

Donut Lab Solid-State Battery V1 Charge Performance Test

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<p>Summary</p> <p>The aim of the project was to conduct independent charging performance tests on the energy storage devices supplied by the customer, which the customer identified as solid-state battery cells. Based on the results of the initial capacity test within the recommended voltage range, the nominal capacity was determined to be 26 Ah.</p> <p>The cell was charged at a 5C rate, that is 130 A, until the maximum charging voltage of 4.3 V was reached, followed by a constant-voltage charge at 4.3 V until a charge capacity of 26 Ah was achieved. The cell was charged also at an 11C rate, that is 286 A, under the same procedure: constant-current charging until 4.3 V, followed by constant-voltage charging until reaching 26 Ah.</p> <p>The test was carried out using one-sided and two-sided heat sinks to simulate different levels of thermal management comparable to real-life applications. Before and after each charge, the cell was discharged at a rate of 1C until the voltage reached 2.7 V to measure the capacity and ensure a consistent initial condition.</p>	
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Contents

1. Description and objectives	4
2. Methods	6
2.1 Initial capacity test and reference cycle (#1, #4)	6
2.2 Fast charge test with 5C current (#2, #5)	7
2.3 Fast charge test with 11C current (#3, #6, #7)	7
3. Results	7
3.1 Initial capacity test and reference cycle	7
3.2 Fast charge test with 5C current	8
3.3 Fast charge test with 11C current	10
4. Conclusions and summary	12

1. Description and objectives

The aim of the project was to conduct independent charging performance tests on the energy storage devices supplied by the customer, which the customer identified as solid-state battery cells. The specification of the device under test is presented in Table 1. All tests described in this report were carried out on the same cell, following the customer's test plan. Tests were performed using a PEC ACT0550 battery tester, with the cell placed in a climate test chamber. The specification of the test equipment is presented in Table 2.

Table 1. Preliminary specification of the device under test, given by the customer.

Type of cell	Donut Solid State Battery V1
Nominal capacity	26 Ah at 1C (standard discharge)
Nominal voltage	3.6 V
Nominal energy	94 Wh
Recommended voltage	2.7–4.15 V
Standard charging method	CC–CV @ 1C, 4.15 V, CV cut-off 0.05C
Maximum charging voltage	4.3 V

Table 2. Specification of the test equipment.

Product	PEC ACT0550 Battery cell tester, 80 channels
Output voltage	0–5 VDC
Voltage measurement accuracy	0.005 % fsd
Voltage measurement resolution	1.9 μ V
Automatically switched current ranges	0–50 mA, 50–500 mA, 0.5–5 A, 5–50 A
Current measurement accuracy	0.03 % fsd (each current range)
Current measurement resolution	8 μ A

The test setup is presented in Figure 1. Current cables were attached to the tabs using nickel plated copper bars secured with bolts and nuts. Voltage-sense wires with ring cable lugs were connected on the opposite side. Temperature sensors were placed as close to the tabs as possible. The cell-surface temperature sensor was positioned under the folded seam on the side of the cell in such a way that it was not in direct contact with the heat sinks.

