

UL 9540A Report
 Cell Level

Report Issued : 2024-02-27
 Report Revised :

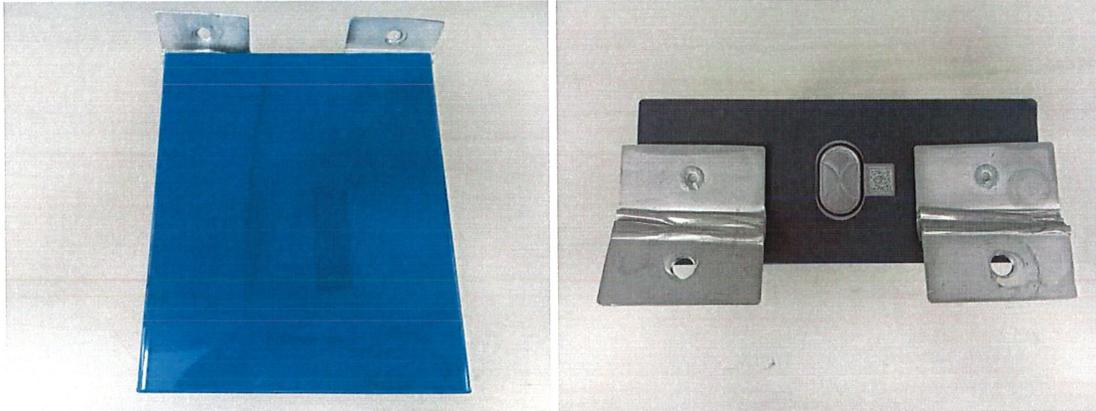
		CELL TEST REPORT UL 9540A Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems (AACD)
Project Number.....:	4791072813	
Date of issue.....:	2024-02-27	
Total number of pages.....:	35	
UL Report Office	UL(Changzhou) Quality Technical Service Co., LTD	
Applicant's name.....:	Xiamen Hithium Energy Storage Technology Co., Ltd.	
Address	201-1, Comprehensive Building 5, No.11, Butang Middle Road, Industrial Base Of Xiamen Torch High Tech Zone (Tongxiang), Xiamen, Fujian, P.R. China	
Test specification:	4 th Edition, Section 7, November 12, 2019	
Standard.....:	UL 9540A, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems	
Test procedure	7.1, 7.2, 7.3.1, 7.4, 7.6.1, 7.7	
Non-standard test method	N/A	
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General disclaimer:		
<p>The test results presented in this report relate only to the sample tested in the test configuration noted on the list of the attachments.</p> <p>UL LLC did not select the sample(s), determine whether the sample(s) was representative of production samples, witness the production of the test sample(s), nor were we provided with information relative to the formulation or identification of component materials used in the test sample(s).</p> <p>The issuance of this report in no way implies Listing, Classification or Recognition by UL and does not authorize the use of UL Listing, Classification or Recognition Marks or any other reference to UL on the product or system. UL LLC authorizes the above named company to reproduce this Report provided it is reproduced in its entirety. UL's name or marks cannot be used in any packaging, advertising, promotion or marketing relating to the data in this Report, without UL's prior written permission.</p> <p>UL LLC, its employees, and its agents shall not be responsible to anyone for the use or non-use of the information contained in this Report, and shall not incur any obligation or liability for damages, including consequential damages, arising out of or in connection with the use of, or inability to use, the information contained in this Report.</p>		

