

Application Note

Hybrid Pulse Power Characterization (HPPC) Testing with Arbin MITS Pro

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Summary

The Hybrid Pulse Power Characterization (HPPC) test measures the pulse resistance and pulse power capability of a battery across its state-of-charge (SOC) range. This application note describes the HPPC method, the cycler characteristics that determine measurement quality, and an HPPC test on an XCell N18650-35E cell at 90% SOC and 25 °C, performed on an Arbin HPS cycler using a MITS Pro schedule.

1. Introduction to HPPC Testing

The HPPC test is defined in the US Department of Energy battery test manuals for hybrid and electric vehicles [1][2]. A short discharge pulse and a short charge (regen) pulse are applied at a series of SOC levels and the voltage response is recorded. The voltage change during each pulse gives the **discharge resistance** and **regen resistance** at that SOC, from which the **pulse power** that the battery can deliver or absorb within its voltage limits is calculated [1].

Capacity measurements quantify stored energy but not the rate at which energy can be delivered or accepted. HPPC provides this information and is used to:

- set the power limits a battery management system (BMS) allows at each SOC;
- parameterise the equivalent circuit models used for SOC and state-of-health estimation [5][6];
- compare cell designs, chemistries or suppliers;
- track resistance growth as a cell ages.

Cell resistance increases and pulse power decreases at lower temperature [4]; HPPC is therefore performed at a controlled temperature and repeated at each temperature of interest.

2. HPPC Methodology

2.1 HPPC Pulse Profile

The HPPC pulse profile is a 10-second discharge pulse, a 40-second rest and a 10-second regen pulse at 75% of the discharge current [1][3]. In a full test the profile is applied at every 10% SOC step; between steps the cell is discharged at a constant rate and rested for one hour, so that each pulse starts from a relaxed, near open-circuit condition [1].

Table 1. HPPC pulse profile

Time increment (s)	Cumulative time (s)	Segment	Relative current
10	10	Discharge pulse	1.00 (discharge)
40	50	Rest	0
10	60	Regen pulse	0.75 (charge)

2.2 Pulse Resistance and Power Calculation

With t_0 just before the discharge pulse, t_1 at the end of the discharge pulse, t_2 at the end of the rest and t_3 at the end of the regen pulse (Figure 1) [1]:

$$R_{dis} = |(V_{t0} - V_{t1}) / (I_{t0} - I_{t1})| \quad (1)$$

$$R_{regen} = |(V_{t3} - V_{t2}) / (I_{t3} - I_{t2})| \quad (2)$$

$$P_{dis} = V_{min} \cdot (OCV_{dis} - V_{min}) / R_{dis} \quad (3)$$

$$P_{regen} = V_{max} \cdot (V_{max} - OCV_{regen}) / R_{regen} \quad (4)$$

OCV_{dis} and OCV_{regen} are the rested voltages before the discharge and regen pulses. Plotted against SOC, these values give the resistance and pulse power curves of the cell.

