Deliverable 7.3 Electrical characterisation of LIC modules

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Publishable summary

The MUSIC project addresses the need for sustainable energy storage solutions that combine the high-power density of supercapacitors with higher energy density, while minimising reliance on critical raw materials. The ultimate technological goal of the project is a 12 V module based on sodium-ion capacitor (SIC) cells developed within MUSIC, integrated with a complete management, monitoring, protection and health-prediction system — the innovative Supercapacitor Management System (i-SMS).

As an intermediate step to accelerate the i-SMS development, a preliminary 12 V module has been built using commercial lithium-ion capacitor (LIC) cells, which are the closest commercially available analogue to SICs. The mechanical and electrical design of this LIC module and the implementation of the i-SMS were reported in Deliverable D7.2. The present deliverable, D7.3, reports the electrical characterization and functional validation of this LIC module, including the i-SMS sensing, passive balancing, protection and thermal management subsystems.

The characterization campaign was carried out on two successive versions of the module. The first version (V1) revealed the limits of the original mechanical and thermal envelope: during high-temperature high-current operation, an incident of irreversible cell swelling occurred, attributable to gas generation under sustained thermal stress. No thermal runaway or external damage occurred, and the i-SMS protections behaved as designed. Following a root-cause analysis, a second version (V2) was constructed with a larger nylon casing, a redesigned cell-module structure for improved heat dissipation, and a lowered overtemperature alarm threshold (from 85 °C to 70 °C at cell level).

The V2 campaign covered four operating temperatures (−20, 0, 25 and 50 °C) and three charge/discharge currents (6, 20 and 40 A). The functional electrical characterization confirms that the module operates safely within the adjusted limits, that the cell-to-cell voltage dispersion has been reduced by approximately an order of magnitude with respect to V1, and that the thermal dispersion across the four cells remains below 4 °C under all tested conditions. The available capacity at module level is reduced with respect to cell level, primarily due to the activation of the current-limiting balancing mechanism (R_{lim}) when any individual cell reaches 3.6 V during charge. This is by design and represents the trade-off between safe serialized operation and energy throughput.

The protection mechanisms of the i-SMS — short-circuit, overcurrent, undervoltage at cell level, overtemperature (warning + alarm) and under temperature — have been validated experimentally. The cell-level overvoltage alarm at 3.8 V could not be triggered under normal operation, since the R_{lim} mechanism acts at 3.6 V; this confirms the expected layered behaviour.

The main outcomes of this deliverable are: (i) a set of validated operating limits for the LIC module that are more conservative than the cell-level capabilities, due to integration and safety considerations; (ii) the experimental confirmation that the i-SMS architecture (sensing, balancing, protections, BTMS) performs as designed and is ready to be transferred to the future SIC module; and (iii) a documented set of lessons learnt — particularly regarding gas-generation behaviour under serialized high-temperature operation — that will inform the mechanical and thermal design of the SIC module.
The absence of measurable cell degradation observed in D7.1 has been confirmed at module level: no floating ageing tests have been performed at module level for this reason, and the SOH algorithm validation continues to rely on the literature-based approach described in D7.2. This remains an open issue (risk WP7.1.1), expected to be addressed when SIC cells become available.

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Abbreviations

SYMBOL	SHORTNAME
CANOpen	Higher-layer communication protocol based on CAN
EIS	Electrochemical Impedance Spectroscopy
ESR	Equivalent Series Resistance
FEC	Full Equivalent Cycle
i-SMS	Innovative Supercapacitor Management System
LIC	Lithium-ion Capacitor
PCB	Printed Circuit Board
R_{lim}	Current-limiting resistor (cell-level voltage threshold protection)
SIC	Sodium-ion Capacitor
SOC	State of Charge
SOH	State of Health
SOP	State of Power
BTMS	Battery Thermal Management System
VTZ	Voltage, Temperature, Impedance (sensor)
WP	Work Package

1 Introduction

This deliverable is part of WP7 "Innovative SMS, implementation and validation" and addresses Task 7.5 "Electrical characterization of LIC modules". The objective of D7.3 is to electrically validate the 12 V LIC module developed in Task 7.2 and described in Deliverable D7.2, in order to confirm that the integrated hardware and software perform as intended and to extract lessons applicable to the subsequent SIC module development.

1.1 Aim of the tests

Following the comprehensive cell-level characterization reported in D7.1, a module-level characterization protocol has been defined that mirrors the cell-level tests as closely as practicable. This approach allows direct comparison between cell and module behaviour, validates the electrical operation of the integrated module under different temperature and current conditions, verifies the correct activation of the i-SMS protection mechanisms under controlled extreme conditions, validates all integrated cell-level and pack-level sensors, and quantifies the electrical and thermal dispersions across the module relevant for shunt management and thermal management.

It should be noted that, by consortium agreement, the module has been built with commercial JTEKT LIC cells — the same cells already characterized in D7.1 — because the WP6 prototype cells were not available within the time window of Task 7.5. This decision ensures continuity with the cell-level characterization while preserving the validation of the module architecture and the i-SMS, which is independent of the specific cell supplier.

No ageing tests have been performed at module level. As reported in D7.1, the JTEKT cells did not show measurable degradation after ~1400 h of floating tests at 0, 50 and 70 °C; replicating these conditions at module level would not have produced additional information relevant to the i-SMS validation. The mitigation of the resulting gap in degradation data (risk WP7.1.1) is addressed through literature-based modelling, as described in D7.2.

The functional tests reported here were carried out on two successive versions of the LIC module. The first version suffered an incident during the high-temperature campaign that required the redesign and reconstruction of the module. Both campaigns and their implications are documented in Section 2.1.

1.2 Module under test

1.2.1 Electrical Architecture

The module under test is the 12 V LIC module developed in Task 7.4 and described in detail in Deliverable D7.2 "Development of complete i-SMS for a LIC module". The module consists of four JTEKT LIC cells (1000 F nominal capacitance) connected in series, with an integrated i-SMS providing real-time monitoring and protection at cell and pack level. Each cell is individually instrumented with a VTZ sensor (Voltage, Temperature, Impedance).

Two successive versions of the module were tested during this Task, referred to throughout this document as V1 and V2. V1 corresponds to the original design as described in D7.2; V2 incorporates the design modifications introduced after the incident described in Section 2.1. The main technical specifications of both versions are summarized in Table 1.

Table 1. Technical specifications of the MUSIC LIC module

<table>
<tr><th>TECHNICAL SPECIFICATIONS</th><th>V1</th><th>V2</th></tr>
<tr><td>Voltage range</td><td colspan="2">9.0 – 15.2 V</td></tr>
<tr><td>Nominal capacitance</td><td colspan="2">250 F</td></tr>
<tr><td>Nominal capacity</td><td colspan="2">0.445 Ah</td></tr>
<tr><td>Max. Specific Energy</td><td colspan="2">6.75 Wh</td></tr>
<tr><td>Cell technology</td><td colspan="2">LIC</td></tr>
<tr><td>Module configuration</td><td colspan="2">4S1P</td></tr>
<tr><td>Communications</td><td colspan="2">CANOpen</td></tr>
<tr><td>Max. current</td><td>200 A (1s)</td><td>55 A (1s)</td></tr>
<tr><td>Operating temperature range (charge and discharge)</td><td>-30 ºC – 85 ºC</td><td>-30 ºC – 70 ºC</td></tr>
<tr><td>Dimensions</td><td>360 x 200 x 150 mm</td><td>400 x 405 x 120 mm</td></tr>
<tr><td>i-SMS</td><td colspan="2">• Algorithms of SOC, SOH and SOP
• Voltage, current, temperature and impedance monitoring
• Cell balancing
• Active protection against overcurrent, overtemperature and overvoltage
• Luminous alarm signalling
• Event history logging
• Turn-on/turn-off push button for safe transport and installation
• Auto turn-off function for cell protection</td></tr>
</table>

As can be seen from the table above, it shows the technical specifications of two different versions, the main differences between which are the housing size and the upper operating temperature limits, as far as the maximum available current.

1.2.2 Cell Baseline

As already detailed in D7.1, the cell used is manufactured by JTEKT, and its main technical specifications are as follows:

Table 2. JTEKT cell main technical parameters

PARAMETER	VALUE	UNIT
Capacitance	1000	F
Capacity	0.444	Ah
Operating voltage range	2.2-3.8	V

PARAMETER	VALUE	UNIT
Internal resistance	2.0	mΩ
Max. Specific Energy	1.69	Wh
Operating temperature range	-40 and 85 ºC (with operating voltage range from 2.2 to 3.8 V) *Note: After 1000 h float charging test (85 ºC, 3.8 V) internal resistance increase rate of 50% or less and capacitance reduction rate of 20% or less.*	°C
	-40 and 100 ºC (with operating voltage range from 2.2 to 3.6 V) *Note: After 1000 h float charging test (100 ºC, 3.6 V) internal resistance increase rate of 50 % or less and capacitance reduction rate of 20 % or less.*	°C
Cell weight	160	g
Cell volume	97	cm^3

In addition, the main conclusions drawn from the tests are as follows:

1. **Actual operating temperature range (not that stated in the datasheet)**
   The JTEKT cell specifies a range of −40 to 85 °C (or up to 100 °C with voltage reduced to 3.6 V), but laboratory tests showed that below 0 °C performance deteriorates and becomes unpredictable: at −40 °C capacity drops to approximately half the nominal value, and results between cells are no longer consistent. Above 0 °C, performance is good, and even at 85 °C the discharged capacity remains around the nominal value with no appreciable loss.
2. **Capacity and resistance versus temperature**
   The discharged capacity decreases as the current increases and decreases at low temperatures; above 25 °C, the nominal capacity (0.444 Ah) is practically restored. As for impedance, the EIS spectra vary little at positive temperatures, but at negative temperatures the charge transfer resistance increases markedly, consistent with the drop in capacity. The internal resistance showed reproducible results in the range of 0 to 50 °C, and no significant dependence on SOC was found (tested at 0, 50 and 100%).
3. **Safety current limit**
   The manufacturer specifies a discharge current of up to 200 A, but in D7.1 a maximum of 40 A was tested as a precaution, corresponding to transient responses of around 40 seconds. As expected, the discharged capacity decreases as the current increases.
4. **Thermal characterisation → BTMS strategy**
   A specific heat of 1.40 J/g·K (±0.07) was measured for the cell and, most importantly, a strongly anisotropic thermal conductivity: of the order of 64 W/(mK) in-plane compared to just 0.25 W/(mK) through-plane. The design conclusion of D7.1 was that heat should be dissipated via the top or bottom faces of the cell (taking

advantage of the high in-plane conductivity) rather than via the sides, in order to extract heat more quickly and maintain a homogeneous distribution between layers.

5. **Absence of degradation — the legacy issue**
   The variations in internal resistance observed at cell level were attributed to the quality of the crocodile clip connections used during cell-level testing, not to actual cell degradation. This is a relevant finding for the present deliverable, since the module connections are bolted (see D7.2), which improves connection reliability but introduces a different source of variability that must be considered when comparing cell and module ESR.