Cell level information		
Model No	LFP71173207/314Ah	
Ratings (Vdc, Ah)	3.2V,314Ah	
Chemistry of test item.....	Lithium iron phosphate	
Original Equipment Manufacturer (OEM):	Xiamen Hithium Energy Storage Technology Co., Ltd.	
Branding Manufacturer (if not OEM):	N/A	
Was the cell certified?	Yes	
Standard test item certified to	UL1973	
Organization that certified test item	UL(MH65937)	
Average cell surface temperature at gas venting, °C:	159	
Average surface temperature at thermal runaway, °C:	251	
Gas Volume:	171.2L	
Lower flammability limit (LFL), % volume in air at the ambient temperature	6.91	
Lower flammability limit (LFL), % volume in air at the venting temperature	5.90	
Burning velocity (S _u) cm/s:	62.87	
Maximum pressure (P _{max}) psig:	101.42	
Cell Gas composition		
Gas		Measured %
Carbon Monoxide	CO	14.507
Carbon Dioxide	CO ₂	23.000
Hydrogen	H ₂	45.167
Methane	CH ₄	4.868
Acetylene	C ₂ H ₂	0.148
Ethylene	C ₂ H ₄	1.804
Ethane	C ₂ H ₆	0.805
Propadiene (Allene)	C ₃ H ₄	0.006
Propylene	C ₃ H ₆	2.256
Propane	C ₃ H ₈	1.379
-	C ₄ (Total)	2.029
-	C ₅ (Total)	0.447
-	C ₆ (Total)	0.021
1-Heptene	C ₇ H ₁₄	0.004
Benzene	C ₆ H ₆	0.018
Toluene	C ₇ H ₈	0.001
Dimethyl Carbonate	C ₃ H ₆ O ₃	3.340
Ethyl Methyl Carbonate	C ₄ H ₈ O ₃	0.198
Total	-	100.000

Cell failure test method performed (summary of method and test clause):	
<input checked="" type="checkbox"/> External heating using thin film with 4°C to 7°C thermal ramp. <input type="checkbox"/> Nail Penetration <input type="checkbox"/> Overcharge <input type="checkbox"/> External short circuit (<i>X Ω external resistance</i>) <input type="checkbox"/> Flow Battery with 2 active electrolyte methods <input type="checkbox"/> Flow Battery with 1 active electrolyte methods <input type="checkbox"/> Others	
Description of method used to fail cells if other than external thin film heater with thermal ramp: N/A	
Description of test methods used for flow battery testing: N/A	
Summary of testing:	
Performance Criteria in accordance with Clause 7.7 and Figure 1.1:	
<input type="checkbox"/> Thermal runaway was not induced in the cell; and <input type="checkbox"/> The cell vent gas did not present a flammability hazard when mixed with any volume of air, as determined in accordance with ASTM E918 at both ambient and vent temperatures.	
Necessity for a module level test	
<input checked="" type="checkbox"/> The performance criteria of the cell level test as indicated in 7.7 of UL 9540A 4th edition has not been met, therefore a module level testing in accordance with UL 9540A will need to be conducted on a complete module employing this cell. <input type="checkbox"/> The performance criteria of the module level tests as indicated in 7.7 of UL 9540A 4th edition has been met, therefore a module level testing in accordance with UL 9540A need not be conducted.	
Testing Laboratory information	
Testing Laboratory and testing location(s):	
Testing Laboratory:	UL(Changzhou) Quality Technical Service Co., LTD
Testing location/ address :	21 Longmen Rd, National High-Tech Industrial Development District, Wujin, Changzhou, Jiangsu, China
Tested by (name, signature)..... :	Vic Zhang/Yangyang Zhu
Witnessed by (for 3rd Party Lab Test Location) (name, signature) :	N/A
Project Handler (name, signature)..... :	Ali Lin <i>Ali Lin</i>
Reviewer (name, signature) :	Benjamin Liu <i>Benjamin Liu</i>

Gas Analysis Testing Laboratory:	
Testing location/ address :	UL SOLUTIONS/333 Pfingsten Rd. Northbrook, IL 60062 USA
Project Handler (name, signature)..... :	Paul Obrochta
Reviewer (name, signature) :	Nicholas Voss
List of Attachments (including a total number of pages in each attachment):	
Attachment A: Cell Conditioning (Charge/discharge) Profiles - <i>(Pages 17 through 19)</i>	
Attachment B: Cell Instrumentation Photos - <i>(Pages 20 through 20)</i>	
Attachment C: Cell Temperature Profiles during testing - <i>(Pages 21 through 23)</i>	
Attachment D: Cell Testing Photos - <i>(Pages 24 through 33)</i>	
Attachment E: Cell vent gas test chamber photo and profile of chamber gas analysis (O ₂ and Pressure) - <i>(Pages 34 through 34)</i>	
Attachment F: Cell Gas Analysis Report - <i>(Pages 35 through 35)</i>	

Photo of cell/Stack:



Test Item Charge/Discharge Specifications:

