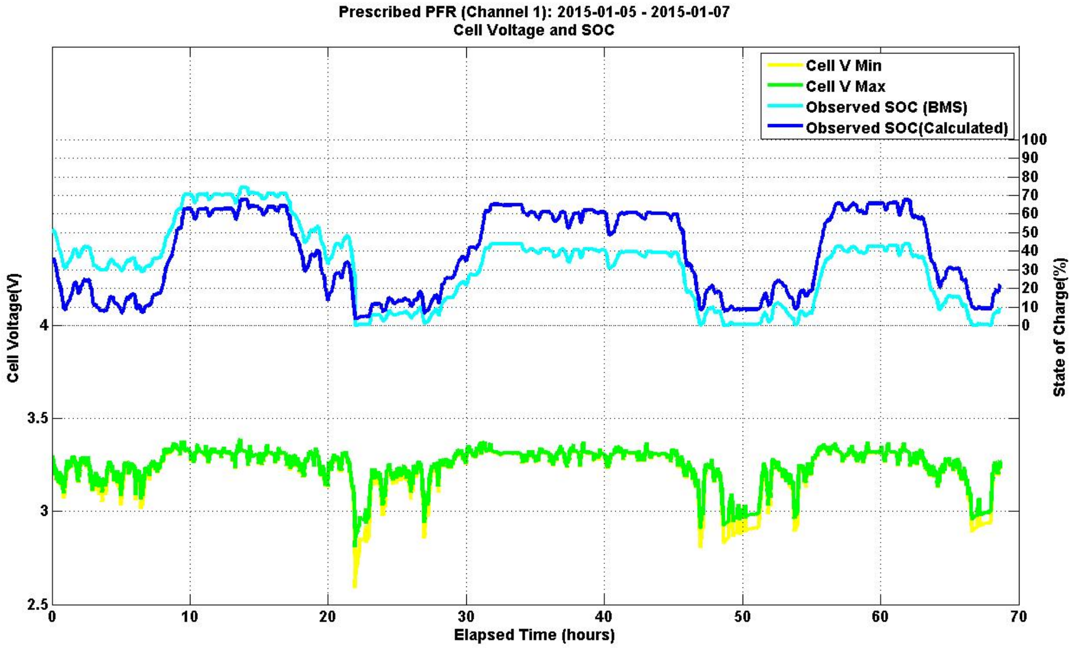

Figure 8: Cell Voltage and SOC Trends for ~2.8-Day PFR Duty Cycle (01-05-2015 to 01-07-2015) on A123 Module #5

b. Real-time PFR

Figure 9 below highlights a day during PFR cycling period 1 (September 25, 2014) when the PFR algorithm was cycled on the EnerDel Pack[13]. In the figure, the local frequency measured for that day is shown in addition to the expected power command. The *expected* power command is curtailed if the battery pack has reached one of its state of charge limits—either 15% or 84% SOC. Figure 10 below highlights this difference between the expected power command and the actual power command. Areas in Figure 10 where the red *expected* power command trend line is visible indicate periods when frequency response was curtailed by the controller because the battery had reached a low (i.e. 15%) or high (i.e. 84%) SOC. Figure 11 and Figure 12 provide actual battery pack data for the sample day, including power, SOC, and cell temperatures. Figure 11 shows that the EnerDel Pack was cycled between approximately +/- 29 kW and about 15% SOC and 100% SOC. Figure 12 indicates that the cell temperatures

[13] The real-time PFR algorithm was only run on the EnerDel Pack and not the A123 Module #5 during this long-term testing protocol. Therefore, no real-time PFR data is included in this report for the A123 Module #5.

of the EnerDel Pack ranged from 28°C to 43°C. Additionally, we can see that frequency mitigation at lower SOCs causes an increase in cell temperature.