1.2.3 i-SMS

Deliverable D7.2 provides a detailed overview of the functionality and the various components that make up the i-SMS.

The key elements of this system are the integration of sensor technology, cell voltage balancing, the protection and alarm system at cell and pack level, the estimation algorithm, and the real-time monitoring of all critical parameters of the LIC module.

All these elements/systems will be validated throughout this deliverable in order to identify potential improvements to be applied to the SIC modules at the end of the project.

1. **Sensor System: the VTZ sensor**
   Each cell is monitored individually by a sensor known as VTZ (Voltage, Temperature, Impedance), with measurements taken directly at the tabs via low-resistance connections. The system's key feature is the measurement of impedance per cell — an uncommon feature in commercial i-SMS systems — as an early indicator of degradation. The temperature sensors were positioned near the tabs (not at the geometric centre, which was ruled out due to the foam), based on the fact that this area accumulates the highest temperatures and is where thermal anomalies first appear.
2. **Passive Balancing**
   Passive balancing during the charging phase, to equalise voltages between the 4 cells in series. Critical in a series configuration, where the weakest cell limits the entire module. This can be viewed in real time in the software.
3. **SOC / SOH / SOP algorithms**
   This is the most significant link to the project's main narrative. D7.2 confirms that, in the absence of measurable degradation in our own tests (the issue carried over from D7.1, risk WP7.1.1), the algorithms were developed by combining our own experimental data with a literature review on the degradation of pouch/prismatic Li-ion cells. Implemented in MATLAB, they consider the following ageing factors: module temperature, number of full equivalent cycles (FEC), time in service and internal resistance.
4. **Monitoring software**
   Grafana-based platform (open-source, time series). Monitors cell voltage, module voltage, current, temperature (4 cells + i-SMS PCB), and impedance. Known limitation: due to memory constraints, the full Nyquist plot is not stored; only five resistance values (real and imaginary) at selected frequencies are recorded — this will be resolved in the SIC module. Includes event logging and alarms.

All these subsystems — sensing, balancing, protections, algorithms and monitoring software — are validated experimentally throughout Section 2 of this deliverable. The sensing is assessed implicitly in Section 2.2 (functional electrical characterization) and 2.3 (thermal management validation) through the comparison between cycler-side and i-SMS-side measurements. The balancing and protection mechanisms are tested in Section 2.4. The monitoring software is the data source for most of the figures and tables reported.

1.3 Test description

1.3.1 Electrochemical performance tests

These electrochemical tests have been performed at different currents and environmental temperatures in the charge and discharge processes, while Electrochemical Impedance Spectroscopy (EIS) measurements are done at each temperature condition.

In the Table 3 below, the description of the different operating conditions tested can be checked:

Table 3. Description of electrochemical test

Voltage window (V)	Currents	Cycles	Temperatures	Tests
15.2 V (3.8 Vcell) – 9.5 V (2.37 Vcell)	6 A, 20 A and 40 A	x5	25 °C	Measurement of module EIS (0.01Hz – 1kHz) at each temperature
			0 °C	
			-20 °C	
			50 °C	
			70 °C*	

**NOTE: This temperature was only tested with the first version of the LICs module*

Five different temperature conditions were tested for V1 (25, 0, −20, 50 and 70 °C) and four for V2 (25, 0, −20 and 50 °C). The reduction to four temperatures in V2 is motivated by the lowered overtemperature alarm threshold (70 °C → 65 °C warning / 70 °C alarm), as discussed in Section 2.1.

EIS measurements were performed at cell level using the VTZ sensor integrated in the i-SMS, in the frequency range from 10 mHz to 10 kHz, at 100% SOC.

In terms of the ageing tests, considering the results obtained at cell level where it was not possible to degrade them below 80% of SOH, the tests have not been performed at module level.

1.3.2 Safety/protection tests

The safety/protection tests have been carried out in accordance with the operating limits defined in the i-SMS; these operating limits have been established on the basis of tests conducted at the cell level. The table below shows the limits for each of the protections integrated into the i-SMS.

Table 4. Protections included in the i-SMS

PARAMETER	PROTECTION	LEVEL	TYPE OF PROTECTION	VALUE		UNIT
				V1	V2	
Temperature	Overtemperature	Cell	ALARM	85	70	ºC
	Overtemperature	Cell	WARNING	75	65	ºC
	Under temperature	Cell	WARNING	- 30		ºC
Voltage	Overvoltage	Cell	ALARM	3.8		V
	Undervoltage	Cell	WARNING	2.5		V
	Undervoltage	Cell	ALARM	2.2	2.3	V
	Undervoltage	Pack	ALARM	9.5	8	V
	Undervoltage	Pack	Delay	30	30	s
	Undervoltage	Pack	ALARM	9	8	V
	Undervoltage	Pack	Delay	1	1	s
Current	Charge	Pack	ALARM	25.5	60	A
	Charge	Pack	Delay	30	30	s
	Charge	Pack	ALARM	30	180	A
	Charge	Pack	Delay	250	250	ms
	Discharge	Pack	ALARM	130	55	A
	Discharge	Pack	Delay	250	250	ms
	Short-circuit	Pack	ALARM	200	55	A
	Short-circuit	Pack	Delay	1	1	ms

Beyond the protection thresholds tabulated above, the i-SMS implements a current-limiting mechanism (R_{lim}) that activates during charge when the most charged cell reaches 3.6 V, in order to initiate the balancing process. R_{lim} is not a protection in the strict sense (it does not stop operation) but rather a balancing-assist mechanism whose effect on the available capacity of the module is significant, as discussed in Section 2.2.

Validation of each protection follows a common protocol: the module is brought to a state just below the alarm threshold and the relevant parameter is gradually increased (or decreased) until the protection activates. The activation point, response time and final state of the module are then recorded.

2 Methods and Results

2.1 Initial validation campaign and module replacement

2.1.1 Validation of the first version of the module

Based on the test plan described in Table 3 of Section 1.3.1, charge and discharge cycles were carried out at the three different currents specified and at five different temperatures.

These tests were conducted on the module described in Deliverable D7.2.

The main results of the tests are shown below:

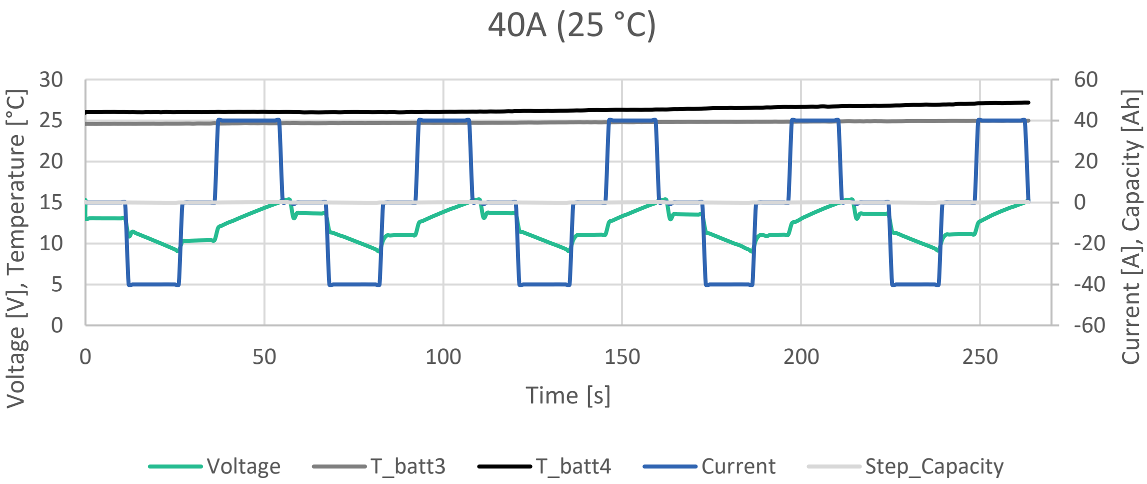

Figure 1 Electrochemical test at 25 ºC and 40 A of charge/discharge

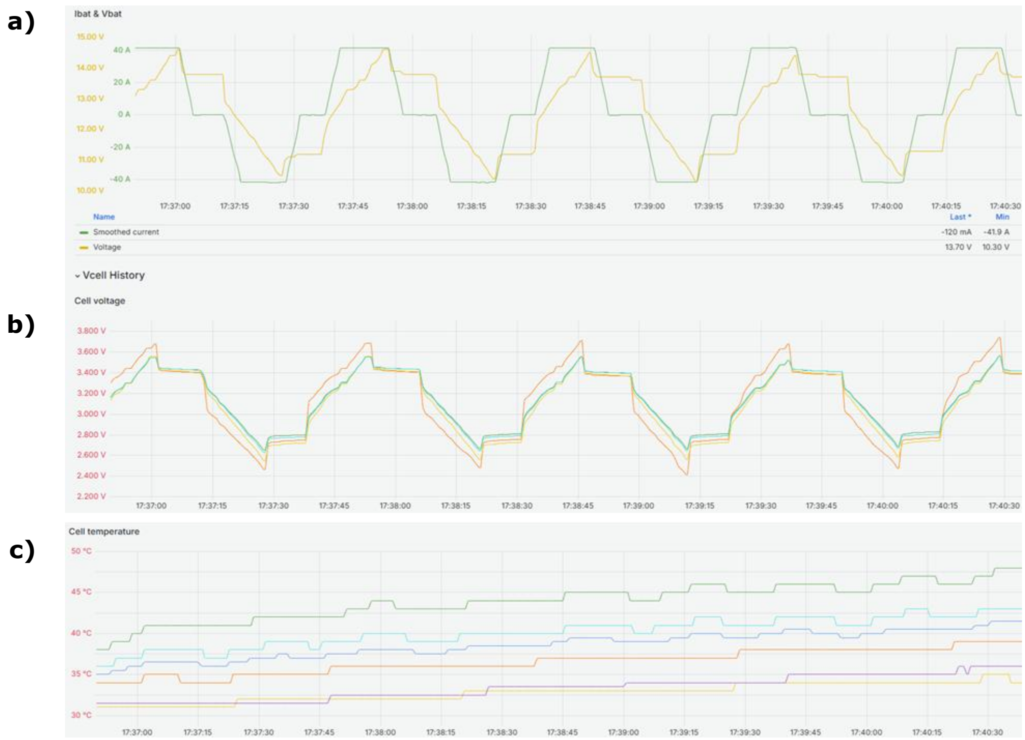

Figure 2 Sensing validation at 25 ºC and 40 A where a) shows current and voltage at module level, b) shows voltage at cell level and c) shows temperatures at cell level

The figures above show the results obtained under the reference conditions at 25 °C and a charge/discharge current of 40 A. The table below shows the dispersion values recorded during the tests carried out at 25 °C during the charging processes:

Table 5. Dispersion values at 25 ºC

CURRENT	Temp_max	Temp_min	Δ Temp	Vmax	Vmin	Δ V
6 A	31 °C	27 °C	4 °C	3.6 V	3.2 V	0.4 V
20 A	40 °C	30 °C	10 °C	3.65 V	3.25 V	0.4 V
40 A	48 °C	35 °C	13 °C	3.65 V	3.55 V	0.1 V

Tables 6 to 8 summarize the dispersion values for the remaining tested temperatures.