• Charge current, A:	157
• Standard full charge voltage, Vdc:	3.65
• Charge temperature range, °C:	0 to 60
• End of charge current, A:	15.7
• Discharge current, A:	157
• End of discharge voltage, Vdc:	2.5
• Discharge temperature range, °C:	-30 to 60
• Heating rate, °C:	5.5

Test item particulars	
Possible test case verdicts:	
- test case does not apply to the test object..... :	N/A
- test object does meet the requirement	P (Pass)
- test object does not meet the requirement..... :	F (Fail)
- test object was completed per the requirement...:	C(Complete)
- test object was completed with modification.....:	M(Modification)
Testing..... :	LFP71173207/314Ah
Date of receipt of test item	2023-11-09
Date (s) of performance of tests	2023-11-14~2023-11-23
General remarks:	
<p>"(See Enclosure #)" refers to additional information appended to the report. "(See appended table)" refers to a table appended to the report.</p> <p>Throughout this report a point is used as the decimal separator.</p>	
Manufacturer's Declaration of samples submitted for test:	
The applicant for this report includes samples from more than one factory location and a declaration from the Manufacturer stating that the sample(s) submitted for evaluation is (are) representative of the products from each factory has been provided	<input type="checkbox"/> Yes <input checked="" type="checkbox"/> Not applicable
Name and address of factory (ies)	Xiamen Hithium Energy Storage Technology Co., Ltd. Northwest Of The Intersection Of Guoshan South 2nd Road & Tongxiang Avenue 12-12 Hongtang North Area, Tongxiang High Tech Industrial Base, Tong'an District Xiamen Fujian 361000 CN
General product information and other remarks:	
<p>The tested cell is a Lithium-ion cell, Model LFP71173207/314Ah. The cell has a capacity of 314Ah and nominal voltage of 3.2 Vdc.</p> <p>The overall dimensions of cell are (Width) 174.70±0.5 mm by (Depth)71.70±0.5mm by (Height) 207.11±0.5mm.</p> <p>The weight of cell is 5600±200g.</p> <p>This report was prepared for Xiamen Hithium Energy Storage Technology Co., Ltd. as requested by Shenzhen Tiansu Calibration and Testing Co.,Ltd.</p>	

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

5.0	CONSTRUCTION		Verdict
5.1. 5.4	Cell/Stack Construction		—
5.1.1, 5.4.1	Generic Chemistry:	Lithium iron phosphate	—
	Electrolyte Chemistry:	LiPF ₆ , DMC, EMC, EC, PC	—
	Flow Battery Electrolyte No. 1 Chemistry:	N/A	—
	Max volume of system electrolyte No. 1, L:	N/A	—
	Flow Battery Electrolyte No. 2 Chemistry:	N/A	—
	Max volume of system electrolyte No. 2, L:	N/A	—
	Separator Melt Temperature, °C:	Not used during test	—
	Format: Cylindrical /Prismatic /Pouch Flow Battery Stack	Prismatic	—
	Overall Dimensions, mm	(Width) 174.70±0.5 mm by (Depth)71.70±0.5mm by (Height) 207.11±0.5mm	—
	Cell Weight, g	5600±200g	—
5.1.2	Cell Certification:	Yes	—
	Standard Used for Cell Certification:	UL1973	—
	Organization that Certified Cell:	UL(MH65937)	—
5.1.1, 5.4.1	Cell/Stack Ratings:	3.2V	—
	• Nominal Voltage, Vdc		—
	•Nominal Capacity, Ah	314Ah	—
5.4.1	Flow Battery: No. of Cells per Stack:	N/A	—
	Flow battery system manufacturer:	N/A	—
	Flow battery system model:	N/A	—
	Flow battery system ratings, Vdc, Ah:	N/A	—
5.4.2	Flow battery system certified to UL 1973:	N/A	—
	Organization that certified flow battery system:	N/A	—
6.0	PERFORMANCE		Verdict
6.1	General		C
7.2	Samples		C
7.2.1	Samples conditioned through charge discharge cycling a minimum of 2 cycles.	See Attachment A for profiles See Table 1 for specifications	C

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Clause	Requirement + Test	Result - Remark	Verdict