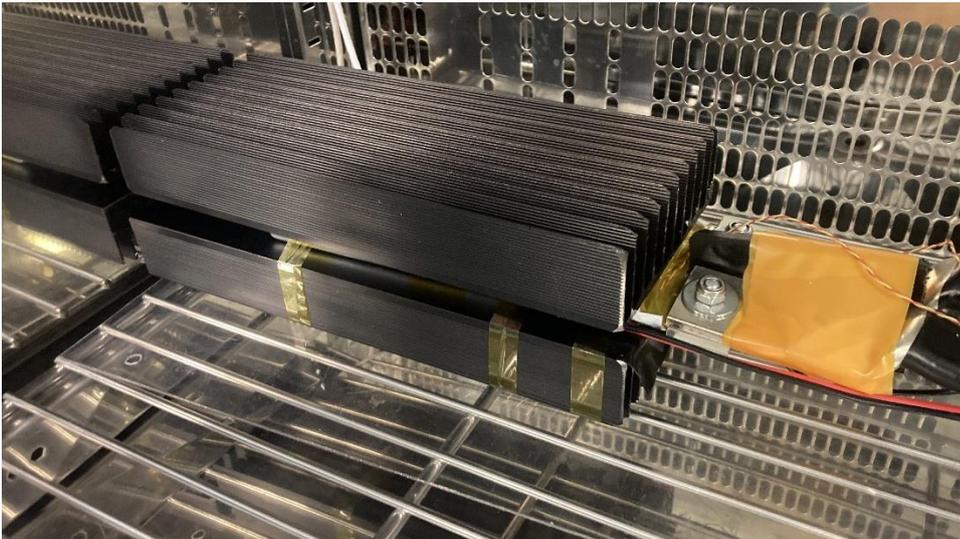


Figure 1. Cell was placed between heat sinks (top image, two-sided heat sink) or on top of a single heat sink (bottom image, one-sided heat sink), with temperature sensors attached to the tabs and under the folded seam on the side.

Tests conducted for the cell:

1. Initial capacity test using two-sided heat sinks
2. Fast-charge test at 5C current using two-sided heat sinks
3. Fast-charge test at 11C current using two-sided heat sinks
4. Reference cycle at 1C current using one-sided heat sink
5. Fast charge test at 5C current using one-sided heat sink
6. Fast charge test at 11C current using one-sided heat sink
7. Fast charge test at 11C current using one-sided heat sink

2. Methods

2.1 Initial capacity test and reference cycle (#1, #4)

Start: The cell was charged with a 24 A current until the highest recommended voltage of 4.15 V was reached, followed by a constant-voltage charge with 4.15 V until the current decreased to 1.2 A.

Cycle 1: After a one-hour idle period, the cell was discharged with a 24 A current until the voltage reached 2.7 V, followed by another one-hour idle period. The cell was then charged again with a 24 A current to 4.15, followed by constant-voltage charging at 4.15 V until the current decreased to 1.2 A.

Cycle 2: After a one-hour idle period, the cell was discharged with a 24 A current until 2.7 V was reached, followed by a one-hour idle period.

