Riskcon engineering

Preliminary Hazard Analysis

120 Houghton Road, Yanco 2703

ACEnergy Pty Ltd
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Preliminary Hazard Analysis

120 Houghton Road, Yanco 2703

ACEnergy Pty Ltd

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Quality Management

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Executive Summary

Background

ACEnergy Pty Ltd to has proposed to develop a new Battery Energy Storage System (BESS) located at 120 Houghton Road, Yanco. The Secretary's Environmental Assessment Requirements (SEARs) require the preparation of a Preliminary Hazard Analysis (PHA) in accordance with the Hazardous Industry Planning Advisory Paper (HIPAP) No. 4 and No. 6 (Ref. [1] and [2]).

The Project will involve the construction and operation of a BESS with a capacity of approximately 250 MW / 1,100 MWh, and associated infrastructure (i.e. Transformers, Control rooms, etc.). The Project will supply electricity to the national electricity grid via a transmission line that will connect to the existing Yanco substation.

This report supports a State Significant Development (SDD) Development Consent approval under Part 4, Division 4.7 of the *Environmental Planning and Assessment Act 1979* (SSD-67478479), as part of the Environmental Impact Statement (EIS) for the Project.

Conclusions

A hazard identification table was developed for the Yanco BESS project to identify potential hazards that may be present at the site as a result of operations or storage of materials. Based on the identified hazards, scenarios were postulated that may result in an incident with the potential for offsite impacts. Postulated scenarios were discussed qualitatively and any scenarios that would not impact offsite were eliminated from further assessment. Scenarios not eliminated were then carried forward for consequence analysis.

A review of the incidents carried forward for further analysis indicates that there were no observed offsite impacts; therefore, based on the analysis conducted, it is concluded that the risks at the site boundary are not considered to exceed the acceptable risk criteria; hence, the project would only be classified as potentially hazardous and would be permitted within the current land zoning for the site. It must be noted that the required bushfire assessment is provided under separate cover.

Recommendations

The following recommendations have been made as a result of the assessment:

- End-to-end spacing (short side) of BESS containerised units shall be a minimum of 3 m
- Back-to-back spacing (long side) of BESS containerised units shall be a minimum of 3 m
- Distance from electrical compartment surface to the wall of other containers 1.1 m.
- Spacing between BESS container accumulations (i.e. 4 containerised units) shall be a minimum of 3 m.
- The BESS containerised units shall be provided with the fire protection system specified by the BESS manufacturer.
- Prior to construction, the total area required for the BESS units shall be verified against the available space to demonstrate there is adequate area to achieve the required spacing.
- The vents shall not be located above battery packs within the BESS container.
- The vent covers of the BESS shall be constructed of non-combustible material.

- Prior to commissioning, the UL test data for the selected battery units shall be made available to the DPHI.

Table of Contents

Executive Summary i

1.0 Introduction 1

1.1 Background 1
1.2 Objectives 1
1.3 Scope of Services 2

2.0 Methodology 3

2.1 Multi-Level Risk Assessment 3
2.2 Risk Assessment Study Approach 4

3.0 Site Description 5

3.1 Site Location 5
3.2 Adjacent Land Uses 5
3.3 Sensitive Receptors 5
3.4 General Description 7
3.5 Detailed Description 8
3.5.1 Medium Voltage Power Station (MVPS) 8
3.5.2 Battery Storage 9
3.6 Quantities of Dangerous Goods Stored and Handled 10

4.0 Hazard Identification 12

4.1 Introduction 12
4.2 Properties of Dangerous Goods 13
4.3 Hazard Identification 13
4.4 Transportation and Storage of Toxics 14
4.5 Li-Ion Battery Fault, Thermal Runaway and Fire 14
4.6 Victorian Big Battery Fire Review 19
4.6.1 Available Space Review 21
4.6.2 Separation Review 22
4.7 Li-ion Battery Fire and Toxic Gas Dispersion 23
4.7.1 Carbon Dioxide 23
4.7.2 Carbon Monoxide 23
4.7.3 Fluoride Gases 24
4.8 Electrical Equipment Failure and Fire 24
4.9 Transformer Internal Arcing, Oil Spill, Ignition and Bund Fire 25
4.10 Transformer Electrical Surge Protection Failure and Explosion 25
4.11 Electromagnetic Field Impacts 26
4.11.1 Introduction 26
4.11.2 Existing Standards 26
4.11.3 Exposure Discussion 26

5.0 Conclusion and Recommendations 28

5.1 Conclusions 28
5.2 Recommendations 28

6.0 References 29

Appendix A Hazard Identification Table 30
A1. Hazard Identification Table 31

Appendix B UL9540 Test Report 32

Appendix C UL9540A Unit Test Report 33

Appendix D UL1973D Test Report 34

Appendix E CATL EnerC+ 306 Container Product Specifications 35

Appendix F UL9540 Certificate 36

Appendix G UL1973 Certification 37

Appendix H Condensed Aerosol Fire Extinguishing System JAD300-U01 38
Appendix I ACTI FIRE Certificate of Conformity 39
Appendix J SMA MV Power Station Model 4200 S2 40
Appendix K SMA Inverter Model SCS 3600-UP 41
Appendix L VBB Fire Report of Technical Findings 42
Appendix M Battery Spacing Review Document 43
Appendix N CATL Battery Spacing Review Documentation 44
Appendix O EVE Power Battery Spacing Review Documentation 45
Appendix P Ruipu Energy Battery Spacing Review Documentation 46

List of Figures

Figure 2-1: The Multi-Level Risk Assessment Approach 3
Figure 3-1: Site Location 5
Figure 3-2: Sensitive Receptors 6
Figure 3-3: Typical MVPS 9
Figure 3-4: Typical BESS Arrangement 10
Figure 3-5: Detailed Site Plan 11
Figure 4-1: Cathode and Anode of a Battery (Source Research Gate) 14
Figure 4-2: Temperature Rise of Lithium-Ion Battery Chemistries (Ref. [5]). 16
Figure 4-3: Test Site Diagram with Separation Distance (Top View) 17
Figure 4-4: Temperature Measured on Rear Wall During the Test 17
Figure 4-5: Detection Systems 18
Figure 4-6: Fire Suppression System Layout 18
Figure 4-7: CATL EnerC+ 0.25P BESS Layout Guide 20
Figure 4-8: BESS Layout 21
Figure 4-9: BESS Dimensioned Layout 22

List of Tables

Table 2-1: Level of Assessment PHA 3
Table 3-1: Maximum Classes and Quantities of Dangerous Goods Stored 10
Table 4-1: Properties* of the Dangerous Goods and Materials Stored at the Site 13
Table 4-2: BESS Layout Dimensions 19
Table 4-3: Minimum separation required between BESS Units 22
Table 4-4: EMF Sources and Magnetic Field Strength 26

Abbreviations

Abbreviation	Description
AC	Alternating Current
ADG	Australian Dangerous Goods Code
AS	Australian Standard
BESS	Battery Energy Storage System
DC	Direct Current
DGs	Dangerous Goods
ELF	Extra Low Frequency
EMF	Electric and Magnetic Field
ERPG	Emergency Response Planning Guideline
FCAS	Frequency Control Ancillary Services
FHA	Final Hazard Analysis
HF	Hydrogen Fluoride
HIPAP	Hazardous Industry Planning Advisory Paper
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IDLH	Immediately Dangerous to Life and Health
LFP	LiFePO4 (Lithium Iron Phosphate)
PHA	Preliminary Hazard Analysis
Pmpy	Per million per year
PV	Photovoltaic
SEARs	Secretary's Environmental Assessment Requirements
SEP	Surface Emissive Power
SEPP	State Environmental Planning Policy
SOC	State of Charge
SSDA	State Significant Development Application
STEL	Short Term Exposure Limit
VBB	Victorian Big Battery

1.0 Introduction

1.1 Background

ACEnergy Pty Ltd to has proposed to develop a new Battery Energy Storage System (BESS) located at 120 Houghton Road, Yanco. The Secretary's Environmental Assessment Requirements (SEARs) require the preparation of a Preliminary Hazard Analysis (PHA) in accordance with the Hazardous Industry Planning Advisory Paper (HIPAP) No. 4 and No. 6 (Ref. [1] and [2]).

The Project will involve the construction and operation of a BESS with a capacity of approximately 250 MW / 1,100 MWh, and associated infrastructure (i.e. Transformers, Control rooms, etc.). The Project will supply electricity to the national electricity grid via a transmission line that will connect to the existing Yanco substation.

This report supports a State Significant Development (SDD) Development Consent approval under Part 4, Division 4.7 of the *Environmental Planning and Assessment Act 1979* (SSD-67478479), as part of the Environmental Impact Statement (EIS) for the Project.

1.2 Objectives

The key objectives of this PHA are to:

- Complete the PHA according to the Hazardous Industry Planning Advisory Paper (HIPAP) No. 6 – Hazard Analysis (Ref. [2]).
- Assess the PHA results using the criteria in HIPAP No. 4 – Risk Criteria for Land Use Planning (Ref. [1]).

This PHA has been prepared in accordance with the Secretary's Environmental Assessment Requirements (SSD-67478479, dated 28/02/2024) as listed below.

Hazards	The EIS must include an assessment of the following:	
	• **Health** – an assessment of potential hazards and risks including but not limited to bushfires, spontaneous ignition, electromagnetic fields or the proposed grid connection infrastructure against the 'International Commission on Non-Ionizing Radiation Protection (ICNIRP) Guidelines for limiting exposure to Time-varying Electric, Magnetic and Electromagnetic Fields';	Section 4
	• **Bushfire** – identify potential hazards and risks associated with bushfires / use of bushfire prone land including the risks that a wind farm would cause bush fire and demonstrate compliance with *Planning for Bush Fire Protection 2019.* It has been noted that this PHA does not contain	Provided by RPS

	the bushfire assessment required by the SEARs and will be provided by RPS.	
	• **Dangerous Goods** – a preliminary risk screening completed in accordance with the State Environmental Planning Policy (Resilience and Hazards);	Section 3.6
	• **Battery Energy Storage System** - a Preliminary Hazard Analysis (PHA) must be prepared in accordance with 'Hazardous Industry Planning Advisory Paper No. 6 – Guideline for Hazard Analysis' (DoP, 2011) and Multi-Level Risk Assessment (DoP, 2011). The PHA must consider all recent standards and codes and verify separation distances to on-site and off-site receptors to prevent fire propagation and compliance with Hazardous Industry Advisory Paper No. 4, 'Risk Criteria for Land Use Safety Planning (DoP, 2011), include the key design parameters identified in the Project description.	Section 4

1.3 Scope of Services

The scope of work is to complete a PHA study for the proposed Yanco BESS project to be located 120 Houghton Road, Yanco, NSW, 2703.

2.0 Methodology

2.1 Multi-Level Risk Assessment

The Multi-Level Risk Assessment approach (Ref. [3]) published by the NSW Department of Planning, Housing and Infrastructure, has been used as the basis for the study to determine the level of risk assessment required. The approach considered the development in context of its location, the quantity and type (i.e. hazardous nature) of Dangerous Goods (DGs) stored and used, and the project's technical and safety management control. The Multi-Level Risk Assessment Guidelines are intended to assist industry, consultants and the consent authorities to carry out and evaluate risk assessments at an appropriate level for the project being studied.

There are three levels of risk assessment set out in Multi-Level Risk Assessment which may be appropriate for a PHA, as detailed in **Table 2-1**.

Table 2-1: Level of Assessment PHA

Level	Type of Analysis	Appropriate If:
1	Qualitative	No major off-site consequences and societal risk is negligible
2	Partially Quantitative	Off-site consequences but with low frequency of occurrence
3	Quantitative	Where 1 and 2 are exceeded

The Multi-Level Risk Assessment approach is schematically presented in **Figure 2-1**.

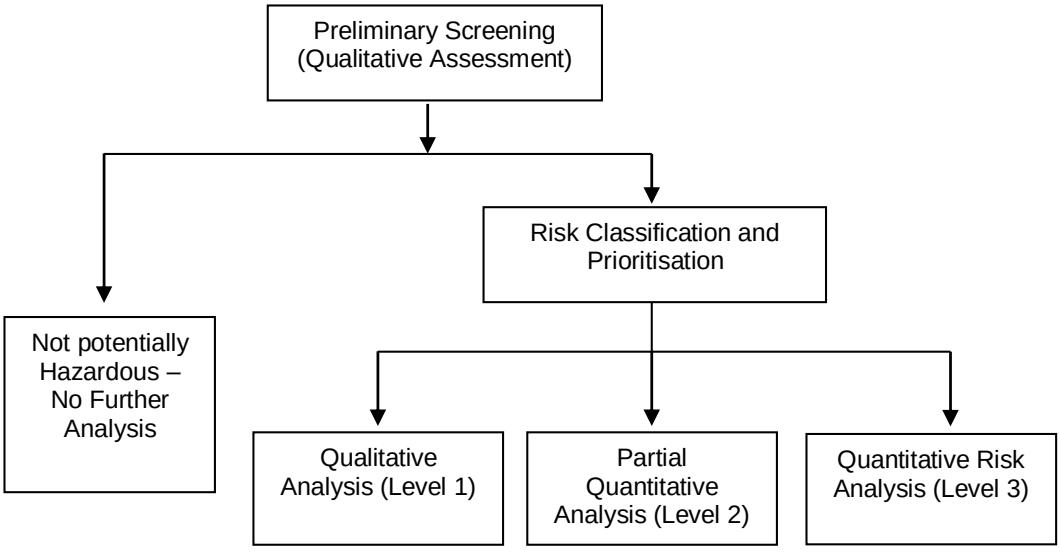


Figure 2-1: The Multi-Level Risk Assessment Approach

Based on the type of DGs to be used and handled at the proposed project, a **Level 1 Assessment** was selected for the Site. This approach provides a qualitative assessment of those DGs of lesser quantities and hazard, and a quantitative approach for the more hazardous materials to be used on-site. This approach is commensurate with the methodologies recommended in "Applying SEPP 33's" Multi Level Risk Assessment approach (DPHI, 2011).

2.2 Risk Assessment Study Approach

The methodology used for the PHA is as follows:

Hazard Analysis – A detailed hazard identification was conducted for the site facilities and operations. Where an incident was identified to have a potential off-site impact, it was included in the recorded hazard identification word diagram (**Appendix A**). The hazard identification word diagram lists incident type, causes, consequences and safeguards. This was performed using the word diagram format recommended in HIPAP No. 6 (Ref. [2]).

Each postulated hazardous incident was assessed qualitatively in light of proposed safeguards (technical and management controls). Where a potential offsite impact was identified, the incident was carried into the main report for further analysis. Where the qualitative review in the main report determined that the safeguards were adequate to control the hazard, or that the consequence would obviously have no offsite impact, no further analysis was performed. **Section 3.1** of this report provides details of values used to assist in selecting incidents required to be carried forward for further analysis.

Consequence Analysis – For those incidents qualitatively identified in the hazard analysis to have a potential offsite impact, a detailed consequence analysis was conducted. The analysis modelled the various postulated hazardous incidents and determined impact distances from the incident source. The results were compared to the consequence criteria listed in HIPAP No. 4 (Ref. [1]). The criteria selected for screening incidents is discussed in **Section 3.1**.

Where an incident was identified to result in an offsite impact, it was carried forward for frequency analysis. Where an incident was identified to not have an offsite impact, and a simple solution was evident (i.e. move the proposed equipment further away from the boundary), the solution was recommended, and no further analysis was performed.

Frequency Analysis – In the event a simple solution for managing consequence impacts was not evident, each incident identified to have potential offsite impact was subjected to a frequency analysis. The analysis considered the initiating event and probability of failure of the safeguards (both hardware and software). The results of the frequency analysis were then carried forward to the risk assessment and reduction stage for combination with the consequence analysis results.

Risk Assessment and Reduction – Where incidents were identified to impact offsite and where a consequence and frequency analysis was conducted, the consequence and frequency analysis for each incident were combined to determine the risk and then compared to the risk criteria published in HIPAP No. 4 (Ref. [1]). Where the criteria were exceeded, a review of the major risk contributors was performed, and the risks reassessed incorporating the recommended risk reduction measures. Recommendations were then made regarding risk reduction measures.

Reporting – On completion of the study, a draft report was developed for review and comment. A final report was then developed, incorporating the comments received for submission to the regulatory authority.

3.0 Site Description

3.1 Site Location

The Project is located at 120 Houghton Road Yanco 2703. The site is within the Leeton Shire Regional Local Government Area (LGA), approximately 1.1 km northeast of the township of Yanco. The Transgrid Yanco Substation borders the Project Area to the east and RU1 primary production land to the North, South and West.

Figure 3-1 shows the regional location of the site in relation to Yanco. The conceptual project layout has been provided in **Figure 3-5**.



Figure 3-1: Site Location

3.2 Adjacent Land Uses

The land is located in a regional / rural area surrounded by the following land used which are adjacent to the site:

- North – RU1 Primary Production
- South – RU1 Primary Production
- East – SP2 Electricity and Transmission Distribution
- West - RU1 Primary Production

3.3 Sensitive Receptors

The nearest residential locations are as follows and shown in **Figure 3-2**.

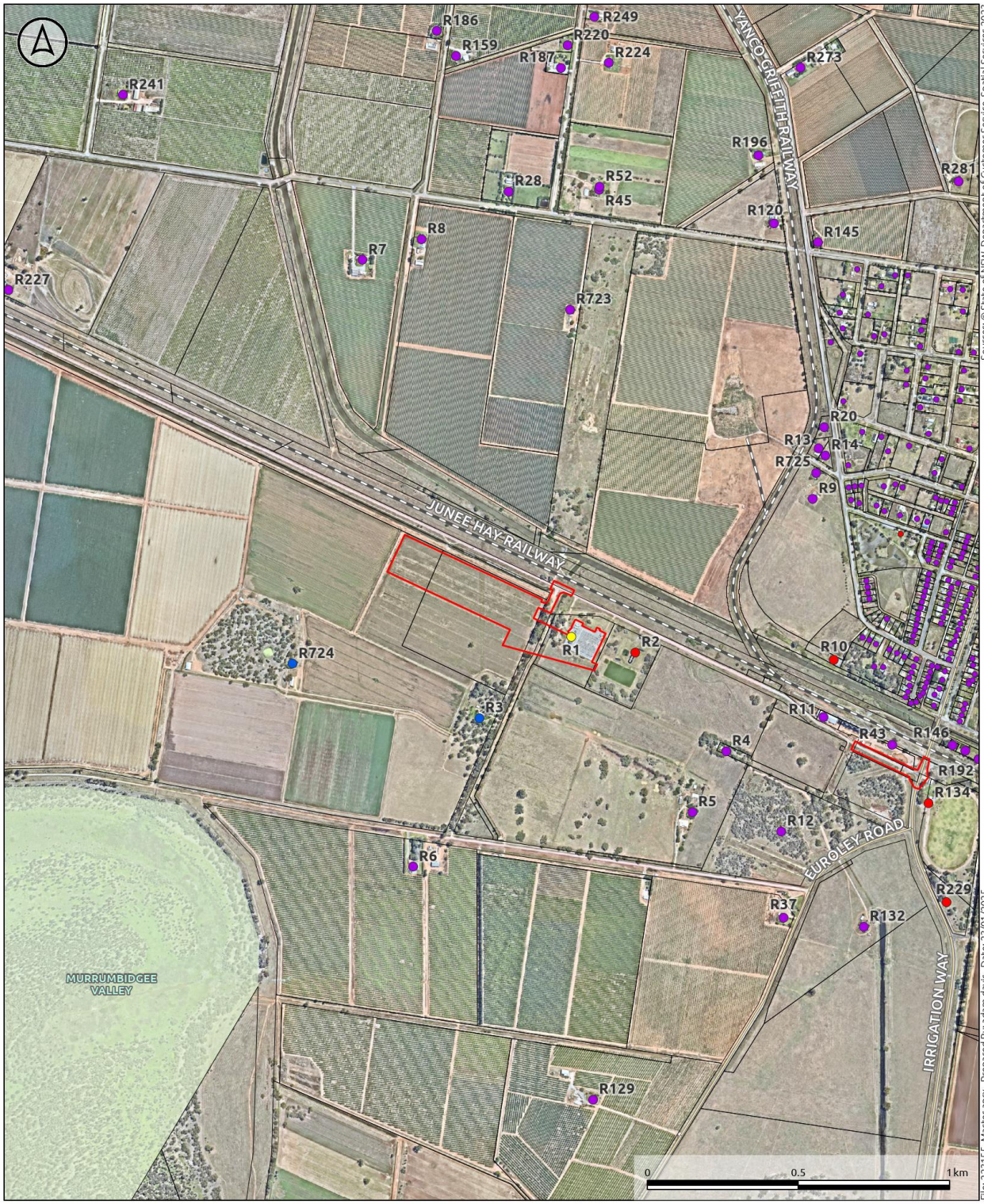


Figure 3-2: Sensitive Receptors

3.4 General Description

The Project will involve the construction, operation and decommissioning of a Battery Energy Storage System (BESS) and associated infrastructure. The conceptual Project includes:

- Operation:
  - BESS with a delivery capacity of up to 250 MW and a storage capacity of 1,100 MWh.
  - Electricity infrastructure:
    - Enclosed lithium-ion batteries.
    - Power Conversion Units (PCU) and associated transformers.
    - Underground power and fibre optic cabling interconnecting the equipment.
    - Grid connection equipment including switchgear, protection and control equipment, metering, reactive power equipment, filtering equipment, auxiliary transformers and enclosures.
    - Underground or overhead 132 kV High Voltage sub-transmission lines to connect Yanco Substation to the BESS and associated structures.
    - Earthing and lightning protection systems.
    - Works will be required within the existing Transgrid substation to enable connection of the BESS to the grid. These works are noted in the application as they are related to the project but it is expected that Transgrid will perform their assessments, approval and setting of conditions for the works.
  - On-site permanent supporting infrastructure:
    - Site access road and entry including the provision of a new site access from Hume Road to the east.
    - Acoustic barriers.
    - Site office, storage area/enclosure, internal access tracks, on-site parking, security fencing, CCTV, and temporary construction laydown area.
    - Operations and Maintenance (O&M) Facility including control room, meeting facilities, storage facilities, benching and earthing, parking, ablutions buildings, septic, static water supply, waste management facilities, lighting and maintenance facility.
    - Vegetation screening.
  - Off-site supporting infrastructure:
    - Road upgrade at Houghton Rd - Irrigation Way intersection.
    - Existing public road and communications network.
  - Development footprint of approximately 10.3 ha.
  - The site shall operate 24 hours a day 7 days a week with up to 5 personnel.
  - 5 light vehicles per day
  - Operational life of 23 years unless updated to extend operational lifetime.
- Construction:

- Total duration of 8 months with a peak period of 4.5 months and up to 70 personnel per day.
- Hours of operation between 7 am to 6 pm weekdays and 8 am to 1 pm Saturdays (no operation on Sundays and NSW public holidays).
- Key stages
  - Establishment, drainage, roads and fencing.
  - Footing installation.
  - Delivery and installation.
  - Steel platform installation.
  - MVPS and BESS delivery and installation.
  - Control room, transformer and switch gear delivery and installation.
  - Commissioning and decommissioning.
- Average of 8 heavy vehicles per day.
- Maximum of 14 heavy vehicles per day during peak construction period.
- Average of 16 light vehicles per day
- Maximum of 25 light vehicles per day during peak construction period.

- Decommissioning:
  - Components above ground and less than one metre below ground would be removed and land rehabilitated to pre-development conditions.

3.5 Detailed Description

The purpose of the project is to provide dispatchable energy to the NSW grid and contribute towards the goals of the NSW government's NSW Electricity Infrastructure Roadmap.

The electricity will be capable of storage in a 250MW / 1,100 MWh BESS which can be dispatched based on electricity demand fluctuations, providing the opportunity for greater supply dispatch flexibility when electricity demand is highest. This is enabled by the fast response times achievable through lithium-ion battery storage. The Project will have the capacity to discharge up to 250 megawatts (MW) of power for 4 hours resulting in a storage of 1,100 MWh.

3.5.1 Medium Voltage Power Station (MVPS)

The MVPS house transformers and inverters which will be sited adjacent to the BESS units. There will be approximately 88 SMA MVPS model 4200-S2 installed throughout the project area which typically comprises:

1. 1 x transformers
2. 1 x inverters

The inverters convert the Direct Current (DC) to Alternating Current (AC), while the transformers increase the voltage from Low Voltage to a Medium or High Voltage, as required for the electricity grid connection. MPVS are a compact, containerised product, with each unit measuring approximately 2.5 m wide by 3 m high, with a depth of 6 metres. **Figure 3-3** provides an example of a typical MVPS.