7.2.2	100% SOC and stabilize from 1h to 8 h before testing		
7.2.3	Pouch Cells constrained per end use during testing.		N/A
7.3	Determination of thermal runaway methodology		
7.3.1	General		
7.3.1.1	Ambient indoor laboratory conditions: 25 ±5°C (77 ±9°F) ≤50 ±25% RH at the initiation of the test.	See Attachment C, See Table 3	C
7.3.1.2	Heat the cell to thermal runaway by externally applied flexible film heaters	See Attachment B	C
	Heater Dimension	152.4 mm by 203.2 mm, two pieces provided, attached on the two largest surfaces of the cell	
	A surface heating rate of 4° C (7.2° F) to 7° C (12.6° F) per minute was applied to the cell.	See Attachment C, D See Table 4	C
	Maximum surface end point temperature, °C	Not used, the cells are heated until the thermal runaway achieved. According to the Certification Requirement Decision: Test Method for Evaluating Thermal Runaway Fire Propagation in Battery. Holding temperature was not utilized during the test and the cell was continuously heated until thermal runaway occurred.	
	The following method(s) was employed to cause thermal runaway: <input type="checkbox"/> Mechanical (e.g. nail penetration); <input type="checkbox"/> Electrical stress in the form of overcharging, <input type="checkbox"/> Electrical stress in the form of over discharging <input type="checkbox"/> Electrical stress in the form of external short-circuiting <input type="checkbox"/> Use of alternate heating sources (e.g. oven). <input type="checkbox"/> Other (explain)	Only external heating in the form of using flexible thin film heaters to cause thermal runaway	N/A
7.3.1.3	Detail of test method when using another cell abuse method to initiate thermal runaway	See Attachment E	N/A
7.3.1.4	Monobloc batteries such as a lead acid battery		N/A

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Clause	Requirement + Test	Result - Remark	Verdict
7.3.1.5	Estimated surface temperature at which internal short circuiting within the cell will occur that could lead to a thermal runaway condition.	Not used, the cells are heated until the thermal runaway achieved According to the Certification Requirement Decision: Test Method for Evaluating Thermal Runaway Fire Propagation in Battery. Holding temperature was not utilized during the test and the cell was continuously heated until thermal runaway occurred.	N/A
7.3.1.6	The cell was heated until thermal runaway has occurred.	Refer to Attachment C	C
	Another external heating method was used to cause cell thermal runaway		N/A
7.3.1.7	The cell's exterior surface temperature was measured	See Attachment B	C
7.3.1.8	The temperature at which the cell case vents due to internal pressure rise was documented.	See Table 3 and 4 See Attachment C, D	C
7.3.1.9	The temperature at the onset of thermal runaway was documented.	See Table 3 and 4 See Attachment C, D	C
	If cell venting occurs first, the cell was heated continuously until thermal runaway occurs.	See Attachment C	C
7.3.1.10	When using methods other than the heater method, the stresses were applied to the cell until thermal runaway occurs.		N/A
7.3.1.11	3 additional samples were tested using the same method and exhibited thermal runaway	See Table 3, 4 and 5 See Attachment C, D	C
7.4	Cell vent gas composition test		
7.4.1	Cell vent gas was generated and captured by forcing a cell into thermal runaway with the methodology developed in 7.3, inside a pressure vessel	Size of pressure vessel used: 100L Refer to Attachment E	C
	The test was initiated with an initial condition of atmospheric pressure and less than 1% oxygen by volume.	Refer to Attachment E Atmospheric pressure (psig):0.10 Oxygen concentration measured (% volume):0.20	C

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Clause	Requirement + Test	Result - Remark	Verdict