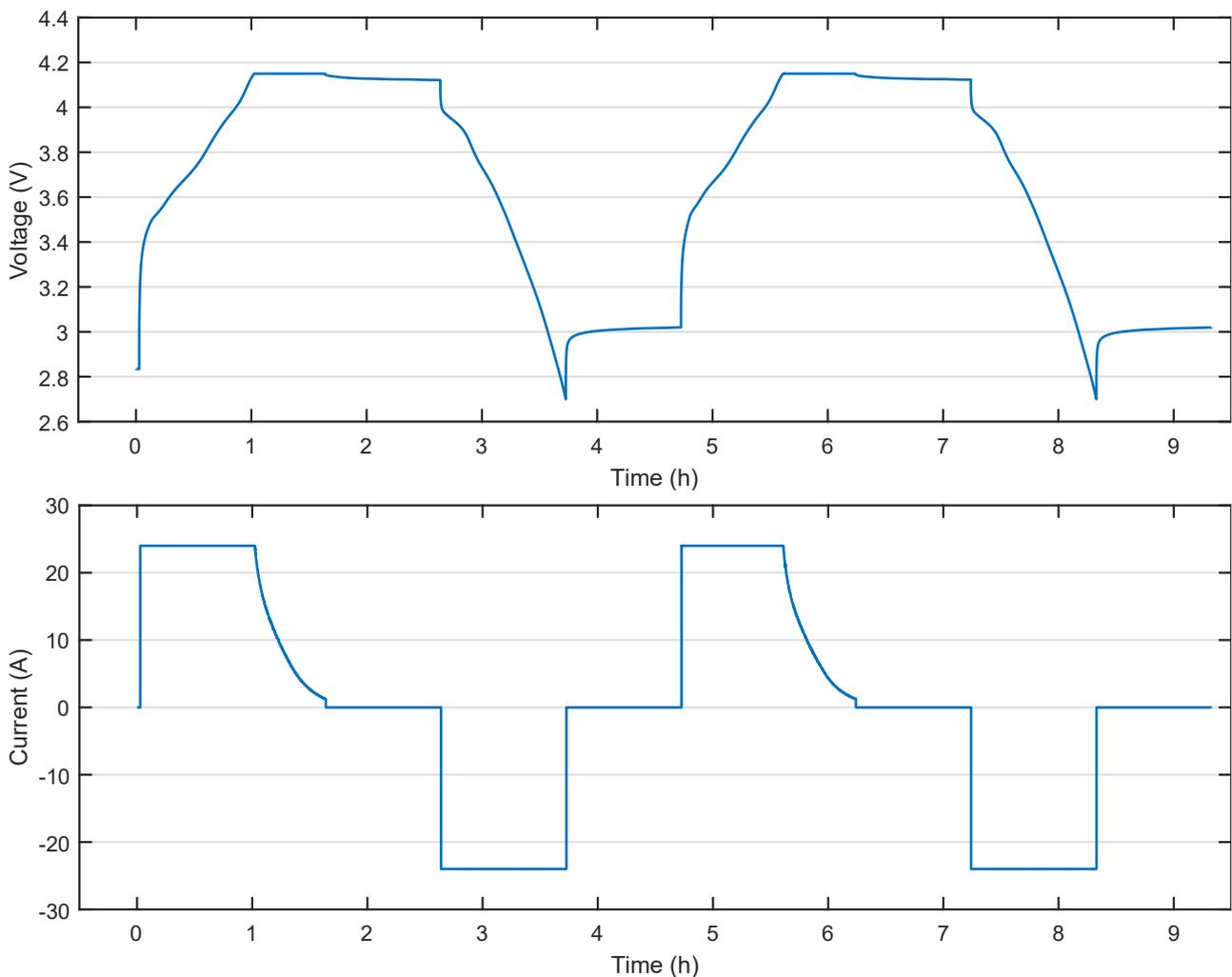


Figure 2. Voltage and current profile from the initial capacity test.

Based on the initial capacity test, the nominal capacity was determined to be 26 Ah (details in section 3.1).

The reference cycle was carried out before the test #5 as a reference using one-sided heat sink as follows: The cell was charged at 1C (26 A) current until reaching the highest recommended voltage of 4.15 V, after which constant-voltage charging at 4.15 V was applied until the current decreased to 1.3 A. Following a one-hour rest period, the cell was discharged at 1C (26 A) until the voltage reached 2.7 V (standard discharge procedure).

2.2 Fast charge test with 5C current (#2, #5)

The cell was charged at a 5C rate, i.e. 130 A, until the maximum charging voltage of 4.3 V was reached, followed by constant-voltage charging at 4.3 V until a total charge of 26 Ah had been delivered. After a one-hour idle period, the cell was discharged at 1C (26 A) until the voltage reached 2.7 V. The test was carried out at room temperature using one-sided and two-sided heat sinks to simulate different levels of thermal management comparable to real-life applications. Following the 5C charge, the cell was again discharged using the standard procedure to verify that the full charged capacity was available and that the ratio of charged capacity to the nominal capacity could be interpreted as the state of charge (SOC).

2.3 Fast charge test with 11C current (#3, #6, #7)

The cell was charged at a rate of 11C (286 A) until the maximum charging voltage of 4.3 V was reached, followed by constant-voltage charging at 4.3 V until a total charge of 26 Ah had been delivered. After a one-hour idle period, the cell was discharged at 1C (26 A) until the voltage reached 2.7 V. The test was conducted at room temperature. After the 11C charge, the cell was discharged again using the standard procedure to verify that the full charged capacity was available and that the ratio of charged capacity to the nominal capacity could be interpreted as the SOC.

3. Results

3.1 Initial capacity test and reference cycle

During the tests #1 and #4, the cell was placed in a climate test chamber that was not operating, and the chamber door remained partially open. The measured capacity for each cycle is presented in Table 3. Reference cycle was carried out using one-sided heat sink.

Table 3. Measured capacity and energy from the initial capacity test and the reference cycle.