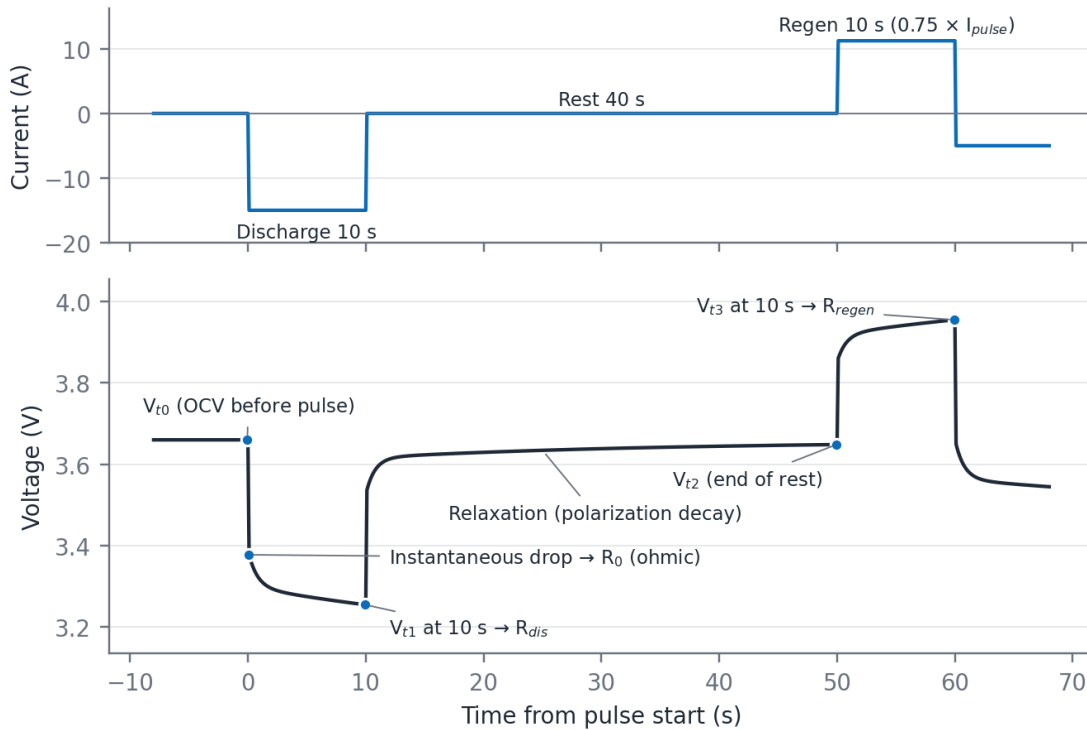


Figure 1. Schematic voltage response to one HPPC pulse sequence, with the points used in Equations (1) and (2). Measured data for the example cell are shown in Section 7.

The measured resistance depends on the time at which it is evaluated (for example 1 s or 10 s after the start of the pulse); the evaluation time is therefore reported with the results [7].

3. Cyclor Requirements for HPPC

HPPC results are calculated from voltage and current readings taken at defined times during fast current steps in both directions. Measurement errors and deviations from the programmed waveform propagate directly into the calculated resistance and power. Table 2 lists the cyclor characteristics that affect HPPC results and the corresponding test-setup considerations.

Table 2. Cyclor characteristics and test-setup choices that affect HPPC results

Characteristic	Relevance to HPPC	Test-setup consideration
Voltage accuracy and resolution	Resistance is the difference of two voltage readings; pulse power also uses the absolute OCV and voltage limits	Insufficient accuracy causes scatter in resistance between channels and repeat tests

Characteristic	Relevance to HPPC	Test-setup consideration
Current accuracy and range	Resistance divides by the pulse current; SOC steps rely on charge counting	Use the smallest range that covers the pulse; an oversized range multiplies the current error
Current rise time and overshoot	Defines when the pulse effectively starts; overshoot can reach voltage limits	Slow rise or overshoot distorts short-time resistance and can trigger limits
Sampling and logging rate	Short-time (ohmic) resistance and model fitting need fast data during pulses [7]	Fast logging during pulses, slower logging during rests; combined time- and voltage-based criteria
Bipolar (bidirectional) circuitry	The regen pulse follows the discharge pulse within one 60 s sequence	Relay-switched charge/discharge circuits can introduce dead time or transients at the transition
Voltage limit handling	Regen at high SOC and discharge at low SOC approach $V_{\max}$ and $V_{\min}$ [1]	Step limits in addition to safety limits, so that the channel responds within the step
Temperature control and logging	Resistance changes strongly with temperature [4]	Temperature chamber, thermal soak before testing, cell temperature logged with the electrical data

3.1 Test Instrument

A precision cycler facilitates meeting the requirements in Table 2. The test in this note was performed on an Arbin HPS ultra-high precision cycler with integrated temperature chambers (Figure 2). Its specifications are listed in Table 3 [9].



Figure 2. Arbin HPS cycler with integrated temperature chambers, one chamber per channel.