		Inert gas used: Nitrogen	
7.4.2	Cell vent gas composition was determined using Gas Chromatography (GC)	Refer to Table 8 Refer to Attachment E	C
	Hydrogen gas was measured	Refer to Table 8	C
	The initial atmospheric conditions prior to testing were noted.	Refer to attachment C	C
7.4.3	The lower flammability limit of the cell vent gas was determined on samples of the synthetically replicated gas mixture in accordance with ASTM E918, testing at both ambient and cell vent temperatures.	Refer to Table 9 and 10	C
7.4.4	The gas burning velocity of the synthetically replicated cell vent gas was determined in accordance with the Method of Test for Burning Velocity Measurement of Flammable Gases Annex in ISO 817.	Refer to Table 9 and 10	C
7.4.5	P_{max} of the synthetically replicated cell vent gas was determined in accordance with EN 15967.	Refer to Table 9 and 10	C
7.6	Cell Level Test Report Information		C
7.6.1	Minimum information provided in the report for items a) through m)		C
7.6.2	Minimum information of items a) through k) was provided in the report for flow battery		N/A
7.7	Performance – cell level test		C
7.7.1	a) Thermal runaway cannot be induced in the cell; and	Thermal runaway can be induced in the cell	F
	b) The cell vent gas does not present a flammability hazard when mixed with any volume of air, at both ambient and vent temperatures.	As a result of gas analysis, the gas generated from the cell were identified flammable	F

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Clause	Requirement + Test	Result - Remark	Verdict

Table 1 – Specified conditioning parameters			
Charging:		Discharging	
Current (CC), A	157A	Current (CC), A	157A
Standard full charge voltage, Vdc	3.65V	Voltage at start of discharge, Vdc	3.65V
End of charge current, A	15.7A	End of discharge voltage, Vdc	2.5V
Charging Test Ambient, °C	0 to 60°C	Discharging Test Ambient, °C	-30 to 60°C
Refer to Attachment A for charge/discharge profiles for each cell.			

Table 2 – Charge completion and cell test initiation times		
Cell Test Number	Charge Completion Date and Time	Cell test Date and Time
1	2023-11-14 07:22:32	2023-11-14 14:21:53
2	2023-11-15 07:53:51	2023-11-15 10:23:01
3	2023-11-15 07:59:30	2023-11-15 14:45:22
4	2023-11-16 09:02:33	2023-11-16 10:31:22
5	2023-11-22 08:54:08	2023-11-22 15:06:25

Table 3 - Test Initiation Details					
	Cell Test 1	Cell Test 2	Cell Test 3	Cell Test 4	Cell Test 5
Test Date	2023-11-14	2023-11-15	2023-11-15	2023-11-16	2023-11-22
Test Start Time	14:21:53	10:23:01	14:45:22	10:31:22	15:06:25
Initial Lab Temperature	23.8°C	21.1°C	24.4°C	24.4°C	21.4°C
Initial Relative Humidity	45.4%	34.9%	28.8%	37.0%	55.8%

Table 4 - Thermal Runaway Results					
	Cell Test 1	Cell Test 2	Cell Test 3	Cell Test 4	Cell Test 5
OCV at start of test, Vdc	3.439	3.491	3.518	3.538	3.503
Average Heating Rate, °C/min	5.5	5.5	5.5	5.5	5.5
Venting Time after the test start (hh:mm:ss)	0:28:17	0:28:25	0:28:22	0:28:05	0:31:46
Venting Temperature, °C	157	159	160	159	170
Thermal Runaway Time after the test start (hh:mm:ss)	0:47:30	0:46:54	0:47:20	0:47:02	0:45:46
Thermal Runaway Temperature, °C	254	250	251	249	244
Refer to Attachment C for surface temperature profiles during testing See attachment E for datasheets					

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Clause	Requirement + Test	Result - Remark	Verdict

Table 5 – Average Vent and Thermal Runaway Temperatures	
Average of Cell Vent Temperatures, °C	159
Average of Cell Thermal Runaway Temperatures, °C	251
#Averages of cell tests other than the gas analysis test	

Table 6 – Parameters Flow Battery
N/A

Table 7 – Results of Flammability Testing of Flow Battery Electrolyte
N/A

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Clause	Requirement + Test	Result - Remark	Verdict