Figure 3-3: Typical MVPS

3.5.2 Battery Storage

352 CATL BESS units will be located within the site compound, laydown and substation footprint area. The BESS converts electrical energy into chemical energy and stores the energy internally. It may also provide additional network support such as Frequency Control Ancillary Services (FCAS) assisting with transmission network grid stability. A typical BESS is shown in **Figure 3-4**.



Figure 3-4: Typical BESS Arrangement

3.6 Quantities of Dangerous Goods Stored and Handled

The classes and quantities of DGs to be approved in the project are summarised **Table 3-1**. The quantities of DG class C1 provided in **Table 3-1** is indicative and will need to be updated once disclosed. The number was adapted from another BESS project with a similar scale and does not accurately represent the Yanco BESS project. Additionally, the SEPP threshold of the individual classes has been provided for the purposes of the SEARs.

As the site exceeds the discharge capacity threshold of 30 MW the site is subject to the SEPP-RH and a PHA is required.

Table 3-1: Maximum Classes and Quantities of Dangerous Goods Stored

Area	Class	Description	Quantity	SEPP Threshold
BESS	9	Lithium Batteries	12,672 T	N/A
MVPS Transformer	C2	Transformer oils	3,259 L	N/A
Substation Transformer	C2	Transformer oils	66,668 L*	N/A
Control room generator	C1	Diesel	80,000 L	N/A
Discharge Capacity	-	-	250 MW	30 MW

*Approximately 33,334 L per transformer.

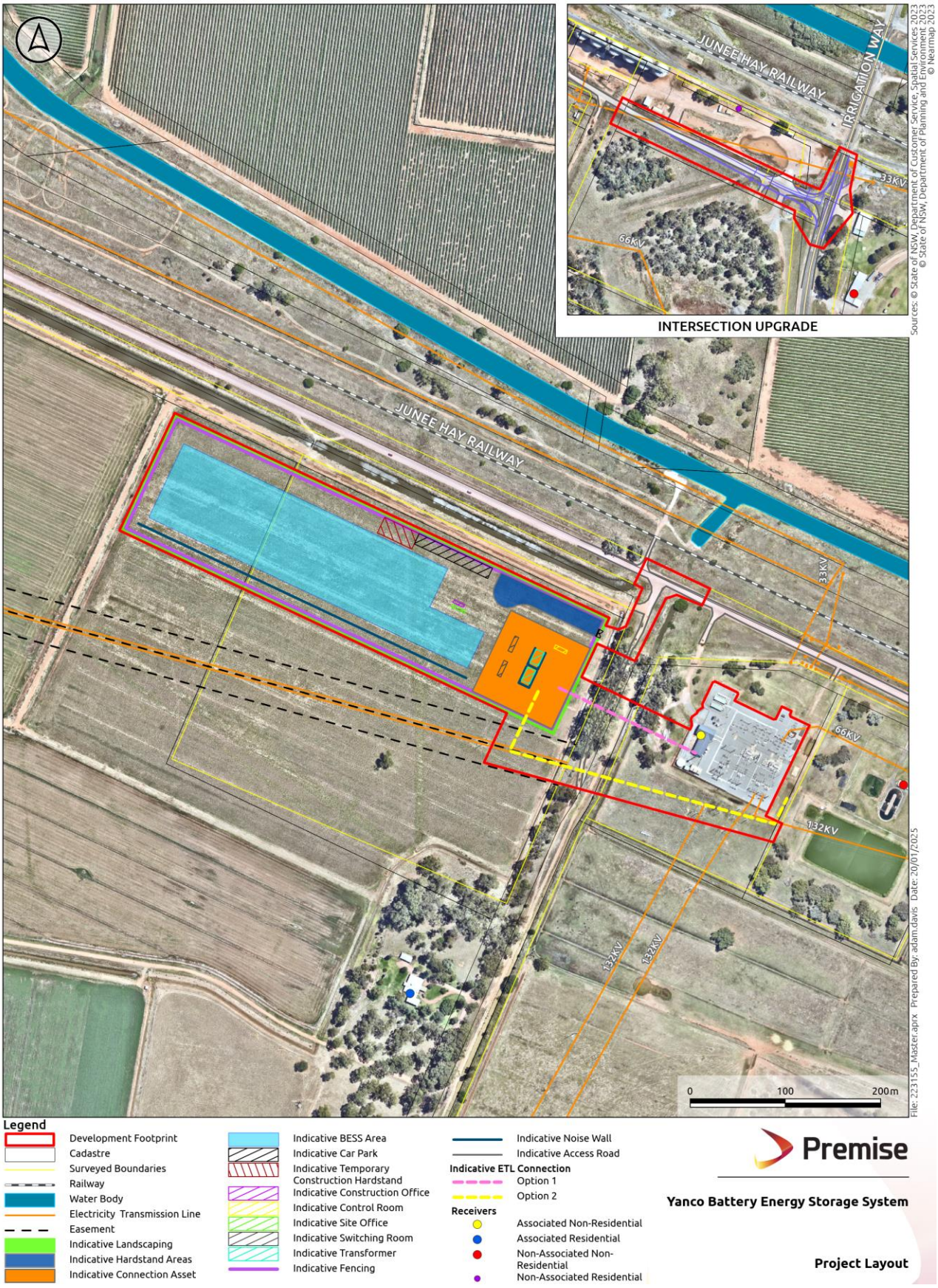


Figure 3-5: Detailed Site Plan

4.0 Hazard Identification

4.1 Introduction

A hazard identification table has been developed and is presented at **Appendix A**. This table has been developed following the recommended approach in Hazardous Industry Planning Advisory Paper No. 6, Hazard Analysis Guidelines (Ref. [2]). The Hazard Identification Table provides a summary of the potential hazards, consequences and safeguards at the site. The table has been used to identify the hazards for further assessment in this section of the study. Each hazard is identified in detail and no hazards have been eliminated from assessment by qualitative risk assessment prior to detailed hazard assessment in this section of the study.

In order to determine acceptable impact criteria for incidents that would not be considered for further analysis, due to limited impact offsite, the following approach has been applied:

- *Fire Impacts* - It is noted in Hazardous Industry Planning Advisory Paper (HIPAP) No. 4 (Ref. [1]) that a criterion is provided for the maximum permissible heat radiation at the site boundary (4.7 kW/m^2) above which the risk of injury may occur and therefore the risk must be assessed. Hence, to assist in screening those incidents that do not pose a significant risk, for this study, incidents that result in a heat radiation less that at 4.7 kW/m^2, at the site boundary, are screened from further assessment.

  Those incidents exceeding 4.7 kW/m^2 at the site boundary are carried forward for further assessment (i.e. frequency and risk). This is a conservative approach, as HIPAP No. 4 (Ref. [1]) indicates that values of heat radiation of 4.7 kW/m^2 should not exceed 50 chances per million per year at sensitive land uses (e.g. residential). It is noted that the closest residential area is several kilometres from the closest BESS, hence, by selecting 4.7 kW/m^2 as the consequence impact criteria the assessment is considered conservative.

- *Explosion* - It is noted in HIPAP No. 4 (Ref. [1]) that a criterion is provided for the maximum permissible explosion over pressure at the site boundary (7 kPa) above which the risk of injury may occur and therefore the risk must be assessed. Hence, to assist in screening those incidents that do not pose a significant risk, for this study, incidents that result in an explosion overpressure less than 7 kPa, at the site boundary, are screened from further assessment. Those incidents exceeding 7 kPa, at the site boundary, are carried forward for further assessment (i.e. frequency and risk). Similarly, to the heat radiation impact discussed above, this is conservative as the 7 kPa value listed in HIPAP No. 4 relates to residential areas, which are over several kilometres from the closest BESS.

- *Toxicity* – Toxic bi-products of combustion may be generated by a BESS fire; hence, toxicity has been assessed with criteria based upon the Emergency Response Planning Guidelines (ERPG).

- *Property Damage and Accident Propagation* - It is noted in HIPAP No. 4 (Ref. [1]) that a criterion is provided for the maximum permissible heat radiation/explosion overpressure at the site boundary (23 kW/m^2/14 kPa) above which the risk of property damage and accident propagation to neighbouring sites must be assessed. Hence, to assist in screening those incidents that do not pose a significant risk to incident propagation, for this study, incidents that result in a heat radiation heat radiation less than 23 kW/m^2 and explosion over pressure less than 14 kPa, at the site boundary, are screened from further assessment. Those incidents

exceeding 23 kW/m^2 at the site boundary are carried forward for further assessment with respect to incident propagation (i.e. frequency and risk).

- *Societal Risk* – HIPAP No. 4 (Ref. [1]) discusses the application of societal risk to populations surrounding the Project. It is noted that HIPAP No. 4 indicates that where a development proposal involves a significant intensification of population, in the vicinity of such a project, the change in societal risk needs to be taken into account. In the case of the project, there is currently no significant intensification of population around the proposed site; hence, societal risk has not been considered in this assessment.

4.2 Properties of Dangerous Goods

The type of DGs and quantities stored and used at the site has been described in **Section 3**. **Table 4-1** provides a description of the DGs to be stored and handled at the site, including the Class and the hazardous material properties of the DG Class.

Table 4-1: Properties* of the Dangerous Goods and Materials Stored at the Site

Class	Hazardous Properties
9 – Miscellaneous DGs	Class 9 substances and articles (miscellaneous dangerous substances and articles) are substances and articles which, during transport present a danger not covered by other classes. Releases to the environment may cause damage to sensitive receptors within the environment. It is noted that the Class 9s stored within this project are lithium-ion batteries which may undergo thermal runaway (i.e. escalating reaction resulting in heat which ultimately leads to failure of the battery and a fire).
Combustible Liquids	Combustible liquids are typically long chain hydrocarbons with flash points exceeding 60.5^{o}C. Combustible liquids are difficult to ignite as the temperature of the liquid must be heated to above the flash point such that vapours are generated which can then ignite. This process requires either sustained heating or a high-energy ignition source.

* The Australian Code for the Transport of Dangerous Goods by Road and Rail (Ref. [4]

4.3 Hazard Identification

Based on the hazard identification table presented in **Appendix A**, the following hazardous scenarios have been developed:

- Transportation and storage of tixics.
- Li-ion battery fault, thermal runaway and fire.
- Victorian Big Battery fire review.
- Li-ion battery fire and toxic gas dispersion.
- Electrical equipment failure and fire.
- Transformer internal arcing, oil spill, ignition and bund fire.
- Transformer electrical surge protection failure and explosion
- Electromagnetic field Impacts.

Each identified scenario is discussed in further detail in the following sections.

4.4 Transportation and Storage of Toxics

The Yanco BESS facility does not store or transport toxic DGs during the construction phase, operational phase and decommissioning stage. Hence, risks associated with toxic goods do not apply to this project. Due to this incident has not been carried forward for further analysis.

4.5 Li-Ion Battery Fault, Thermal Runaway and Fire

Lithium ion (Li-ion) batteries are composed of a metallic anode and cathode which allows for electrons released from the anode to travel to the cathode where positively charged ions in the solute migrate to the cathode and are reduced. The flow of electrons provides the source of energy which is discharged from a battery and used for work. In a Li-ion battery, the lithium metal composites (a composite of lithium with other metals such as cobalt, manganese, nickel, or any combination of these metals) oxidises (loses an electron) becoming a positively charged ion in solution which migrates through the battery separator to the cathode. At the same time, the lost electron travels through the circuit to the cathode. The lithium ions in solution then recombine with the electron at the cathode forming lithium metal within the cathodic metal composite. This process is shown in **Figure 4-1**.

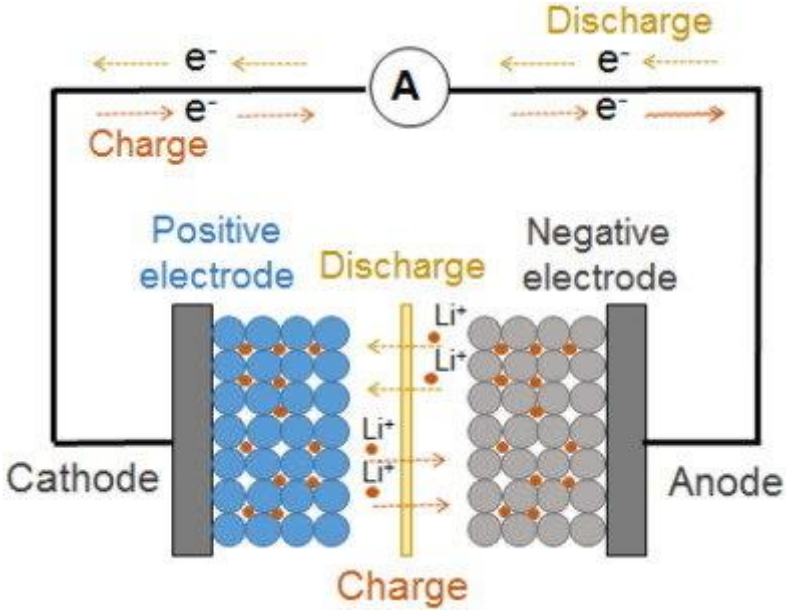


Figure 4-1: Cathode and Anode of a Battery (Source Research Gate)

Initial lithium batteries were designed around lithium metal (i.e. no composite structure) due to the high energy density yielded by the metal. However, when overcharging a battery, lithium ions can begin to plate on the anode in the form of lithium dendrites. Eventually, the dendrites pierce the separator within the battery resulting in a short of the battery which could result in heat, fire, or explosion of the battery. The technology evolved to move away from lithium metal to lithium ions (held within composite materials) which reduced the incidence of lithium dendrites forming resulting in an overall safer battery.

Despite the improvement in battery technology, there are several degradation mechanisms that are still present within the battery which can result in thermal runaway. These include:

- Chemical reduction of the electrolyte at the anode
- Thermal decomposition of the electrolyte

- Chemical reduction of the electrolyte at the cathode
- Thermal decomposition by the cathode and the anode
- Internal short circuit by charge effects

These effects arise primarily as a result of high discharge, overcharging, or water ingress into the battery which results in a host of bi-products being formed within the battery during charge and discharge cycles.

As a result, Li-ion batteries are equipped with several safety features to prevent the batteries from charging or discharging at voltages which result in battery degradation, leading to shorting of the battery and thermal runaway. Safety features generally include:

- Shut-down separator (for overheating)
- Tear-away tab (for internal pressure relief)
- Vent (pressure relief in case of severe outgassing)
- Thermal interrupt (overcurrent/overcharging/environmental exposure)

These features are designed to prevent overcharging or excessive discharge, pressurisation arising from heat generated at the anode or from battery contamination. Protection techniques for Li-ion batteries are standard; hence, the potential for thermal runaway to occur in normal operation is very low with the only exceptions being due to manufacturing faults or battery damage (i.e. battery cell is ruptured as this can short circuit the battery resulting in thermal runaway).

In terms of physical damage, the batteries are contained within in modules which are located within a fenced area; therefore, there is a low potential for damage to occur to the batteries which may initiate an incident.

A review of the batteries proposed to be used as part of this project indicates the battery chemistry is lithium-Ion phosphate (LiFePO4, or simply LFP) which are considered to be one of the safest battery chemistries within the industry. When exposed to external heat the thermal rise of typical lithium-ion battery chemistries is 200-400 ^{o}C / min resulting thermal run away and fire which can then propagate to adjacent batteries escalating the incident to a full container fire. For LFP batteries, the thermal rise of the batteries at peak is 1.5^{o}C/min which results in a gradual temperature rise and does not result in fire and thus incident propagation to other batteries. The thermal rise of various battery chemistries is provided in **Figure 4-2** with a zoomed in temperature rise for LFP provided in the top right of **Figure 4-2**. The stability of the batteries is due to the cathode which does not release oxygen therefore preventing violent redox reactions resulting in rapid temperature rise as the oxygen oxides the electrolyte.

Additional testing for shock and damage to batteries (i.e. nail puncture test) has been shown that LFP batteries when punctured through membranes which typically results in a shorting of the battery and fire does not result in ignition of the battery demonstrating that the battery chemistry is protected against shock damage.

In the event that LFP chemistries do ignite by artificial means, the combustion by products release carbon dioxide which reduces the oxygen concentration within a confined space reducing the combustion rate. Finally, the containers are fitted with a fire suppression system which will activate to suppress and control a fire preventing escalation to other battery units.

In addition to this, manufacturers and integrators can implement different means of preventing battery ignition or controlling if it occurs (such as physical construction arrangements, battery monitoring, heat detection, etc). These are implemented on a system-by-system basis and are specific to the system needs.

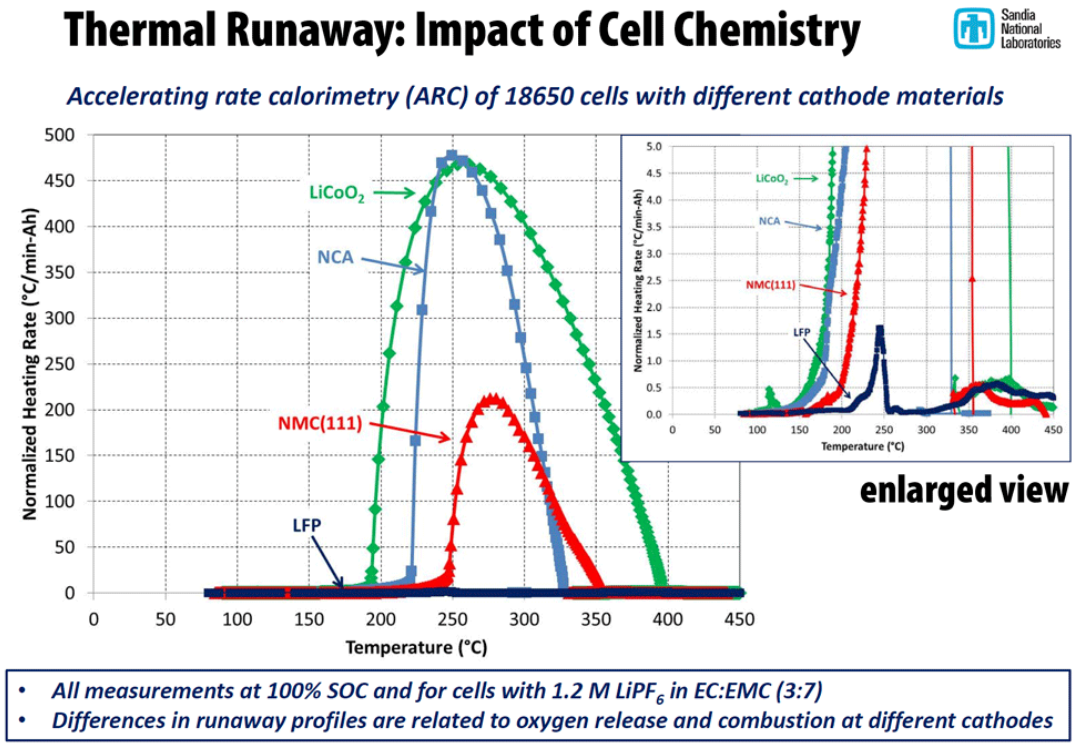


Figure 4-2: Temperature Rise of Lithium-Ion Battery Chemistries (Ref. [5]).

The preliminary battery product proposed for the Yanco project is CATL EnerC+ 0.25P. The UL9540A report (Appendix B) for this product demonstrates that when thermal runaway is triggered in one cell in a BESS container, the heat generated would neither be transferred to all cells within one battery module, nor from the test module to adjacent ones. This is attributed to the nature of LFP technology as well as the sheer mass of the battery module (heavier objects have higher thermal capacity).

The UL9540A report also supports the findings that the temperature rise caused on a nearby object by thermal runaway within one module is negligible. To be specific, **Figure 4-3** shows the test setup where the rear wall is distanced 200 mm from the test battery racks.

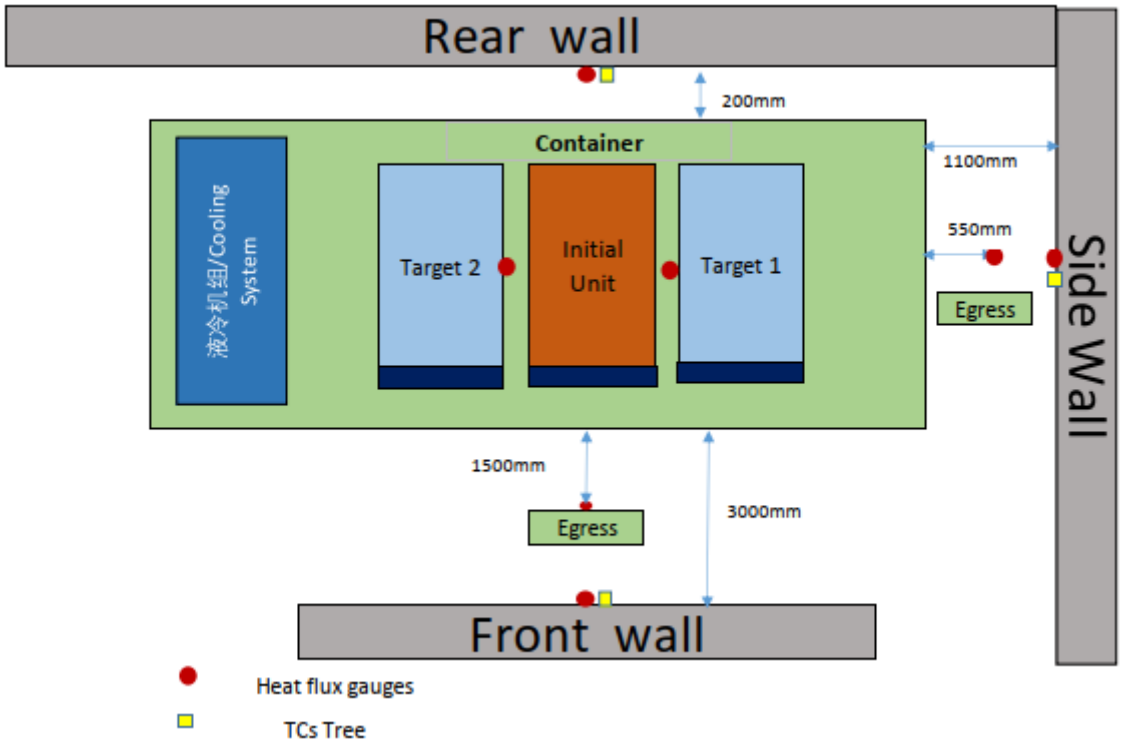


Figure 4-3: Test Site Diagram with Separation Distance (Top View)

The temperatures on the rear wall during the thermal runaway test are recorded by thermal couples across the wall surface facing the test battery racks. The recorded temperature rises are no more than 30 ^{o}C as shown in Figure 4-4.

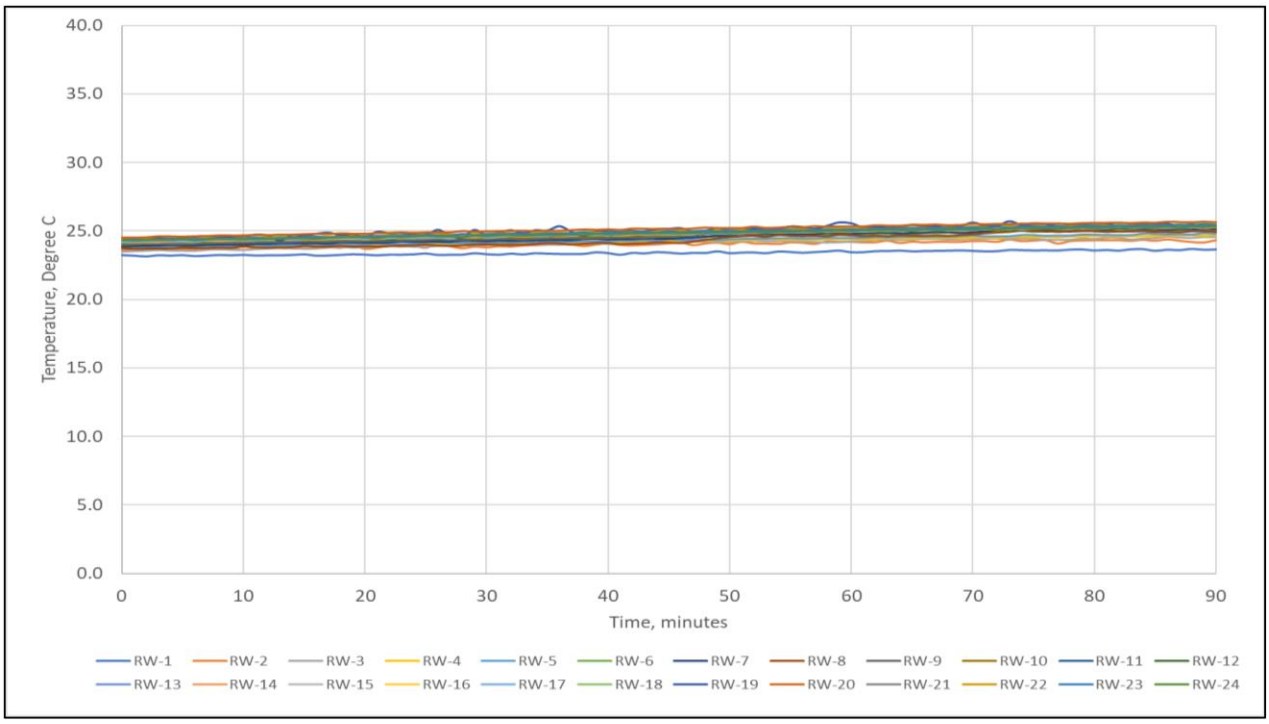


Figure 4-4: Temperature Measured on Rear Wall During the Test

There were also no external flames observed during the UL9540A test. All findings and observations combined mean the proposed LFP batteries would not cause fire due to thermal runaway.