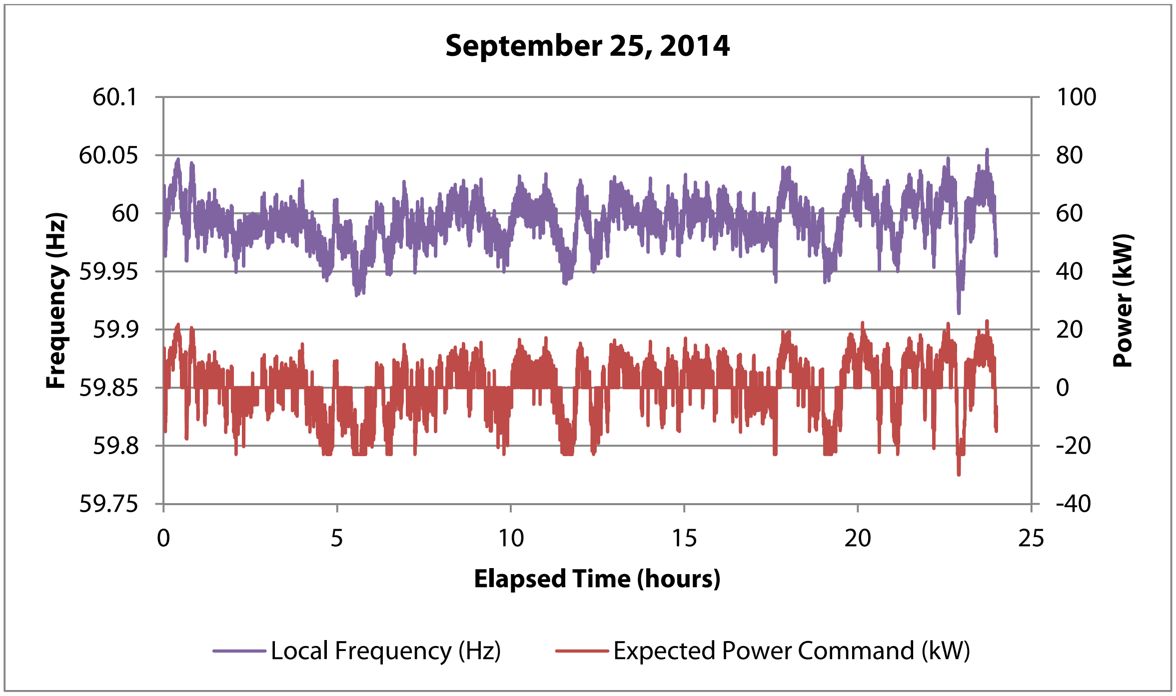

Figure 9: Local Frequency Measurement and Expected Power Command for September 25, 2014, under PFR Cycling

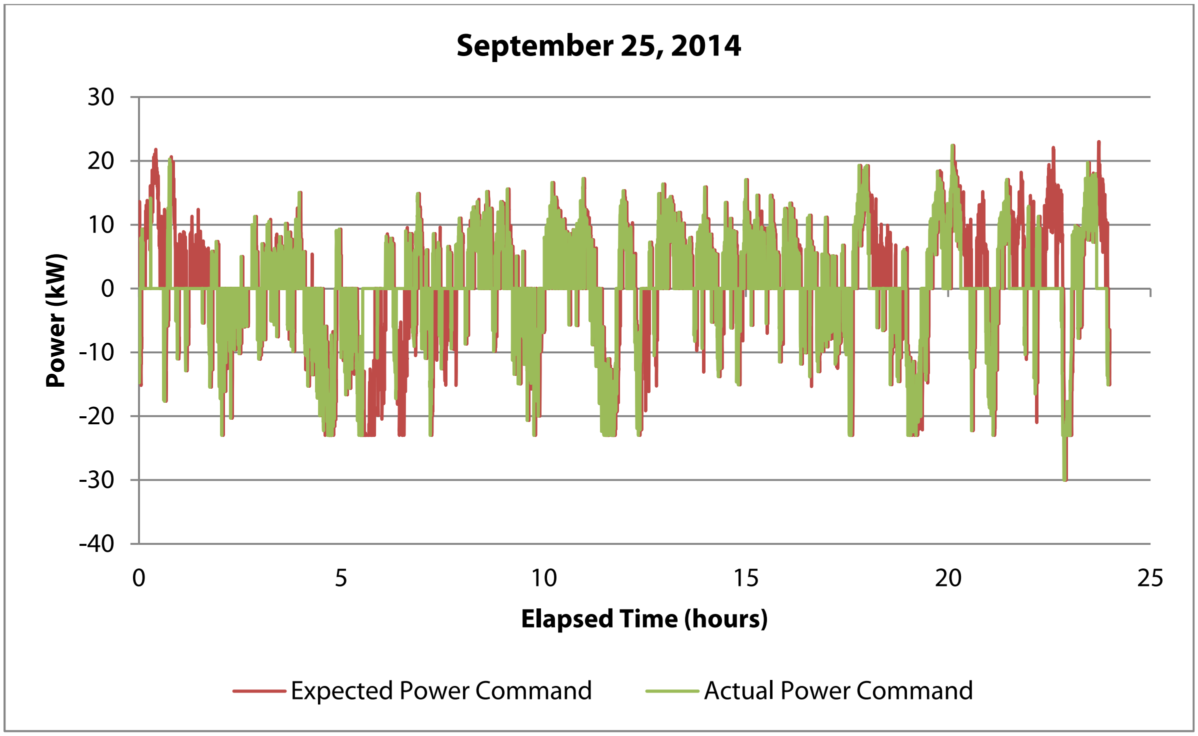

Figure 10: Expected Power Command and Actual Power Command for September 25, 2014, under PFR Cycling