Table 8 – Results of Gas Analysis (Excluding O ₂ and N ₂)			
Gas		Measured %	Component LFL ¹
Carbon Monoxide	CO	14.507	10.9
Carbon Dioxide	CO ₂	23.000	N/A
Hydrogen	H ₂	45.167	4.0
Methane	CH ₄	4.868	4.4
Acetylene	C ₂ H ₂	0.148	2.3
Ethylene	C ₂ H ₄	1.804	2.4
Ethane	C ₂ H ₆	0.805	2.4
Propadiene (Allene)	C ₃ H ₄	0.006	1.9
Propylene	C ₃ H ₆	2.256	1.8
Propane	C ₃ H ₈	1.379	1.7
-	C ₄ (Total)	2.029	N/A
-	C ₅ (Total)	0.447	N/A
-	C ₆ (Total)	0.021	N/A
1-Heptene	C ₇ H ₁₄	0.004	N/A
Benzene	C ₆ H ₆	0.018	1.2
Toluene	C ₇ H ₈	0.001	1.0
Dimethyl Carbonate	C ₃ H ₆ O ₃	3.340	N/A
Ethyl Methyl Carbonate	C ₄ H ₈ O ₃	0.198	N/A
Total	-	100.000	-

¹ Extracted LFL values from ISO 10156-2017

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Clause	Requirement + Test	Result - Remark	Verdict

Table 9 – Gas composition excluding the constituents with boiling points higher than 60°C ²			
Gas		Measured %	Component LFL
Carbon Monoxide	CO	15.05	10.9
Carbon Dioxide	CO ₂	23.85	N/A
Hydrogen	H ₂	46.85	4.0
Methane	CH ₄	5.05	4.4
Acetylene	C ₂ H ₂	0.15	2.3
Ethylene	C ₂ H ₄	1.87	2.4
Ethane	C ₂ H ₆	0.83	2.4
Propylene	C ₃ H ₆	2.34	1.8
Propane	C ₃ H ₈	1.43	1.7
Propadiene	C ₃ H ₄	0.01	1.9
-	C ₄ (Total)	2.10	N/A
-	C ₅ (Total)	0.46	N/A
Total	-	100.00	-

² The constituents with a higher boiling point were excluded for the flammability characteristic analysis as these components will turn into a liquid state at room temperature and will not release from the gas bottle as a homogenous mixture.

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

Table 10 – Properties of Vent Gas Analysis	
Lower Flammability limit at Ambient Temperature, 25°C (% vol in air)	6.91
Lower Flammability limit at Vent Temperature, [159 °C] (% vol in air)	5.90
Burning Velocity Measurement, S _u cm/sec	62.87
Maximum Pressure P _{max} , psig	101.42

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TABLE: Critical components information					
Object / part No.	Manufacturer/ trademark	Type / model	Technical data	Standard	Mark(s) of conformity
Cell Model	Xiamen Hithium Energy Storage Technology Co., Ltd	LFP71173207/314Ah	3.2V,314Ah	UL1973	UL (MH65937)
Separator	Shenzhen Senior Technology Material Co., Ltd	30140GMB0004	(Thickness)11±3µm by (Width)197.0±2mm by (Length)31670±400mm	-	-
Electrolyte	Henan Farnlet New Energy Technology Co.Ltd.	-	LIPF6/EC/VC/EMC/DMC	-	-
Case	Xiamen Zongling Precision Manufacturing Co., Ltd	71173	Material: Aluminum laminate film Thickness: 0.64±0.1mm (front) 0.8±0.1mm(side) 1.5±0.1mm(bottom) Case Dimensions: (Length) 174.70±0.5mm by (Width) 71.70±0.5mm by (Height) 204.47±0.5mm (Excluding terminal) 207.11±0.5mm (Including terminal)	-	-
Vent	Dongguan TengMei Metal Technology Co.,Ltd.	311101010037-ALMFX2	Material: Aluminium Opening pressure: 0.6±0.2Mpa	-	-

Attachment A: Cell Conditioning (Charge/discharge) Profiles - (Pages 17 through 19)