Although the LFP technology does not cause fire, there can be a few circumstances where battery modules catch fire due to leaking coolant or electric faults. In those cases, fire will be constrained by the metal enclosure. The BESS container wall has been tested to this scenario. The report (**Appendix C**) shows that the container wall remains intact after sustaining heating in a furnace to the temperatures intended for use.

Furthermore, each container also has multiple built-in fire protection devices that work collaboratively, including smoke and thermal sensors, combustible gas detector, pressure relief system, and aerosol fire extinguishing system outlined in **Figure 4-5**, **Figure 4-6 and** (**Appendix D**). Therefore, a container will automatically suppress an internal fire in the first instance. The diagram below provided by CATL shows a typical arrangement for fire safety devices within a BESS container.

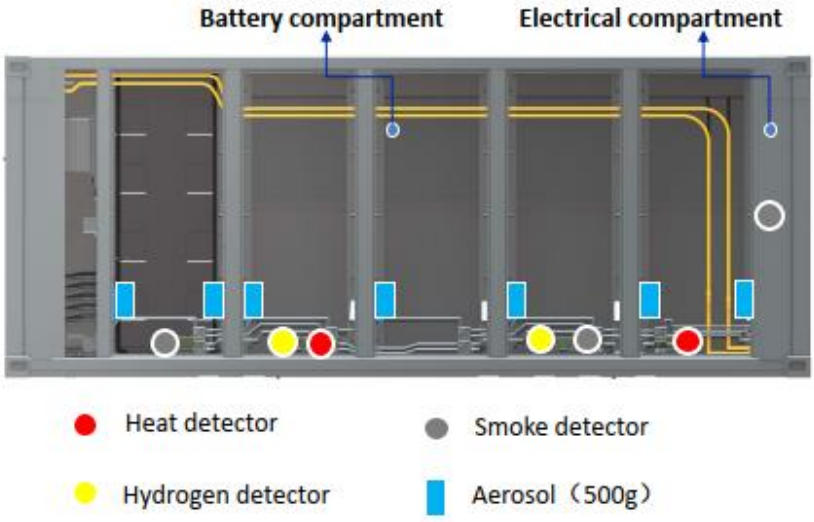


Figure 4-5: Detection Systems

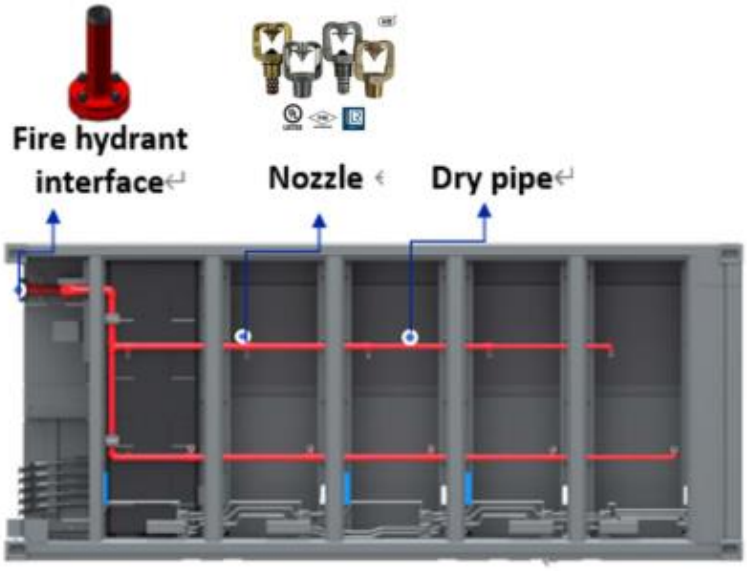


Figure 4-6: Fire Suppression System Layout

Apart from UL9540A, CATL Ener C+ 0.25P battery holds UL9540 and UL1973 certificates (see **Appendix F, G**). In addition, the product's NFPA-855 Compliance Guide (**Appendix H**) demonstrates fire-related compliance with NFPA-855 standards. These certificates collectively demonstrate that thermal runaway on the chosen LFP BESS product does not propagate from one module to another.

In conclusion, the LFP technology does not cause fire during thermal runaway. Should fire be developed within one CATL EnerC+ 0.25P BESS container it would not transfer to nearby containers due to the fire safety design features; hence, this incident has not been carried forward for further analysis.

4.6 Victorian Big Battery Fire Review

Notwithstanding the findings of **Section 4.4**, it is necessary to review recent large-scale BESS fires to determine whether similar incidents could occur with the Yanco BESS.

The Yanco BESS has thoroughly considered the separation distance considering fire safety, and operation and maintenance. The fire safety assessment is essentially around heat transfer which has been discussed in detail in **Section 4.4**.

The Yanco BESS preliminary design is based on the installation requirements of CATL EnerC+ 0.25P BESS. **Figure 4-7** shows the CATLs approved BESS installation layout, which has considered fire propagation, the thermal test result of the module thermal runaway and heat flux assessment from the UL9540A report (**Appendix C**). **Table 4-2** outlines the dimensions of the BESS layout in **Figure 4-7** (**Appendix E**) . The BESS configuration for the site is summarised in **Figure 4-9** which shows the conformity of the layout outlined by CATL requirements.

Table 4-2: BESS Layout Dimensions

BESS Layout Dimensions	L1 (m)	L2 (m)	L3 (m)	L4 (m)	L5 (m)
Minimum Acceptable by Manufacturer	3	3	3	1.1	3
Recommended by Manufacturer	3.5	3	3.5	1.1	3.5

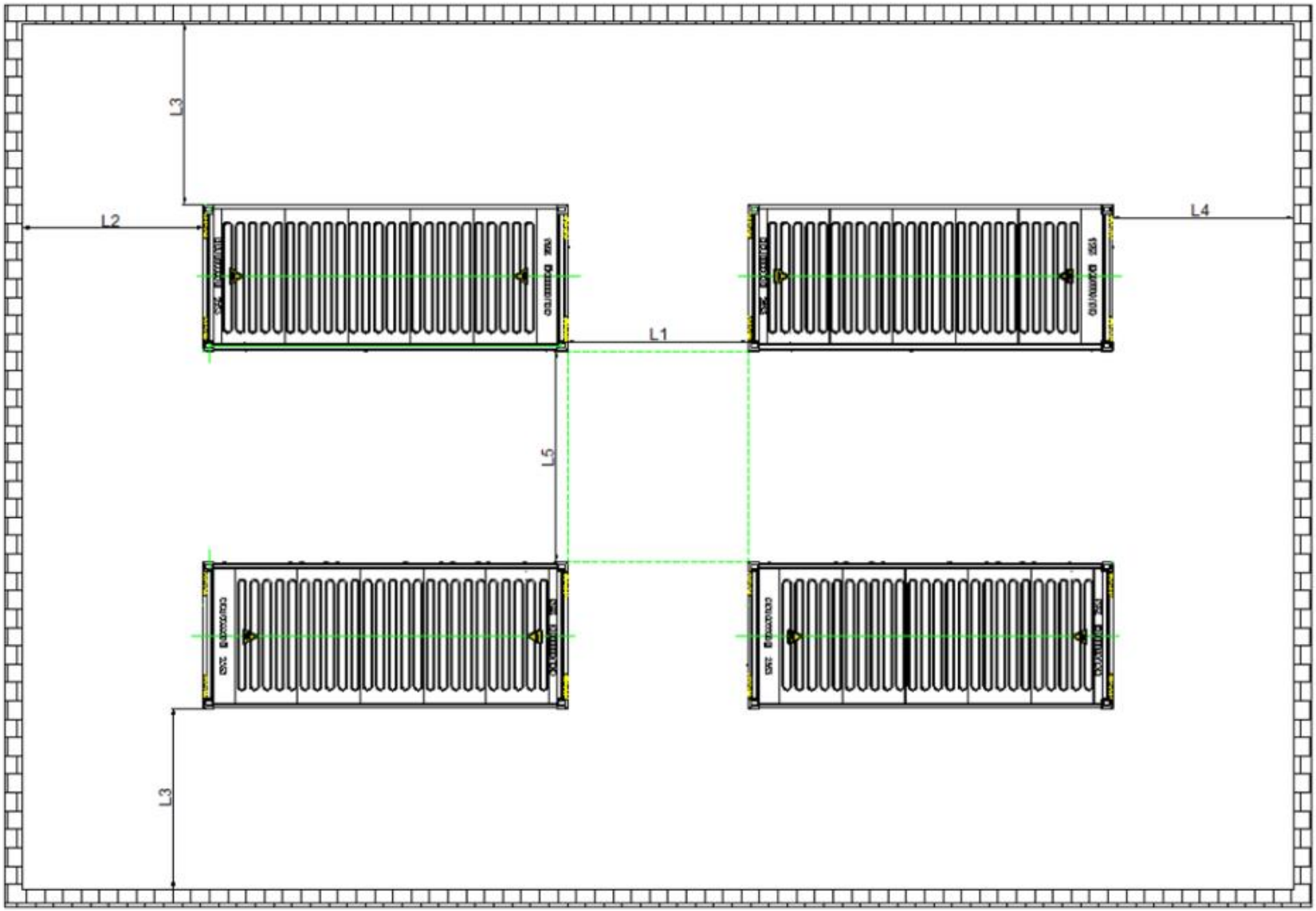


Figure 4-7: CATL EnerC+ 0.25P BESS Layout Guide

The Victorian Big Battery (VBB) also has a back-to-back layout. According to the independent investigation report on its fire incidence (**Appendix L**), the back-to-back layout was not the cause. The main reason for fire propagation was strong wind blowing flames from one Megapack into the unprotected vent atop of an adjacent Megapack which resulted in the ignition of the plastic fan which was able to impact the battery modules directly beneath the fan.

Lessons learnt from the VBB incident results in fire safety precautions on the design of the Yanco BESS. The vent of the containers is to be constructed of metal instead of plastic and covered by a metallic mesh shield. Furthermore, the placement of the fans shall be such that batteries or flammable materials shall not be located directly beneath ventilation openings.

To ensure the above are captured the following recommendations have been made:

- The vent covers of the BESS shall be constructed of non-combustible material.
- The vents shall not be located above battery packs within the BESS container.

4.6.1 Available Space Review

An additional review has been conducted to demonstrate that there is sufficient space within the site to maintain the required separation distances to prevent incident propagation between BESS subunits. Provided in **Figure 4-8** is the proposed BESS layout and in **Figure 4-9** is a summary of the dimensions required to inhibit fire propagation between MVPS and BESS units. It can be noted that all 88 MVPS and 352 BESS units fit within the project area with the appropriate segregation measures in place to prevent propagation.

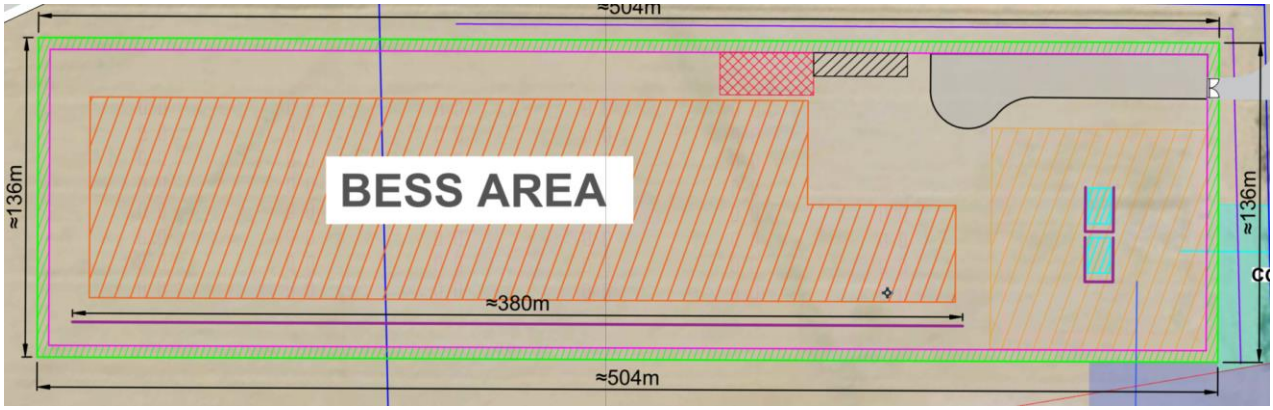


Figure 4-8: BESS Layout

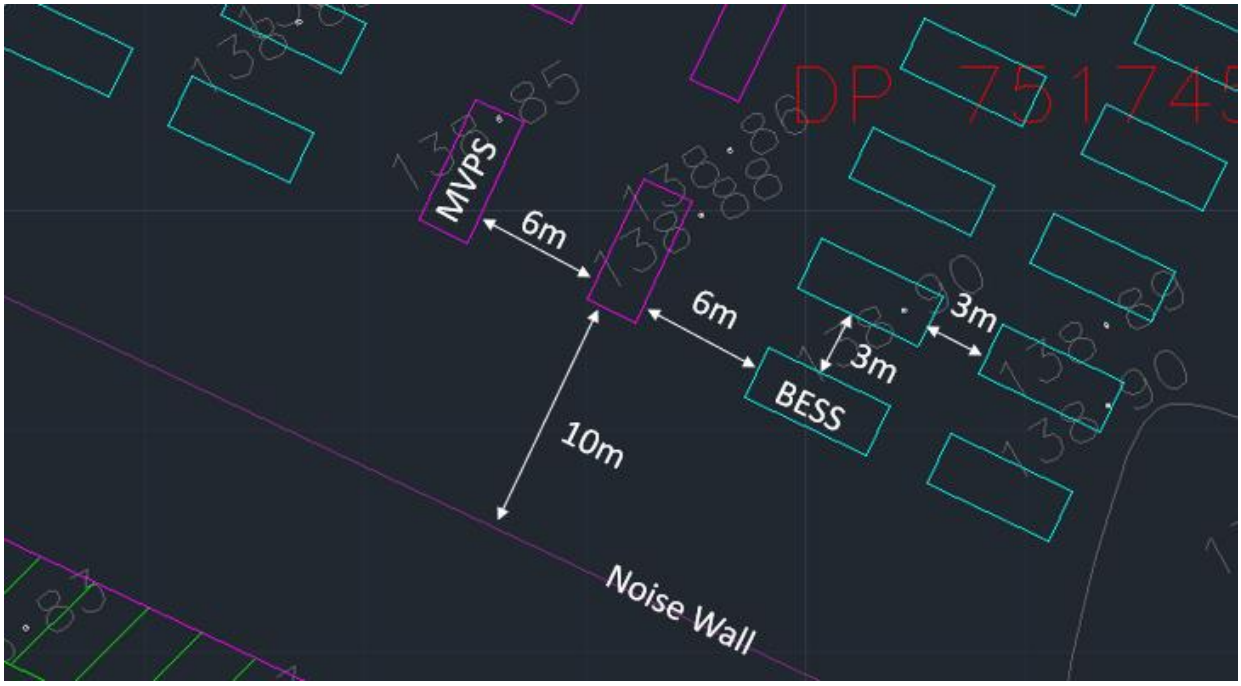


Figure 4-9: BESS Dimensioned Layout

4.6.2 Separation Review

Multiple LFP battery products are assessed among limited options currently available in the Australian market, which meet the requirements of a utility application, containerized solution, and LFP chemistry at the same time. Their UL9540A unit-level test reports are assessed. A key takeaway message from the UL9540A test is the minimum required spacing between two battery units (racks) without propagating thermal runaway from one unit to another summarised in **Table 4-3**. This is then used to guide the separation distance requirement between BESS containers summarised in **Figure 4-9**.

Table 4-3: Minimum separation required between BESS Units

No.	Battery Manufacturer	Minimum Required Spacing Between Battery Units
1	Sungrow (Appendix M)	160mm
2	CATL (Appendix N)	10 mm
3	EVE POWER (Appendix O)	160 mm
4	Ruipu Energy (Appendix P)	160 mm

The CATL EnerC+ 0.25P requires a minimum separation of 0.2 m as outlined in **(Appendix E)**. As can be seen in **Figure 4-9**, the spacing utilised between two CATL EnerC+ 0.25P BESS units is 3 m which is far greater than the required spacing between LFP battery units. Therefore, the minimum proposed battery container separation distance for Yanco BESS of 3 m, is considered appropriate based on a generic analysis.

Based upon the designs incorporated with the container based upon the VBB fire, the available area assessment and the separation distance assessment, it is considered that the propagation between two units is unlikely; hence, this incident has not been carried forward for further analysis.

4.7 Li-ion Battery Fire and Toxic Gas Dispersion

If a BESS failure occurs resulting in a fire, toxic by-products of combustion may form. A literature review was conducted on lithium-ion battery fires to identify the toxic gases that may be generated in the event of a fire. The review identified the following gases or classes of gases can form:

- Carbon dioxide;
- Carbon monoxide; and
- Fluorine gases.

Each of these has been discussed in further detail in the following subsections.

4.7.1 Carbon Dioxide

Carbon dioxide is a colourless, odourless, dense gas that is naturally forming and is present in the atmosphere at concentrations around 415 ppm (0.0415%). At low concentrations, carbon dioxide is physiologically impotent and at low concentrations does not appear to have any toxicological effects. However, as the concentration grows it increases the respiration rate with short-term Exposure Limit (STEL) occurring at 30,000 ppm (3%), above 50,000 ppm (5%) a strong respiration effect is observed along with dizziness, confusion, headaches, and shortness of breath. Concentrations in excess of 100,000 ppm (10%) may result in coma or death.

Carbon dioxide is a by-product of combustion where hydrocarbon or carbon-based materials are involved. A typical combustion reaction producing carbon from a hydrocarbon has been provided in **Equation 4-1**. This reaction proceeds when there is an excess of oxygen in the fuel being consumed and is known as complete combustion as it is the most efficient reaction pathway.

$$\boldsymbol{C_3H_8(g) + 5O_2(g) \rightarrow 3Co_2(g) + 4H_2O(g)} \qquad \textbf{Equation 4-1}$$

The lithium-ion batteries are predominantly composed of metal structures. However, during a fire event ancillary equipment and materials within the batteries will be involved in the fire including wiring, plastics, anodes, etc. which will liberate carbon dioxide. However, a review of the toxicological impacts indicates high concentrations would be required to result in injury or fatality. Based upon a review of the sensitive areas, and the similar BESS fires (i.e. Victoria BESS fire), it is not considered that the formation of carbon dioxide in a fire would be sufficient to result in downwind impacts sufficient to cause injury or fatality. In other words, there would be insufficient production of carbon dioxide to generate a plume of sufficient concentration to displace the required oxygen for a significant downwind consequence to occur. Therefore, this incident has not been carried forward for further analysis.

4.7.2 Carbon Monoxide

Carbon monoxide is an odourless, colourless gas that is slightly denser than air and occurs naturally in the atmosphere at concentrations around 80 ppb. Carbon monoxide is a toxic gas as it irreversibly binds with haemoglobin which prevents these molecules from carrying out the function of oxygen / carbon dioxide exchange. The loss of 50% of the haemoglobin may result in seizures, coma or death which can occur at concentration exposures of approximately 600 ppm (0.06%).

Carbon monoxide is by-product of combustion if there is insufficient oxygen to enable complete combustion. The reaction pathway for the formation of carbon monoxide is provided in **Equation 4-2**.

$$2C_3H_8(g) + 7O_2(g) \rightarrow 6CO(g) + 8H_2O(g)$$ **Equation 4-2**

As noted, in **Section 4.7.1** there is the potential for a fire to occur with the BESS units which could form carbon monoxide if there is insufficient oxygen to sustain complete combustion. However, it is noted that the combustible load within the BESS which could result in the formation of carbon monoxide is relatively low compared to the available oxygen in the surrounding atmosphere. Therefore, it is considered that the formation of carbon monoxide at levels that would result in a substantial downwind impact is not considered credible and subsequent analysis of, this incident is not required.

4.7.3 Fluoride Gases

The electrolyte used in Li-ion batteries typically is lithium hexafluorophosphate ($LiPF_6$) or other li-salts containing fluorine. In the event of a thermal runaway, the electrolyte will expand and be vented from the battery. In the event of a fire, the vented gas and other components such as the polyvinylidene fluoride binders may form gases such as hydrogen fluoride (HF), phosphorous pentafluoride (PF_5) and phosphoryl fluoride (POF_3) (Ref. [6]).

The decomposition of $LiPF_6$ can be promoted by the presence of water / humidity according to reactions **Equation 4-3** to **Equation 4-5**.

$$LiPF_6 \rightarrow LiF + PF_5$$ **Equation 4-3**

$$PF_5 + H_2O \rightarrow POF_3 + 2HF$$ **Equation 4-4**

$$LiPF_6 + H_2O \rightarrow LiF + POF_3 + 2HF$$ **Equation 4-5**

Of the fluorine gases formed, PF_5 is a short-lived gas while POF_3 is a reactive intermediate. Thermal destruction of several battery chemistry, configurations and State of Charge (SOC) indicated the vast majority of these did not produce observable POF_3 with the only observance occurring in a specific battery chemistry at 0% SOC (Ref. [6]). Therefore, the main fluorine gas of concern in a Li-ion battery fire is HF.

HF gas is hydroscopic readily dissolving into water vapour / humidity or moisture in airways forming hydrofluoric acid. Hydrofluoric acid is a weak acid although is highly corrosive and may result in chemical burns. In addition, it is calcium scavenging. Hence, it will readily bind with calcium in cells and tissues disrupting the nerve signalling. The immediate danger to life or Health (IDLH) for HF is 30 ppm and the 10-minute lethal concentration is 170 ppm.

For a toxic gas dispersion, a battery container fire is necessary as the initiating event. As discussed in **Section 4.4** the potential for a fire to occur is considered negligible due to the highly stable and safe battery chemistries used. As the potential for the initiating event is considered unlikely, this incident has not been carried forward for further analysis.

4.8 Electrical Equipment Failure and Fire

Electrical equipment is located within the switch room which may fail resulting in overheating, arcing, etc. which could initiate a fire. In the event of a fire, it may begin to propagate to adjacent combustible materials (i.e. wiring). It is noted that electrical equipment fires typically start by smouldering before flame ignition occurs resulting in a slow fire development.

The type of equipment used within the Project is ubiquitous throughout the world and across industry segments and is therefore not a unique fire scenario. Based upon fire development within

switch rooms the fire would be considered to be relatively slow in growth and would be unlikely to result in substantial impacts in terms of offsite impact or incident propagation. Therefore, this incident has not been carried forward for further analysis.

4.9 Transformer Internal Arcing, Oil Spill, Ignition and Bund Fire

Transformers contain oil which is used to insulate the transformers during operation. If arcing occurs within the transformer (e.g. due to a low oil level), the high energy passing through the coolant vaporises the oil into light hydrocarbons (methane, ethane, acetylene, etc.) resulting in rapid pressurisation within the reservoir.

Notwithstanding the protection systems, if the pressure rise exceeds the structural integrity of the reservoir, and the installed pressure relief devices, the reservoir can rupture allowing the release of oil into the bund. The rupture also allows oxygen to enter the reservoir. The temperature of the gases is above the auto ignition point, but this does not occur until oxygen is present. When oxygen enters the reservoir, the gases auto-ignite which generates sufficient heat to ignite the oil in the bund.

Notwithstanding this, transformers are ubiquitous units with a low potential for failure and the separation distance to the site boundary and other adjacent units would be unlikely to result in incident propagation and offsite impacts. Therefore, this incident has not been carried forward for further analysis.