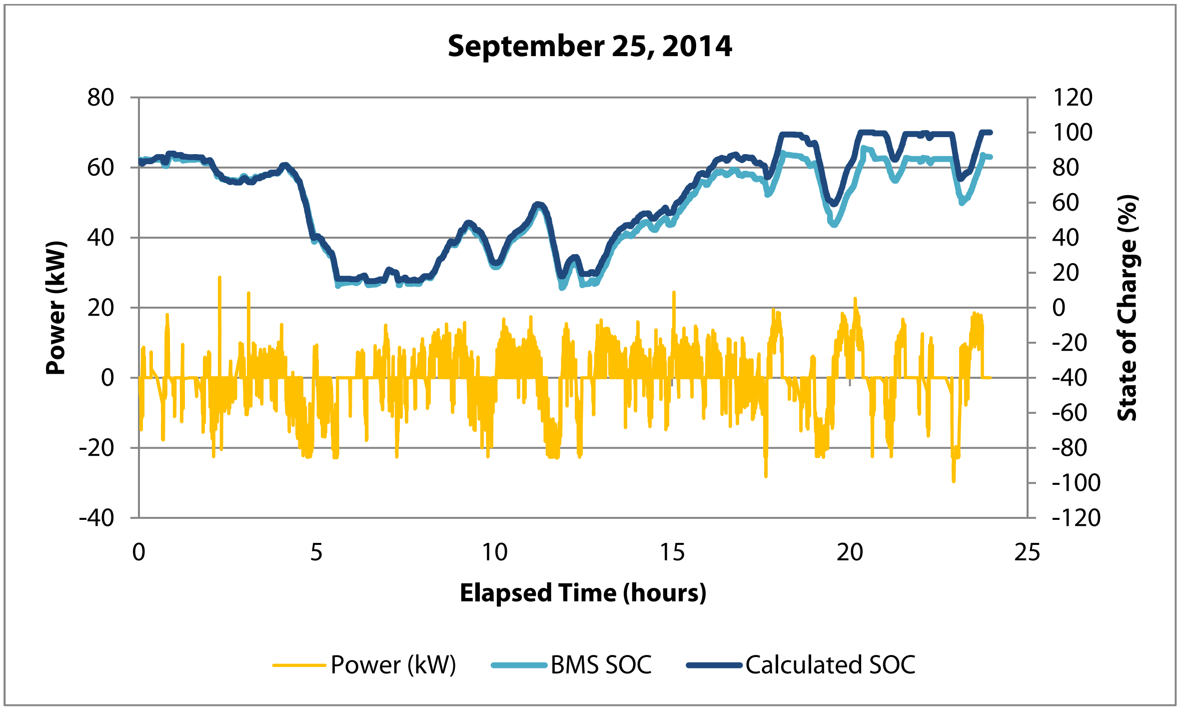

Figure 11: Actual Power Measured, BMS Recorded SOC, and Calculated SOC for September 25, 2014, under PFR Cycling