Product page: [Arbin HPS Ultra-High Precision Battery Cycler](#)

Arbin HPS key specifications [9]

±6 V Bipolar voltage range	5 A to 100 µA Six auto-switching current ranges per channel	±0.002% FSR Voltage measurement accuracy (20 ppm)	±0.001% FSR Voltage measurement precision (10 ppm, 120 µV)
±0.004% FSR Current measurement accuracy (control ±0.005% FSR)	±0.002% FSR Current measurement precision (20 ppm; 4 nA on 100 µA range)	24-bit Measurement and control resolution	≤ 200 µs Current rise/fall time; 2 ms minimum pulse width

In the integrated-chamber version, each channel has a dedicated chamber (10 to 60 °C, ±0.5 °C stability) and a PT100 input mapped to the channel, so that temperature is controlled and recorded together with the electrical data.

Table 3. Arbin HPS specifications relevant to HPPC [9]

Requirement	Arbin HPS specification	Relevance to HPPC
Voltage accuracy and precision	Measurement accuracy ±0.002% FSR (20 ppm); precision ±0.001% FSR (10 ppm, 120 µV); 24-bit measurement	Sub-millivolt resolution of the pulse voltage change
Current accuracy and range	Six auto-switching ranges per channel (5 A to 100 µA); control accuracy ±0.005% FSR; measurement accuracy ±0.004% FSR	Each step is measured on a suitable range, from the pulses to the CV taper
Rise time	Current rise/fall time ≤ 200 µs; minimum pulse width 2 ms; minimum step time 5 ms	Sharp pulse edges and fine time resolution for short-time resistance
Bipolar operation	Bipolar -6 V to +6 V range; charge and discharge on the same channel	Discharge, rest and regen performed as one sequence on one channel
Temperature control	Integrated chamber per channel, 10 to 60 °C, ±0.5 °C stability; PT100 input mapped to the channel	Temperature controlled and recorded with the electrical data
Software	MITS Pro: 30+ control types, 90+ meta variables, nested loops	HPPC programmed once as a schedule and reused for other cells

4. Cell, Module and Pack Level Testing

HPPC can be performed at cell, module or pack level. The pulse profile is the same at each level; currents, voltages and limits are scaled to the device under test [2].

Table 4. HPPC test levels

Level	Typical application	Test setup	Arbin systems
Cell	Cell development and selection, model parameterisation, ageing studies	Single channel; cell-level currents and voltage limits	LBT-Cell, RBT-Cell, HPS

Level	Typical application	Test setup	Arbin systems
Module	Module resistance including interconnects	Higher voltage; module limits; cell voltage monitoring	LBTS-Module, RBT-Module
Pack	System validation and BMS power-limit verification	Pack-level voltage and power; BMS communication; pack safety limits	RBT-Pack

The experiment described in this note is performed at **cell level**.

5. Device Under Test: XCell N18650-35E

The device under test is an XCell N18650-35E, a 3350 mAh cylindrical 18650 lithium-ion cell (Figure 3). The datasheet values [8] are listed in Table 5 and were entered in the MITS Pro cell definition.

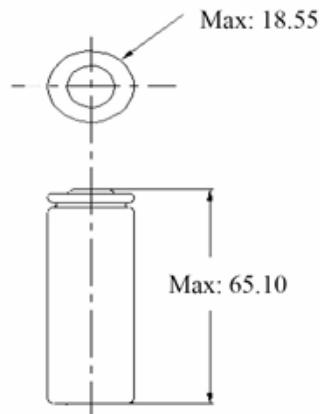


Figure 3. XCell N18650-35E outline and maximum dimensions in mm [8].