4.10 Transformer Electrical Surge Protection Failure and Explosion

Transformers generate large amounts of heat as a result of the high electrical currents that pass through them; hence, oil is used as an insulating material within the transformers to protect the mechanical components. However, if the transformer gets an extreme surge of energy, such as that which could occur due to a lightning strike, and the electrical surge protection measures fail, the mineral oil may start to decompose and vapourise, resulting in gas bubbles of hydrogen and methane (Ref. [7]) as temperatures above the autoignition of the gases.

The formation of gases will increase the pressure within the transformer which can result in the transformer structure rupturing which allows the ingress of oxygen. As the oxygen enters, the concentration of flammable gases falls within the explosive limits which are above their autoignition temperatures which ignite resulting in increased formation of hot gaseous products resulting in an explosion. The explosion may generate significant overpressure, sparks and fire and would result in a whole transformer fire, as discussed in **Section 4.9**.

In order to protect against overheating and explosions, transformers generally have surge protection devices which shunt electrical surges safely to ground. However, this surge detection and protection devices are not universally installed, nor do they protect against all events such as in the case of a major lightning strike or significant oil deterioration, leakage of water into the transformer, and physical damage such as a fallen tree (Ref. [8]). Therefore, there is the potential for an explosion to occur which may result in offsite impacts; however, as previously noted, these units are ubiquitous and have a low potential for failure. Therefore, this incident has not been carried forward for further analysis.

4.11 Electromagnetic Field Impacts

4.11.1 Introduction

Electric and Magnetic Fields (EMFs) are associated with a wide range of sources and occur both naturally as well as man-made. Naturally occurring EMFs, occurring during lightning storms, are generated from Earth's magnetic field. Man-made EMFs are present wherever there is electricity; hence, EMFs are present in almost all built environments where electricity is used.

Extremely low frequency (ELF) electric and magnetic fields (EMF) occupy the lower part of the electromagnetic spectrum in the frequency range 0-3,000 Hz which is the current will change direction 0-3,000 times a second. ELF EMF result from electrically charged particles. Artificial sources are the dominant sources of ELF EMF and are usually associated with the generation, distribution and use of electricity at the frequency of 50 Hz in Australia. The electric field is produced by the voltage whereas the magnetic field is produced by the current.

BESS create EMFs from operational electrical equipment, such as transmission lines, transformers and the electrical components found within BESS units, inverters, etc. This equipment has the potential to produce ELF EMF's in the range of 30 to 300 Hz.

4.11.2 Existing Standards

There are currently no existing standards in Australia for governing the exposure limits to ELF EMFs; however, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) has provided some guidelines around exposure limits for prolonged exposure which limits the exposure to 2,000 milligauss (mG) for members of the public in a 24 hour period (Ref. [9]).

Table 4-4 provides typical magnetic field measurements and ranges associated with EMF sources. It is noted that electric fields around devices are generally close to 0 due to the shielding provided around the equipment. In addition, EMF levels drop away quickly with distance; hence, while a value may be measurable at the source, within a short distance the EMF is undetectable.

Table 4-4: EMF Sources and Magnetic Field Strength

Source	Typical Measurement (mG)	Measurement Range (mG)
Television	1	0.2 – 2
Refrigerator	2	2 – 5
Kettle	3	2 – 10
Personal computer	5	2 – 20
Electric blanket	20	5 – 30
Hair dryer	25	10 – 70
Distribution powerline (under the line)	10	2 – 20
Transmission power line (under the line)	20	10 – 200
Edge of easement	10	2 – 50

4.11.3 Exposure Discussion

A review of the site indicates there are no immediate residences adjacent to the area where the solar farm or BESS will be developed providing substantial distance for attenuation of EMFs. Based upon the typical levels which may be generated by transmission equipment the cumulative effect

would not exceed the 2,000 mG limit for prolonged exposure. In addition, the closest residence is over 200 m away from the EMF generating sources at the BESS; hence, the potential for the EMF to exceed the accepted levels is considered negligible.

The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) advises that the strength of radiation decreases exponentially with distance from the source, and it will become indistinguishable from background radiation within 50 m of a high voltage power line and within 5 to 10 m of a substation. (Ref. [10]).

A field study was undertaken to characterise the EMF between the frequencies of 0 – 3 GHz at two large scale solar facilities operated by the Southern California Edison Company in Porterville and San Bernardino, (Ref. [11]).

The field study findings were adopted to estimate the EMF measurements for the project. The findings are as follows:

• The highest DC magnetic fields were measured adjacent to the inverter (277 µT) and transformer (258 µT). These fields were lower than the ICNIRP's occupational exposure limit.

• The highest AC magnetic fields were measured adjacent to the inverter (110 µT) and transformer (177 µT). These fields were lower than the ICNIRP's occupational exposure limit.

• The strength of the magnetic field attenuated rapidly with distance (i.e. within 2-3 metres away, the fields drop to background levels).

• Electric fields were negligible to non-detectable. This is mostly likely attributed to the enclosures provided for the electricity generating equipment.

As the strengths of EMF attenuate rapidly with distance, the ICNIRP reference level for exposure to the general public will not be exceeded and impact to the general public in surrounding land uses is negligible.

As the potential for exposure to EMF exceeding the international guidelines is negligible, this incident has not been carried forward for further analysis.

5.0 Conclusion and Recommendations

5.1 Conclusions

A hazard identification table was developed for the Yanco BESS project to identify potential hazards that may be present at the site as a result of operations or storage of materials. Based on the identified hazards, scenarios were postulated that may result in an incident with the potential for offsite impacts. Postulated scenarios were discussed qualitatively and any scenarios that would not impact offsite were eliminated from further assessment. Scenarios not eliminated were then carried forward for consequence analysis.

A review of the incidents carried forward for further analysis indicates that there were no observed offsite impacts; therefore, based on the analysis conducted, it is concluded that the risks at the site boundary are not considered to exceed the acceptable risk criteria; hence, the project would only be classified as potentially hazardous and would be permitted within the current land zoning for the site. It must be noted that the required bushfire assessment is provided under separate cover.

5.2 Recommendations

The following recommendations have been made as a result of the assessment:

- End-to-end spacing (short side) of BESS containerised units shall be a minimum of 3 m
- Back-to-back spacing (long side) of BESS containerised units shall be a minimum of 3 m
- Distance from electrical compartment surface to the wall of other containers 1.1 m.
- Spacing between BESS container accumulations (i.e. 4 containerised units) shall be a minimum of 3 m.
- The BESS containerised units shall be provided with the fire protection system specified by the BESS manufacturer.
- Prior to construction, the total area required for the BESS units shall be verified against the available space to demonstrate there is adequate area to achieve the required spacing.
- The vents shall not be located above battery packs within the BESS container.
- The vent covers of the BESS shall be constructed of non-combustible material.
- Prior to commissioning, the UL test data for the selected battery units shall be made available to the DPHI.

6.0 References

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Appendix A

Hazard Identification Table

A1. Hazard Identification Table

Area/Operation	Hazard Cause	Hazard Consequence	Safeguards
Battery Storage	• Failure of Li-ion battery protection systems	• Thermal runaway resulting in fire or explosion • Incident propagation through battery cells • Toxic smoke dispersion	• Batteries are tested by the manufacturer prior to sale / installation • Overcharging and electrical circuit protection • Battery monitoring systems • Batteries composed of subcomponents (i.e. BBU, cells) reducing risk of substantial component failure • Batteries are not located in areas where damage could easily occur (i.e. within the fenced property) • Electrical systems designed per AS/NZS 3000:2007 (Ref. [12]) • Acoustic barriers
Switch rooms, communications, etc.	• Arcing, overheating, sparking, etc. of electrical systems	• Ignition of processors and other combustible material within servers and subsequent fire	• Fires tend to smoulder rather than burn • Isolated location • Switch room separation from other sources of fire
Substation	• Arcing within transformer, vaporisation of oil and rupture of oil reservoir	• Transformer oil spill into bund and bund fire	• Bunded • Isolated location
	• Power surge to transformers (e.g. from lightning)	• Major failure of surge protection in transformer, vapourisation of mineral oil, ignition and explosion	• Transformers have surge protection system to shut down upon detection of extreme energy input • Lightning protection to prevent lightning strikes impacting transformers • Control of ignition sources – no smoking / open flames around the transformers
EMF	• Electric and magnetic equipment	• Generation of ELF EMF and injury / nuisance to surrounding area	• Large separation distances allow for attenuation of EMFs • Cumulative impacts from equipment below acceptable thresholds. • Low occupancy density within vicinity of the development

Appendix B

UL9540 Test Report

Prüfbericht-Nr.: *Test report no.*:	**CN23J9GR 001**	**Auftrags-Nr.:** *Order no.*:	244501240	Seite 1 von 42 *Page 1 of 42*
Kunden-Referenz-Nr.: *Client reference no.*:	2057436	**Auftragsdatum:** *Order date:*	2023-03-06	
Auftraggeber: *Client*:	**Contemporary Amperex Technology Co., Limited.** No. 2, Xingang Road, Zhangwan Town, Jiaocheng District,Ningde City, 352100 Fujian, P.R. China			
Prüfgegenstand: *Test item*:	Rechargeable Lithium-ion Battery System			
Bezeichnung / Typ-Nr.: *Identification / Type no.*:	C02306P05L01			
Auftrags-Inhalt: *Order content*:	cTÜVus mark approval			
Prüfgrundlage: *Test specification*:	ANSI/CAN/UL 9540: 2020			

Wareneingangsdatum: *Date of sample receipt*:	2023-05-05
Prüfmuster-Nr.: *Test sample no:*	Engineering sample
Prüfzeitraum: *Testing period*:	2023-06-05 to 2023-08-12
Ort der Prüfung: *Place of testing*:	See page 5
Prüflaboratorium: *Testing laboratory:*	TÜV Rheinland (Shanghai) Co., Ltd.
Prüfergebnis*: *Test result**:	Pass



geprüft von:
tested by:Wilson Zhou

genehmigt von:
authorized by:Stone Wang

Datum:
Date: 2023-11-18

Ausstellungsdatum:
Issue date: 2023-11-18

Stellung / Position: Sachverständige(r)/Expert

Stellung / Position: Sachverständige(r)/Expert

Sonstiges / *Other*: See the following pages for General product information and comment for details.

Zustand des Prüfgegenstandes bei Anlieferung: *Condition of the test item at delivery*: Prüfmuster vollständig und unbeschädigt *Test item complete and undamaged*

* Legende:	P(ass) = entspricht o.g. Prüfgrundlage(n)	F(ail) = entspricht nicht o.g. Prüfgrundlage(n)	N/A = nicht anwendbar	N/T = nicht getestet
** Legend:*	*P(ass) = passed a.m. test specification(s)*	*F(ail) = failed a.m. test specification(s)*	*N/A = not applicable*	*N/T = not tested*

Dieser Prüfbericht bezieht sich nur auf das o.g. Prüfmuster und darf ohne Genehmigung der Prüfstelle nicht auszugsweise vervielfältigt werden. Dieser Bericht berechtigt nicht zur Verwendung eines Prüfzeichens.
This test report only relates to the above mentioned test sample. Without permission of the test center this test report is not permitted to be duplicated in extracts. This test report does not entitle to carry any test mark.

Anmerkungen
Remarks

1	Alle eingesetzten Prüfmittel waren zum angegebenen Prüfzeitraum gemäß eines festgelegten Kalibrierungsprogramms unseres Prüfhauses kalibriert. Sie entsprechen den in den Prüfprogrammen hinterlegten Anforderungen. Die Rückverfolgbarkeit der eingesetzten Prüfmittel ist durch die Einhaltung der Regelungen unseres Managementsystems gegeben. Detaillierte Informationen bezüglich Prüfkonditionen, Prüfequipment und Messunsicherheiten sind im Prüflabor vorhanden und können auf Wunsch bereitgestellt werden. *The equipment used during the specified testing period was calibrated according to our test laboratory calibration program. The equipment fulfils the requirements included in the relevant standards. The traceability of the test equipment used is ensured by compliance with the regulations of our management system.* *Detailed information regarding test conditions, equipment and measurement uncertainty is available in the test laboratory and could be provided on request.*
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4	Die Entscheidungsregel für Konformitätserklärungen basierend auf numerischen Messergebnisen in diesem Prüfbericht basiert auf der "Null-Grenzwert-Regel" und der "Einfachen Akzeptanz" gemäß ILAC G8:2019 und IEC Guide 115:2021, es sei denn, in der auf Seite 1 dieses Berichts genannten angewandten Norm ist etwas anderes festgelegt oder vom Kunden gewünscht. Dies bedeutet, dass die Messunsicherheit nicht berücksichtigt wird und daher auch nicht im Prüfbericht angegeben wird. Zu weiteren Informationen bezueglich des Risikos durch diese Entscheidungsregel siehe ILAC G8:2019. *The decision rule for statements of conformity, based on numerical measurement results, in this test report is based on the "Zero Guard Band Rule" and "Simple Acceptance" in accordance with ILAC G8:2019 and IEC Guide 115:2021, unless otherwise specified in the applied standard mentioned on Page 1 of this report or requested by the customer. This means that measurement uncertainty is not taken in account and hence also not declared in the test report. For additional information to the resulting risk based of this decision rule please refer to ILAC G8:2019.*

General disclaimer:	
The test results presented in this report relate only to the object tested. This report shall not be reproduced, except in full, without the written approval of the Issuing Testing Laboratory. The authenticity of this Test Report and its contents can be verified by contacting the Laboratory responsible for this Test Report.	
Manufacturer:	**Contemporary Amperex Technology Co., Limited.** No. 2, Xingang Road, Zhangwan Town, Jiaocheng District,Ningde City, 352100 Fujian, P.R. China
Factory:	**Contemporary Amperex Technology Co., Limited.** No. 2, Xingang Road, Zhangwan Town, Jiaocheng District,Ningde City, 352100 Fujian, P.R. China
Purpose of This Report: Certificate	
Report History:	

Responsible Testing Laboratory (as applicable), testing procedure and testing location(s):			
☒	**Testing Laboratory:**	TÜV Rheinland (Shanghai) Co., Ltd.	
Testing location/ address .....:		No. 177, Lane 777, West Guangzhong Road, Jing'an District, Shanghai 200072, P. R. China	
Tested by (name, function, signature).....:		See cover	
Approved by (name, function, signature) ..:		See cover	
☒	**Testing procedure: CTF Stage 1/TMP:**	**Contemporary Amperex Technology Co., Limited.**	
Testing location/ address .....:		No. 2, Xingang Road, Zhangwan Town, Jiaocheng District,Ningde City, 352100 Fujian, P.R. China	
Tested by (name, function, signature).....:			
Approved by (name, function, signature) ..:			
☐	**Testing procedure: CTF Stage 2/WMT:**		
Testing location/ address .....:			
Tested by (name + signature).....:			
Witnessed by (name, function, signature) .:			
Approved by (name, function, signature) ..:			
☐	**Testing procedure: CTF Stage 3/SMT:**		
☐	**Testing procedure: CTF Stage 4:**		
Testing location/ address .....:			
Tested by (name, function, signature).....:			
Witnessed by (name, function, signature) .:			
Approved by (name, function, signature) ..:			
Supervised by (name, function, signature) :			
List of Attachments (including a total number of pages in each attachment): Attachment 1: Photo documentation (13 pages). Attachment 2: Critical components information (18 pages).			

Tests performed (name of test and test clause):

Following tests performed during evaluation:

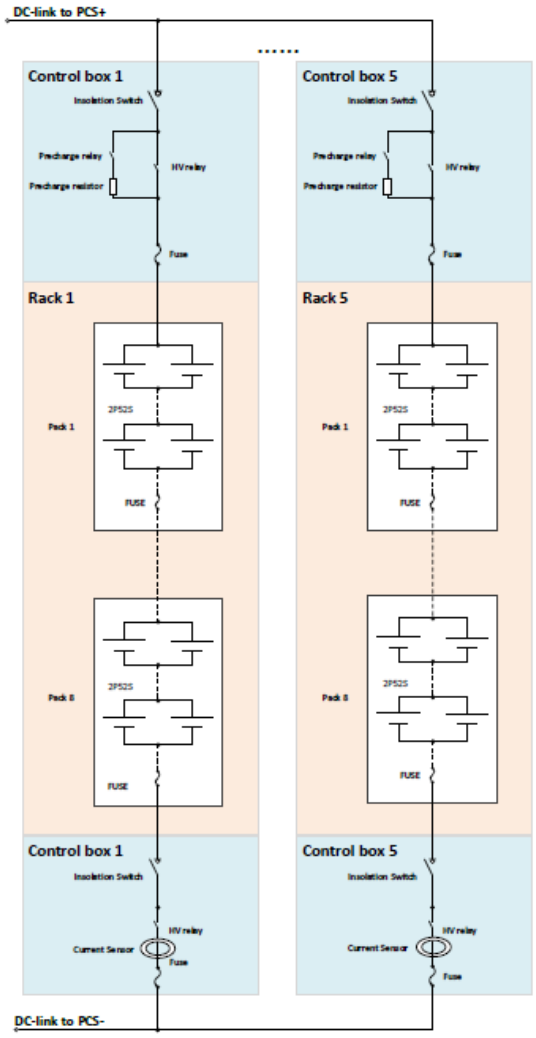
Clause(s)	Test(s)
27	Normal Operations Test
28	Dielectric Voltage Withstand Test
29	Impulse Test
30	Equipment Grounding and Bonding test
31	Insulation Resistance Test
32	Electromagnetic Immunity Tests
35.2	Hydrostatic strength test
37.2	Outdoors installations subject to moisture exposure

Testing location:

Contemporary Amperex Technology Co., Limited.
No. 2, Xingang Road, Zhangwan Town, Jiaocheng District,Ningde City, 352100 Fujian, P.R. China

Test item particulars:	
Description ..... :	Rechargeable Lithium-ion Battery system
Trademark ..... :	CATL
Model and/or type reference..... :	C02306P05L01
Electrical Ratings:	See Page 9
Input Voltage/Current	-
Output Voltage/Current	-
Maximum Operating ambient	-
Additional Rating Information:	See Page 9
Input voltage range ..... :	-
Energy (kwh)	-
Power (Mw)	-
Output Short Circuit Current..... :	-
Maximum Current per DC Feed	-
Maximum Number of Battery Racks	-
Installation mode..... :	-
Additional Product Information:	See Page 9
Software/Firmware tested within the unit……..:	-
Pollution degree ..... :	PD3(outside) PD2(inside)
Overvoltage category..... :	OVC II (DC) OVC III (AC)
Rated ambient temperature..... :	-
Enclosure index / type ..... :	IP55(Battery room); IP55(Electrical room); IP67(Chiller control box)
Equipment mobility..... :	-
Protection class of equipment ..... :	I
Mass of equipment (Kg) ..... :	36000
Overall size (W x D x H) (m)..... :	2.438*6.058 *2.896
Possible test case verdicts:	
- test case does not apply to the test object..... :	N/A
- test object does meet the requirement ..... :	F(ail)
- test object does not meet the requirement ..... :	P(ass)
Testing..... :	P
Date(s) of performance of tests..... :	See cover

Product Description:



The model C02306P05L01-R Battery rack is the core unit in the energy storage sys-tem and acts as the equipment for storing electrical energy. It can be applied to many applications includ-ing renewable energy integration, frequency regulation, and voltage regulation.Battery rack includes battery , battery management system（BMS）, thermal management system (TMS),auxiliary distribution system, and fire suppression system (FSS).

The battery rack contains 8 battery modules. Each battery module is composed of 52 lithium iron cells (306Ah/3.2V) in series connection.The control box is for providing the auxiliary power for whole BMS control system and TMS liquid cooling system, and the battery system is composed of 416 battery cells. For safety protection, an internal high speed DC fuse is included.

The BMS functional safety was evaluated according to IEC 60730-1 Annex H and UL 60730-1 Annex H by TÜV Rheinland.

Block diagram as below:

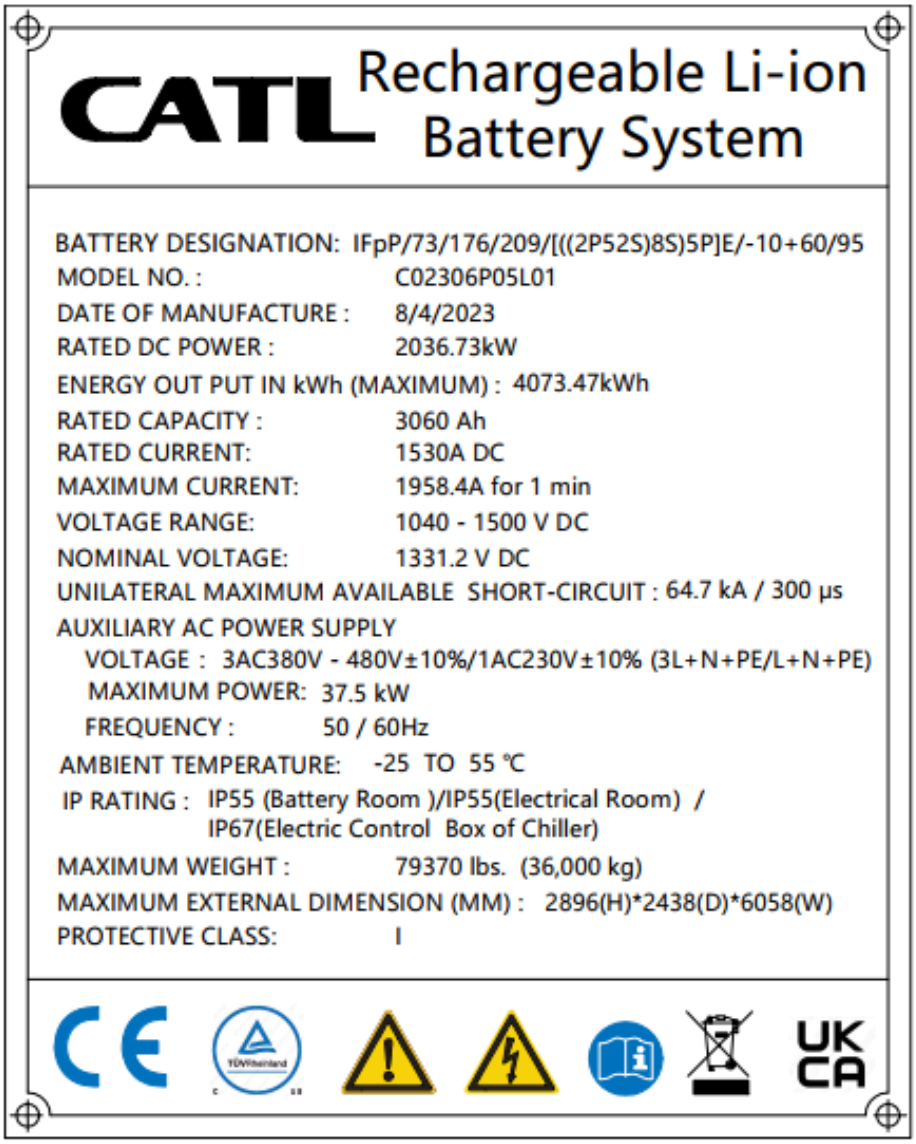
Model List:

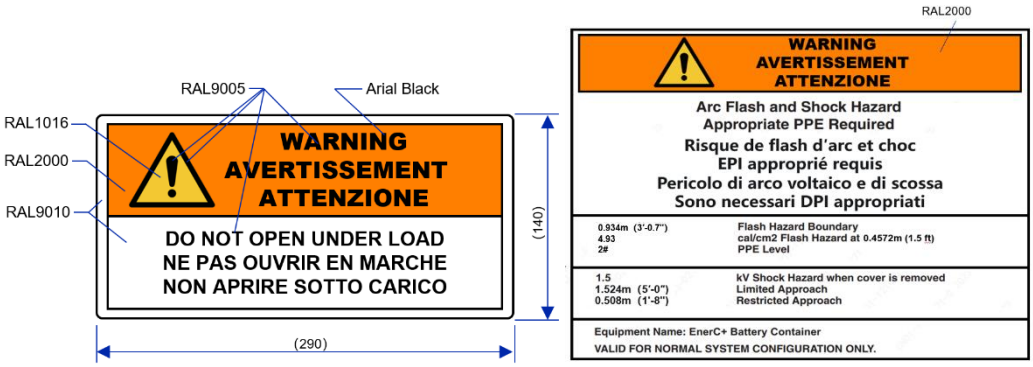
Item	Specifications			
Product name	Rechargeable Li ion Cell	Rechargeable Li ion Battery Module	Rechargeable Li ion Battery Rack	Rechargeable Li ion Battery System
Type/model	CBDD0	M02306P05L01	C02306P05L01-R	C02306P05L01
Nominal voltage	3.2V	166.4V	1331.2V	1331.2V
Rated capacity	306Ah	612Ah	612Ah	3060Ah
Voltage range	2.5-3.65	130~189.8V	1040~1500V	1040~1500V
Upper limit charging voltage	3.95V	-	-	-
Recommended charging current by manufacturer	153A	306A	306A	1530A
Recommended charging power by manufacturer	489.6W	50.91kW	407.34kW	2036.73kW
Maximum continuous charging current	153A	306A	306A	1530A
Recommended discharging current by manufacturer	153A	306A	306A	1530A
Recommended discharging power by manufacturer	489.6W	50.91kW	407.34kW	2036.73kW
Maximum continuous discharging current	195.9A	306A	306A	1530A
Standard temperature range for charging	0°C to 60°C	-	-	-
Standard temperature range for discharging	-20°C to 60°C	-	-	-
Operating ambient temperature range	-	-	-25°C to 55°C	-25°C to 55°C
Storage temperature range	-30°C to 60°C	-	-30°C to 60°C	-30°C to 60°C
Standard charging method by manufacturer	153A CC to 3.65V，CV to 15.3A	Charge at constant power 50.91kW until any cell voltage reaches 3.65V then derate until charge with 0.05P till 189.8V	Charge at constant power 407.34kW until any cell voltage reaches 3.65V then derate until charge with 0.05P till 1500V or	Charge at constant power 2036.73kW until any cell voltage reaches 3.65V then derate until charge with 0.05P till 1500V or

		or any cell voltage reaches 3.65V	any cell voltage reaches 3.65V	any cell voltage reaches 3.65V
Charging method for internal short-circuit test	153A CC to 3.65V，CV to 15.3A	-	-	-
Standard discharging method by manufacturer	153A DC to 2.5V	Discharge at constant power 50.91kW until 130V or any cell voltage reaches 2.5V	Discharge at constant power 407.34kW until 1040V or any cell voltage reaches 2.5V	Discharge at constant power 2036.73kW until 1040V or any cell voltage reaches 2.5V
Lower limit discharging voltage	2V	-	-	-
Over voltage protection value	-	-	max. cell voltage reaches 3.81V	max. cell voltage reaches 3.81V
Under voltage protection value	-	-	min. cell voltage reaches 2.32V	min. cell voltage reaches 2.32V
Overcurrent protection value	-	-	Max(I*135%，10A)	Max(I*135%，10A)
Over temperature protection value	-	-	57℃	57℃
Dimension	Width*Depth*Height: 174.7±0.8mm*71.6±0.8mm*207.3±0.8mm	Width*Depth*Height: 830mm*2235mm *250mm	Width*Length*Height: 2252.5mm*936mm *2698mm	Width*Length*Height: 2,438mm*6,058mm *2,896mm
Weight	5500±300g	Approx.653±5kg	Approx.7200kg	Approx.36000kg
Configuration	-	2P52S	(2P52S)8S	((2P52S)8S)5P
Max.short circuit current declared by manufacturer	-	-	12.94kA	64.7kA
Duration at max.short circuit current declared by manufacturer	-	-	300 μs	300 μs

The Operating ambient temperature range is the outdoor temperature.
The container controls the temperature of cell through the chiller,so that the cell can work within the operating temperature range of the cell.