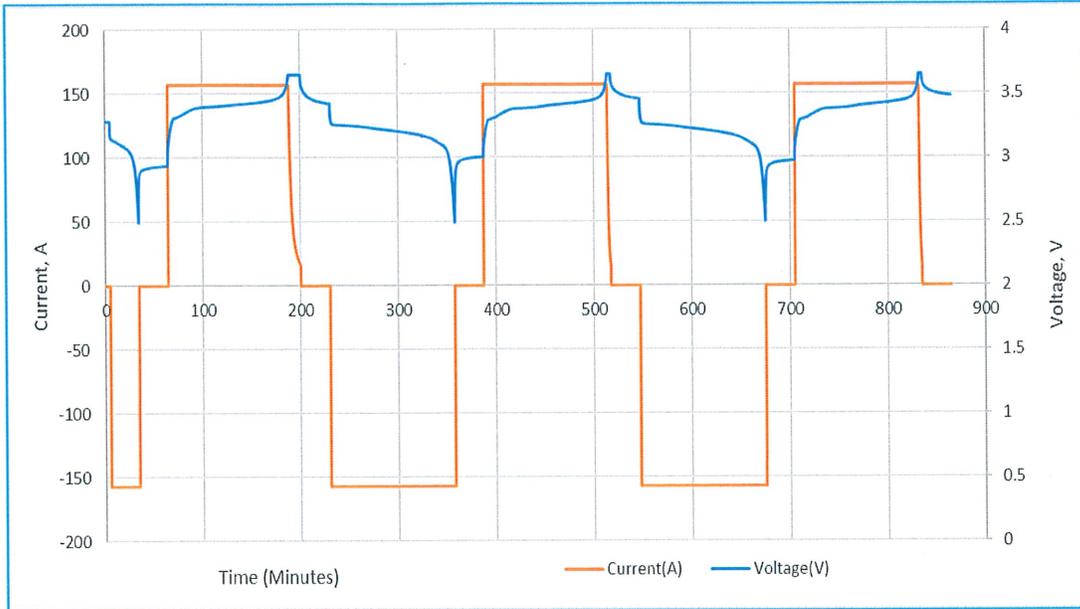


Figure 1: Cell 1 Conditioning (Charge/discharge) Profiles

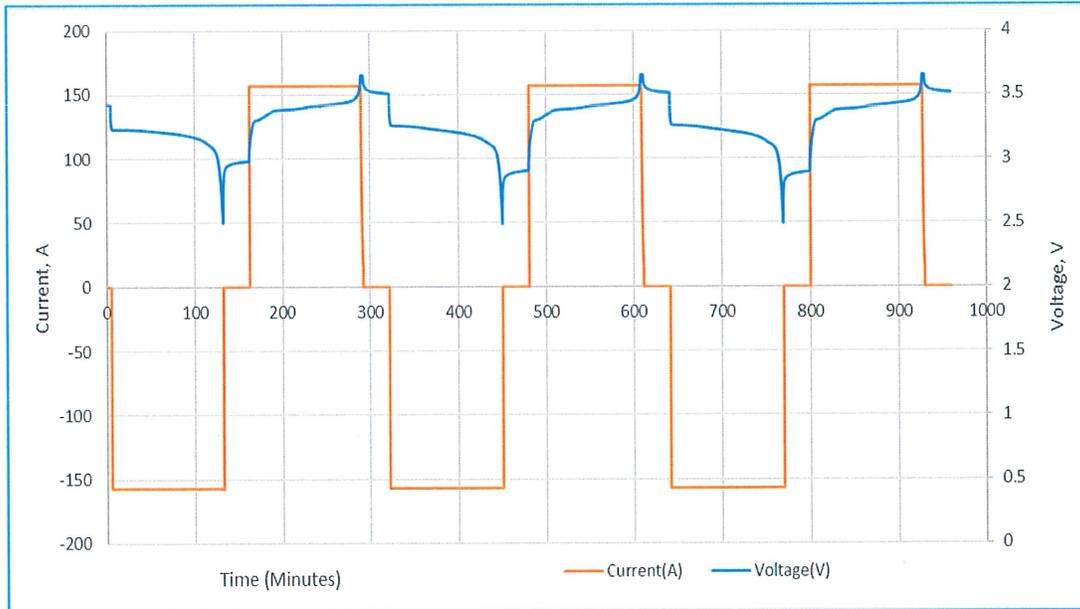


Figure 2: Cell 2 Conditioning (Charge/discharge) Profiles

