Model Development for State-of-Power Estimation of Large-Capacity Nickel-Manganese-Cobalt Oxide-Based Lithium-ion Cell Validated Using a Real-life ProfileE

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Supplementary Information

Methods

In this research, the aging of the cells was implemented with an efficient lifetime characterization methodology; a huge experimental dataset was collected from the 43 Ah NMC cells, where the cycling and calendar aging were conducted for more than two years. For the lifetime characterization, 40 cells were tested under cycling aging and 6 cells for calendar aging, and all 46 cells were completely tested using an ACT-type battery cycler and the ambient temperature of the cells was controlled by CTS-made climate chambers. From the total of 46 cells, 4 representative cells were selected for the state-of-power (SoP) investigations. To understand the aging impacts, two types of capacity check-up protocols were performed: short check-up (SCU) and detailed check-up (DCU). The first one was performed every 100 FEC, and the later one every 300 FEC. For calendar aging, the capacity was checked every 28 days. While the cells underwent aging tests, different reference performance tests (RPTs) were conducted to evaluate the performance of the cells in terms of their capacity degradation and internal resistance increase.

Table S1. Lifetime check-up description.

Detailed check-up			
Step	Action	C-Rate	Limit
		NMC	
1	Full capacity test C/2	0.5C	Testing temperature
2	HPPC		Testing temperature
3	Full capacity test C/2	0.5C	Ambient temperature (25°C)
4	HPPC		Ambient temperature (25°C)
5	OCV		Ambient temperature (25°C)
Steps 1-5 are performed every 300 FECs			
Short check-up			
Step	Action	C-Rate	Limit
		NMC	
1	Full capacity test C/2	0.5C	Testing temperature
2	HPPC		Testing temperature
Steps 1-2 are performed every 100 FECs			

Data Generation

The lifetime characterization test campaign is considered from beginning of life (BoL) to end of life (EoL), interpreted in terms of their relative capacity degradation. The first life–end of life (FL-EoL) criteria of the cell are considered 80% of the nominal capacity of the cell. Based on the lifetime checkup procedure, from the lifetime characterization test, the capacity of the cell at each instant is generated from the capacity test and the internal resistance increase of the cell is generated from HPPC test, as shown in **Table S1**. The flowchart of the overall lifetime test is presented in **Figure 2** of the main manuscript.

Testing Profile

The cycling aging profile considered for one of the many conditions is displayed in **Figure S1**. The number of cycles that are performed by a battery cell is named as the number of FECs. The lifetime comparison of various cycling conditions can be interpreted with the sample of one FEC, which is defined as the overwhelming of 100% of the nominal capacity pursued by the recharging of 100% of the nominal battery cell capacity.

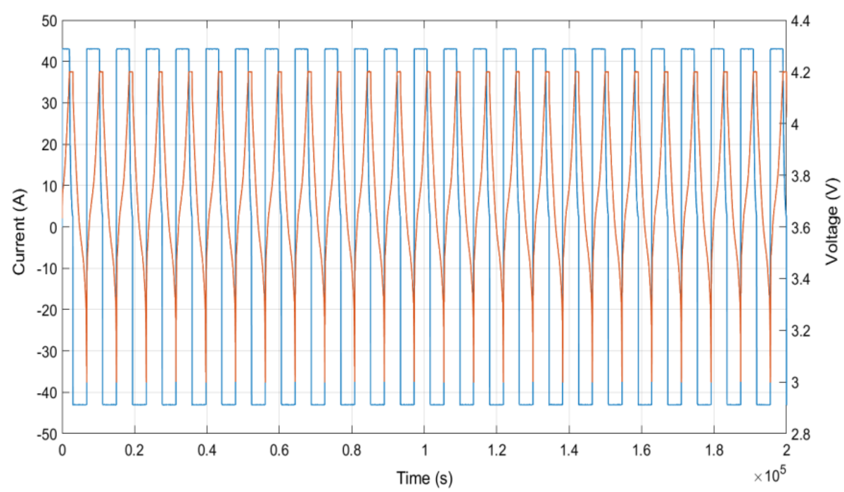

Figure S1. Cycling profile of cell 001 (100% DoD, 50% Mid-SoC, 1C charge–discharge rate).