Nameplate, Warning, and Label, etc.:





UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
1	**Scope**		P
1.1	System designed to store energy		P
1.2	Standalone or utility interactive	Depended on PCS connected.	P
1.3	Requirements for installation		P
1.4	Location of ESS	Outdoor	P
1.5	Systems using lead-acid or Ni-Cad falling under UL 1778		N/A
1.6	Maximum Energy Capacities: a) Outdoor wall mounted electrochemical ESS shall not exceed 20 kWh (72 MJ); b) Residential use electrochemical ESS shall not exceed 20 kWh (72 MJ); and c) Non-residential use electrochemical ESS shall not exceed 50 kWh (180 MJ), except as allowed in 1.7 – 1.11.	Clause 1.8 applied.	N/A
1.7	Limit of c) of exceeded if UL 9540A Unit level.	Unit level tested.	N/A
1.8	Non-residential unit tested per UL 9540A for the energy level involved.	unit level test report provided.	P
1.9	Non-residential unit tested per UL 9540A performance for the energy level involved.	Unit level tested.	N/A
1.10	Remote locations		N/A
1.11	Exceptions for lead acid and Ni-Cad systems		N/A
2	**Components**		P
2.1	Components comply with standard covering that component	See CDF for details.	P
3	**Units of Measure**		P
3.1	Values without parentheses are the requirement		P
4	**Undated References**		P
4.1	Undated references imply the latest edition of the standard.		P
5	**Normative References**		P
5.1	Refer to Standard document for list of references.		P
6	**Glossary**		P
6.1	Refer to Standard for a list of definitions		P

UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
	Construction		P
7	**Non Metallic Materials**	Metal enclosure.	N/A
7.1	The materials employed for enclosures shall comply with UL 746C,		N/A
7.2	The following factors in (a) – (e) are taken into consideration		N/A
	a) Resistance to impact;		N/A
	b) Crush resistance;		N/A
	c) Abnormal operations;		N/A
	d) Severe conditions; and		N/A
	e) Mold-Stress Relief Distortion		N/A
7.3	Additional properties: a) 5VA flame rating b) Material Property Considerations table UL 746C c) Strain relief and mold stress of UL 746C d) UV exposure test of UL 746C e) Water exposure test of UL 746C f) Conduit connections of UL 746C)		N/A
7.4	Materials employed as electrical insulation shall be resistant to deterioration that would result in an electrical shock, fire or other safety hazard. And shall comply with UL 746C. Insulated wiring is subjected to the requirements outlined in Section 11.		N/A
7.5	Gaskets and Seals relied upon for safety, shall be determined suitable for the environmental conditions and chemical substances they are anticipated to be exposed to in their end use.		N/A
8	**Metallic Parts Resistance to Corrosion**		P
8.1	Metallic enclosures shall be corrosion resistant.		P
8.2	Dissimilar metals not subject to corrosion due to electrochemical action		P
9	**Enclosures and Guarding of Hazardous Parts**		P
9.1	The enclosure(s) shall have the strength and rigidity required to resist the possible physical during its intended use		P

UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
9.2	Openings in the enclosure shall be designed to prevent inadvertent access to hazardous parts. For a minimum IP rating of IP2X with consideration of the end use installation	IP55(Battery room); IP55(Electrical room); IP67(Chiller control box)	P
	Exception: An Energy storage system intended for location in restricted access locations need not meet this accessibility criterion if provided with warning markings for service and other personnel having access to the system		P
9.3	In a service access areas, bare parts of hazardous voltage circuits, shall be located or guarded		P
9.4	Enclosures of systems located where they will be subject to exposure to water and other elements shall be rated for the level of intended exposure	IP55(Battery room); IP55(Electrical room); IP67(Chiller control box)	P
10	**General Electrical Safety and Walk-in Systems**		P
10.1	Instructions include measures and procedures for worker safety per NFPA70E, CSA Z463 and section 2 of the C22.1		P
10.2	Walk in enclosures have suitable mechanical load ratings for equipment and persons inside.	Not a walk-in System	N/A
10.3	Shipping container type enclosures if modified comply with ASTM D3169	Not such type enclosure.	N/A
10.4	Outdoor walk in enclosures exceeding 53x8.5x9.5ft shall be evaluated as an indoor environment.	Not a walk-in System	N/A
10.5	Explosion venting system		N/A
10.6	Procedures for safe entry and exit		N/A
10.7	Entrances to the enclosure shall be designed to prevent persons from becoming trapped within the enclosure		N/A
10.8	Work space dimensions and requirements within walk in enclosures shall be in accordance with the National Electrical (Safety) Code		N/A
10.9	Areas of access shall be designed to prevent tripping, slipping or falling when persons enter, exit		N/A

UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
10.10	Protection against contact with hazardous voltage parts in the energy storage system		P
10.11	Type of protection per an arc flash assessment report	See warning label	P
10.12	Unprotected arc flash boundary 5 J/cm^2		P
10.13	Ventilation for a fully walk in enclosure		N/A
10.14	Electrical circuits that are an integral part of the energy storage system including those that are part of a walk-in enclosure including lighting, controls, power, HVAC (heating, ventilation and air-conditioning), emergency lighting, alarm circuits, and the like shall comply with the appropriate requirements for the type of equipment and the specific application within the energy storage system.		N/A
10.15	Electrical equipment subject to condensation		N/A
10.16	Lighting shall be supplied in enclosed working spaces in accordance with Article 410 of the NFPA 70 or Section 30 of C22.1		N/A
10.17	More than one source of supply		N/A
10.18	Protection against lightning surges in accordance with NFPA 70, C22.1 or IEEE C2 as applicable		P
11	**Wiring and Electrical Supply Connections**		
11.1	Wiring shall be insulated and acceptable for the purpose		P
11.2	Wiring methods and electrical supply connections shall be in accordance with the NEC, NFPA 70 or the National Electrical Safety Code, IEEE C2		P
11.3	Field-wiring compartments in which branch circuit connections are to be made shall:		P
	a) Wiring terminals or wiring leads;		P
	b) A means for connection of cable or conduit in accordance with the codes in 11.2.		P

UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
11.4	A wiring terminal or lead that is supplied as a component of the energy storage system shall be rated and sized for connection to a field wiring conductor having an ampacity of no less than 125% of the ac or dc current that the circuit carries during rated conditions and in accordance with the codes in 11.2.		P
11.5	A field-wiring lead shall not be more than two wire sizes smaller than the copper conductor to which it is to be connected, and shall not be smaller than 2.08 mm^2 (14 AWG). A field-wiring lead shall not be less than 152.4-mm (6-in) long.		P
11.6	Field wiring compartments shall: a) Permit the connection of the supply wires after the energy storage system is installed; b) Permit the connection to be introduced and connected easily and safely; and c) Be located so that the connections may be readily inspected after the energy storage system is installed.		P
11.7	Internal wiring shall be routed, supported, clamped or secured in a manner that reduces the likelihood of excessive strain		P
11.8	Insulated wires pass through a metal wall shall be provided with a smoothly rounded bushing or shall have smooth surfaces, free of burrs, fins, sharp edges, and the like		P
11.9	Grouping of parallel conductors		P
12	**General Electrical Service Equipment**		P
12.1	A replaceable fuses marking with the fuse ratings & type shall be located adjacent to each fuse or fuse holder. Information on proper fuse shall also be included in the routine service manual instructions		P
12.2	A hazardous voltage ESS shall have a manual disconnect to prevent inadvertent access to hazardous voltage parts during servicing.		P
12.3	Fuses, circuit breakers and disconnect devices shall be rated for the application	Provided	P

UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
12.4	Power transformers installed as part of the ESS shall be of the dry type or type filled with a noncombustible dielectric medium in accordance with NEC NFPA 70. Exception: Oil filled transformers may be utilized if located outdoors and in accordance with the local codes or utility requirements.		P
12.5	Oil filled transformers		N/A
12.6	Convenience receptacles provided for maintenance and servicing of the ESS shall be rated for outdoor use if located where exposed to the environment		N/A
12.7	SCCR rating of interconnected components	No such equipment	N/A
13	**Electrical Spacings and Separation of Circuits**		P
13.1	Electrical circuits shall be provided with reliable physical spacing to prevent inadvertent short circuits		P
13.2	Electrical spacings in circuits shall have the following minimum over surface and through air spacings as outlined in Table 13.1		P
	Exception No. 1: As an alternative, the spacing requirements in UL 840 may be used.		P
	Exception No. 2: Electrical spacings within components and parts of ESS previously determined to comply with an appropriate safety standard for the equipment need not be evaluated.		P
13.3	There are no minimum spacings applicable to parts where insulating compound completely fills the casing of a compound		N/A
13.4	Conductors of circuits operating at different voltages shall be reliably separated from each other through the use of mechanical securements unless they are each provided with insulation acceptable for the highest voltage involved.		P
14	**Insulation Levels and Protective Grounding**		P

UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
14.1	Hazardous voltage circuits shall be insulated from accessible conductive parts and SELV circuits as outlined in 14.2 through the following: a) Basic insulation and provided with a protective grounding system for protection in the event of a fault of the basic insulation that complies with 14.3; b) A system of double or reinforced insulation; or c) A combination of (a) and (b).		P
14.2	SELV circuits that are insulated from accessible conductive parts through functional insulation only are considered accessible. Another term used for similar circuits is protective extra low voltage (PELV)		P
14.3	Accessible non-current carrying metal parts that could become live in the event of an insulation fault shall be bonded to the equipment ground terminal.		P
14.4	The protective grounding methods of an energy storage system shall be in accordance with Article 250 of the NEC, NFPA 70 or Section 9 of the NESC, IEEE C2 as applicable to where the system is located. In Canada, the method of bonding and grounding an energy storage system shall be in accordance with Section 10 and 36 of the Canadian Electrical Code, Part I Safety Standard for Electrical Installations, C22.1.		P
14.5	Parts of the protective grounding system shall be reliable secured and provided with good metal-to-metal contact		P
14.6	Connection methods in bonding path		P
14.7	Methods of securement for 14.5		P
14.8	For ESS >100V batteries can be floating if provided with GFD		P
15	**Safety Analysis and Control Systems**		P

UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
15.1	ESS shall be provided with a safety analysis such as a failure modes and effects analysis (FMEA) that identifies critical safety components and circuits of the system. Guidance for analysis can be found in the following standards:		P
	a) The Standard for Analysis Techniques for System Reliability – Procedures for Failure Mode and Effects Analysis (FMEA), IEC 60812; b) The Standard for Fault Tree Analysis (FTA), IEC 61502; and c) The Procedures for Performing a Failure Mode, Effects, and Criticality Analysis, MIL STD 882A.	FMEA provided.	P
15.2	Interconnection of components already evaluated to 15.1 additionally evaluated o 15.1 as a group.		P
15.3	Mechanical and other hazards besides electrical to be considered.	Non-mechanical energy storage system	P
15.4	Electrical and electronic controls of the ESS that are determined to be critical for safety are to comply with an appropriate safety standard for the control and used within their ratings.		P
	a) The Standard for Tests for Safety Related Control Employing Solid-State Devices, UL 991; b) The Standard for Software in Programmable Components, UL 1998; c) The Standard for Automatic Electrical Controls for Household and Similar Use – Part 1: General Requirements, UL 60730-1; or d) The Standard for Functional Safety of Electrical/Electronic/Programmable Electronic Safety Related Systems, IEC 61508 (all parts).	UL 60730-1	P
15.5	Required SIL, PL or ASI		N/A
15.6	Types of interactions between equipment		P
15.7	Software that can be updated remotely to meet UL 5500	Software can't be updated remotely.	N/A
16	**Remote Controls**		N/A

UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
16.1	ESS which have the ability to be controlled remotely are to be provided with a local means to disconnect the system from the remote control	No such function	N/A
16.2	Remote disconnect controls marking		N/A
17	**Communication Systems**		P
17.1	Communication protocols used by ESS for communication between its various parts and the grid shall be in accordance with those of the intended grid application.		P
18	**Heating and Cooling Systems**		P
18.1	ESS that rely upon integral thermal management systems to prevent overheating or operation outside the specified safe operating range, shall be designed to safely shutdown upon failure of the thermal management system		P
19	**Piping Systems, Pressure Vessels, Fuel and Other Fluid Supply Connections and Controls**		P
19.1	Piping Systems, pressure vessels, fuel or other supply systems shall comply with 19.2-19.9		P
19.2	Piping systems utilized to carry fluids in an ESS such as water, heated air, fuel gases, etc. shall comply with ASME B31 (all applicable parts), or CSA B51, or CSA B52, or CSA Z662, or CSA B149.1 as applicable.	Liquid cooling system certified.	P
19.3	Pressure vessels and related equipment including pressure relief devices that fall under the scope of the Boilers and Pressure Vessels Code, ASME BPVC or CSA B51 shall comply with the applicable requirements	Not flow battery system	N/A
19.4	Flammable fuel supply connections to the energy storage system shall be in accordance with the National Fuel Gas Code, NFPA 54. Hydrogen supply connections to the energy storage system shall be in accordance with the Hydrogen Technologies Code, NFPA 2.		N/A
19.5	Means is to be provided to prevent backflow of process gases, etc. into the fuel supply lines		N/A

UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
19.6	The energy storage system shall be designed so that process water used in the system shall be prevented from contaminating potable water sources in accordance with local regulations through the use of check valves or other means as part of the system design.		N/A
19.7	Piping, hose, and tubing containing liquids, shall be routed and secured to prevent leakage that could result in a fire, explosion or shock hazard.		N/A
19.8	Manual shut off valves shall be provided near the energy storage system in a location where they can be accessed to allow for disconnection of the fuel or water supply from the energy storage system for maintenance, etc. Automatic (nonelectric type) and manual valves intended for the use in flammable fluid lines shall comply with the Standard for Valves for Flammable Fluids, UL 842. Solenoid valves shall comply with the Standard for Electrically Operated Valves, UL 429.		N/A
19.9	Pressure regulators used on flammable or other hazardous gas lines shall comply with the Standard for Compressed Gas Regulators, UL 252.		N/A
20	**Containment of Moving Parts**		P
20.1	Moving parts shall be provided with a means to contain the parts in the event they could become loosened during operating.		P
21	**Hazardous Fluid Control**	Not flow battery	N/A
21.1	Where the system contains fluid in excess of 208 L (55 gal) in a single vessel or an aggregate of more than 3785 L (1000 gal), secondary containment shall be provided.	No fluid in excess of 208L in a single vessel.	N/A
21.2	Systems containing conductive fluids		N/A
21.3	Neutralization of spills		N/A
21.4	Venting of toxic vapours		N/A
22	**Combustible Concentrations**		P
22.1	Enclosures or areas that contain flammable fluid systems or batteries that vent hydrogen to the atmosphere shall be ventilated to prevent hazardous concentrations of flammable materials.	No flammable gases occur under normal operation.	N/A

UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
22.2	ESS Systems not addressed in 22.1	Depend on mechanical ventilation as a protection measure, ventilation volume and rate were evaluated to comply with NFPA 69. Depend on deflagration panels as a protection measure, deflagration pressure and vent area were evaluate to comply with NFPA 68.	P
22.3	For battery and similar systems, openings to prevent hazardous concentrations within an enclosure can be used.	Li-ion battery used	N/A
22.4	Minimum opening area for ventilation openings.		N/A
22.5	ESS located within dilution boundaries (i.e. concentrations above 25% LFL) or classified locations shall be suitable for the classification in accordance with the National Electrical Code, NFPA 70.		N/A
22.6	Electrical compartments adjacent to classified zones or locations shall be maintained at positive pressure in accordance with the Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas, NFPA 497.		N/A
23	**Fire Detection and Suppression**		P
23.1	**General**		P
23.1.1	Fire detection and fire suppression equipment provided as an integral part of an ESS shall comply with applicable product safety standards and shall be installed in accordance with the applicable safety product standards and the manufacturer's instructions.	Fire detection provided as an integral part of an ESS.	P
23.1.2	Energy storage systems with integral fire detection or fire suppression systems shall be provided with instructions for installing, commissioning, maintaining and testing these systems in accordance with applicable installation codes and standards. NFPA 1 and ICC IFC provide information on applicable requirements and codes for fire suppression systems. See also Appendix A.		P
23.1.3	If fire suppression optional the ESS meets applicable requirements with or without it.		N/A
23.2	**Large Scale Fire Testing**		P

UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
23.2.1	Fire testing to UL 9540A	unit level test report provided.	P
23.2.2	ESS for habitable or living space meet UL 9540A cell level	Not such ESS.	P
24	**Utility Grid Interaction**	Only BESS container, no PCS	N/A
24.1	General		N/A
24.1.1	Inverters, chargers, and charging charge control equipment that are part of an energy storage system shall be designed and rated for use with the battery system employed in the energy storage system and evaluated to UL 1741, UL 62109-1 or CAN/CSA C22.2 No. 62109-1, UL 1012, UL 1564, or CAN/CSA C22.2 No. 107.1 as applicable to the power conversion equipment and its application in the system.		N/A
24.2	**Utility Grid Interaction**		N/A
24.2.1	Energy storage systems intended to export energy to the electric power systems (EPS)/electric utility shall be designated as utility-interactive, grid support utility-interactive, or special purpose utilityinteractive and shall utilize the appropriately evaluated power conditioning systems. See 6.29, 6.30, and 6.31.		
24.2.2	The inverter shall be designed to properly interconnect with the particular energy storage technology it is connected to as determined by the system safety analysis.		N/A
24.2.3	Products that rely upon internal or external utility interconnection protection functions or devices shall be specifically identified for the particular product in the ESS instructions.		N/A
24.3	**Utility grid interactive inverter**		N/A
24.3.1	A utility-interactive inverter, grid support, utility interactive inverter ahall comply with UL 1741, UL 62109-1 or CAN/CSA C22.2 No. 62109-1, or CSA C22.2 No. 107.1.		N/A
24.3.2	The utility-interactive inverters or converters may also include additional grid support and or special purpose utility-interactive features and/or functions that may be enabled in accordance with localutility interconnection protection requirements		N/A
24.4	**Standalone and multi-mode power conditioning systems**		N/A
24.3.1	Power conditioning systems for standalone and multi-mode applications shall comply with UL 1741, UL 62109-1 or CAN/CSA C22.2 No. 62109-1, or CSA C22.2 No. 107.1.		N/A

UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
25	**Energy Storage System Technologies**		P
25.1	**Electrochemical energy storage systems**		P
25.1.1	Systems composed of batteries, electrochemical capacitors, hybrid battery capacitors systems or flow batteries shall comply with the requirements of the Standard for Batteries for Use in Light Electric Rail (LER) Applications and Stationary Applications, UL 1973.		P
25.2	**Chemical energy storage systems**		N/A
25.2.1	Fuel Cell Systems shall comply with the Standard for Fuel Cell Technologies – Part 3-100: Stationary Fuel Cell Power Systems – Safety, ANSI/CSA FC 1. Fuel Cell Power Systems and shall be installed in energy storage systems in accordance with NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems or other applicable regional or local installation codes.		N/A
25.2.2	Stationary engine generators shall comply with the Standard for Stationary Engine Generators Assemblies, UL 2200 or C22.2 No. 100 and C22 No. 14.		N/A
25.2.3	Water electrolysis type hydrogen generators used in an energy storage system to provide hydrogen for storage shall be evaluated and found to be in compliance to an appropriate safety standard for the equipment.		N/A
25.2.4	Hydrogen fuel containing parts of a chemical energy storage system shall be constructed of materials suitable for gaseous hydrogen service at the pressures and temperatures of use. Pressure vessels used for storage of gaseous hydrogen and piping employed as part of a chemical energy storage system shall comply with Section 19.		N/A
25.3	**Mechanical Energy Storage Systems**		N/A
25.3.1	Hazards associated with moving parts of Mechanical Energy storage systems		N/A
25.3.2	Flywheel systems and other systems with moving parts with the capacity to store kinetic energy shall comply with the Containment of Moving Parts tests of Section 32 and the Strength Tests of Section 34. Parts containing hazardous fluids shall comply with the Leakage Tests of Section 33 and the Strength Tests of Section 34.		N/A
25.4	**Thermal Energy Storage systems**		N/A

UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
25.4.1	Thermal energy storage systems shall be evaluated to determine hazards associated with containment of high temperature and high pressure and potentially hazardous fluids are mitigated.		N/A
	PERFORMANCE		P
26	**General**		P
26.1	To be tested and determined compliant to an applicable technology safety standard. Where no applicable safety standard exists, they are to be tested in accordance with this standard.		P
26.2	All tests, unless noted otherwise, are conducted in a room ambient 25 ± 5°C (77 ± 9°F).	25 ± 5°C	P
26.3	Temperature shall be measured using thermocouples consisting of wires not larger than 0.21 mm2 (24 AWG) and not smaller than 0.05 mm2 (30 AWG)		P
26.4	The tests contained in this outline of investigation may result in explosions, fire and emissions of flammable and/or toxic fumes as well as electric shock.		P
27	**Normal Operations Test**		P
27.1	A normal operations test can be waived for those ES systems where a similar evaluation such as a temperature test has already been conducted under the specific technology standard.		P
27.2	An ES is operated through a maximum of 2 cycles of charge and discharge of the system under maximum loading conditions.		P
27.3	During the test, consideration shall be given to maximum and minimum room ambient conditions. and: Wall mounted equipment	Considered	N/A
27.4	During the normal operations test, the manufacturer's specified limits shall not be exceeded during the charging and discharging cycles. Temperatures measured on components shall not exceed their specifications		P
28	**Dielectric Voltage Withstand Test**		P
28.1	Purpose of Test	See table 28&29	P
28.2	Test Potential		P
28.3	Locations of test		P
28.4	Locations of Test (enclosure)		P
28.5	Duration of Test		P

UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
28.6	Test Equipment		P
28.7	Result of Test		P
29	**Impulse Test**		P
29.1	The impulse voltage test is intended to evaluate the energy storage system's ability to withstand lightning or similar surges. Systems provided with protection that has already been evaluated for voltage surges (e.g. inverters meeting the Standard for Interconnecting Distributed Resources with Electric Power Systems, IEEE 1547 criteria) need not be tested.		P
29.2	Impulse test voltage and waveform		P
29.3	Application of the pulses		P
29.4	No insulation puncture, flashover, or spark-over		P
30	**Grounding and Bonding Test**		P
30.1	Method of measurement and result	See table 30.	P
30.2	Resistance does not exceed 0.1ohm.		P
31	**Insulation Resistance Test**		P
31.1	To be Greater than 1MΩ	See table 31.	P
31.2	Method of Measurement		P
31.3	Resistors and/or resistor networks may be removed for the test		P
32	Electromagnetic Immunity Tests		P
32.1	General		P
32.1.1	Electronics and software controls determined to be critical for safety shall demonstrate sufficient immunity to electromagnetic interference by complying with the tests specified in these sections.		P
32.1.2	Each test begins with an operation unit		P
32.1.3	Modes of operation		P
32.1.4	Inspection after test		P
32.1.5	All samples used comply with section 32.8 after the test.		P

UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
32.2	**Electrostatic Discharge**	See EMC report CN235IL2 001 for details.	P
32.2.1	Immunity to discharge per IEC 61000-4-2		P
32.2.2	6kV contact discharge 8kV air discharge		P
32.2.3	Complies with 32.1.4 after test		P
32.3	**Radio-frequency electromagnetic field**		P
32.3.1	Immunity to IEC 61000-4-3		P
32.3.2	a) 10 V/m from 80 MHz to 1 GHz, 1 kHz (80% AM); and b) 3 V/m from 1.4 GHz to 6.0 GHz, 1 kHz (80% AM).		P
32.3.3	During the test compies with 32.1.3		P
32.3.4	After test complies with 32.1.4		P
32.4	Fast transient/burst Immunity		P
32.4.1	Comply with IEC 610004-4		P
32.4.2	a) On signal/control ports intended to be connected to cables longer than 3 m (118.1 in), ±1 kV (5/50 ns, 5 kHz); capacitive clamp shall be used; b) On input and output DC ports, ±1 kV (5/50 ns, 5 kHz); and c) On input and output AC ports, ±2 kV (5/50 ns, 5 kHz).		P
32.4.3	Test levels applied to al ports		P
32.4.4	After test complies with 32.1.4		P
32.5	Surge Immunity		P
32.5.1	Comply with IEC 61000-4-5		P
32.5.2	a) For I/O signal/control ports intended to be connected to long-distance cables longer than 30 m (118.1 in), which leave the building, and/or are for outdoor use, ±1 kV line-to-ground; b) For input and output DC ports, ±0.5 kV line-to-line, and ±1 kV line-to-ground; and c) For input and output AC ports, ±1 kV line-to-line, and ±2 kV line-to-ground.		P
32.5.3	Applied to all ports		P

UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
32.5.4	After test complies with 32.1.4		P
32.6	Radio Frequency Common Mode		P
32.6.1	Comply with IEC 61000-4-6		P
32.6.2	a) For I/O signal/control ports intended to be connected to cables longer than 3 m (118.1 in), 10 V (150 kHz to 80 MHz, 1 kHz, 80% AM); b) For input and output DC ports, 10 V (150 kHz to 80 MHz, 1 kHz, 80% AM); and c) For input and output AC ports, 10 V (150 kHz to 80 MHz, 1 kHz, 80% AM).		P
32.6.3	Applied to all ports		P
32.6.4	During test complies with 32.1.3		P
32.6.5	After test complies with 32.1.4		P
32.7	**Power Ferquency Magnetic Field**		P
32.7.1	Comply with IEC 61000-4-8		P
32.7.2	Test level 10A/m		P
32.7.3	During test complies with 32.1.3		P
32.7.4	After test complies with 32.1.4		P
32.8	Operational Verification		P
32.8.1	After the tests in 32.2 – 32.7 have been completed, all samples used during these tests shall comply with the following.		P
32.8.2	The manufacturer shall declare the anticipated performance of all safety functions performed by electronics and software controls.		P
32.8.3	The manufacturer shall provide test procedures to verify that each of the safety functions performed by electronics and software controls is working correctly. This may include, for example, verification of correct safety function performance by simulation.		P
32.8.2	During the test procedures specified in 32.8.3, each DUT shall exhibit one of the following behaviors: a) No loss of safety functions; or b) Transition to an appropriate state to ensure safe operation of the DUT.		P
	MECHANICAL TESTS		N/A
33	**Containment of Moving Parts**		N/A
33.1	**Over speed test qualification test**		N/A

UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
33.1.1	The energy storage system with hazardous moving parts that may be subject to over speed conditions through a fault in the system controls shall be subjected to an over speed test.		N/A
33.1.2	The system controls shall be subjected to single fault in the controls that would allow over speed of the hazardous moving parts. The DUT shall be operated at over speed conditions until a secondary protection control operates to stop operation of the DUT		N/A
33.1.3	As a result of the over speed condition, the hazardous moving part(s) shall not become loosened or disconnected in a manner that would result in a hazardous condition.		N/A
33.2	**Faulted securement test**		N/A
33.2.1	The energy storage system with hazardous moving parts shall be subjected to the faulted securement test if faulting of the moving parts securement means may result in a hazard.		N/A
33.2.2	The hazard moving parts of the system shall be subjected to a single fault of their securement		N/A
32.2.3	The system shall be operated until:		N/A
	a) The part has operated for 30 min under the faulted condition and then as gradually slowed down after discontinuation of operation;		N/A
	b) A protection control operates to stop operation of the DUT or hazardous moving part; or		N/A
	c) The part has loosened and is completely or partially disconnected from its securement means.		N/A
33.2.4	As a result of the operation with a faulted securement condition, the hazardous moving part(s) shall not become loosened or disconnected to result in a hazardous condition.		N/A
33.3	**Blocked Shaft Qualification Test**		N/A
33.3.1	An energy storage system with moving parts with the capacity to store kinetic energy shall be subjected to the blocked shaft qualification test if blocking the shaft or moving parts may result in a hazard.		N/A
33.3.2	With the moving part blocked to prevent movement, the system shall be operated at maximum operating conditions.		N/A

UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
33.3.3	The system shall be operated: a) With the part blocked for 30 min and then stopped; b) Until a protection control operates to stop operation of the DUT with the blocked part; or c) Until any moving parts break off or become completely or partially disconnected from its securement means. Exception: Moving parts already evaluated for blocked shaft conditions as part of a component evaluation, need not be tested.		N/A
33.3.4	Pass criteria		N/A
33.4	**Mechanical Failure Test**		N/A
334.1	An energy storage system with any moving part having the capacity to store kinetic energy shall have the rotating energy storage elements subjected to a mechanical failure qualification test. A margin of safety of a factor of at least 2.0 between the stress that exists in the mechanical energy storage element at maximum normal operating speed and the ultimate tensile strength of the mechanical energy storage element material at room temperature.		N/A
33.4.2	Test force to create at least two times maximum working stress.		N/A
33.4.3	Solid mechanical energy storage system		N/A
33.4.4	Hollow cylindrical mechanical storage systems		N/A
33.4.5	Condition of DUT before the test		N/A
33.4.6	Alternative to 22.4.2		N/A
33.4.7	With reference to 33.4.2, in the event of a deviation of any mechanical characteristic or material property that results in an increase of more than 15% between calculated stress in production mechanical energy storage elements and demonstrated stress in the previously qualified mechanical energy storage elements, the mechanical failure qualification test shall be repeated.		N/A
33.5	**Bearing Failure Test**		N/A
33.5.1	An ESS with moving parts with the capacity to store kinetic energy that relies upon bearings in their moving mechanism shall be subjected to the bearing failure test if failing bearings may have the potential to result in a hazard.		N/A

UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
33.5.2	With the system operating at maximum operating conditions, a failure in the bearings shall be induced through the injection of materials that result in blockage and damage to the bearings or through some other mechanism that creates a bearing failure and that results in abrupt stopping of the moving mechanism.		N/A
33.5.3	The system shall be operated: a) Until the rotor has stopped through inertia of the damaged parts; b) Until a protection control operates to stop operation of the DUT; or c) Until any moving parts break off or become completely or partially disconnected from its securement means.		N/A
33.5.4	As a result of operating the system with a failed bearing condition, the moving parts shall not become loosened or disconnected to result in a hazardous condition. If the part becomes completely loosed or disconnected, the containment means for the part shall safely contain the part(s). There shall be no overheating of parts that will result in a hazard such as fire or explosion.		N/A
34	**Leakage Tests**		P
34.1	Energy storage systems that contain hazardous fluids shall be subjected to the Leakage Test in accordance with 33.2 and 33.3.		N/A
34.2	Leakage from energy storage systems containing hazardous fluids shall not result in the risk of fire, electric shock, or injury to persons.		P
34.3	Compliance is determined by subjecting the fluid-containing parts and their connections to a fluid pressure of 1.5 times the maximum pressure (if testing with liquid) or 1.1 times the maximum pressure (if air pneumatic testing) of intended use during operation of the system. There shall be no leaks from fluid-containing parts or their connections as a result.		P
35	**Strength Tests**		P
35.1	General		P

UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
35.1	Energy storage systems that contain hazardous fluids shall comply with the Strength Tests in accordance with 34.2 and 34.3.		P
35.2	**Hydrostatic Strength Test**		P
35.2.1	Parts of the energy storage system containing hazardous fluids (gases or liquids) shall be subjected to a hydrostatic strength test of 1.5 times the design pressure of the system for a period of 1 min after reaching the maximum pressure.		P
35.2.2	As a result of the hydrostatic strength test, there shall be no fracture, distortion, rupture or other damage to the fluid containing parts.		P
35.3	**Pneumatic Strength Test**		N/A
35.3.1	The pneumatic strength test is an alternative to the hydrostatic strength test of 34.2 and is conducted in accordance with 34.3.2.		N/A
35.3.2	Parts of the energy storage system containing hazardous fluids (gases or liquids) shall be subjected to a pneumatic strength test of 1.3 times the design pressure of the system for a period of 1 min after reaching the maximum pressure		N/A
35.3.3	As a result of the pneumatic strength test, there shall be no fracture, distortion, rupture or other damage to the fluid containing parts.		N/A
36	**Wall Mounted Fixture/Test**		N/A
36.1	Sufficient Strength to support the system		N/A
36.2	The wall mounting apparatus and ESS shall be installed in accordance with the manufacturer's specifications. A force equal to three times the weight of the ESS is additionally applied to the center of the mounting apparatus in a downward direction. The force shall be held for 1 min.		N/A
36.3	As a result of the applied force, there shall be no damage to the mounting apparatus and its securement means when testing the wall mounting fixture.		N/A
	ENVIRONMENTAL TESTS		P
37	**Special Environmental Installations**		P
37.1	**General**		P
37.1.1	Intended for installation in special environments shall be evaluated for their ability to operate safety in those environments.		P

UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
37.2	**Outdoor Installations subject to moisture exposure**		P
37.2.1	Energy storage systems intended for installation outdoors where they will be subject to rated levels of moisture exposure shall be tested in accordance with their environmental ratings outlined in their nameplate labels and installation instructions of 39.8 and 40.4.		P
37.2.2	Based upon the ratings of the system, moisture resistance testing shall be done in accordance with either the Standard for Degrees of Protection Provided by Enclosures (IP Code), IEC 60529, Enclosures for Electrical Equipment, Environmental Considerations, UL 50E, or the Standard for Enclosures for Electrical Equipment, Environmental Considerations, C22.2 No. 94.2.	IP55(Battery room); IP55(Electrical room); IP67(Chiller control box)	P
37.2.3	At the conclusion of the test, the sample is to be subjected to the electric insulation tests of Sections 28 and 31 and examined for signs of water in the system that could result in a hazardous condition.		P
37.2.4	As a result of the water exposure, there shall be no evidence of water on parts that could result in a hazard and no reduction of spacings or breakdown/deterioration in insulation levels.		P
37.3	**Outdoor installation near marine environments**	Not evaluated.	N/A
37.3.1	Energy Storage Systems intended for installation outdoors near marine environments in accordance with the installation instructions in 40.6 where they will be subject to salt fog exposure, shall be tested as outlined below.		N/A
37.3.2	Tested to IEC 60068-2-52 severities 1 or 2		N/A
37.3.3	At the conclusion of the testing, the systems shall be subjected to the electrical insulation tests of Sections 28 and 31 to determine that insulation has not been damaged in a manner that would result in an electric shock hazard.		N/A
37.3.4	The system shall be examined for signs of damage as a result of salt exposure that would indicate a potential for a safety hazard (e.g. corrosion of parts that could result in weakening of a securement or an enclosure, damage to insulation). If operational, the system is to be operated to determine that it can do so without hazard.		N/A
37.3.5	As a result of the test, the energy storage system shall not show evidence of damage from salt fog exposure that could result in a hazard such as electrical, shock, overheating or damage that could result in a physical hazard.		N/A

UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
37.4	**Installation in seismic environments**		N/A
37.4.1	Energy storage systems intended for installation where they will be subject to seismic activity shall be evaluated and if necessary tested in accordance with their seismic ratings and installations instructions per 41.3 and 42.13.	Not evaluated	N/A
37.4.2	The energy storage system shall be examined for signs of explosion, fire, combustible concentrations (if applicable to technology), rupture of the enclosure, electrolyte leakage, electric shock and loss of protection controls that may lead to any of the other non-compliant results in 35.4.3.		N/A
37.4.3	Compliance conditions		N/A
	MANUFACTURING AND PRODUCTION TESTS		
38	**Electrical Production Tests**		P
38.1	**Dielectric Voltage Withstand Test**		P
38.1.1	Value for production test	See CDF	P
38.2	**Grounding and Bonding systems Check**		P
38.2.1	Impedance to be of grounding and bonding system to be checked	See CDF	P
38.2.2	Resistance <0.1 Ω		P
38.3	**Check of Safety Controls**		P
38.3.1	Energy storage systems shall be subjected to 100% production screening to determine that any active controls utilized for safety are functioning.		P
39	**Mechanical Production Tests**		N/A
39.1	**Maximum Abnormal Operating Speed**		N/A
39.1.1	Every production mechanical storage element shall be subjected to a maximum abnormal operating speed test.		N/A
39.2	**Production Screening of Rotors**		N/A
39.2.1	Rotor assemblies for mechanical ESS shall be subject to 100% production screening through the use of ultrasonic testing or other means to check for cracks and other flaws in the rotor in order to determine that the rotor is manufactured in accordance with the manufacturer's specifications.		N/A
40	**Production Quality Control**		P
40.1	Manufacturers of ESS shall have documented production process controls in place	See factory inspection report.	P
	MARKINGS		P
41	**General**		P

UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
41.1	Markings shall be legible and permanent		P
41.2	Markings and signage shall be in lettering that is sized so that it is legible from the distance from which is must be read and shall have lettering in a color that contrasts with the background.		P
41.3	Marked with the manufacturer's name, trade name, trademark or other descriptive marking which may identify the organization responsible for the product, part number or model number, and electrical ratings.		P
41.4	Multi-part ESS Marked with the date of manufacture, which may be in the form of a code that does not repeat within 10 years. All external terminals and connections shall be provided with identification.		P
41.5	Contact information marked on system		P
41.6	Date of manufacture		P
41.7	The point of connection to the charger earth grounding system shall be identified by the word "Ground" r the letters "G" or "GR" or the grounding symbol		P
41.8	System that contains hazardous voltage circuits shall be marked "Warning: Hazardous Voltage Circuits"or be marked with the electric shock hazard symbol		P
41.9	Shall be marked as follows: "WARNING – To reduce the risk of injury, read all instructions"or the sign M002 of ISO 7010, No. W001		P
41.10	Walk in system marked		N/A
41.11	An energy storage system shall be marked with the environmental rating of its enclosure	IP55(Battery room); IP55(Electrical room); IP67(Chiller control box)	P
41.12	The control devices and indicators required for operation or maintenance are to be marked with their function on or adjacent to the control.		P
41.13	Egress door marked with "Exit"	No such door	N/A
41.14	A non-residential use electrochemical ESS that complies with 1.9 shall be marked, "ESS with capacities exceeding 50 kWh shall include the additional fire suppression and/or fire protection identified in the installation instructions.		N/A
41.15	A non-residential use electrochemical ESS intended for use in remote outdoor locations per 1.10 shall be marked "For use only in remote outdoor locations as permitted in applicable installation codes and standards.		N/A
41.16	Disconnect Controls marked		P

UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
	INSTRUCTIONS		P
42	**General**		P
42.1	The ESS shall be provided with complete instructions for installation, commissioning, operation and maintenance		P
42.2	The installation instructions shall identify the maximum rated energy capacity for the system and minimum separation distances from other ESS and from exposures (e. g. combustibles, structures) in accordance with the limitations to the system based on applicable codes or in accordance with the large scale fire testing of 23.2.		P
42.3	Instructions for wall mounted ESSs	Not wall mounted ESS	N/A
42.4	Non residential systems identify 9540A test report	Unit level tested. Identify UL 9540A test report.	P
42.5	Non-residential use ESS requiring large scale fire testing per 23.2, the additional fire suppression and/or fire protection identified in the UL 9540A test report shall be included in the installation instructions.		N/A
42.6	Installation instructions for indoor residential electrochemical ESS shall indicate that the units are only intended to be installed in attached or detached garages, sheds and locations more than 152.4 cm (5 ft) from dwelling units, and are not intended for installation in habitable spaces and livings spaces in dwelling units, including bathrooms, toilet rooms, closets, halls and storage spaces, except as allowed in 42.7.	Not indoor residential	N/A
42.7	Instructions if intended for use in residential dwellings		N/A
42.8	Instructions in accordance with NFPA79 or CSA C22.1 No. 201 and in accordance with 42.2 to 42.10		P
42.9	Cautionary markings and ratings in the instructions		P
42.10	The installation information shall include instructions for making all necessary connections for electrical, communications, piping for fuels and other fluids, etc. as well as connections to other equipment that are part of the system.		P
42.11	Instructions specify installation to be in accordance with local codes		P

UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
42.12	With reference to 42.9, the installation instructions for ESS, such as flow batteries, lead acid batteries, etc., containing free electrolyte (greater than 208 L (55 gal) in a single vessel or an aggregate of 3785 L (1000 gal)) shall be provided with instructions for location of eye wash stations. In addition, if necessary in accordance with building codes, installation instructions shall provide information on spill control to be installed with the system per 21.1 and 21.3.		N/A
42.13	Instructions for installation in certain environments		P
42.14	ESS for residential use		N/A
42.15	Smoke alarm instructions for indoor use		N/A
42.16	Instructions for special handling		P
42.17	Instructions for proper use		P
42.18	Maintenance instructions		P
42.19	Instructions for filed replacement of replaceable materials		P
42.20	Schedule of routine maintenance mechanical systems		P
42.21	The installation instructions shall contain all ESS operation mode/settings, operation function/settings and protection/settings, which the inverters can provide.		P
	General Battery Safety Considerations		-
B1	**General**		-
B1.1	The battery specific safety requirements for this standard can be found in the Standard for Batteries for Use in Light Electric Rail (LER) Applications and Stationary Applications, UL 1973.		-
B2	**Design Considerations**		-
B2.1	Battery systems should have two-fault tolerance for all catastrophic failures including overcharge, overdischarge, short circuit and extreme temperatures		-
B2.2	The chargers used for charging the energy storage battery systems should be designed for the chemistry of the battery to be charged		-
B2.3	Protection circuits should be verified by test in the relevant battery design configuration		-
B2.4	Cell level protection should not be relied upon for battery pack protection		-
B2.5	Requirements for lithium ion batteries		-
B2.6	Requirements for aqueous batteries		-

UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
B2.7	Thermal analysis		-
B2.8	Temperature Monitoring		-
B2.9	Prevention of over discharge		-
B2.10	Prevention of thermal runaway propagation		-
B2.11	Failure of heating cooling system		-
B2.12	Heaters do not cause excessive operating ambient if they fail.		-
B12.13	Cooling system leak does cause short circuiting of a cell.		-
B12.14	Thermal runaway propagation test		-
B12.15	Verification that battery operating parameters are with specification.		-
D	**Alternative Approach for Evaluating Valve Regulated or Vented Lead Acid or Nickel Cadmium Battery Systems**	Li-ion battery	N/A
D1	**General**		N/A
D1.1	Scope of appendix		N/A
D1,2	Safety concerns of lead acid or nickel cadmium		N/A
D2	**Construction**		N/A
D2.1	The batteries and components of the battery systems shall be installed in accordance with Articles 480 and 706 of NFPA 70 or Section 64 of CSA C22.1.		N/A
D2.2	Batteries comply with UL 1989		N/A
D2.3	With reference to D2.2, valve regulated batteries shall additionally be evaluated for high discharge/short circuit conditions in accordance with the high current tolerance test of IEC 60896-21 if not conducting the UL 1973 short circuit test per D3.3.		N/A
D2.4	With reference to D2.2, valve regulated batteries shall additionally be evaluated for high discharge/short circuit conditions in accordance with the high current tolerance test of IEC 60896-21 if not conducting the UL 1973 short circuit test per D3.3.		N/A
D2.5	Short circuit protection		N/A
D2.6	Current and temperature to prevent overcharge		N/A
D2.7	Hydrogen concentration <25% LFL		N/A

UL 9540			
Clause	Requirement – Test	Result – Remark	Verdict
D2.8	The battery system exceeding 240 Vdc shall be provided with disconnects in accordance with Article 706 of NFPA 70 or Section 64 of CSA C22.1, for servicing of the battery system.		N/A
D2.9	Installation of lead acid and nickel cadmium batteries in ESS systems shall consider applicable fire and building code requirements related to ventilation and explosion protection mechanisms to address hazards associated with the off gassing of hydrogen from these batteries.		N/A
D2.10	Spill Control		N/A
D3	**Performance**		N/A
D3.1	General		N/A
D3.1.1	UL 1973 tests to be applied		N/A
D3.1	**Overcharge**		N/A
D3.2.1	Modifications to UL 1973 overcharge test		N/A
D3.2.2	Test results		N/A
D3.3	Short Circuit		N/A
D3.3.1	Short circuit current		N/A
D3.3.2	Setting of short circuit protection		N/A
D3.3.3	Alternate method Short circuit test of UL 1973		N/A
D3.3.4	Test Reults		N/A
D3.4	**Overdischarge**		N/A
D3.4.1	Method of UL 1973 applied		N/A
D3.4.2	Test results		N/A
D3.5	**Imbalanced charging**		N/A
D3.5.1	One battery at 50% SOC the other at 0% and string charged		N/A
D3.5.2	Test Results		N/A
D3.6	Failure of the cooling/thermal stability		N/A
D3.6.1	This test shall only be conducted on systems that have a cooling/thermal stability system for the batteries.		N/A
D3.6.2	The Failure of Cooling/Thermal Stability System test of UL 1973 shall be conducted.		N/A
D3.6.3	Test Results		N/A

2	Table: Component Data					P
Item No.	**Object/part no.**	**Manufacturer/ Trademark**	**Type/Model**	**Technical Data**	**Standard**	**Mark(s) of Conformity**
-	-	-	-	-	-	-
See Attachment No. 1 CDF for component data.						

13	TABLE: Electrical spacings and Separation of Circuits					P
Clearance (cl) and creepage distance (cr) at/of/between:	U peak (V)	U r.m.s. (V)	Required cl (mm)	cl (mm)	Required cr (mm)	cr (mm)
Battery +/- to metal enclosure (OVC 2 considered)	1500	1500	5.5	15.7	15	45
Auxiliary power L/N to metal enclosure (OVC 3 considered)	480	277	3.0	8.3	5.0	8.3
Supplementary information: The battery system certified by UL 1973. Approved components usded for the insulation between live circuit and Selv circuit.						