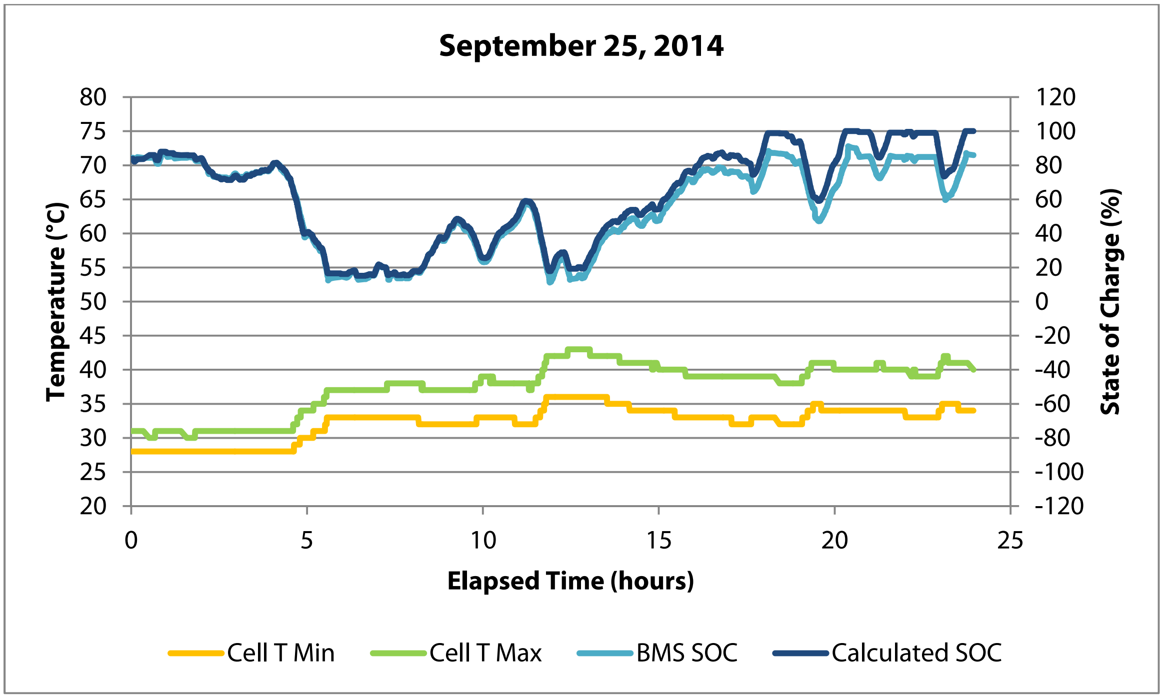

Figure 12: Min/Max Cell Temperature, BMS Recorded SOC, and Calculated SOC for September 25, 2014, under PFR Cycling

c. One-way Energy Efficiency

Table 4 summarizes the effective one-way energy efficiency of a representative complete prescribed PFR ~2.8-day duty cycle run from each of the PFR cycling periods. The effective one-way energy efficiency of the EnerDel Pack decreases between long-term PFR periods 1 and 2, which agrees well with the RPT data that suggests EnerDel Pack resistance increases under PFR cycling. The single effective one-way energy efficiency of the A123 Module #5 for period 3 is not sufficient enough to determine long-term resistance degradation of the battery module due to PFR cycling. See below for the methodology used to calculate the effective one-way energy efficiency of the battery in each cycling period.

Table 4: Effective One-way Energy Efficiency of Batteries during each PFR Cycling Period

	Period 1	Period 2	Period 3
	EnerDel Pack	EnerDel Pack	A123 Module #5
Energy Efficiency (%)	95.13	93.60[14]	90.93

Effective One-way Energy Efficiency (*eff*) Calculation Methodology:

$$E_{end} = E_{start} + [E_{in} * eff] - \left[\frac{E_{out}}{eff}\right]$$

$$E_{end} = \left[SOC(Ah)_{ending}\right] * \left[\frac{C}{5} measured\ discharge\ energy\right]$$

$$E_{start} = \left[SOC(Ah)_{starting}\right] * \left[\frac{C}{5} measured\ discharge\ energy\right]$$

Where

- E_{end} = Stored energy in the battery at the end of the test
- E_{start} = Stored energy in the battery at the beginning of the test
- E_{in} = Integral of DC charge power over the test
- E_{out} = Integral of DC discharge power over the test
- eff = Effective one-way energy efficiency

[14] There were no full ~2.8-day prescribed PFR duty cycles completed in this testing period. Therefore, the effective one-way energy efficiency was calculated for period 2 using a partial ~2.8-day prescribed PFR duty cycle.

III. Conclusions

We have learned about the performance of Lithium-ion batteries, in particular, the EnerDel Pack and the A123 Module #5, under long-term primary frequency response (PFR) duty cycle testing. Performance of the batteries was measured by studying their ability to follow the prescribed duty cycle as requested by the intended PFR power profile and the real-time PFR algorithm while operating within safety limits and via direct measurement of capacity, energy, and resistance using a Reference Performance Test (RPT). In addition, we gained insight into the effects of cell temperature and cell imbalance on capacity measurements, the effects of cell temperature on impedance measurements, and mitigation strategies for future research to control for these effects.