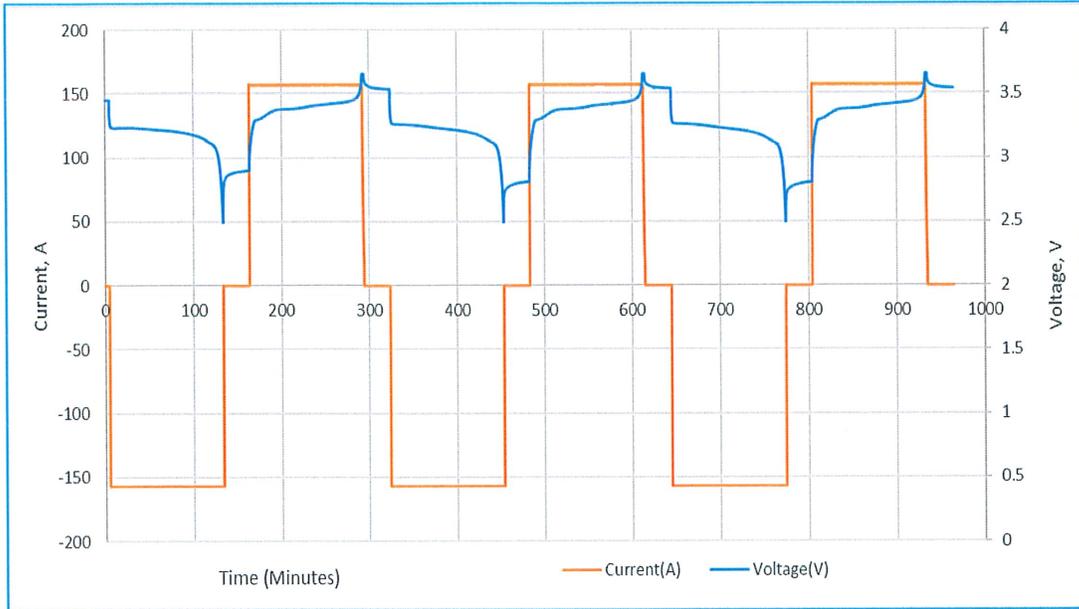


Figure 3: Cell 3 Conditioning (Charge/discharge) Profiles

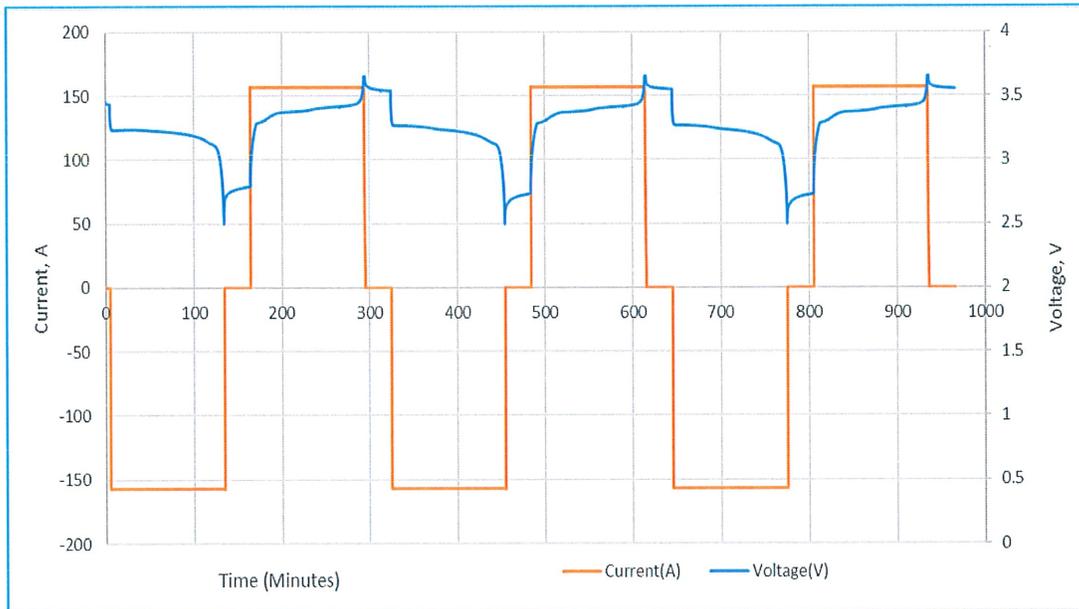


Figure 4: Cell 4 Conditioning (Charge/discharge) Profiles