27A	TABLEL: Normal Operation-Temperature					P
Table 27B	TABLE: Normal Operation-Voltage and Current					P
Rated Voltage (V)	Rated Current (A)	Rated Power (kw)	Measured Voltage (V)	Measured Current (A)	Measured Power (kW)	Comments
1331.24	1530*2	2036.73	1447.9/1240.4	104.8	2036.73max	charging
1331.24	1530*2	2036.73	1404.6/1108.1	-181.2	2036.73max	discharging

Work condition	Rated Battery System voltage	Battery System current	Remark
Standard Charging and Discharging	1331.2Vd.c.	181.2A max	Constant power

Thermocouple Locations	Max. temperature measured corrected to max. ambient, (°C)	Max. temperature limit, (°C)
Top of cluster 1, 4# electrical box	35.52	90
Cluster 1, 4# electrical box at CSC	53.80	125
High voltage wiring harness on the	91.25	125
Positive bus bar	84.55	125
Positive bus and insulator joint	66.39	135
Insulating paper	69.76	140
Sealing gasket for the outlet hole of	58.17	80

Air switch	59.31	70
relay	62.27	75
Terminal strip	57.15	105
transformer	81.00	155
AC-DC	62.40	70
DC-DC	58.90	70
PCB of IMM chip accessories (need	57.64	130
IMM optocoupler (need to open the	58.55	85
Fire protection system - Control	55.23	65
Isolation switch - ring temperature	72.19	75
Contactor/relay - Ring temperature	73.87	85
Hall Sensor - Ring temperature	73.53	85
Copper bus base body (Cluster 1	64.54	100
Fuse- Ring temperature (Cluster 1	86.67	100
Fan-ring temperature (Cluster 1 main	70.42	75
Prefilled relay - Ring temperature	69.08	85
SBMU High Voltage Connector body	64.90	125
SBMU isolation chip body (in SBMU of Cluster 1 main control box)	71.89	85
Ambient	55	Ref.

Supplementary information:
The test was conducted at ambient temperature 55°C, Operation mode: Constant power 2036.73kw. The cooling system is continuous working during the test.

28, 29	Table: Dielectric Strength and Impulse		P
Test Location	**Dielectric Applied Voltage**	**Impulse Voltage**	**Pass / Fail**
Battery system HV (+) to PE (BI)	4414Vd.c.	6000	Pass
Battery system HV (-) to PE (BI)	4414Vd.c.	6000	Pass
Battery system HV (+) to Communication circuit (RI)	4700Vd.c.	8000	Pass
Battery system HV (-) to Communication circuit (RI)	4700Vd.c.	8000	Pass
AC input to PE (BI)	2120Vd.c.	2500	Pass

AC input to Communication circuit (RI)	4240Vd.c.	6000	Pass
AC input to PE (BI)	2121Vd.c.	2500	Pass
Notes: UL 1741 considered			

30	**TABLE: Ground Continuity Test**		**P**
Tested between:	Voltage	Current	Ohms
Door of electrical room to electrical room grounding bar PE phase	-	25A	14.6mΩ
1#Rack module ground point to electrical room grounding bar PE phase	-	25A	14.5mΩ
1#Rack Control box ground point to 1#Rack module ground point	-	25A	14.9mΩ
Cooling system ground point to electrical room grounding bar PE phase		25A	14.6mΩ

31	**TABLE: Insulation Resistance**	**P**
Tested between:	Measure Resistance (MΩ)	Comments
Main DC+ to Ground	710	Limit: > 1 MΩ
Main DC- to Ground	142	Limit: > 1 MΩ
Auxiliary Power L to Ground	1651	Limit: > 1 MΩ
Auxiliary Power N to Ground	1651	Limit: > 1 MΩ
Main +/- to Communication	2678	Limit: > 1 MΩ
Auxiliary Power L/N to Communication	371	Limit: > 1 MΩ
Supplementary information:		

--End of test report--

Appendix C

UL9540A Unit Test Report

UNIT TEST REPORT
UL 9540A
Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems (AACD)

Project Number.....:	**4790931774**
Date of issue.....:	**2023-10-27**
Total number of pages.....:	**44**

UL Report Office .....:	**UL(Changzhou) Quality Technical Service Co., LTD**
Applicant's name.....:	**Contemporary Amperex Technology Co., Limited**
Address .....:	**No.2 Xin'gang Road, Zhangwan Town, Jiaocheng District, Ningde, Fujian, China**
Test specification:	4th Edition, Section 9, November 12, 2019
Standard.....:	UL 9540A, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems
Test procedure .....:	9.1 – 9.8
Non-standard test method .....:	UL 9540A, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

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General disclaimer:

The test results presented in this report relate only to the sample tested in the test configuration noted on the list of the attachments.

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).

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Cell level information	
Cells in Module:	
●Manufacturer Name	**Contemporary Amperex Technology Co., Limited**
●Part Number	**CBDD0**
●Chemistry	**Lithium Iron Phosphate**
●Format	**Prismatic**
Ratings (Vdc, Ah) :	**3.2V, 306Ah**
Cell certified? :	**Yes**
Standard the cell was certified to:	**UL 1973**
Organization that certified the cell:	**MH62898**
Average cell surface temperature at gas venting, °C:	**154**
Average cell surface temperature at thermal runaway, °C:	**241**
Gas Volume:	**204L**
Lower flammability limit (LFL), % volume in air at the ambient temperature:	**8.595**
Lower flammability limits (LFL), % volume in air at the venting temperature:	**7.24**
Burning velocity (S_u) cm/s:	**54.20**
Maximum pressure (P_{max}) psig:	**102.74**

Cell level Gas Composition:

Gas		Measured %
Carbon Monoxide	CO	14.596
Carbon Dioxide	CO_2	26.925
Hydrogen	H_2	43.066
Methane	CH_4	7.051
Acetylene	C_2H_2	0.119
Ethylene	C_2H_4	3.289
Ethane	C_2H_6	1.060
Propylene	C_3H_6	0.686
Propane	C_3H_8	0.260
-	C4 (Total)	0.865
-	C5 (Total)	0.399
-	C6 (Total)	0.148
1-Heptene	C7H14	0.025
Styrene	C8H8	0.013
Benzene	C_6H_6	0.082
Toluene	C_7H_8	0.012
Dimethyl Carbonate	$C_3H_6O_3$	1.304
Ethyl Methyl Carbonate	$C_4H_8O_3$	0.101
Total	**-**	**100**

Module level Information	
Model No..... :	M02306P05L01

Ratings (Vdc, Ah)..... :	166.4V, 612Ah
Module dimensions (X x **Y** x **Z** (mm)**)…….:**	830mm*2235mm * 250mm
Module cell configuration (xS/**y**P**) …...:**	52S2P
Module weight (kgs)…… :	653±5kg
Module enclosure material…….. :	Bottom enclosure -Material: Al6063.T6 -Thickness: ≥2mm -Size: L*W*H(mm) (2235±3.5)*(830±3)*(31±3) Top Plastic enclosure: -Material: PP -Thickness: ≥2.5mm -Size: L*W*H（mm）2203.1*830*218.5 -Fire rating: V-0 -Maximum ambient temperature: 90±2°C
Was the module certified? …….:	No
Standard the module was certified to ……..:	N/A
Organization that certified test item …….:	N/A
Number of initiating cells failed to achieve propagation.	1
Thermal Runaway Propagation:	Initiating cell went into thermal runaway and propagated to three adjacent cells.
External Flaming:	No external flaming occurred
Location(s) of Flame Venting:	No flaming occurred
Flying Debris:	No flying debris occurred
Re-ignitions:	No further re-ignitions were observed during post test observation
Test Maximum Smoke Release Rate (m^2/s)	0.52
Test Total Smoke Released: (m^2)	1.41
Test Peak Chemical Heat Release Rate: (kW):	No flaming occurred

Module level test Gas Composition & Volume for Each Compound (Pre-flaming and After flame) :

Gas Compound	Gas Type	Pre-Flaming (L)	Flaming (L)	Minimum detectable flow rate(LPM)
Total Hydrocarbons (Propane Equivalent)	Hydrocarbons	260.29	No flaming	0.50
Carbon Monoxide	Carbon Containing	77.57	No flaming	0.61
Carbon Dioxide	Carbon Containing	217.03	No flaming	1.82
Hydrogen	Hydrogen	263.37	No flaming	14.29

Unit level Information	
Model No. :	C02306P05L01-R
Ratings (Vdc, Ah) ..... :	1331.2V, 612Ah
BESS dimensions (W x **D** x **H** (mm)**)…….:**	2698mm(H)*936mm(W)*2252.5mm(D)
BESS module configuration	8S1P
Number of modules in BESS	8
Module cell configuration (xS/**y**P**) …...:**	52S2P
Number of cells in module.:	104
BESS weight (kgs)…… :	7200kg
BESS enclosure material…….. :	No enclosure provided for BESS unit, racks are directly mounted on the container frames
BESS Intended Installation: **Non Residential:** outdoor ground mounted, indoor floor mounted, outdoor wall mounted, indoor wall mounted, roof top, open garage **Residential:** Outdoor ground mounted, indoor floor mounted, outdoor wall mounted, indoor wall mounted	Non Residential: indoor floor mounted in a container. For a container system BESS including those intended for outdoor installation only, the unit level test shall be in accordance with the indoor floor mounted unit level test using the battery system racks as the test units and with the test installation set up in accordance with the installation layout within the container. According to 9.1.2.1 from the CRD, it should be treated as indoor floor mounted application
Residential Indoor Use: Smallest volume room installations specified.	N/A
Original Equipment Manufacturer (OEM):	Contemporary Amperex Technology Co., Limited
Branding Manufacturer (if not OEM):	N/A
Was the unit certified? …….:	No
Standard the unit was certified to ……..:	N/A
Organization that certified the unit …….:	N/A
Cell failure test method performed (summary of method and test clause): ☒ External heating using thin film with 4°C to 7°C thermal ramp. ☐ Nail Penetration ☐ Overcharge ☐ External short circuit (***X*** Ω *external resistance*) ☐ Others	
Description of method used to fail cells if other than external thin film heater with thermal ramp, :N/A	

Description of components employed within the BESS unit that serve to suppress propagation (fire protection features)

N/A

Deviation from the module level test

N/A

Number of initiating cell(s)	1
Thermal Runaway Propagation:	Initiating cell went into thermal runaway and propagated to at least two adjacent cells.
External Flaming from BESS:	No external flaming occurred
Location(s) of Flame Venting:	No flaming occurred
Maximum Target BESS Temperature, °C	30.5
Maximum Wall Surface Temperature[1], °C	28.3
Peak Chemical Heat Release Rate, kW	No flaming occurred
Peak Convective Heat Release Rate, kW	No flaming occurred
Maximum Smoke Heat Release Rate, m^2/s	0.12
Maximum Heat Flux on Target Modules, kW/m^2	0.01
Maximum Heat Flux of Egress Path, kW/m^2	0
Flying Debris:	No flaming occurred
Re-ignitions:	No further re-ignitions were observed during post test observation

Gas Analysis:

☒ Flame ionization detection (FID)

☒ Non-Dispersive Infrared Spectrometer (NDIR)

☐ Fourier-Transform infrared Spectrometer

☒ Hydrogen Sensor (palladium-nickel, thin-film solid state sensor)

☒ White light source with photo detector (smoke release rate)

Summary of Unit level test Gas Analysis Data:

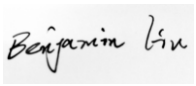
Unit level Gas Composition & Volume for Each Compound (Pre-flaming and After flame):

Gas Compound	Gas Type	Pre-Flaming (L)	Flaming (L)	Minimum detectable flow rate(LPM)
Total Hydrocarbons (Propane Equivalent)	Hydrocarbons	111.98	No flaming	4.13
Carbon Monoxide	Carbon Containing	59.54	No flaming	3.08
Carbon Dioxide	Carbon Containing	138.34	No flaming	3.97
Hydrogen	Hydrogen	3.54	No flaming	104.03

Summary of BESS Unit Test Results

Performance Criteria in accordance with Table 9.1 for Indoor Floor Mounted non-residential unit

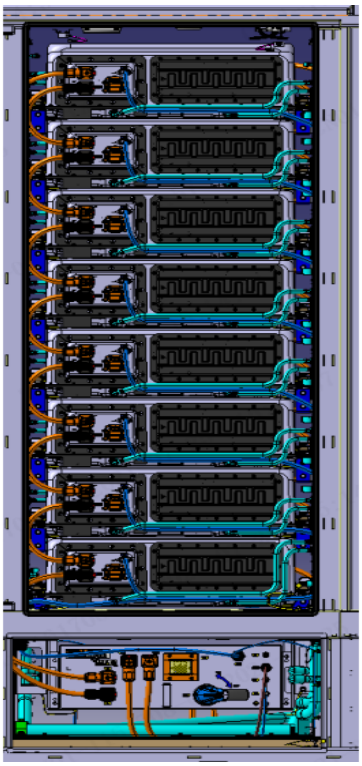
[1] Maximum wall surface temperature averaged on 60 seconds.

[X] Flaming outside the initiating BESS unit was not observed; **[X]** Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit did not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8; **[X]** For BESS units intended for installation in locations with combustible constructions, surface temperature measurements on wall surfaces did not exceed 97°C (175°F) of temperature rise above ambient per 9.2.15; **[X]** Explosion hazards were not observed, including deflagration, detonation; and **[X]** Heat flux in the center of the accessible means of egress did not exceed 1.3 kW/m^2.		
Necessity for an Installation level test		
[ ] The performance criteria of the unit level test as indicated in Table 9.1 of UL 9540A 4th edition has not been met, therefore an installation level testing in accordance with UL 9540A will need to be conducted on the representative the installation with this unit installed. **[X]** The performance criteria of the unit level tests as indicated in Table 9.1 of UL 9540A 4th edition has been met, therefore an installation level testing in accordance with UL 9540A need not be conducted.		
Testing Laboratory Information		
Testing Laboratory and testing location(s):		
Testing Laboratory:	Beijing Building Materials Testing Academy	
Testing location/ address..... :	Block 1, B15 Yaxin Road, Doudian Town, Fangshan district, Beijing 102402, CN PSN: 3369533	
Tested by (name, signature) ..... :	Zhang Qi, Oliver Zhao	
Witnessed by (for 3rd Party Lab Test Location) (name, signature) ..... :	N/A	N/A
Project Handler (name, signature)..... :	Arui Zhou	
Reviewer (name, signature) ……:	Benjamin Liu	

List of Attachments (including a total number of pages in each attachment):
Attachment A: Sample Charging, OCV and SOC Measurement Profiles - (*Pages **27** through **30***)
Attachment B: BESS (including module and any integral fire detection and suppression systems) Construction Photos/Diagrams - (*Pages **31** through **31***)
Attachment C: BESS and Equipment Instrumentation and Test Installation Layout Photos/Diagrams - (*Pages **32** through **35***)
Attachment D: Temperature Profiles and Heat Flux Measurements During Testing (Initiating Cell and Module, Target Modules, Wall Surfaces, etc. - (*Pages **36** through **39***)
Attachment E: BESS Unit Testing and Post Testing Photos - (*Pages **40** through **41***)
Attachment F: BESS Unit Gas Flow Rate and Heat Release and Smoke Release Profiles - (*Pages **42** through **44***)

Photo(s) of BESS unit:





Test Item Charge/Discharge Specifications:	C02306P05L01-R
• Charge Power, kW:	50.91 kW, then 5.091 kW for module 407.34 kW, then 40.734 kW for rack
• Standard Full charge voltage, Vdc:	Any cell reaches of 3.65V or 189.8V for module Any cell reaches of 3.65V or 1500V for rack
• Charge temperature range, °C:	-25~55
• End of charge Power, kW:	Any cell reaches of 3.65V or 189.8V for module Any cell reaches of 3.65V or 1500V for rack
• Discharge Power, kW:	50.91 kW for module, 407.34 kW for rack
• End of discharge voltage, Vdc:	Any cell reaches of 2.5V or 130V for module Any cell reaches of 2.5V or 1040V for rack
• Discharge temperature range, °C:	-25~55
• Storage temperature range, °C:	-30~60

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.....:	
Date of receipt of test item .....:	2023.08.27
Date (s) of performance of tests.....:	2023.09.22

General remarks:

"(See Enclosure #)" refers to additional information appended to the report.
"(See appended table)" refers to a table appended to the report.

Throughout this report a point is used as the decimal separator.

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.....:	☐ **Yes** ☒ **Not applicable**
Name and address of factory (ies) ..... :	Contemporary Amperex Technology Co., Limited Xin'gang Road, Zhangwan Town, Jiaocheng District, Ningde, Fujian, China

General product information and other remarks:

Battery Unit Model C02306P05L01-R is lithium-ion racks manufacturer by Contemporary Amperex Technology Co., Limited. The rack consists of 8 battery modules Model M02306P05L01 connected in series with a control box. The rack frame is part of the container frame and test was conducted with initiating rack and target racks installed in the container enclosure.

In the test, 3 racks were placed inside the container. Container size: 2698mm(H)*936mm(W)*2252.5mm(D).

Battery Module Model M02306P05L01 employs cell Models CBDD0 manufactured by Contemporary Amperex Technology Co., Limited, rated 166.4V, 612Ah.

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

5.0	**CONSTRUCTION**		**Verdict**
5.3	**Battery energy storage system unit Construction**		—
5.3.1, 5.3.2	Construction information	See Test Item Description at the beginning of this report	—
5.3.2	General layout of BESS unit contents	See Attachment B	—
5.3.3	Details of integral fire suppression system		
5.3.1	BESS certified to UL 9540		
	Organization that certified BESS:		—
6.0	**PERFORMANCE**		**Verdict**
6.1	**General**		C
9.1	**Sample and test configuration**		C
9.1.1	The unit level test conducted with BESS units installed as described in the manufacturer's instructions.	See Attachment C for test installations Installation type: Indoor floor mounted, non-residential use, container type	C
9.1.2	The unit level test required one initiating BESS unit in which an internal fire condition in accordance with the module level test is initiated and target adjacent BESS units representative of an installation.	See Attachment C for test installations	C
	Tests conducted for indoor floor mounted installations are representative of both indoor floor mounted and outdoor ground mounted installations.		N/A
	Tests conducted indoors with fire propagation hazards and separation distances between initiating and target units representative of the installation.		C
	Testing conducted outdoors for outdoor only installations with following in place: a) Wind screens with wind speed of ≤ 12 mph; b) Temperature range is 10°C to 40°C (50°F to 104°F); c) Humidity is < 90% RH; d) Sufficient light to observe the testing; e) There is no precipitation; f) There is control of vegetation and combustibles in the test area; and g) There are protection mechanisms in place to prevent inadvertent access by unauthorized persons in the test area.		N/A

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
9.1.3	Testing to determine fire characterization was done at the battery system level rather than a complete BESS	One initiating unit sample and two target unit samples were used for test. Power Conversion System was not involved in the test.	C
9.1.4	The initiating BESS contained components representative of a BESS unit in a complete installation.		C
	Combustible components that interconnect the initiating and target BESS units was included.		C
9.1.5	Target BESS units include the outer cabinet (if part of the design), racking, module enclosures, and components that retain cells components.		C
9.1.6	The initiating BESS was at the maximum operating state of charge (MOSOC),	See Table 2 and Attachment A	C
	After charging and prior to testing, the initiating BESS was at rest for a maximum period of 8 hours at room ambient.	See Table 2 All modules were fully charged before test for test setup. All module voltages were checked just before the test, and the voltages did not drop further compared to 1h to 8h after cycles.	M
9.1.7	The BESS unit included an integral fire suppression system.	No include integral fire suppression system.	N/A
9.1.8	Electronics and software controls such as the battery management system (BMS) are not relied upon for this testing.		C
	Included a fire suppression control in accordance with UL 864 that is external to the BESS.		N/A
9.2	**Test method – Indoor floor mounted BESS units**		C
9.2.1	Test room ambient temperature within 10°C (50°F) to 32°C (90°F).	See Table 2 See Attachment F	C
9.2.2	Access door(s) or panels on the initiating BESS unit and adjacent target BESS units were closed, latched and locked duration of the test.	There are no doors or panels for racks, racks are mounted on the container frame.	C
9.2.3	The initiating BESS unit was positioned adjacent to two instrumented wall sections.	Attachment C	C
9.2.4	Instrumented wall sections extend not less than 0.49 m (1.6 ft) horizontally beyond the exterior of target BESS units.	Front wall was 3.6m length, side wall was 7.2m length, rear wall was 6.2m length.	C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
9.2.5	Instrumented wall sections were at least 0.61-m (2-ft) taller than the BESS unit height, but not less than 3.66 m (12 ft) in height above the bottom surface of the unit.	Front wall, side wall and rear wall were 3.7m high.	C
9.2.6	The surface of the instrumented wall sections were covered with 16-mm (5/8-in) gypsum wall board and painted flat black.	See Attachment C	C
9.2.7	The initiating BESS unit was centered underneath an appropriately sized smoke collection hood of an oxygen consumption calorimeter.		C
9.2.8	The light transmission in the calorimeter's exhaust duct was measured using a white light source and photo detector. The smoke release rate was calculated.	See Table 11 See Attachment F	C
9.2.9	The chemical and convective heat release rates were measured for the duration of the test.	See Table 11 See Attachment F	C
9.2.10	The heat release rate measurement system was calibrated using an atomized heptane diffusion burner. The calibration was performed using flows of 3.8, 7.6, 11.4 and 15.2 L/min (1, 2, 3 and 4 gpm) of heptane.		C
9.2.11	The chemical heat release rate was measured using the following equipment: ● Paramagnetic oxygen analyser ● Non-dispersive infrared carbon dioxide and carbon monoxide analyser ● Velocity probe ● Type K thermocouple		C
9.2.12	The chemical heat release rate at each of the flows was calculated.		C
9.2.13	The physical spacing between BESS units (both initiating and target) and adjacent walls was representative of the intended installation.	See Attachment C Racks were installed inside container frame. The spacing between the initiating rack and adjacent target racks (left and right of initiating unit) was 0mm. The spacing from the front wall to the container frame was 3000mm, side wall to the container frame was 1100mm and rear wall to the container frame was 200mm	C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
9.2.14	Separation distances were specified by the manufacturer for distance between: a) The BESS units and the instrumented wall sections; and b) Adjacent BESS units.	See Attachment C	C
9.2.15	Wall surface temperature measurements were collected	See Table 6 See Attachment D	C
	The intended installation is composed completely of non-combustible construction		N/A
9.2.16	Wall surface temperatures were measured in vertical array(s) at 152-mm (6-in) intervals for the full height of the instrumented wall sections using No. 24-gauge or smaller, Type-K exposed junction thermocouples.		C
	The thermocouples for measuring the temperature on wall surfaces were horizontally positioned in the wall locations to receive greatest thermal exposure from the initiating BESS unit.		C
9.2.17	Thermocouples were secured to gypsum surfaces and the thermocouple tip was depressed into the gypsum so as to be flush with the gypsum surface at the point of measurement .		C
9.2.18	Heat flux was measured with at least two water-cooled Schmidt-Boelter gauges at the surface of each instrumented wall: a) Both are collinear with the vertical thermocouple array; b) One is positioned to receive the greatest heat from the initiating module; and c) One is positioned to receive the greatest heat flux during potential propagation within the initiating BESS unit.	See Table 7	C
9.2.19	Heat flux was measured with 2 water-cooled Schmidt-Boelter gauges at the surface of each adjacent target BESS units facing initiating BESS unit: a) One is positioned at the elevation estimated to receive the greatest heat flux from the initiating module; and b) One is positioned at the elevation estimated to receive the greatest surface heat flux due to initiating BESS.	See table 7	C
9.2.20	Heat flux was measured with the sensing element of at least one water-cooled Schmidt-Boelter gauge positioned in the center of the accessible means of egress.	See table 7	C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
9.2.21	No. 24-gauge or smaller, Type-K exposed junction thermocouples were installed to measure the temperature of the surface proximate to the cells and between the cells and exposed face of the initiating module.	See Attachment C	C
	Each non-initiating module enclosure within the initiating BESS unit was instrumented with at least one No. 24-gauge or smaller Type-K thermocouple(s) within non-initiating modules.	See Attachment C	C
	Additional thermocouples were placed to account for convoluted geometries.		N/A
9.2.22	For residential use, the DUT was covered with a single layer of cheese cloth ignition indicator. The cheesecloth was untreated cotton cloth running 26 – 28 m2/kg with a count of 28 – 32 threads in either direction within a 6.45 cm^2 (1 in^2) area.	Non-residential use.	N/A
9.2.23	An internal fire condition in accordance with the module level test was created within a single module in the initiating BESS unit: a) The position selected to present the greatest thermal exposure to adjacent modules; and b) The setup was the same as that used to initiate and propagate thermal runaway within the module level test.	See Attachment C	C
9.2.24	The composition, velocity and temperature of the initiating BESS unit vent gases was measured within the calorimeter's exhaust duct. Composition, velocity and temperature instrumentation shall be collocated with heat release rate calorimetry instrumentation.		C
	Hydrogen gas shall be measured with a palladium-nickel thin-film solid state sensor.		
	The hydrocarbon content of the vent gas may also be measured using a Fourier-Transform Infrared Spectrometer with a minimum resolution of 1 cm-1 and a path length of at least 2 m (6.6 ft), or equivalent gas analyzer.	FTIR analysis was not used in accordance with the Certification Requirement Decision: Corrections to gas measurement methods to make FTIR as an option for measuring hydrocarbon contents of gas emissions and to include Hydrogen measurements during the Unit Level Test.	N/A
9.2.25	The hydrocarbon content of the vent gas was measured using flame ionization detection.	See Tables 8, 9, 10 and 11	C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
9.2.26	The test shall be terminated if: a) Temperatures measured inside each module within the initiating BESS unit return to ambient temperature; b) The fire propagates to adjacent units or to adjacent walls; or c) A condition hazardous to test staff or the test facility requires mitigation.	Test temperature recording was terminated until no noticeable phenomenon observed and all measured temperatures of the initiating unit return to ambient temperature.	C
9.2.27	For residential use systems, the gas collection data gathered in 9.2 shall be compared to the smallest room installation specified by the manufacturer to determine if the flammable gas collected exceeds 25% LFL in air.	Non-residential unit.	C
9.7	**Unit level test report**		
9.7.1	Installation type tested:	Indoor floor mounted, non-Residential, container type For a container system BESS including those intended for outdoor installation only, the unit level test shall be in accordance with the indoor floor mounted unit level test using the battery system racks as the test units and with the test installation set up in accordance with the installation layout within the container. According to 9.1.2.1 from the CRD, it should be treated as indoor floor mounted application.	C
9.7.2	Testing is intended to represent more than one installation type.	See Test Item Description in beginning of this report.	C
9.7.3	a. Unit manufacturer name and model number (and whether UL 9540 compliant);		C
	b. Number of modules in the initiating BESS unit		C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
	c. BESS construction features;	See Attachment C See Critical Components Table See Also “Description of components employed within the module that impact propagation (fire protection features)” at the beginning of this report.	C
	d. Fire protection features/ detection/ suppression systems within unit		N/A
	e. Module voltages corresponding to the tested SOC;	See Table 13 See Attachment F	C
	f. Thermal runaway initiation method used;	See Attachment C and F	C
	g. Location of the initiating module within the BESS unit;	See Attachment C	C
	h. Diagram and dimensions of the test setup including mounting location of the initiating and target BESS units, and the locations of walls, ceilings, and soffits;	See Attachment C	C
	i. Observation of any flaming outside the initiating BESS enclosure and the maximum flame extension;	See Table 14 No flame observed outside of the initiating rack.	C
	j. Chemical and convective heat release rate versus time data;	See Table 11 See Attachment F	C
	k. Separation distances from the initiating BESS unit to target walls	See Attachment C	C
	l. Separation distances from the initiating BESS unit to target BESS units	See Attachment C	C
	m. The maximum wall surface and target BESS temperatures achieved during the test and the location of the measuring thermocouple;	Tables 5 and 6	C
	n. The maximum ceiling or soffit surface temperatures achieved during the indoor or outdoor wall mounted test and the location of the measuring thermocouple;		N/A
	o) The maximum incident heat flux on target wall surfaces and target BESS units;	Table 7	C
	p) The maximum incident heat flux on target ceiling or soffit surfaces achieved during the indoor or outdoor wall mounted test;		N/A
	q. Flammable gas generation and composition data;	See Attachment F See Tables 7, 8, 9, and 10	C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
	r. Peak smoke release rate and total smoke release data.	See Table 12 See Attachments F	C
	s. Indication of the activation of integral fire protection systems and if activated the time into the test at which activation occurred;	See Table 13 No fire protection systems	N/A
	t. Observation(s) of flying debris or explosive discharge of gases;	See Table 15	C
	u. Observation of re-ignition(s) from thermal runaway events	See Table 15	C
	v. Observation(s) of sparks, electrical arcs, or other electrical events;	See Table 15	C
	w. Observations of the damage to: 1) The initiating BESS unit; 2) Target BESS units; 3) Adjacent walls, ceilings, or soffits;	See Table 15	C
	x. Video of the test.		C
9.8	**Performance at Unit level testing**		P
9.8.1	Installation level testing in Section 10 was not required if the following performance conditions outlined in Table 9.1 are met during the unit level test.	See Attachment F	P
Non-Residential Installations – Indoor floor mounted:			
	a) Flaming outside the initiating BESS unit is not observed;	No flaming observed	P
	b) Surface temperatures of modules within target BESS units do not exceed the cell venting temperature;	Max surface temperature 30.5°C didn't exceed the cell venting temperature 154°C	P
	c) For BESS units intended for installation in locations with combustible constructions, surface temperature measurements on wall surfaces do not exceed 97°C (175°F) rise above ambient;	Max wall surface temperature 28.3°C didn't exceed 97°C rise above ambient	P
	d) Explosion hazards are not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases;	No explosion observed	P
	e) Heat flux in the center of the accessible means of egress did not exceed 1.3 kW/m^2.	Measured heat flux 0kW/m2 didn't exceed 1.3 kW/m2	P