Table 5. XCell N18650-35E datasheet values [8]

Parameter	Value
Nominal / minimum capacity	3350 mAh / 3250 mAh
Nominal voltage	3.6 V
Charge cut-off voltage (V_{max})	4.20 V
Discharge cut-off voltage (V_{min})	2.50 V
Standard charge	CC 0.5C to 4.20 V, CV at 4.20 V until current $\leq 0.01C$
Maximum charge current	1C at 25 °C
Maximum continuous discharge current	3C at 25 °C
Internal resistance	$\leq 35 \text{ m}\Omega$ (AC, 1 kHz)
Dimensions (max.)	$\varnothing 18.55 \text{ mm} \times 65.10 \text{ mm}$
Weight	$\leq 49 \text{ g}$
Operating temperature	Charge 0 to 45 °C; discharge -20 to 60 °C
Cycle life	≥ 800 cycles to 80% capacity (1C/1C)

6. Experimental Setup

The HPPC pulse sequence is applied at a single SOC point, **90% SOC**, with the cell at **25 °C** in the integrated chamber of the Arbin HPS. 25 °C lies within the datasheet charge and discharge temperature ranges and is the common reference temperature for HPPC [1][8]. A full SOC sweep is obtained by repeating steps 5 to 11 at each 10% SOC step.

Table 6. Test conditions

Condition	Value
Equipment	Arbin HPS with integrated chamber, MITS Pro
Temperature	25 °C in the HPS integrated chamber (MITS Pro test setting TestStg_25C)
SOC	90% (single pulse set)
Charge	CC 0.5C to 4.20 V, then CV at 4.20 V until the current falls to 0.01C (datasheet standard charge)
SOC adjustment	Discharge 10% of nominal capacity (0.335 Ah) at 0.5C
HPPC discharge pulse	2.50 A (0.75C), 10 s
HPPC regen pulse	1.88 A (0.75 × 2.50 A), 10 s
Safety limits	$V_{\min} = 2.50 \text{ V}$, $V_{\max} = 4.20 \text{ V}$, discharge $\leq 3C$, charge $\leq 1C$, cell temperature within datasheet range

6.1 Test Procedure at 90% SOC and 25 °C

- Soak at 25 °C for 1 hour.
[log every 1 minute]
- Charge at 0.5C (CC) to 4.20 V.
[log every 30 seconds and every 10 mV change]
- Hold at 4.20 V (CV) until the current falls to 0.01C.
[log every 30 seconds]
- Rest for 1 hour.
[log every 10 seconds]
- Reset the charge and discharge capacity counters.
- Discharge at 0.5C until 10% of nominal capacity (0.335 Ah) has been removed, bringing the cell to 90% SOC. End test if 2.50 V is reached.
[log every 10 seconds and every 10 mV change]
- Rest for 1 hour.
[log every 10 seconds]
- HPPC discharge at 2.50 A for 10 seconds. End test if 2.50 V is reached.
[log every 0.1 second and every 5 mV change]
- HPPC rest for 40 seconds.
[log every 0.1 second]

10. HPPC regen at 1.88 A for 10 seconds. End test if 4.20 V is reached.

[log every 0.1 second and every 5 mV change]

11. Rest for 1 hour, then end the test.

[log every 10 seconds]