	Discharge capacity	Charge capacity	Discharge energy	Charge energy
Cycle 1	26.109 Ah	26.159 Ah	91.021 Wh	100.793 Wh
Cycle 2	26.125 Ah		91.118 Wh	
Reference	26.520 Ah	26.068 Ah	92.511 Wh	100.375 Wh

3.2 Fast charge test with 5C current

During the test #2 (the first 5C charge test), the cell was placed between two heat sinks. The initial surface temperature of the cell was 23.4 °C, and the highest recorded temperature during the test was 47 °C. This test was performed after the initial capacity test, which ended with a standard discharge

During the test #5 (the second 5C charge test), the cell was placed on top of a single heat sink. The initial surface temperature of the cell was 27 °C, and the highest recorded temperature during the test was 61.5 °C. This test was conducted after the first 11C fast-charge test and one full 1C reference cycle ending with a standard discharge.

Capacity and energy results for each test are presented in Table 4. Charging times are presented in Table 5. The measured voltage, current, cell surface temperature and charge capacity in the 5C charge tests are presented in Figure 3.

Table 4. Measured capacity and energy from the 5C fast-charge test.

	Discharge capacity	Charge capacity	Discharge energy	Charge energy
Test #2	26.001 Ah	26.004 Ah	90.540 Wh	106.303 Wh
Test #5	26.039 Ah	26.004 Ah	90.582 Wh	103.956 Wh

Table 5. Charging times from 0 % to 80 %, 90 % and 100 % SOC from the 5C fast-charge test.

	Charging time 0–80 %	Charging time 0–90 %	Charging time 0–100 %
Test #2	573 s	677 s	813 s
Test #5	569 s	642 s	735 s