Table 6. Dispersion values at 50 ºC

CURRENT	Temp_max	Temp_min	Δ Temp	Vmax	Vmin	Δ V
6 A	55 °C	49 °C	6 °C	3.6 V	3.2 V	0.4 V
20 A	68 °C	53 °C	15 °C	3.6 V	3.25 V	0,35 V
40 A	75 °C	58 °C	17 °C	3.65 V	3.4 V	0.25 V

Table 7. Dispersion values at 70 ºC

CURRENT	Temp_max	Temp_min	Δ Temp	Vmax	Vmin	Δ V
6 A	79 °C	72 °C	7 °C	3.6 V	3.2 V	0.4 V
20 A	85 °C	72 °C	13 °C	3.6 V	3.2 V	0.4 V
40 A	N/A	N/A	N/A	N/A	N/A	N/A

Tests at 70 °C and 40 A could not be completed, as the overtemperature alarm at cell level (85 °C, V1) was triggered during the charge phase. This event is one of the precursors of the incident discussed in Section 2.1.2.

Table 8. Dispersion values at 0 ºC

CURRENT	Temp_max	Temp_min	Δ Temp	Vmax	Vmin	Δ V
6 A	7 °C	0 °C	7 °C	3.6 V	3.05 V	0.85 V
20 A	8 °C	1 °C	7 °C	3.65 V	3.25 V	0.4 V
40 A	N/A	N/A	N/A	N/A	N/A	N/A

Tests at 0 °C and 40 A were interrupted due to the anomalous voltage profile shown in Figure 3, which is discussed below.

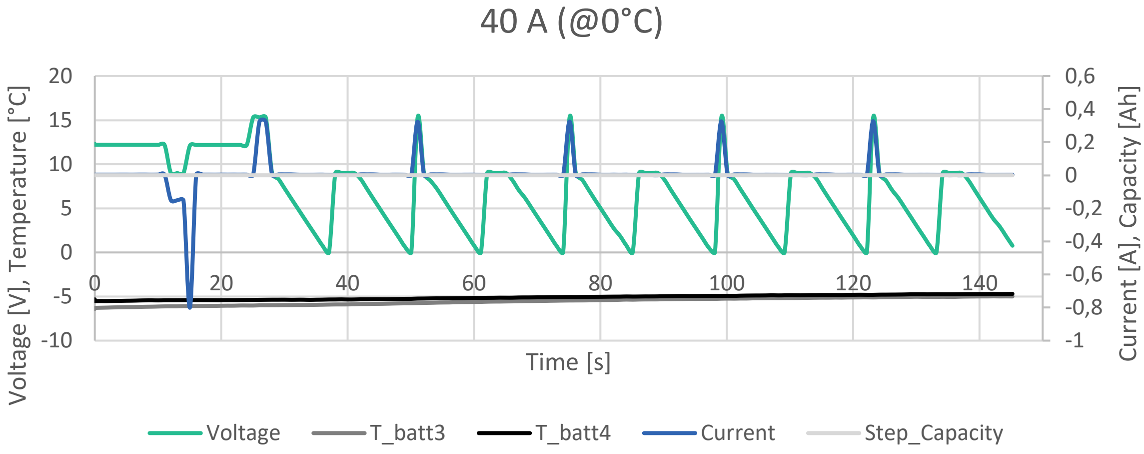

Figure 3 Electrochemical test at 0 ºC and 40 A of charge/discharge

Figure 3 shows the charge/discharge profile recorded at 0 °C and 40 A. Unlike the profiles obtained at higher temperatures, it is not possible to detect that the charge has been activated, and because the charge cannot be applied, the discharge is zero; this process repeats from the first cycle onwards and it is not possible to restore normal operation. This pattern was the trigger for stopping the test campaign and inspecting the module.

2.1.2 Incident description

Once certain unusual patterns are observed in the battery's charge/discharge profiles, the test is halted in order to investigate the cause.

One of the initial hypotheses was a fault in the associated electronics, so the housing was opened in order to make a direct connection to the module's i-SMS.

Upon opening the housing, it was found that the LICs had swollen excessively, to the point of deforming even the plastic plates that make up the cell module.

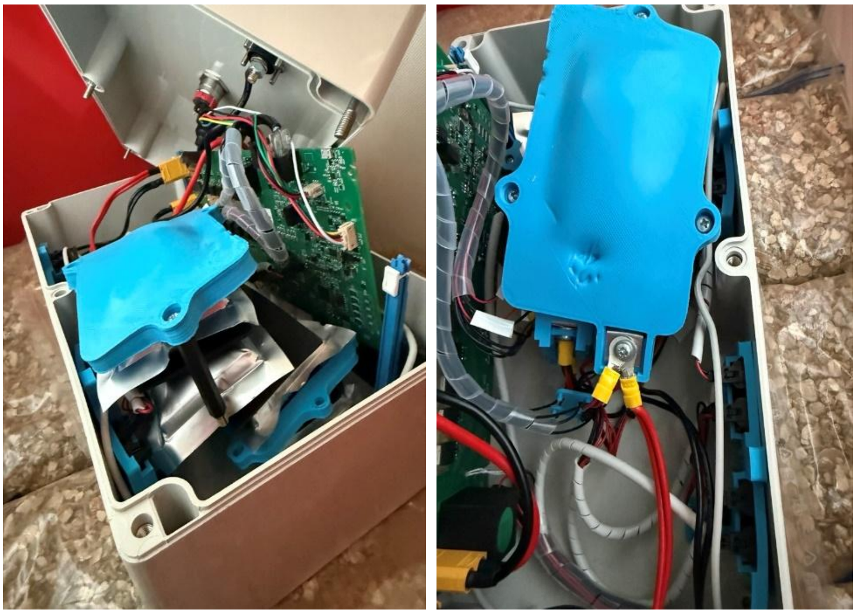

Figure 4 Images of the module after the inspection

It should be noted that, despite the striking degree of cell swelling, no incident occurred that would have jeopardised the safety of the system.

The observed swelling is consistent with the gas-generation phenomenon already anticipated in the mechanical design of the module (D7.2, Section 2.1), which incorporates technical foams between cells to buffer thickness variations during cycling. In this case, however, the magnitude of the swelling exceeded the absorption capacity provided by the foams, leading to permanent deformation of the PLA end-plates. No thermal runaway, electrolyte leakage or external damage to the i-SMS electronics occurred.

2.1.3 Root cause analysis

An analysis of the data and the possible causes of this incident leads to the conclusion that it was primarily caused by uncontrolled gas generation within the cell, which occurred mainly during the tests carried out at 70 °C, consistent with the gas-generation behaviour of LICs at high temperatures already observed during cell-level characterization. Consequently, the thermal behaviour of the cells during this test is analysed in detail, and it is verified that at an ambient temperature of 70 °C and a charge/discharge current of 40 A, one of the cells reaches 85 °C, triggering the overtemperature alarm and thereby halting the module's operation.

The opaque housing prevented direct visual observation of cell swelling during the test, so the exact onset of gas generation cannot be determined from the available data.

In addition to the main hypothesis, it is also believed that an imbalance between cells may have caused this event. This imbalance may have resulted from a previous over-discharge of the module following a long period of storage.

2.1.4 Corrective action and construction of the second version of the module

Following the incident and an analysis of the possible causes of failure, it was concluded that the validation process was incomplete; consequently, a new version of the LIC module was designed and manufactured, incorporating modifications based on the lessons learnt.

Four principal corrective actions were implemented in V2:

1. Casing redesign. A larger plastic enclosure (400 × 405 × 120 mm vs. 360 × 200 × 150 mm in V1) was selected, providing more internal volume for heat dissipation and easier component handling.

Figure 5 New version of the casing for the LIC module

2. Cell module structure. The cells are now connected through a stepped cell holder architecture, which improves access to the inter-cell connections and facilitates heat dissipation between cells.

3. Material change in structural parts. The end-plates and cell holders, originally manufactured in recycled PLA, were replaced by nylon. PLA shows a heat deflection temperature of around 60 °C, below the cell-level temperatures recorded at 70 °C ambient with 40 A cycling. Nylon, with a heat deflection temperature above 100 °C, prevents structural deformation at the operating temperatures targeted for V2.

Figure 6 Cell module structure

4. Lowered overtemperature alarm threshold. The cell-level overtemperature alarm was lowered from 85 °C (V1) to 70 °C (V2), with the warning threshold lowered accordingly from 75 °C to 65 °C. The maximum ambient validation temperature was correspondingly lowered from 70 °C to 50 °C. This conservative adjustment aims to minimize the risk of gas generation in subsequent campaigns.

The internal i-SMS electronics were inspected after the incident and showed no damage, so they were reused in V2 without modifications.

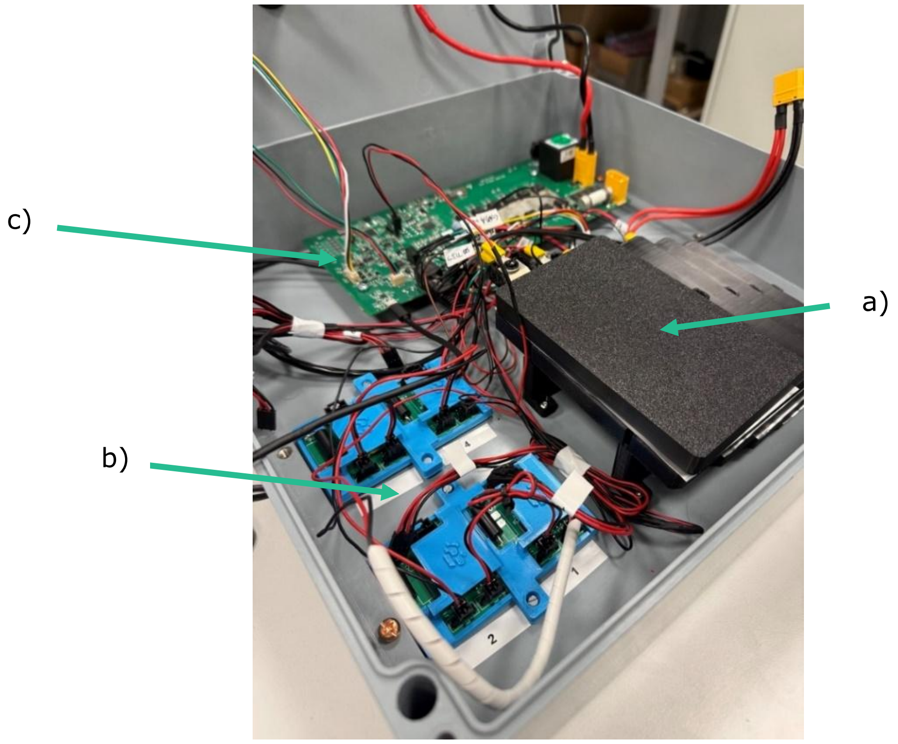

Figure 7 a) Connection of cell module, b) sensing and c) i-SMS

2.1.5 Implications for the test plan of the second version of the module

Taking into account everything we have learnt, this new version of the module will undergo slight changes to the test plan.

