**Documentation (ANR26650M1-B from A123)**

**Experimental Setup**

A test environment for battery characterizations has been built in the laboratory as shown in Figure 1. The commercial LiFePO4 battery cells (ANR26650M1-B from A123 Systems) were used in the experiments. The key specification of the battery cell is tabulated in Table 1. Battery cell or battery pack was placed in the temperature chamber to perform a series of tests under different controlled temperatures. The ambient temperatures 5 °C, 15 °C, 25 °C, 35 °C and 45 °C were used to determine the model parameters of the 12-cell battery. The load current is created using a programmable DC electronic load, and a programmable DC power supply for charging the battery cells. The power supply is utilized as a controlled voltage or current source with the output voltage from 0 to 36 V and current from 0 to 20 A. A current sensor LEM 50-P is used to measure the charge and discharge current. The NTC temperature sensors are utilized to measure the temperatures of the battery cells and the ambient temperature. The National Instruments DAQ device controlled all input and output data. The host PC communicates with the DAQ device to monitor the power supply and charge and discharge status of the battery in real-time. As the data acquisition rate is limited in the embedded system, it is one sample per second. The host PC performs the model simulation and algorithm development using the battery’s data received. A custom-designed pulse relaxation that includes the transient part and non-transient part (rather than simple constant current cycles often adopted in the literature) is employed in the SOC estimation as seen in Figure 2.

**Table 1.** Battery cell and thermal specifications (ANR26650M1-B from A123 Systems)

|  |  |
| --- | --- |
| Cell Dimensions (mm) | Ø 26 × 65 |
| Cell Weight (g) | 76 |
| Cell Capacity (nominal/minimum) (0.5 C Rate) | 2.5/2.4 |
| Voltage (nominal, V) | 3.3 |
| Recommended Standard Charge Method | 2.5 A to 3.6 V CCCV for 60 min |
| Cycle Life at 20 A Discharge, 100% DOD | >1000 cycles |
| Maximum Continuous Discharge | 50 A |
| Operating Temperature | −30 °C to 55 °C |
| Storage Temperature | −40 °C to 60 °C |
| Specific Heat Capacity of the Cell | 810.53 |
| Convective Heat Transfer Coefficient (W/m2/K) | 5 |
| Surface Area of Heat Exchange (m2) | 0.0149 |
| Ambient Temperature (°C) | 25 |



**Figure 1.** Battery test bench.



**Figure 2.** Relaxation process example of battery pulse discharge test (PDT).

**Data Structure (1RC pair)**

Capacity(Ah) in Ah, Capacitance(C1) in F, Current (Curr) in A, Initial Capacity(InitCapacity) in Ah, Internal Resistance (R0) in Ω, Resistance (R1) in Ω, Ambient Temperature(Tamb) in oC, Terminal Voltage (volt) in V at different ambient temperatures (5 oC, 15 oC, 25 oC, 35 oC, 45 oC)

**References**

1. **CS. Chin**, ZC. Gao. State-of-Charge Estimation of Battery Pack under Varying Ambient Temperature Using an Adaptive Sequential Extreme Learning Machine, Energies 2018, 11(4), 711, Mar 2018.
2. ZC. Gao, **CS. Chin**, JHK. Chiew, JB. Jia, CZ. Zhang. Design and Implementation of Smart Lithium-ion Battery System with Real-time Fault Diagnosis Capability for Electric Vehicles. Energies, 10(10), 1503, Sept 2017.
3. ZC. Gao, **CS. Chin**, WL. Woo, J. Jia. Integrated Equivalent Circuit and Thermal Model for Simulation of Temperature-Dependent LiFePO4 Battery in Actual Embedded Application, Energies, Special Issue on Control of Energy Storage, 10(1), 85-85, Jan 2017.
4. **CS. Chin**, ZC. Gao, JHK. Chiew , C. Zhang, Nonlinear Temperature-Dependent State Model of Cylindrical LiFePO4 Battery for Open-Circuit Voltage, Terminal Voltage and State-of-Charge Estimation with Extended Kalman Filter, Energies 2018 (Special Issue 10 Years Energies - Horizon 2028), 11(9), 2467, Sept 2018.