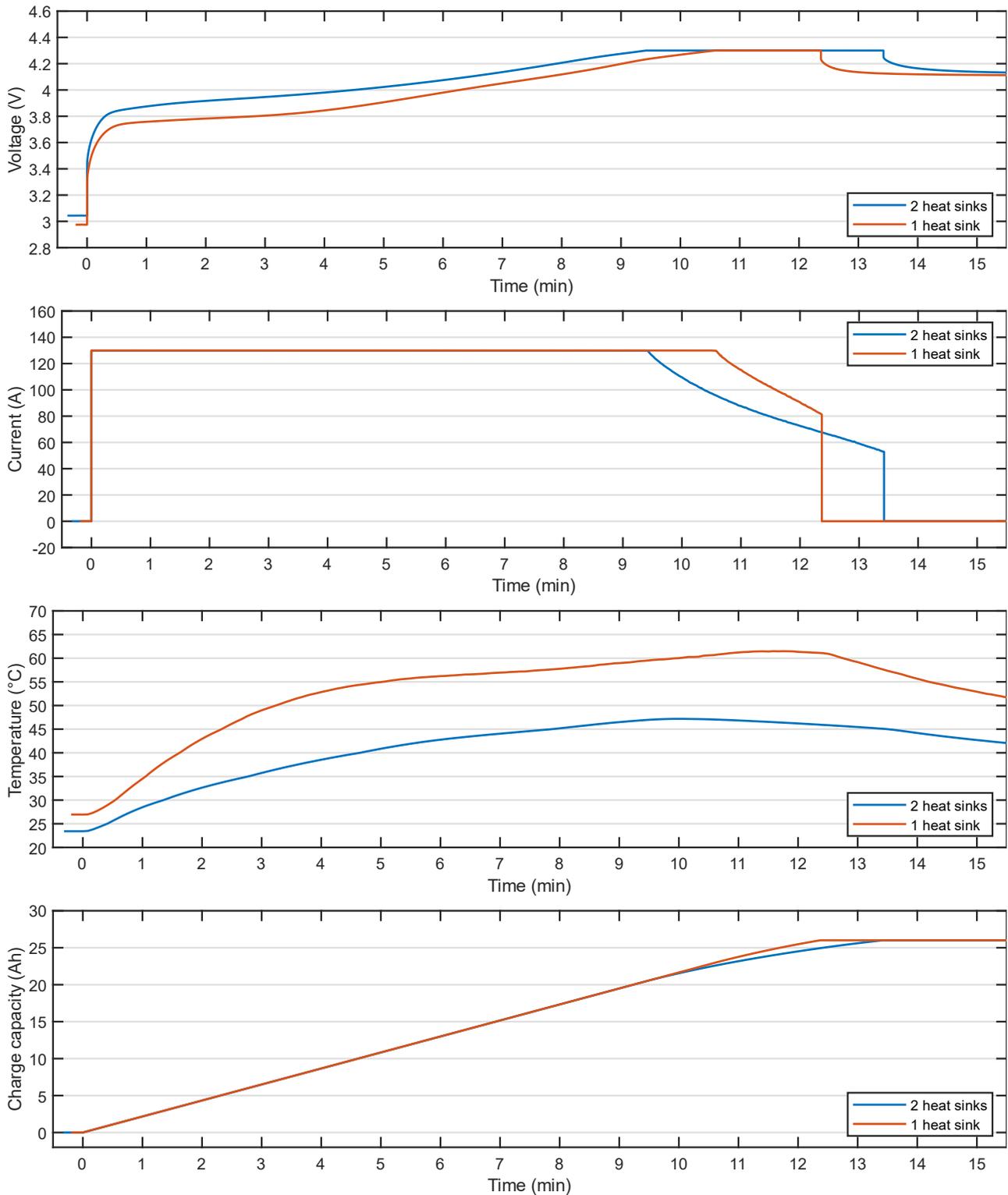


Figure 3. Voltage, current, cell surface temperature and charge capacity graphs during 5C charge tests. Blue curves for test with two heat sinks and red curves for test with one heat sink.

3.3 Fast charge test with 11C current

During the test #3 (the first 11C charge test), the cell was placed between two heat sinks. The initial surface temperature of the cell was 26.5 °C and the highest recorded temperature during the test was 63 °C. This test followed the 5C fast-charge test, which ended with a standard discharge.

During the test #6 (the second 11C charge test), the cell was placed on top of a single heat sink. The first attempt was interrupted when the surface temperature reached the safety limit of 90 °C. After a four-minute cooling period, the test was resumed. Following this run, the cell was strapped to the heat sink to improve thermal contact, and consequently, heat transfer. The test was repeated once the cell had both discharged and cooled sufficiently.

During the test #7 (the third 11C charge test), the cell was placed on top of a single heat sink. The initial surface temperature of the cell was 27 °C and the highest recorded temperature during the test was 89 °C. This test was conducted after the previous run, which ended with a standard discharge.

Capacity and energy results for each test are presented in Table 6, and charging times are provided in Table 7. The measured voltage, current, cell surface temperature and charge capacity in the 11C charge tests are presented in Figure 4.

Table 6. Measured capacity and energy from the 11C fast-charge test.

	Discharge capacity	Charge capacity	Discharge energy	Charge energy
Test #3	25.894 Ah	26.004 Ah	90.200 Wh	109.563 Wh
Test #6	25.592 Ah	26.004 Ah	88.925 Wh	107.702 Wh
Test #7	25.731 Ah	26.004 Ah	89.229 Wh	108.735 Wh

Table 7. Charging times from 0 % to 80 %, 90 % and 100 % SOC from the 11C fast-charge test.

	Charge time 0–80 %	Charge time 0–90 %	Charge time 0–100 %
Test #3	293 s	366 s	477 s
Test #6	267 s	N/A	N/A
Test #7	276 s	338 s	438 s