As previously mentioned, the overtemperature alarm threshold has been lowered, meaning that the maximum temperature at which the module will be validated is 50 °C, whilst ensuring at all times that the temperature of the cells and the electronics does not exceed the set limits.

Furthermore, the order of the temperatures to be analysed ranges from the least critical to the most critical, in order to ensure validation and/or testing under specific conditions.

After verifying the module's operation under the various conditions described, testing of the module's protective features will proceed as originally planned.

2.1.6 Overall outcomes of V1 LIC module

Despite the incident detected, the main conclusions of the V1 LIC module drawn are as follows:

- The cell-to-cell voltage balancing strategy is not sufficiently effective under certain operating conditions which leads to an uneven current distribution and increase in cell temperature.
- The module shows stable and consistent behaviour when operated at 40 A within the 25–50 °C temperature range, confirming suitable performance under nominal conditions.
- A non-expected behaviour has been identified at 40 A and 0 °C, which has triggered a detailed analysis of the module in order to better understand the underlying mechanisms.

- The current test setup does not allow direct verification of potential gas generation at cell level, which limits the assessment of this specific phenomenon within the present validation scope.
- Protection functions operate correctly within the software-defined thresholds, even though these limit conditions have not been explicitly tested during the current tests.

2.2 Functional electrical characterization at module level

Functional charge/discharge cycles were performed on V2 according to the test plan described in Section 1.3.1. Both data sources — the cycling equipment and the i-SMS internal monitoring — have been used in a complementary way: the cycler provides high-resolution module-level voltage and current data, while the i-SMS provides per-cell voltage, temperature and impedance.

Given the volume of data (4 temperatures x 3 currents × multiple cycles, recorded by two systems), this section reports the most representative results. Complete dispersion datasets per condition are summarized in Tables 9 and 10.

2.2.1 Effect of current and temperature on available capacity

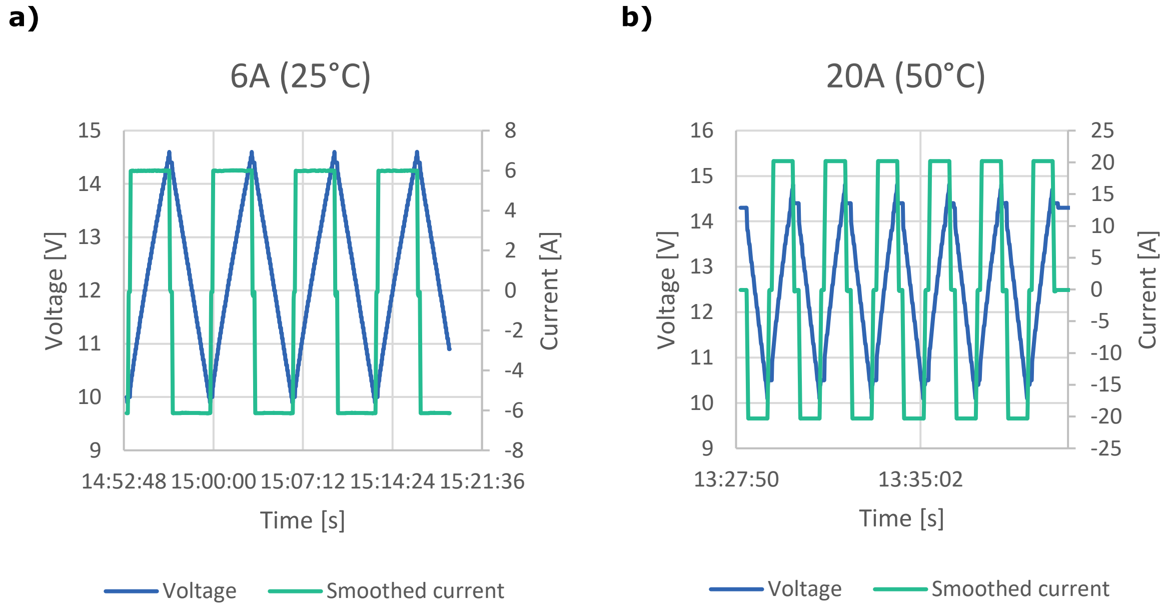

Figure 8 Module behaviour at two different operating points: a) 25ºC and 6 A and b) 50ºC and 20 A

Figure 8 compares the module behaviour at two operating points: 25 °C / 6 A (low current, ambient temperature) and 50 °C / 20 A (intermediate current, high temperature). The charge phase at higher current shows a reduced effective voltage window: when any individual cell reaches 3.6 V, the i-SMS activates the current-limiting resistor (R_{lim}) to initiate balancing. As a result, the charge phase is shortened and the depth of discharge accessible to the module is reduced. This mechanism explains why the available capacity reported in Table 9 falls below the nominal cell capacity (0.444 Ah) even under favourable operating conditions.

Table 9. Module available capacity per cycling condition

Temperature	CURRENT	Charge capacity	Discharge capacity	Efficiency
25 ºC	**6 A**	0.32 Ah	0.3 Ah	95%
	20 A	0.26 Ah	0.25 Ah	96%
	40 A	0.16 Ah	0.16 Ah	100%
0 ºC	**6 A**	0.29 Ah	0.28 Ah	96%
	20 A	0.23 Ah	0.22 Ah	94%
	40 A	0.13 Ah	0.13 Ah	100%
-20 ºC	**6 A**	0.23 Ah	0.22 Ah	96%
	20 A	0.08 Ah	0.07 Ah	88%
	40 A	0.02 Ah	0.02 Ah	100%
50 ºC	**6 A**	0.33 Ah	0.32 Ah	96%
	20 A	0.27 Ah	0.26 Ah	96%
	40 A	0.18 Ah	0.18 Ah	100%

The available capacity decreases both with increasing current and with decreasing temperature. The most extreme reduction is observed at −20 °C / 40 A, where the discharged capacity drops to 0.02 Ah (4.5% of nominal). At ambient and high temperatures (25 °C and 50 °C), the available capacity at 6 A reaches 67–72 % of nominal, with the gap to nominal attributable to the R_{lim}-induced reduction of the operating voltage window.

While D7.1 reported discharged capacities close to nominal at 25 °C across all currents tested (6, 20, 40 A), the module operates within a narrower voltage window (2.3–3.6 V per cell on average due to R_{lim} activation, vs. 2.2–3.8 V at cell level). This reduction is by design — driven by the balancing strategy — and should not be interpreted as a degradation of the module.

The efficiency values reported in Table 9 (94–100 %) reflect the charge-to-discharge ratio within the R_{lim}-constrained window, not the intrinsic coulombic efficiency of the cells. Values approaching 100 % at high currents indicate that both charge and discharge are limited by the same voltage thresholds, not improved efficiency.

2.2.2 Cell-to-cell voltage dispersion

All voltage measurements at cell level were performed with the VTZ sensor, with an accuracy of ±2 mV. This sets the noise floor for any dispersion analysis presented in this section.

Table 10. Cell voltage dispersion per cycling condition

Temperature	Current	CHARGE					DISCHARGE				
		Vmax	ID	Vmin	ID	ΔV	Vmax	ID	Vmin	ID	ΔV
25 ºC	6 A	3.59 V	4	3.54V	1	48 mV	2.44 V	4	2.38 V	1	65 mV
	20 A	3.61 V	4	3.57 V	1	44 mV	2.5 V	2	2.44 V	1	66 mV
	40 A	3.54 V	4	3.49 V	1	47 mV	2.63 V	2	2.57 V	1	68 mV
0 ºC	6 A	3.6 V	4	3.56 V	1	46 mV	2.44 V	2	2.37 V	1	71.5 mV
	20 A	3.6 V	4	3.55 V	1	49 mV	2.52 V	2	2.44 V	1	78 mV
	40 A	3.52 V	4	3.46 V	1	62 mV	2.66 V	2	2.58 V	1	84 mV
-20 ºC	6 A	3.58 V	4	3.53 V	1	50 mV	2.45 V	2	2.37 V	1	76.5 mV
	20 A	3.64 V	4	3.59 V	1	53 mV	2.72 V	2	2.65 V	1	74 mV
	40 A	3.53 V	4	3.47 V	1	63 mV	2.66 V	2	2.59 V	1	77 mV
50 ºC	6 A	3.6 V	4	3.55 V	1	47 mV	2.44 V	2	2.38 V	1	63 mV
	20 A	3.61 V	4	3.56 V	1	49 mV	2.53 V	2	2.47 V	1	66 mV
	40 A	3.55 V	4	3.5 V	1	49 mV	2.65 V	2	2.59 V	1	66 mV

Table 10 shows the cell-to-cell voltage dispersion recorded by the i-SMS at the end of charge and at the end of discharge. The maximum dispersion at end of charge is 62 mV (0 °C / 40 A), which represents an improvement of approximately one order of magnitude with respect to the dispersion observed in V1 (Tables 5–8). The balancing strategy can therefore be considered validated under nominal operating conditions.

Dispersion at end of discharge is systematically higher than at end of charge (up to 84 mV at 0 °C / 40 A). This is consistent with the design of the balancing system, which operates exclusively during charge.

A consistent finding is that cell #1 systematically shows the lowest voltage at end of charge and the highest voltage at end of discharge, while cell #2 (or #4) shows the opposite behaviour. This persistent asymmetry suggests a small but reproducible mismatch in cell parameters (capacity or ESR) that the balancing system corrects partially but not fully. Cell

#1 is the candidate for first-degraded cell and should be the priority for SOH monitoring in future campaigns.