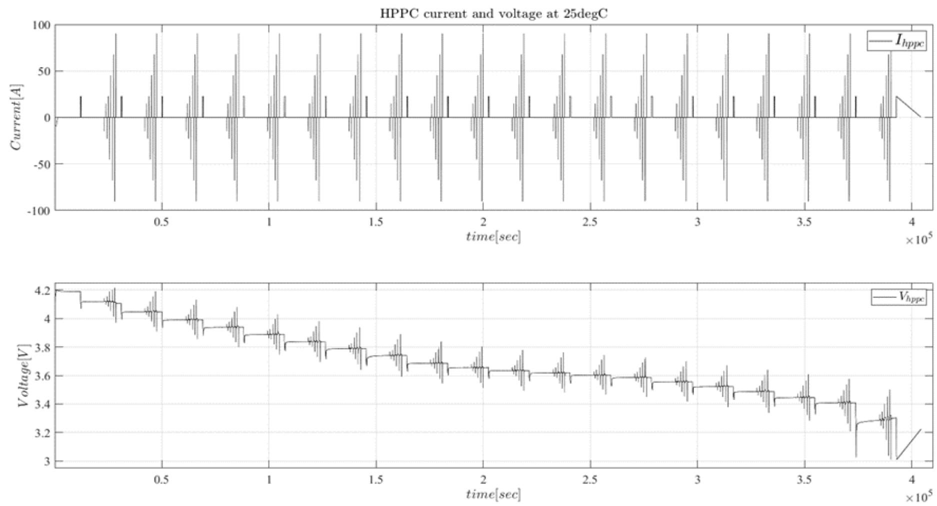

Figure S2. HPPC pulse train at 25°C with current profile and voltage output response.

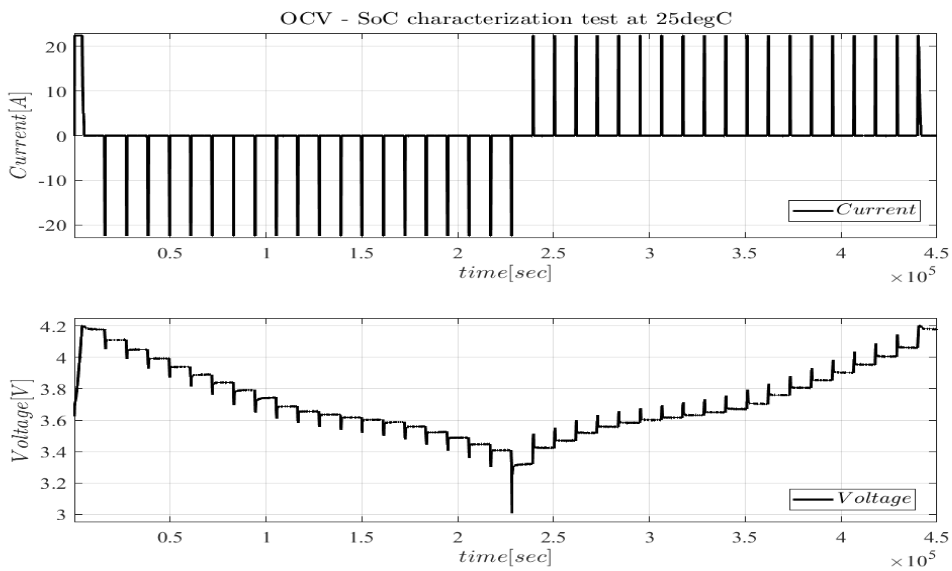

Figure S3. Results of the OCV test at 25°C with the current profile and output voltage.

Description of the validation profile

To prove the model's rationality, cycling aging tests were performed as a validation test where the WLTC profile was chosen for validation purposes in addition to the static profile. **Figure S4** shows a single WLTC cycle comprised of two parts: suburban and urban. The single WLTC profile performed on the cells consists of two urban and two suburban sets (900 s each), making an hour-long profile of 3600 seconds. Using theWLTC profile at SoC of 90% and temperature of 25°C, continuous cycling was conducted for validation purposes. To follow the degradation of capacity during aging as per the real condition, short RPTs were performed regularly in the validation process. From the WLTC validation result of the model, the measured internal resistance output parameters were in turn used for SoP estimation and model validation.

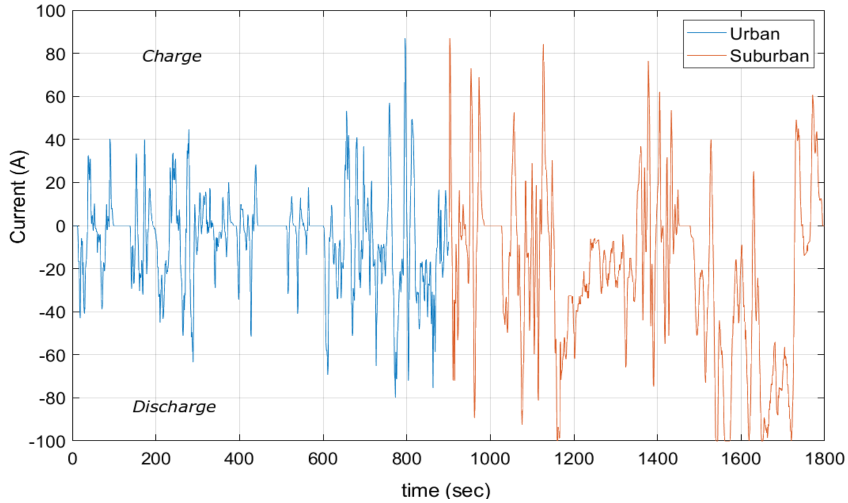

Figure S4. Single WLTC cycle current profile.