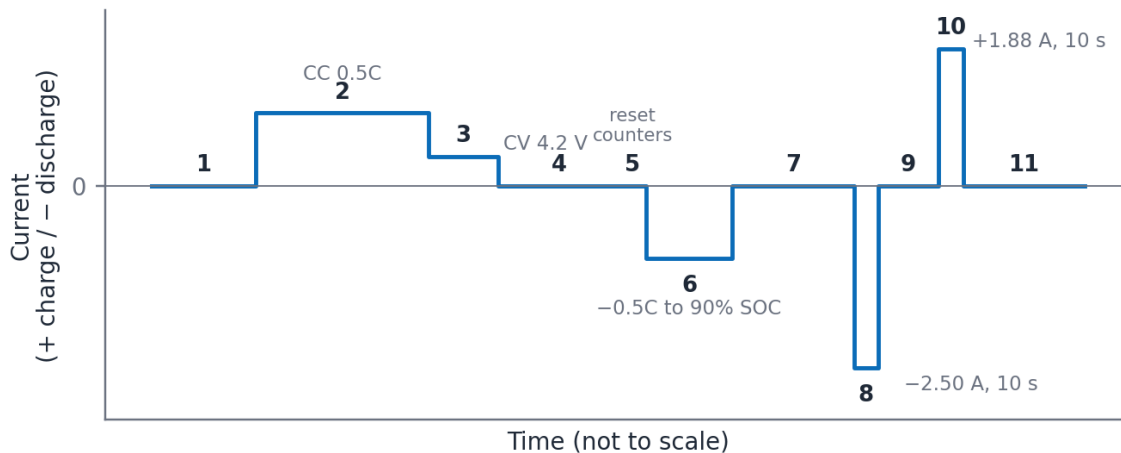


Figure 4. Current profile of the test (not to scale). Numbers refer to the steps in Section 6.1.

6.2 MITS Pro Schedule Implementation

Figure 5 shows the schedule in MITS Pro, programmed as one step per line (sequential method). Table 7 lists the control, step limits and log limits of each step. Capacity-based limits refer to MV_NominalCapacity, the nominal capacity in the MITS Pro cell definition (3.35 Ah), which allows the schedule to be reused for other cells. The CV step holds $1 \times \text{LS_CHAN_Voltage}$, the voltage at the end of the CC step (4.20 V). Charge current is positive and discharge current is negative.

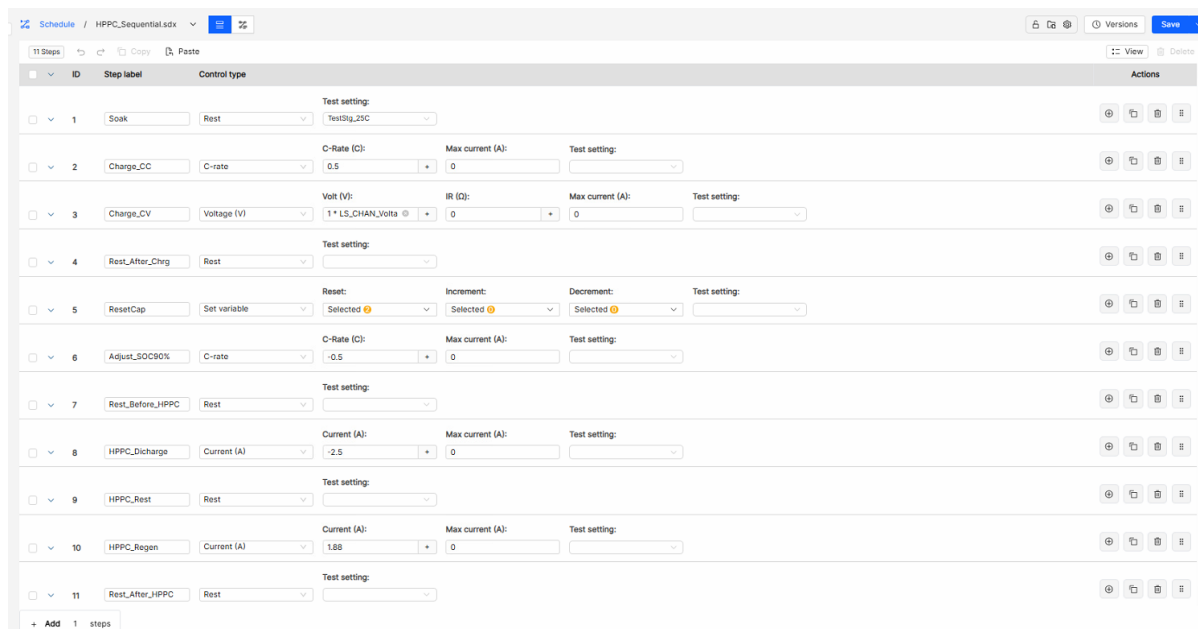


Figure 5. HPPC schedule (HPPC_Sequential.sdx) in MITS Pro.