2.2.3 Cell-level impedance (EIS)

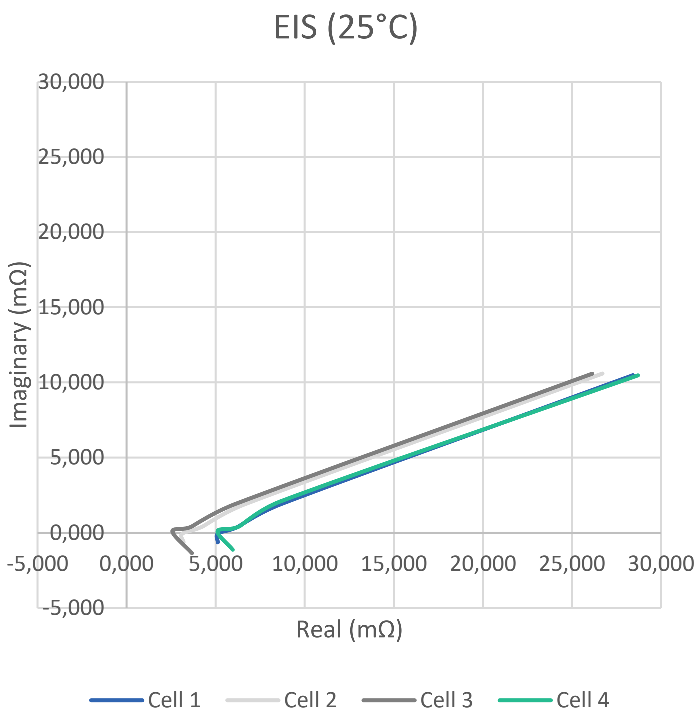

Figure 9 EIS measurements at 25ºC

Cell-level EIS measurements at 25 °C reveal a clear bimodal distribution of internal resistance: cells #1 and #4 (end positions) show an internal resistance approximately 2.5 mΩ higher than cells #2 and #3 (centre positions). This is a relevant finding for module design and thermal management:

- The higher ESR of end cells contributes to slightly higher local heating, although this is not visible in the thermal dispersion of Table 11 (limited to 1–4 °C across the module).
- It supports the rationale of the BTMS strategy derived from D7.1 (cooling through the top/bottom faces aligned with the high in-plane conductivity).
- It also explains, partially, why cell #1 is the first to reach voltage thresholds during charge (higher ESR → larger voltage drop → earlier R_{lim} activation).

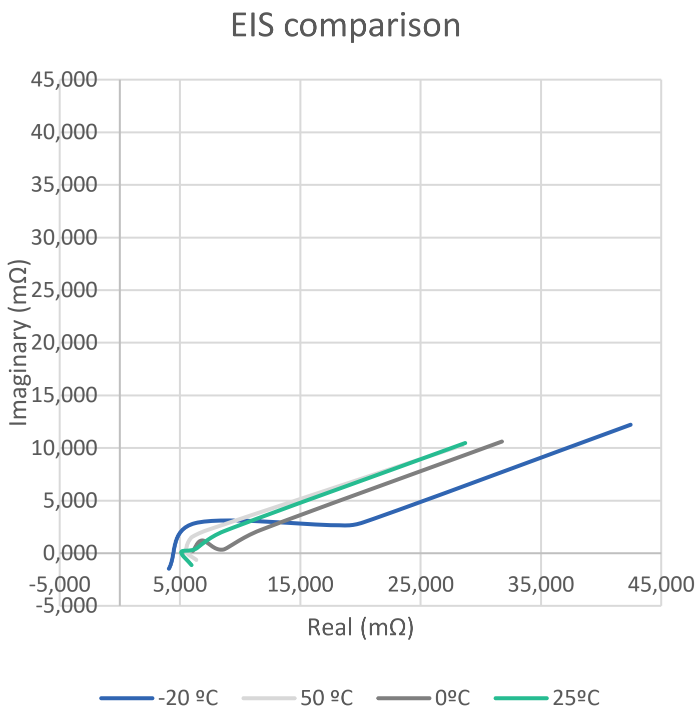

Figure 10 EIS measurement comparison at different temperatures

At low temperatures (0 °C and below), the internal resistance increases substantially, consistent with the cell-level findings reported in D7.1. This effect is the dominant contributor to the capacity reduction observed at −20 °C (Table 9).

2.3 Thermal management validation

Cell-level temperature is monitored continuously by the VTZ sensors during all cycling tests. Two aspects are evaluated: (i) the absolute temperatures reached during operation relative to the protection thresholds, and (ii) the temperature dispersion across the four cells of the module.

Table 11. Cell temperature dispersion per cycling condition

Temperature	**Current**	**Temp. Max (absolute)**	**ID**	**Temp. min**	**ID**	**ΔT**
25 ºC	**6 A**	26 ºC	1, 3, 4	25 ºC	2	1 ºC
	20 A	28 ºC	1, 4	27 ºC	2, 3	1 ºC
	40 A	30 ºC	1, 2, 3, 4	30 ºC	1, 2, 3, 4	0 ºC
0 ºC	**6 A**	2 ºC	1	1 ºC	2, 3, 4	1 ºC
	20 A	4 ºC	1, 4	3 ºC	2, 3	1 ºC
	40 A	5 ºC	1, 4	4 ºC	2, 3	1 ºC

Temperature	Current	Temp. Max (absolute)	ID	Temp. min	ID	ΔT
-20 ºC	**6 A**	-18 ºC	1, 3, 4	-19 ºC	2	1 ºC
	20 A	-16 ºC	1, 3, 4	-17 ºC	2	1 ºC
	40 A	-14 ºC	4	-16 ºC	2	2 ºC
50 ºC	**6 A**	51 ºC	3, 4	50 ºC	1, 2	1 ºC
	20 A	53 ºC	3	52 ºC	1, 2, 4	1 ºC
	40 A	58 ºC	2	54 ºC	2 ,3	4 ºC

Maximum absolute temperatures.
The most thermally demanding condition is 50 °C ambient with 40 A cycling, where cell temperature reaches 58 °C — a margin of 12 °C below the alarm threshold (70 °C in V2). Under all other operating conditions, the temperature rise above ambient does not exceed 8 °C. The 70 °C alarm threshold is therefore not approached in any of the V2 validation tests, which confirms the conservative selection of the threshold and the absence of gas-generation risk under V2 operating conditions.

Cell-to-cell thermal dispersion.
ΔT between cells remains below 4 °C across all tested conditions, with the maximum recorded at 50 °C / 40 A. End-position cells (cells #1 and #4) tend to be slightly warmer than centre-position cells under low-current conditions, while at 40 A the dispersion pattern is less clear, suggesting that internal heating dominates over conduction asymmetries at high currents.

Coherence with the BTMS strategy.
The thermal performance of the module is consistent with the BTMS strategy derived from the cell-level anisotropic thermal characterization reported in D7.1, which recommended heat dissipation through the cell faces (in-plane direction, ~64 W/m·K) rather than through the cell edges (through-plane, ~0.25 W/m·K). The low ΔT observed at module level (≤4 °C) supports this design choice.

Reversible swelling observed during 50 °C tests.
During the 50 °C / 40 A tests of V2, a slight cell swelling was observed at the end of the cycling campaign. Unlike the irreversible swelling that triggered the V1 redesign, this swelling was reabsorbed after leaving the module at ambient temperature (20-25 °C) for 24h. This behaviour is interpreted as consistent with the reversible gas-generation/reabsorption phenomena that characterize LIC cells under prolonged thermal stress, and provides the empirical basis for the operational recommendation in Section 3 to limit the ambient operating temperature of the module to 50 °C, despite the cell-level rating of 85 °C.

2.4 Protection and safety validation

In addition to validating the module's functionality throughout this task and deliverable, the safeguards defined within the i-SMS have also been validated to ensure the module operates safely, thereby preventing critical situations and events that could lead to unnecessary incidents.

The table below shows the list and thresholds of the safeguards defined in the second version of the module. As the first version of the module suffered an undesirable incident, tests relating to the module's safety were carried out.

Table 12. i-SMS protections and its values for the second version of the module

i-SMS PROTECTIONS			
1	Dch. Overcurrent/short-circuit	PACK	55 A
2	Ch. Overcurrent	PACK	60 A
3	Overtemperature (warning)	CELL	65 °C
4	Overtemperature (alarm)	CELL	70 °C
5	Under-temperature	CELL	-30 °C
6	Vcell max to start balancing	CELL	3.6V
7	Vcell min to stop process	CELL	3.6V
8	Vcell max	CELL	3.8V
9	Vcell min	CELL	2.3V
10	Auto shutdown	PACK	8V

Based on this table, tests have been carried out to assess each of the module's limitations. These tests have been divided into three broad categories: verification of current-related, voltage-related and temperature-related protection mechanisms.

2.4.1 Current related protections

Among the protections relating to operating current limits, these include short-circuit protection, discharge overcurrent protection and load overcurrent protection.

To verify these three protections, the following protocol is used: bring the module to a state just below the alarm threshold in the three situations described and gradually increase the current value to check the exact point at which the designed electronics activate the alarm signal and shut down the module to ensure system safety.

The figures below show the tests carried out in accordance with the protocol described above.

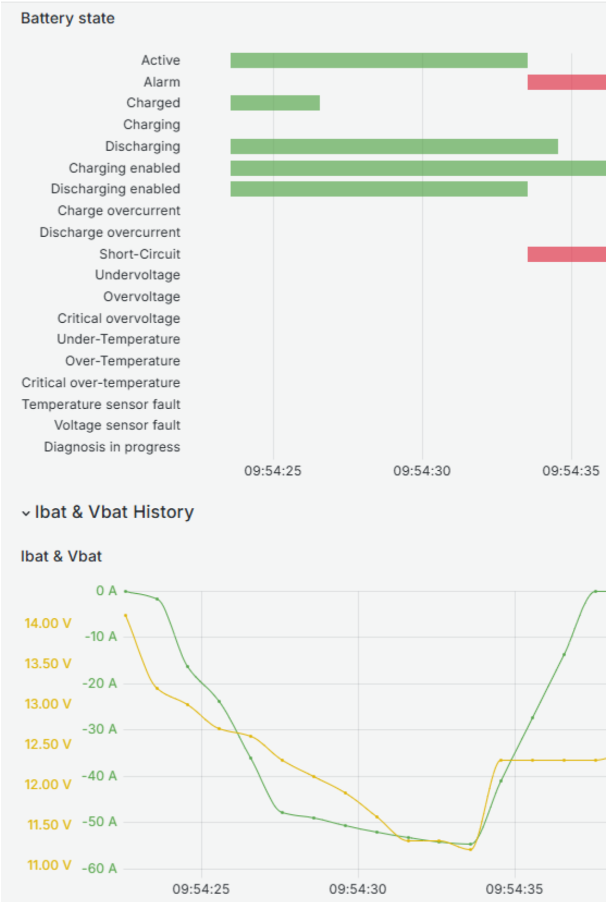

Figure 11 Short-circuit alarm activation

The module is initially discharged at 50 A, and the current is gradually increased up to 55 A. It is verified that the discharge stops and the short-circuit alarm is triggered.

The discharge overcurrent protections (warning at 130 A, alarm at 150 A in V1; consolidated to 55 A in V2) were not validated as standalone tests, since the V2 short-circuit protection at 55 A acts as the binding limit during discharge. Any discharge current exceeding 55 A triggers the short-circuit protection (validated in Figure 11), which provides equivalent safety coverage.