Cell Temperature and PFR Cycling

The primary frequency response application is a more aggressive duty cycle than the demand charge management and regulation energy management duty cycles, which results in elevated cell temperatures. The primary finding of this study is the negative impact of PFR cycling on cell temperature of a Lithium Metal Oxide battery pack (i.e. EnerDel Pack). During both prescribed and real-time occurrences of PFR application cycling, the EnerDel Pack's cell temperatures rose during frequency mitigation at low SOCs. We don't see as big of a cell temperature increase at low SOCs with the A123 Module #5 which has Lithium Iron Phosphate chemistry; although, because the A123 Module #5 utilized a slightly different testing protocol than that of the EnerDel Pack, it is difficult to draw conclusions on the impact of battery chemistry on cell temperature changes during cycling. When cycling the A123 Module #5 under the PFR application, the maximum cell temperature reached was 25°C compared to 44°C and 42°C on the EnerDel Pack during periods 1 and 2, respectively.

Capacity Measurement

Over the course of long-term PFR cycling (over 120 cycling days), the EnerDel Pack's capacity remained relatively constant. Over period 1, the EnerDel Pack's capacity degraded by less than 2% of nameplate capacity – from 59.4 Ah to 58.3 Ah. Over period 2, the EnerDel Pack's capacity increased by less than 1% of nameplate capacity – from 58.3 Ah to 58.9 Ah. There is not enough data on the A123 Module #5 for comparison purposes with the EnerDel Pack on capacity degradation (regain) rates, but between the beginning and end of period 3 of long-term PFR cycling (over 65 cycling days), the A123 Module #5's capacity increased by less than 0.5% of nameplate capacity – from 42.8 Ah to 43.1 Ah. It was determined that cell temperature variation and cell imbalance were not contributors to the apparent increase in measured capacity in either battery nor was the apparent increase an actual capacity increase. The likely contributor to the apparent capacity increase of the two batteries between October 2014 and March 2015 is measurement error. The change in measured capacity of the EnerDel Pack and change in measured capacity of the A123 Module #5 over the approximate 4 months and 2 months of PFR cycling, respectively, is negligible.

Percent Capacity Change per PFR Discharge Energy Throughput

According to the data, period 1 is the only PFR cycling period in which there is a positive percent capacity change per PFR discharge energy throughput, which is indicative of the degradation rate of the EnerDel Pack. Periods 2 and 3 both have negative percent capacity changes per PFR discharge energy throughput, which are indicate that over periods 2 and 3, capacity is increasing. The regain rate is greater for the EnerDel Pack in period 2 than it is for the A123 Module #5 in period 3. What is not captured in the percent capacity change per PFR discharge energy throughput is the amount of cycling conducted during a test period that is not a PFR application and the effects of elapsed calendar time for each test period. Additional cycling other than PFR in a PFR test period and greater overall calendar time elapsed should, in theory, contribute to a greater percent capacity change per PFR discharge energy throughput.

DC Impedance

The change in DC impedance of the EnerDel Pack's cells is difficult to quantify because cell temperature was not controlled for during the pulse characterization tests; however, the impedance measurements we have suggest a slight increase in DC impedance for the EnerDel Pack over period 1 and potentially period 2. Calculation of effective one-way energy efficiency under PFR cycling supports this conclusion, as the effective one-way energy efficiency of the EnerDel Pack decreases between periods 1 and 2. There is not enough data on the A123 Module #5's cells to make any significant conclusions on the effect of PFR cycling on DC impedance of this battery's cells.

In conclusion, the results of the EnerDel Pack indicate that there is an increase in DC impedance of its cells due to PFR cycling. This is most likely perpetuated by the increase in cell temperature when the battery is being operated under the PFR application. Increased cell temperatures can lead to faster and further battery degradation. The single test period of PFR cycling data on the A123 Module #5 also indicates that PFR cycling leads to an increase in DC impedance of module cells, but with limited data, it is difficult to make any justifiable correlations between cell temperature during PFR application cycling and DC impedance degradation with the A123 Module #5.

Future Research

Future PFR application cycling and data collection are needed on the EnerDel Pack and A123 Module #5. Cycling an A123 Pack would add valuable insight into the effects of battery chemistry. Running the exact same PFR algorithm and prescribed PFR power profile on two battery packs of different chemistries versus one pack and one module would make it easier to compare the performance of two different battery chemistries under PFR cycling. Thus, we could eliminate the variation in power achieved and power swing frequency, though these differences could have been adjusted by normalizing the power achieved and power swings as a percentage of the maximum power limit and swings. Lastly, completing at least 180 days of PFR cycling on each battery is important in assessing total PFR service life of a battery as is controlling for cell temperature and cell imbalance during each appropriate Reference Performance Test. However, on an initial level, the data collected in this report was important in showcasing that second-use batteries are capable of meeting the demands of a primary frequency response application as long as they are monitored to ensure health and safety.