Table 7. HPPC schedule steps and limits

#	Step label	Control type	Control value	Step limit (goto)	Log limit
1	Soak	Rest	Test setting TestStg_25C	PV_CHAN_Step_Time $\geq$ 1 h → next	DV_Time $\geq$ 60 s
2	Charge_CC	C-rate	+0.5C	PV_CHAN_Voltage $\geq$ 4.20 V → next	DV_Time $\geq$ 30 s; DV_Voltage $\geq$ 0.01 V
3	Charge_CV	Voltage(V)	1 × LS_CHAN_Voltage (4.20 V)	PV_CHAN_Current $\leq$ 0.01 × MV_NominalCapacity → next	DV_Time $\geq$ 30 s
4	Rest_After_Chrg	Rest	-	PV_CHAN_Step_Time $\geq$ 1 h → next	DV_Time $\geq$ 10 s
5	ResetCap	Set variable	Reset capacity counters	PV_CHAN_Step_Time $\geq$ 0 → next	-
6	Adjust_SOC90%	C-rate	-0.5C	PV_CHAN_Discharge_Capacity $\geq$ 0.1 × MV_NominalCapacity → next PV_CHAN_Voltage $\leq$ 2.50 V → end	DV_Time $\geq$ 10 s; DV_Voltage $\geq$ 0.01 V
7	Rest_Before_HPPC	Rest	-	PV_CHAN_Step_Time $\geq$ 1 h → next	DV_Time $\geq$ 10 s
8	HPPC_Discharge	Current(A)	-2.50 A	PV_CHAN_Step_Time $\geq$ 10 s → next PV_CHAN_Voltage $\leq$ 2.50 V → end	DV_Time $\geq$ 0.1 s; DV_Voltage $\geq$ 0.005 V
9	HPPC_Rest	Rest	-	PV_CHAN_Step_Time $\geq$ 40 s → next	DV_Time $\geq$ 0.1 s
10	HPPC_Regen	Current(A)	+1.88 A	PV_CHAN_Step_Time $\geq$ 10 s → next PV_CHAN_Voltage $\geq$ 4.20 V → end	DV_Time $\geq$ 0.1 s; DV_Voltage $\geq$ 0.005 V
11	Rest_After_HPPC	Rest	-	PV_CHAN_Step_Time $\geq$ 1 h → end	DV_Time $\geq$ 10 s

7. Results

Figure 6 shows the complete test recorded in MITS Pro: soak, CC-CV charge to 4.20 V, rest, 0.5C discharge to 90% SOC, rest, HPPC pulse sequence and final rest. Figure 7 shows the pulse sequence in detail.

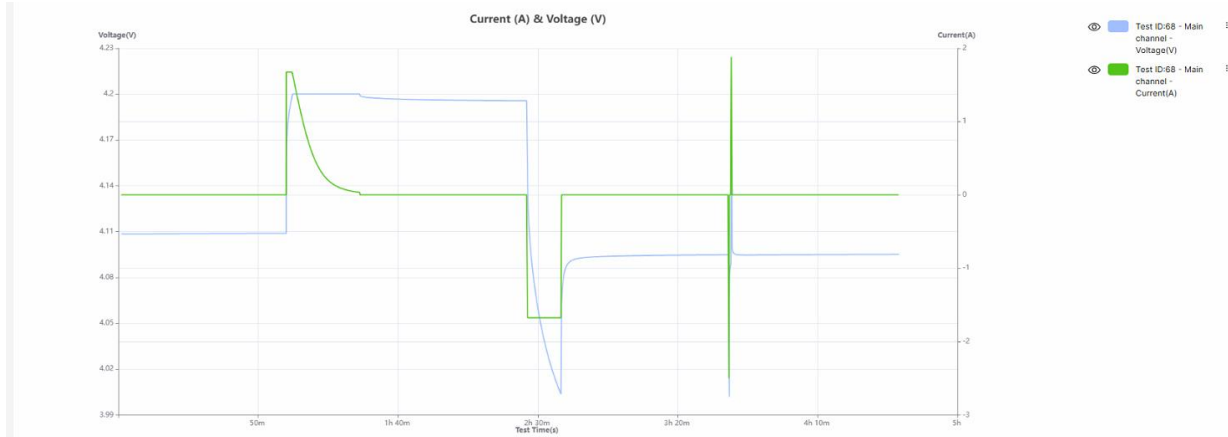


Figure 6. Voltage (blue) and current (green) over the complete test at 25 °C.