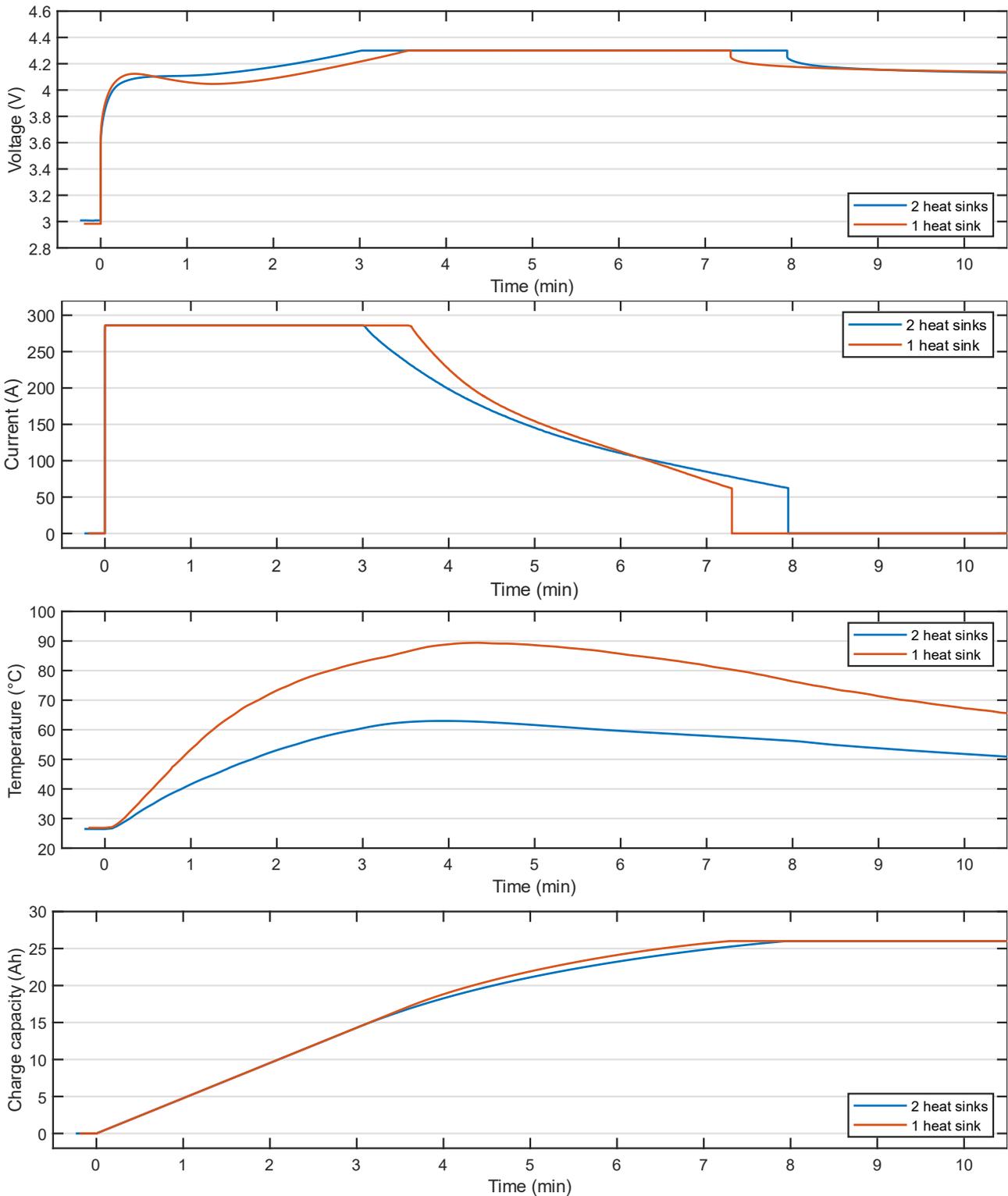


Figure 4. Voltage, current, cell surface temperature and charge capacity graphs during 11C charge test. Blue curves for test with two heat sinks and red curves for first uninterrupted test with one heat sink.

4. Conclusions and summary

This project included independent charging performance tests on the energy storage devices supplied by the customer, which the customer identified as solid-state battery cells. Based on the initial capacity test, the nominal capacity was determined to be 26 Ah. The cell was charged at 5C (130 A) and 11C (286 A) in accordance with the customer's test plan, and capacity, energy, cell temperature, and charging times were recorded.

Under the specified test conditions, the cell was successfully charged at 5C for more than 9 minutes, and 100 % of the charged capacity was available during the subsequent discharge. The cell was also successfully charged at 11C for more than 3 minutes, with 98.4–99.6 % of the charged capacity available after a full charge.