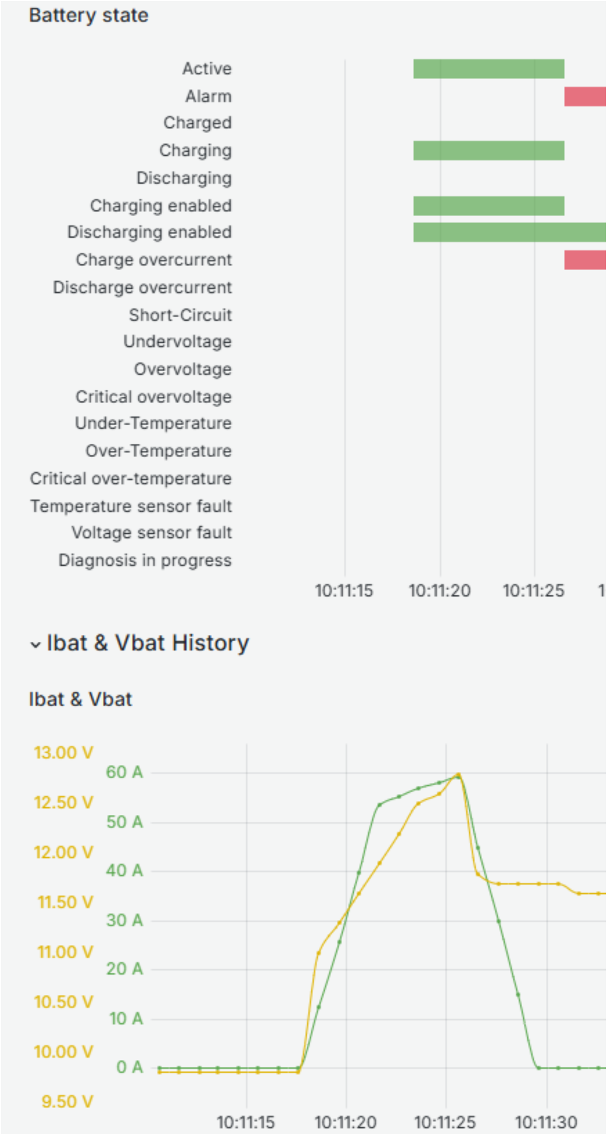

Figure 12 Charge over current alarm activation

The battery is charged at 55 A, and the current is gradually increased up to 60 A. It is verified that the i-SMS stops the current and triggers the charge overcurrent alarm.

2.4.2 Voltage related protections

As far as voltage protection is concerned, the i-SMS has four different limit settings. These limits affect the cell voltage and are divided into two groups: the maximum and minimum values that trigger the load current limit, which ensures correct balancing; and, secondly, the maximum and minimum cell voltages that trigger the overvoltage and undervoltage limit alarms.

To test these parameters, the module was charged or discharged until the thresholds defined in the i-SMS were reached, and it was verified that the corresponding systems were activated upon reaching the limits.

Below, you can see the activation and deactivation of the current limitation system based on the voltage values of the most heavily loaded cell.

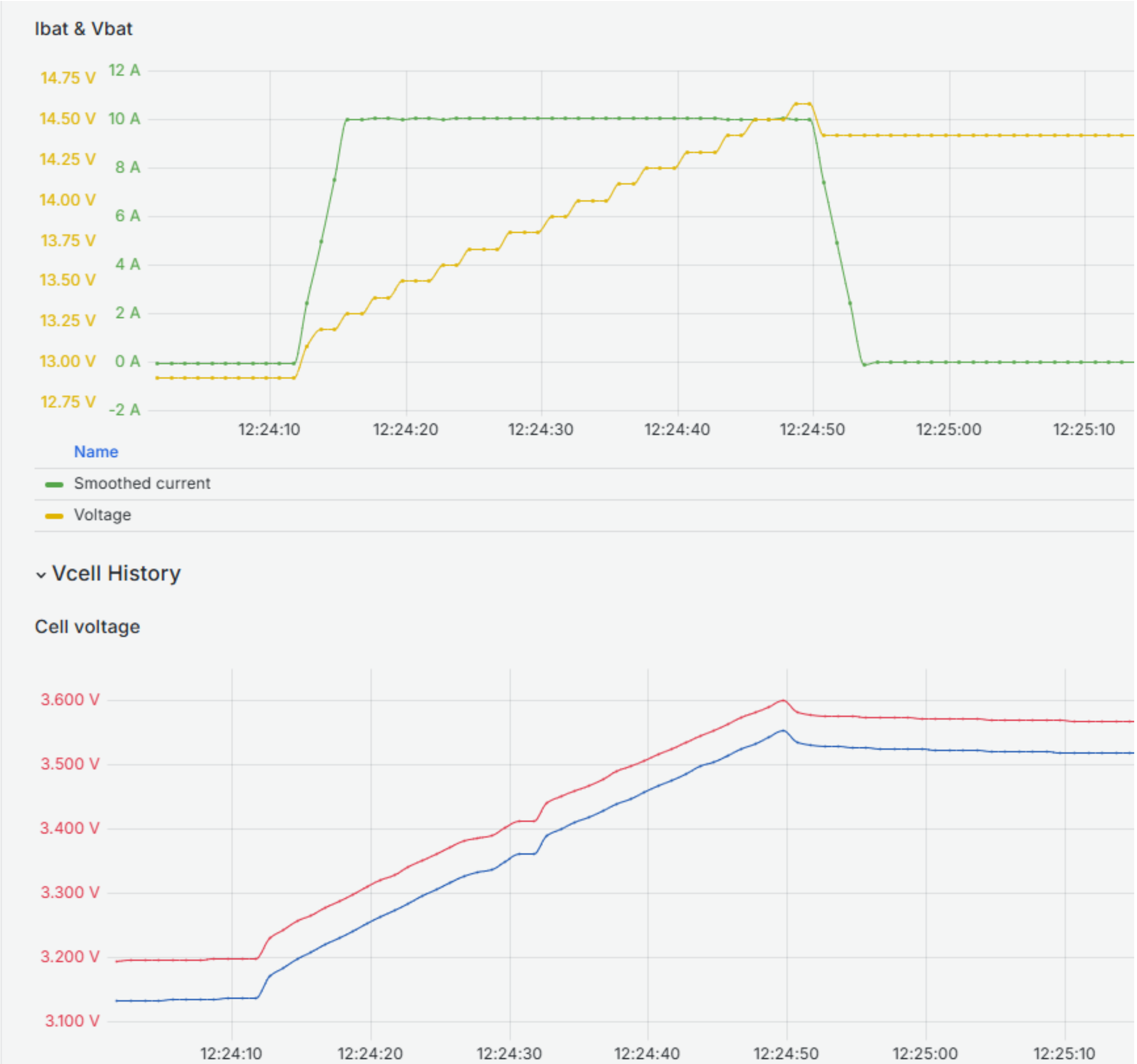

Figure 13 Current limitation activation

When the i-SMS detects that the most charged cell reaches 3.6 V, it introduces a current-limiting resistor that reduces the charging current to nearly zero, in order to initiate cell balancing.

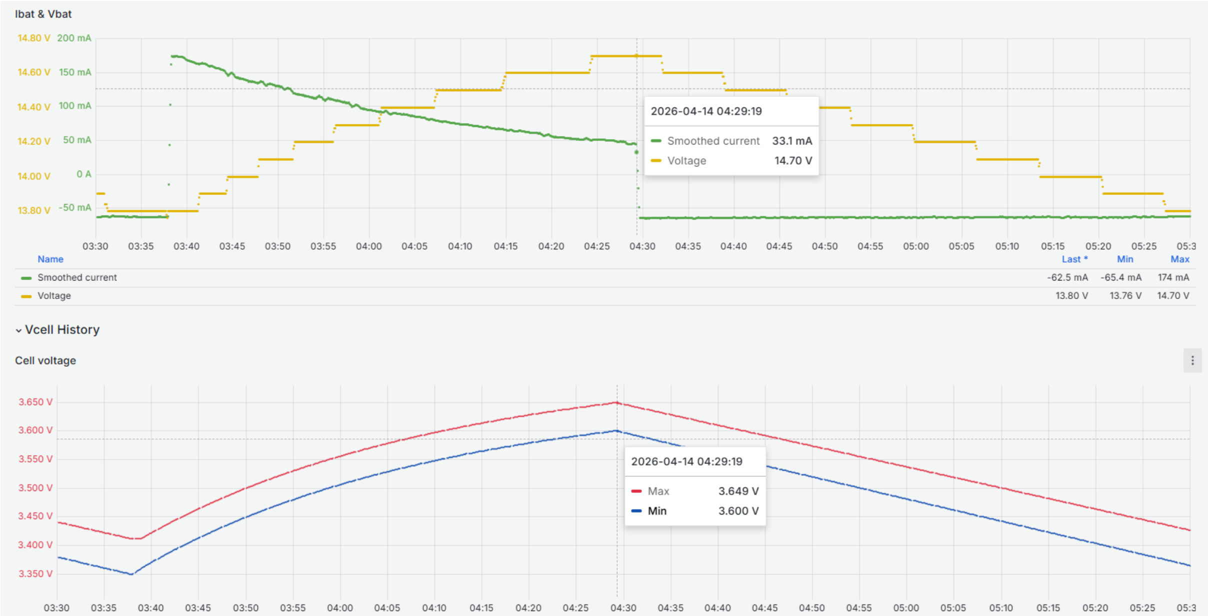

Figure 14 Current limitation deactivation

The figure shows one charge cycle of the module, where it can be observed that when the voltage of the least charged cell reaches 3.6 V, the charging process is stopped.

Furthermore, the figure below shows the undervoltage alarm being triggered once the most discharged cell drops below 2.3V.