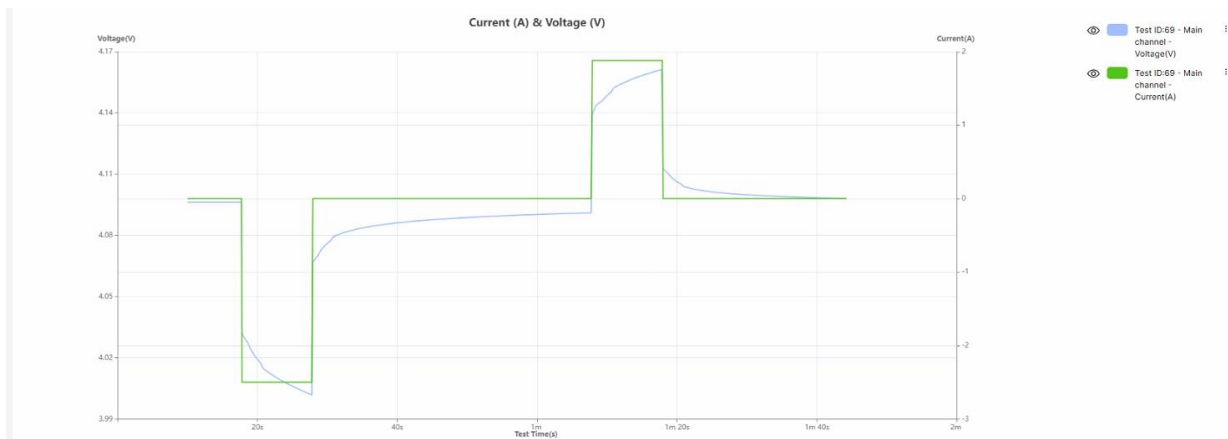


Figure 7. HPPC pulse sequence at 90% SOC: 10 s discharge at 2.50 A, 40 s rest, 10 s regen at 1.88 A, followed by the rest.

The recorded data show the following:

- **Pulse current.** The current steps to -2.50 A and $+1.88\text{ A}$ and remains constant for the full 10 s, so that the resistance is calculated against a defined current.
- **Transitions.** Discharge, rest and charge follow each other within one minute without visible overshoot or dead time, as provided by bipolar circuitry.
- **Data logging.** Time- and voltage-based logging records the voltage step at the start of each pulse, the response during the pulse and the subsequent relaxation, while the long rest periods are logged at a lower rate.
- **Voltage limits.** The voltage remained between 2.50 V and 4.20 V throughout the test, with step limits programmed to end the test if either limit was reached.

V_{t0} to V_{t3} are taken from the data file, and the resistance and pulse power at this SOC are calculated with Equations (1) to (4).

8. Conclusion

HPPC is a short protocol consisting of a 10 s discharge pulse, a 40 s rest and a 10 s charge pulse, repeated across the SOC range. It characterises the power delivery and acceptance of a battery, which capacity testing does not.

Since the results are derived from small voltage changes measured during fast current steps, the quality of HPPC results depends largely on the cycler. Accurate voltage and current measurement, suitable current ranges, fast current steps, flexible data logging, bipolar operation, step-level limit handling and integrated temperature control allow small differences between cells, and small changes as a cell ages, to be measured reproducibly.

A precision cycler with these characteristics improves the reliability and comparability of HPPC results. In MITS Pro, the protocol is programmed once as a schedule, uses the cell definition for capacity-based limits, and applies the appropriate logging and limits to each step.

References

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- [2] Battery Test Manual for Electric Vehicles, Revision 3, INL/EXT-15-34184, Idaho National Laboratory, June 2015.
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- [9] Arbin Instruments, "HPS Ultra-High Precision Battery Cycler," <https://www.arbin.com/battery-research/high-precision-tester.html>