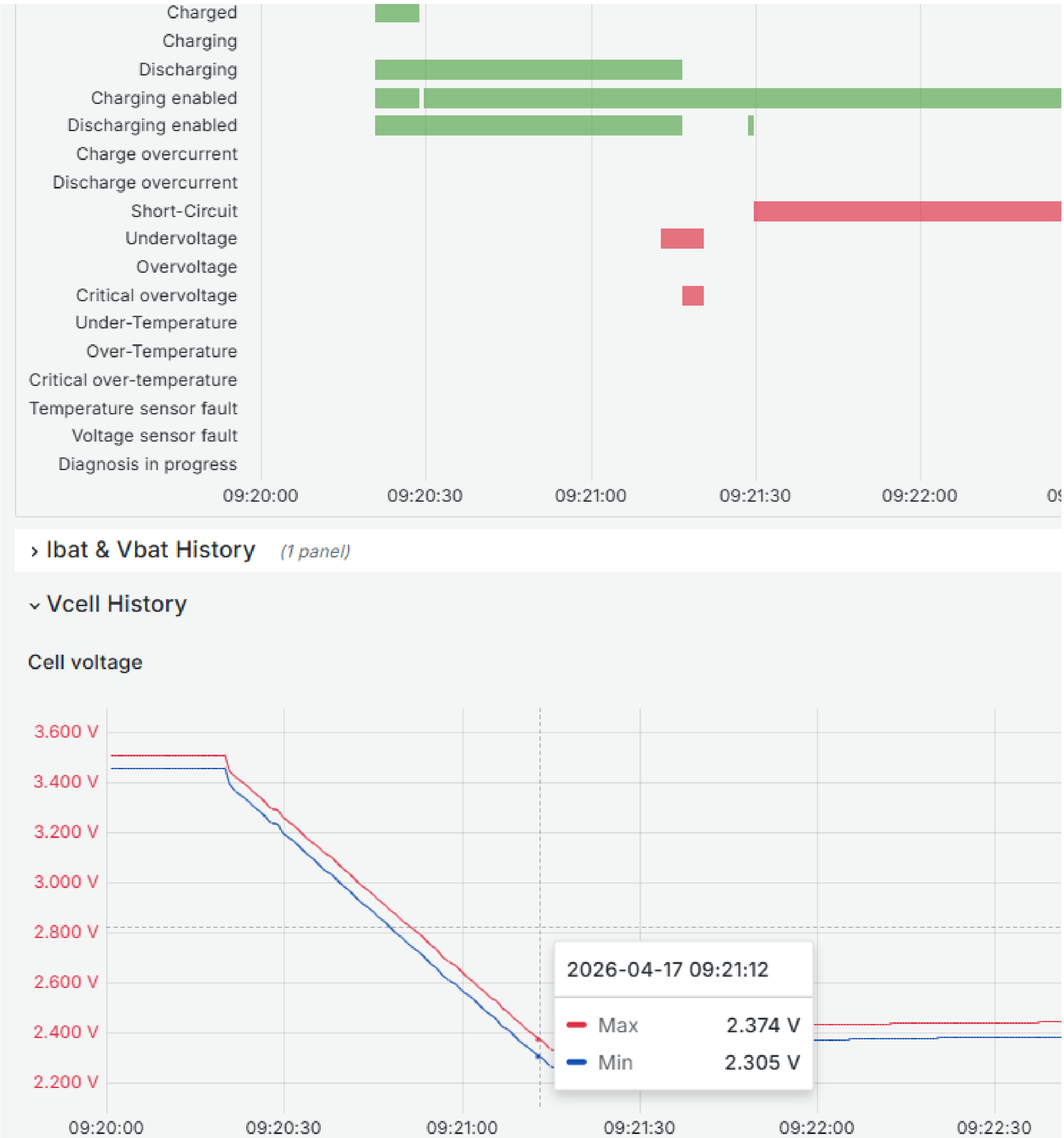

Figure 15 Under voltage alarm activation

Finally, the cell-level overvoltage alarm at 3.8 V could not be triggered experimentally during normal operation. This is the expected behaviour, since the R_{lim} current limiter activates at 3.6 V per cell and prevents any individual cell from reaching 3.8 V under controlled cycling. Triggering the 3.8 V alarm would require a significant cell imbalance combined with the failure of the R_{lim} mechanism, a scenario not reproduced in this campaign. The protection is therefore considered functionally redundant under normal R_{lim} operation, but remains in place as a safety net for fault conditions.

2.4.3 Temperature related protections

Finally, the safeguards relating to thermal operating limits have been tested to prevent accelerated degradation of the system should it operate outside the defined thresholds. In this case, there are two alarms: one for overtemperature and another for under temperature.

In the case of the overtemperature protection, before reaching the alarm value (70 °C), the system issues a warning when the temperature of one of the cells reaches 65 °C. To verify both the alarm and the warning, the module was heated continuously until it reached the defined thresholds.

Cell 1 is heated beyond the overtemperature limits to verify that the i-SMS stops the discharge current and triggers the alarm. The SMS stops the discharge current and triggers the critical overtemperature alarm when the cell temperature exceeds 70°C.

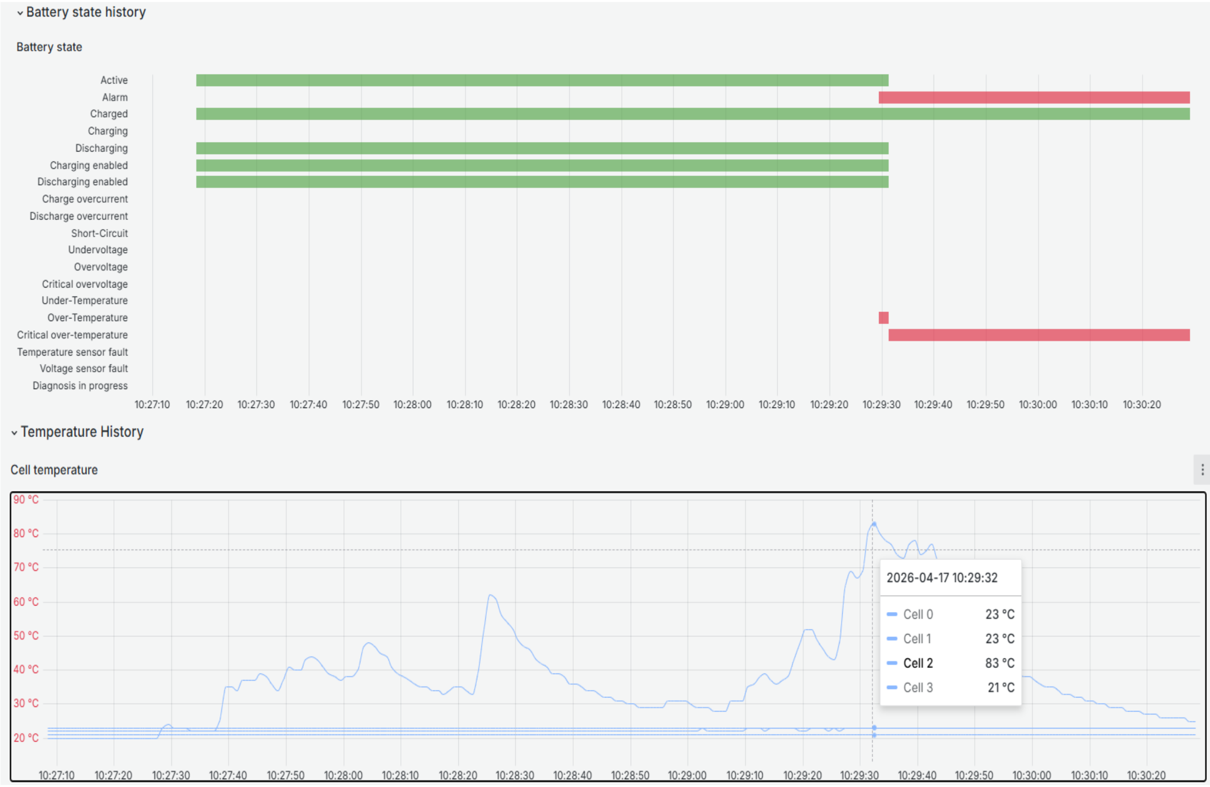

Figure 16 Over temperature warning and alarm activation

The hardware lower temperature limit of the i-SMS electronics is −30 °C. This is more restrictive than the cell-level lower limit (−40 °C declared by the manufacturer, with reproducible behaviour only above 0 °C per D7.1). Consequently, the lower operating limit of the module is determined by the i-SMS electronics, not by the cell. When the cell temperature drops below −30 °C during the controlled cooling test, the temperature-sensor fault alarm activates first (immediate) and the under-temperature alarm follows after the 1 s delay, as designed.

This finding has implications for the SIC module roadmap (Section 4): if the SIC cells exhibit better low-temperature behaviour than LICs, the lower operating limit of the future SIC module will still be constrained by the i-SMS electronics unless the i-SMS hardware is upgraded.

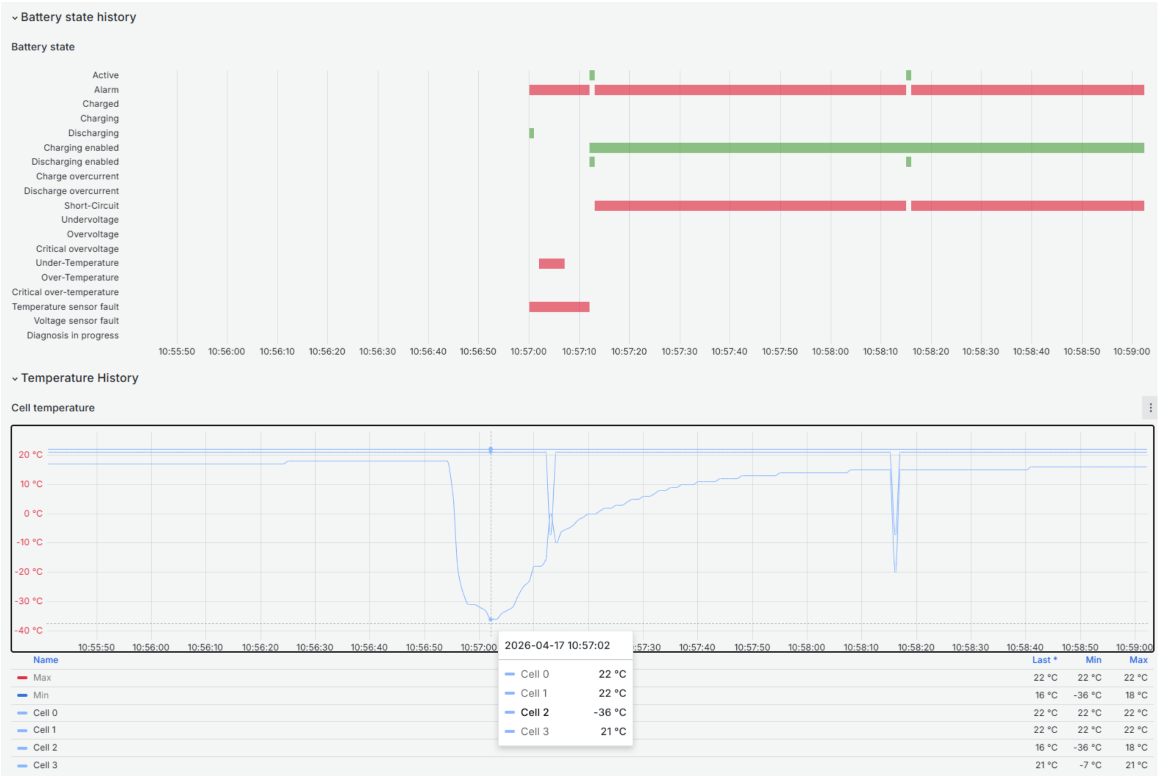

Figure 17 Under temperature alarm activation

2.5 Preliminary module adequacy checks

Following the validation tests described in Sections 2.2 to 2.4, the operating limits of the LIC module V2 have been finalized. Table 13 summarizes the adjusted limits, compared with the cell-level limits established in D7.1.

Table 13. Module adequacy checks

Parameter	**Cell limit (D7.1)**	**Module limit (V2)**	**Determined by**
Upper operating voltage (per cell)	3.8 V	3.6 V	R_{lim} balancing strategy
Lower operating voltage (per cell)	2.2 V	2.3 V	i-SMS alarm threshold
Module voltage range	n/a	9.2 – 14.4 V	Sum of per-cell limits
Maximum operating temperature (ambient)	85 °C	50 °C	Gas-generation risk in V1
Minimum operating temperature	0 °C (reproducible)	−30 °C	i-SMS hardware
Maximum discharge current	40 A (tested)	55 A	i-SMS alarm threshold
Maximum charge current	40 A (tested)	60 A	i-SMS alarm threshold

Within these adjusted limits, the module operates safely and the i-SMS validates correctly. The reduction in upper voltage and upper temperature with respect to cell-level capabilities is a consequence of the integration into a 4S module and of the lessons learnt from the V1 incident, and represents the trade-off between cell intrinsic capabilities and safe module-level operation.

3 Discussion and Conclusions

This section consolidates the main conclusions of the deliverable, organized by the three validation pillars addressed in Section 2: cell-to-module correlation, system validation, and thermal validation, followed by an overall outcome.

3.1 Cell – module correlation

- The available capacity at module level is consistently lower than at cell level across all tested conditions. The dominant cause is the activation of the current-limiting mechanism (R_{lim}) when any individual cell reaches 3.6 V during charge, which restricts the operational voltage window of the module to approximately 2.3–3.6 V per cell, against the 2.2–3.8 V available at cell level (D7.1). The accessible energy is therefore reduced by a factor that depends on the operating current and the cell-to-cell voltage dispersion, ranging from approximately 4 Wh under favourable conditions (50 °C / 6 A) to less than 0.3 Wh in the most demanding tested condition (−20 °C / 40 A), against a maximum value of 6.75 Wh declared at module level (Table 1).
- The cell-to-cell voltage dispersion at end of charge (max. 62 mV at 0 °C / 40 A in V2) is small in absolute terms but operationally significant, since it determines when R_{lim} activates and therefore how much of the available capacity is accessible. The VTZ sensor accuracy is ±2 mV, which is more than one order of magnitude below the observed dispersion; the values reported can therefore be confidently attributed to genuine cell-to-cell variability rather than measurement noise. Reducing this dispersion is the most direct lever to increase the module-level energy.
- The cell-level finding of D7.1 that the actual usable temperature range is 0–85 °C (below the −40 °C / +85 °C of the datasheet) is partially preserved at module level: the lower limit shifts to −30 °C due to the i-SMS electronics, and the upper limit shifts to 50 °C due to the gas-generation risk observed in V1. Notably, the operational span is almost fully preserved (50 °C span at module level vs. 85 °C at cell level), and the ability of the module to operate down to −30 °C represents a particularly relevant capability for applications where low-temperature performance is harder to achieve through thermal management alone."
- The bimodal distribution of cell internal resistance (end cells ~2.5 mΩ higher than centre cells, see Section 2.2.3) is a module-level finding that did not appear at cell level in D7.1, where cells were characterized individually. It is a consequence of integration (interconnection geometry, asymmetric heat exchange) and confirms the value of module-level characterization beyond the simple "sum of cells" approach.

3.2 System validation

- The i-SMS sensing has been validated functionally throughout the test campaign: the cell-level voltage, current and temperature measurements provided by the VTZ sensors are consistent with the cycler-side measurements and allow real-time tracking of cell-to-cell dispersion and per-cell impedance.
- Protections have been validated experimentally for short-circuit, charge overcurrent, voltage R_{lim} activation/deactivation, undervoltage at cell level, overtemperature (warning + alarm) and undertemperature. The cell-level overvoltage alarm at 3.8 V could not be triggered experimentally due to R_{lim} acting at 3.6 V — this is the expected behaviour and confirms the layered protection strategy.

- The balancing strategy implemented during charge reduces cell-to-cell dispersion by approximately one order of magnitude with respect to V1, validating the design choice. A persistent asymmetric pattern remains (cell #1 systematically more discharged at end of charge), which should be monitored as the candidate first-degrading cell.
- All these validations support the readiness of the i-SMS architecture for transfer to the SIC module. The cell-specific aspects (electrochemical behaviour, gas-generation thresholds, low-temperature performance) will need to be re-validated with the SIC cells, but the architecture, sensing, balancing and protection logic are transferable.

3.3 Thermal validation

- The module operates within safe thermal limits under all tested conditions of V2, with a margin of at least 12 °C below the alarm threshold (70 °C). The highest cell temperature recorded was 58 °C, at 50 °C ambient with 40 A.
- Cell-to-cell temperature dispersion remains below 4 °C across the module, confirming the adequacy of the BTMS strategy inherited from D7.1 (heat dissipation aligned with the high in-plane conductivity direction of the pouch cells).
- Slight reversible cell swelling was observed during 50 °C / 40 A tests of V2, fully reabsorbed after leaving the module at ambient temperature (20-25 °C) within 24h. This behaviour, combined with the V1 incident, supports the recommendation to limit the operating ambient temperature of the LIC module to 50 °C, despite the cell-level capability of 85 °C. The serialization of cells appears to amplify the gas-generation effect with respect to single-cell behaviour, presumably through cumulative thermal coupling and the limited absorption capacity of the inter-cell foams.

3.4 Overall outcome

The 12 V LIC module developed in Task 7.4 has been electrically characterized and its i-SMS has been validated functionally and in terms of protection mechanisms. The campaign required two successive versions of the module: the V1 campaign revealed the limits of the original mechanical and thermal envelope, leading to a redesign in V2 that incorporates a larger casing, nylon structural parts and a lowered overtemperature alarm threshold. V2 has been validated as functional within the operating limits summarized in Section 2.5.

The aspects of this work that are directly transferable to the future SIC module are the i-SMS architecture, the VTZ sensing concept, the balancing strategy, the protection logic and the BTMS approach. The aspects that will require revalidation with SIC cells are the cell-specific electrochemical performance, gas-generation behaviour, low-temperature performance and the actual operating window.

4 Recommendation

This section consolidates the actions and forward-looking guidance derived from the D7.3 validation campaign, organized by destination.

4.1 Hardware adjustments for the next module iteration

- Casing and structural materials. The V2 design (larger nylon casing) addresses the V1 deficiencies. Future iterations should retain nylon (or equivalent high-temperature-resistant material) for structural parts in contact with cells.
- Inter-cell foams capacity. The V1 incident showed that the foam absorption capacity can be exceeded under sustained high-temperature, high-current operation. For the SIC module, a re-sizing of the foams (or alternative pressure-management approach) based on the expected gas-generation rate of the SIC cells is recommended.

4.2 Tests to be replicated with SIC cells

When SIC cells become available, the following tests should be repeated, since their outcome is cell-specific:

- Full electrochemical characterization (capacity, ESR, EIS) at module level across the temperature/current matrix.
- Floating tests at intermediate and high temperatures, since SIC degradation behaviour is expected to differ from LIC.
- Gas-generation behaviour under sustained high-temperature operation, to redefine the upper ambient temperature limit of the module.
- Low-temperature behaviour, both at cell level and at module level (within the i-SMS hardware constraints).

4.3 Conclusions valid independently of the cell technology

The following findings are architectural and remain valid for the SIC module:

- The VTZ sensing concept (V, T, impedance per cell) operates correctly under the tested conditions.
- The two-level protection strategy (warning + alarm) at cell and pack level is functionally validated.
- The R_{lim} mechanism is effective in preventing individual cells from exceeding their upper voltage limit during charge, at the cost of a reduced effective voltage window.
- The BTMS approach inherited from D7.1 (heat dissipation aligned with the in-plane conductivity direction) results in a cell-to-cell thermal dispersion below 4 °C, which is acceptable for serialized operation.
- The bolted connections approach, motivated by recyclability, is functionally compatible with the high-current operation of the LIC module.

4.4 Open issues

- The SOH algorithm validation remains incomplete due to the absence of measurable cell degradation (risk WP7.1.1, inherited from D7.1). The current literature-based approach (D7.2) provides a working baseline, but ground-truth validation will only be possible with SIC cells operated over long durations.
- The contribution of the V1 incident to the understanding of LIC behaviour in serialized configuration is significant but qualitative. A more systematic study of

gas-generation thresholds at module level would strengthen the basis for the upper temperature limit recommendation.

5 Risk register

Table 14. Risk Register

Risk No.	What is the risk	Probability of risk occurrence[1]	Effect of risk[2]	Solutions to overcome the risk
R1	LIC module performance limitation (current limit)	Medium	Decrease electrical performance	i-SMS protection limits adaptation to ensure safety
R2	Algorithm SoX estimation accuracy	Medium/High	Prediction non-exhaustive	In-depth knowledge of cell performance
R3	Cell swelling under sustained high-temperature operation (gas generation)	High → Materialized	Mechanical deformation of module structure	Materialized in V1. Mitigated in V2 by lowered overtemperature alarm threshold (85 °C → 70 °C), nylon end-plates, larger casing, and ambient temperature limit reduced from 70 °C to 50 °C.
R4	Representativeness of validation with commercial JTEKT cells vs. future SIC cells	Medium	Some module-level conclusions may need re-validation	Cell-specific aspects (electrochemistry, gas generation, low-T) listed for re-test with SIC cells in Section 4. Architecture, sensing, balancing, protections and BTMS remain transferable.

[1] Probability risk will occur: 1 = high, 2 = medium, 3 = low

[2] Effect when risk occurs: 1 = high, 2 = medium, 3 = low

6 References

D7.1_Electrochemical characterization of LICs

D7.2_Development of complete i-SMS for a LIC module

7 Acknowledgement

The author(s) would like to thank the partners in the project for their valuable comments on previous drafts and for performing the review.

Table 15. Project partners

#	PARTICIPANT SHORT NAME	PARTNER ORGANISATION NAME	COUNTRY
1	CICE	CENTRO DE INVESTIGACION COOPERATIVA DE ENERGIAS ALTERNATIVAS FUNDACION, CIC ENERGIGUNE FUNDAZIOA	Spain
2	EUR	CLANCY HAUSSLER RITA	Austria
3	KIT	KARLSRUHER INSTITUT FUER TECHNOLOGIE	Germany
4	CNRS	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS	France
4.1	IMN	NANTES UNIVERSITE (Affiliated)	France
5	UPS	UNIVERSITE PAUL SABATIER TOULOUSE III	France
6	FSU	FRIEDRICH-SCHILLER-UNIVERSITAT JENA	Germany
7	IRT-JV	INSTITUT DE RECHERCHE TECHNOLOGIQUE JULES VERNE	France
8	ELY	E-LYTE INNOVATIONS GMBH	Germany
9	BYD	BEYONDER AS	Norway
10	BCARE	BATTERYCARE S. L.	Spain
12	TALGO	PATENTES TALGO SL	Spain
13	UPC	UP CATALYST	Estonia

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