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

Table 1 – Specified Unit charging and discharging parameters			
Charging:		**Discharging:**	
Power (CP), kW	50.91 kW, then 5.091 kW for module 407.34 kW, then 40.734 kW for rack	Power (CP), kW	50.91 kW for module, 407.34 kW for rack
Standard Full Charge Voltage ,Vdc	Any cell reaches of 3.65V or 189.8V for module Any cell reaches of 3.65V or 1500V for rack	End of discharge voltage, Vdc	Any cell reaches of 2.5V or 130V for module Any cell reaches of 2.5V or 1040V for rack
End of Charge Voltage，Vdc	Any cell reaches of 3.65V or 189.8V for module Any cell reaches of 3.65V or 1500V for rack	Discharging Test Ambient, °C	-25~55
Charge temperature range, °C:	-25~55	-	-
Refer to Attachment A for charge/discharge profiles.			

Table 2 - Test Initiation Details	
Test Date	2023-09-22
Test Start Time (HH:MM:SS)	09:49:14
Initial Lab Temperature, °C	24.0°C
Initial Relative Humidity % RH	49% RH
Module OCV at Start of Test, Vdc	173.2V

Table 3 – Approximate time of thermal runaway propagation through module		
Locations (Cell #)	**Event**	**Time**
Cell 20-2	Vent	0:41:08
Cell 20-2	Thermal runaway	0:41:48
Cell 20-1	Thermal runaway	0:44:40
Cell 21-1	Thermal runaway	0:46:03
*	Thermal runaway	1:05:26
*Note: Suspect there is another one cell went into thermal runaway, as there is no more TC in the module, cannot determine the cell location, refer to the temperature curve of Cell 21-1, voltage drop of module, gases generation and video, another cell was suspected to be propagated around 65.5 mintues.		

Table 4 – Test overview timeline		
Time (HH:MM:SS)	**Event**	**Description**
00:00:00	Test Start	The test started and the heater was turned on to heat the initiating cell (Cell 20-2) at a ratio of 4 ~ 7 °C/min.
00:41:08	Venting of initiating Cell	Initiating cell (Cell 20-2) vented at around 168.4 °C measured through TC 2-1 by an indication of sudden dip in cell's temperature curve. See Figure (b)
00:41:48	Thermal runaway of initiating cell	Initiating cell (Cell 20-2) was at around 145.1 °C measured through T2-1. The temperature of cell 20-2

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

		began to increase inan uncontrollable manner, With the release of smoke. See Figure (c)
00:44:40	Thermal runaway of adjacent cell	Thermal runaway propagated to nearby cell (cell 20-1). More gas released. See Figure (d)
00:46:03	Thermal runaway of adjacent cell	Thermal runaway propagated to nearby cell (cell 21-1). More gas released. See Figure (e)
01:05:26	Thermal runaway of adjacent cell	Gas released.(Refer to the temperature curve of Cell 21-1, voltage drop of module, gases generation and video, another cell was suspected to be propagated around 65.5 mintues.) See Figure(f)
01:25:00	Test Termination	Data acquisition was stopped. The module was left in the test overnight and with video monitored.

Table 5 - Maximum Temperatures in Target Units			
Cell vent temperature from cell test data, °C			154°C
Target Unit 1		**Target Unit 2**	
Module Location No.	Temperature (°C)	Module Location No.	Temperature (°C)
Module -1	27.2	Module -1	26.9
Module -2	28.8	Module -2	28.1
Module -3	30.5	Module -3	28.7
Module -4	28.5	Module -4	28.0
Module -5	27.5	Module -5	27.7
Module -6	27.3	Module -6	27.2
Module -7	27.3	Module -7	27.0
Module -8	27.8	Module -8	27.5
Note: Temperatures are measured constantly and then averaged every 60-seconds			

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

Table 6.1 - Maximum Temperatures on Instrumented Wall- Front Wall					
Ambient Temperature: 24.0°C					
UL 9540A performance criteria, Ambient + 97°C: 121.0°C					
Height, mm	Maximum Temperature (°C)	Height, mm	Maximum Temperature (°C)	Height	Maximum Temperature (°C)
152	26.8	1368	27.2	2584	24.7
304	27.0	1520	27.0	2736	27.2
456	27.1	1672	27.0	2888	27.1
608	25.3	1824	27.2	3040	27.2
760	27.3	1976	27.2	3192	27.4
912	27.3	2128	27.4	3344	27.4
1064	27.0	2280	27.4	3496	27.4
1216	27.0	2432	27.2	3648	27.7
Note: Temperatures are measured constantly and then averaged every 60-seconds					

Table 6.2 - Maximum Temperatures on Instrumented Wall- Side Wall					
Ambient Temperature: 24.0°C					
UL 9540A performance criteria, Ambient + 97°C: 121.0°C					
Height, mm	Maximum Temperature (°C)	Height, mm	Maximum Temperature (°C)	Height	Maximum Temperature (°C)
152	24.9	1368	26.8	2584	26.9
304	25.8	1520	26.9	2736	27.0
456	25.5	1672	26.9	2888	27.3
608	26.1	1824	26.8	3040	27.3
760	26.3	1976	26.7	3192	27.0
912	26.6	2128	26.8	3344	27.1
1064	26.7	2280	26.8	3496	27.0
1216	26.5	2432	27.0	3648	27.0
Note: Temperatures are measured constantly and then averaged every 60-seconds					

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

Table 6.3 - Maximum Temperatures on Instrumented Wall- Rear Wall					
Ambient Temperature: 24.0°C					
UL 9540A performance criteria, Ambient + 97°C: 121.0°C					
Height, mm	Maximum Temperature (°C)	Height, mm	Maximum Temperature (°C)	Height	Maximum Temperature (°C)
152	26.7	1368	27.6	2584	27.2
304	27.2	1520	27.4	2736	27.5
456	26.8	1672	27.3	2888	27.5
608	26.9	1824	27.6	3040	27.6
760	27.0	1976	27.2	3192	27.6
912	27.1	2128	27.2	3344	27.5
1064	27.2	2280	28.1	3496	28.3
1216	27.1	2432	26.9	3648	27.7
Note: Temperatures are measured constantly and then averaged every 60-seconds					

Table 7 – Heat Flux Measurements			
Summary of maximum heat flux in target units		Summary of maximum heat flux measured on instrumented wall	
Maximum Heat Flux, kW/m^2			
Target Unit 1 Module No.3: 1#	0	Heat Flux Gauge No.	kW/m^2
Target Unit 1 Module No.4: 5#	0	Front wall 1350 mm high, 11#	0
Target Unit 2 Module No.3: 8#	0	Front wall 1600 mm high, 7#	0
Target Unit 2 Module No.4: 9#	0.01	Side wall 1350 mm high, 6#	0
-		Rear wall 1350 mm high, 10 #	0
-		Rear wall 1600 mm high, 4#	0
Egress path measurement- 1: 3 #			0
Egress path measurement- 2: 2#			0

Table 8 – Gases measured and measurement methods used in unit level testing			
Measurement Method	**Gases Measured**	**Chemical Formula**	**Gas Type**
Flame Ionization Detection (FID)	Total Hydrocarbons	-	Hydrocarbons
Solid-state Hydrogen Sensor	Hydrogen	H_2	
Non-dispersive infrared spectroscopy (NDIR)	Carbon Dioxide	CO_2	Carbon Containing
	Carbon Monoxide	CO	Carbon Containing
# - This table was modified to reflect the gases measured during testing.			

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

Table 9 - Gas generation periods	
Time	**Condition**
From the venting point 0:41:08 to the end of test 2:00:00	Pre-Flaming
Flaming was not observed during the test.	Flaming
External Flaming of Gas	
Condition	**Duration (hh:mm:ss)**
External Flaming of Vent Gases:	Flaming was not observed during the test.

Table 10 – Summary of battery gas volumes for deflagration hazard calculations				
Gas Component	Gas Type	During Pre-flaming (L)	During Flaming (L)	Minimum detectable flow rate(LPM)
Total Hydrocarbons (Propane Equivalent)	Hydrocarbons	111.98	No flaming	4.13
Carbon Dioxide	Carbon Containing	59.54	No flaming	3.08
Carbon Monoxide	Carbon Containing	138.34	No flaming	3.97
Hydrogen	Hydrogen	3.54	No flaming	104.03

Table 11 – Smoke and heat release rate			
Heat Release Rate (HRR)		**Smoke Release Rate (SRR)**	
Peak Chemical HRR (kW)	No flaming observed	Maximum SRR (m^2/s)	0.12
Peak Convective HRR, (kW)	No flaming observed	Total Smoke Released (m^2)	0.23

Table 12 – Integral Fire suppression system Details of Operation
N/A

Table 13 - Module OCV voltage measurement comparison before and after testing			
Module Location In Rack	OCV Prior to Test (V)	OCV Post Test (V)	Difference (V)
1	173.2	173.2	0
2	173.2	173.2	0
3 (Initiating Module)	173.2	166.4	6.8
4	173.6	173.5	0.1
5	173.2	173.2	0
6	172.3	173.2	0.1
7	173.3	173.3	0
8	173.8	173.7	0.1

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

Table 14 – Other Observations during Unit test			
	Observed, Yes/No	Comments/Location	
Flaming outside of Unit	No	Length of flame:	N/A
Flying debris	No	-	
Explosive discharge of gas	No	-	
Sparks or electrical arcs	No	-	

Table 15 - Post Test Observations	
Thermal runaway behaviour	No further thermal runaway after the test was completed
Re-ignitions	No re-ignition occurred
Explosions	No explosion occurred
Other Observations	N/A

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

	TABLE: Critical components information				
Object / Part No.	**Manufacturer/ trademark**	**Type / model**	**Technical data**	**Standard**	**Mark(s) of conformity**
Module construction					
Cells	CATL	CBDB0	Nominal voltage：3.2V d.c Rated capacity：306Ah	UL 1973 IEC 62619：2022	UL MH 62898 JPTUV-146897
Module	CATL	-	Nominal voltage：166.4V Rated capacity：612Ah	-	-
Metal enclosure	CATL	-	Material: Al6063.T6 Thickness: ≥2mm Size: L*W*H(mm) (2235±3.5)*(830±3)*(31±3)	–	–
Plastic enclosure	0000013277	NHPP-FR NHPP-FR-2	Fire rating：V-0 Material: PP RTI: 65°C	UL746	UL E171666
Connector	0000007975	REA4	Voltage：1500VDC Current：350A for TUV, 300A for UL Fire rating：V-0	UL4818 EN 61984	UL E526230 J 50586193
Connecting wire for HV	0000009966	3932	Voltage: 2000V Current-carrying capability: 75°C 350A Maximum ambient temperature:-40°C~+125°C	UL 758 EN 50525 IEC 60227 IEC 60228:2004	E214184 M.2021.206.C63716
Wire for LV	0000009966	3666	Voltage: 600V Wire diameter: (0.5~4mm2) Maximum ambient temperature: -40°C~+105°C	UL 758 EN 50525 IEC 60227 IEC 60228:2004	E214184 0B160705.DNTDS30
Plastic material (Harness isolation plate)	0000015262	PP C6540R-G20HF	Fire rating: V-0 Maximum ambient temperature: 90±2°C	UL94	SHMR220800424401
Plastic material (Output pole base)	0000007541	46GF30	Fire rating: V-0 Maximum ambient temperature: 180°C	UL94	UL E225348

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

Plastic material (Buffer pad)	0000007929	MPP	Fire rating: V-0 Maximum ambient temperature: 100°C	UL94	UL E509966
Container					
Enclosure	0000014067	-	Material: steel High weather resistance rolled steel Thickness: 1.6mm/12mm Size: 6058*2438*2896(mm)	-	-
Plastic enclosure	0000014067	FR-4 Board	Material: epoxy plate Thickness: (4mm) Size: 516*70*4(mm) Fire rating: V0	ROHS UL 94	STT/22T1032-ROHS 2015-L738
Connector	0000007975	REA4	Voltage: 1500VDC Current: 350A for TUV, 300A for UL Fire rating: V-0	UL4818 EN 61984	UL E526230 J 50586193
Connecting wire for HV	0000009966	3932	Voltage: 2000V Current-carrying capability: 75°C 350A Maximum ambient temperature:-40°C~+125°C	UL 758 EN 50525 IEC 60227 IEC 60228:2004	E214184 M.2021.206.C63716
Main control box					
Enclosure	0000003592	-	Material: steel DC51D+Z&DC01 Thickness: ≥1.5mm Size: 751.5±5*741.4±5*239.3±5 mm	-	-
Wire for LV	0000009966	3666	Voltage: 600V Wire diameter: (0.5~4mm2) Maximum ambient temperature: -40°C~+105°C	UL 758 EN 50525 IEC 60227 IEC 60228:2004	E214184 0B160705.DNTDS30
Connector	0000007975	REA4	Voltage: 1500VDC Current: 350A for TUV, 300A for UL Fire rating: V-0	UL4818 EN 61984	UL E526230 J 50586193

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

Connecting wire for HV	0000009966	3932	Voltage: 2000V Current-carrying capability: 75°C 350A Maximum ambient temperature: -40°C~+125°C	UL 758 EN 50525 IEC 60227 IEC 60228:2004	E214184 M.2021.206.C63716
Sealing element	0000011532	LZ302Z(Sec A)	Fire rating: ≥V-0 Maximum ambient temperature: -50~+200°C	UL94	UL E529227

Attachment A: Sample Charging, OCV and SOC Measurement Profiles - (*Pages **27** through**30***)

Note: There were 8 modules in the initiating unit. Due to the voltage limitation of the charging device, the modules in the unit were divided into 8 groups and were then fully charged separately. The charging current of each module is 50.91 kW, then 5.091 kW, and the charging ends when any cell reaches of 3.65V or 1500V for rack.

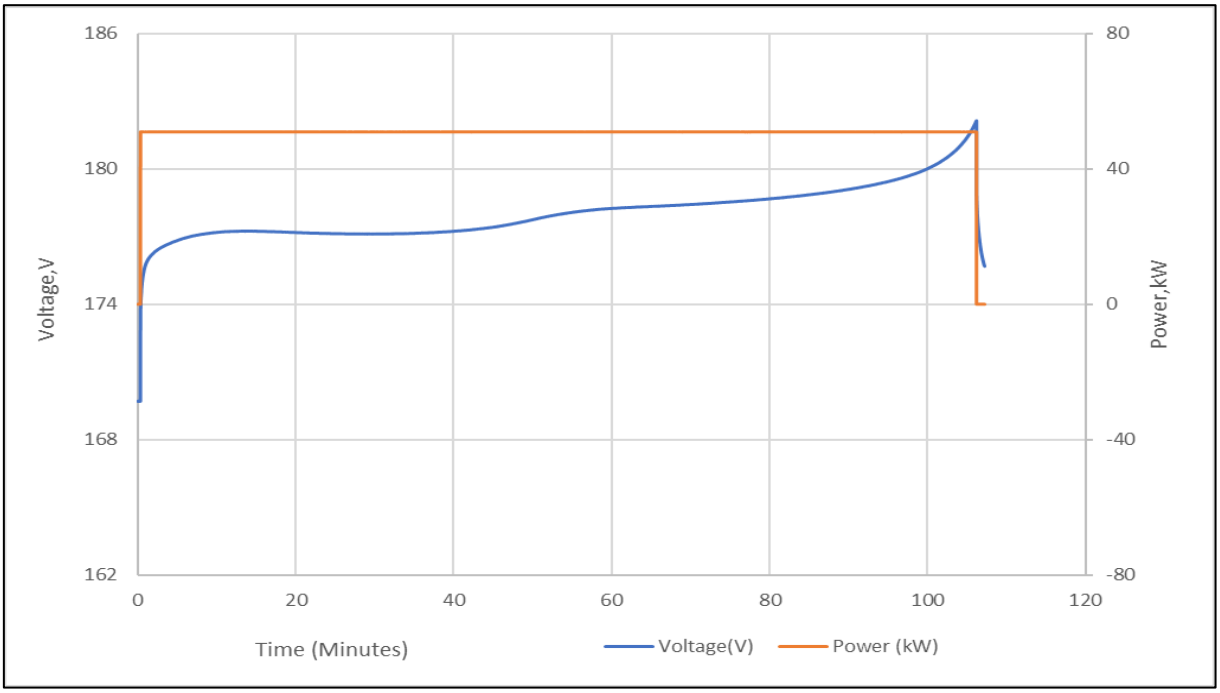


Figure 1: Initiating unit, module 1 charge to 100% SOC

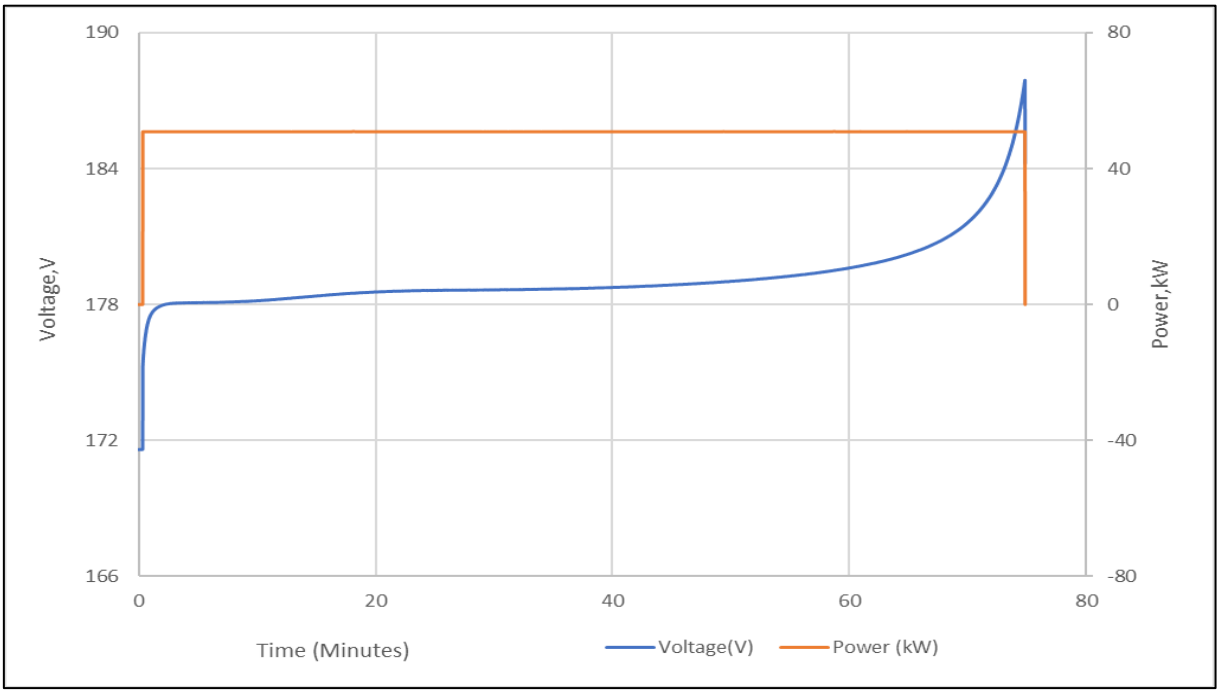


Figure 2: Initiating unit, module 2 charge to 100% SOC

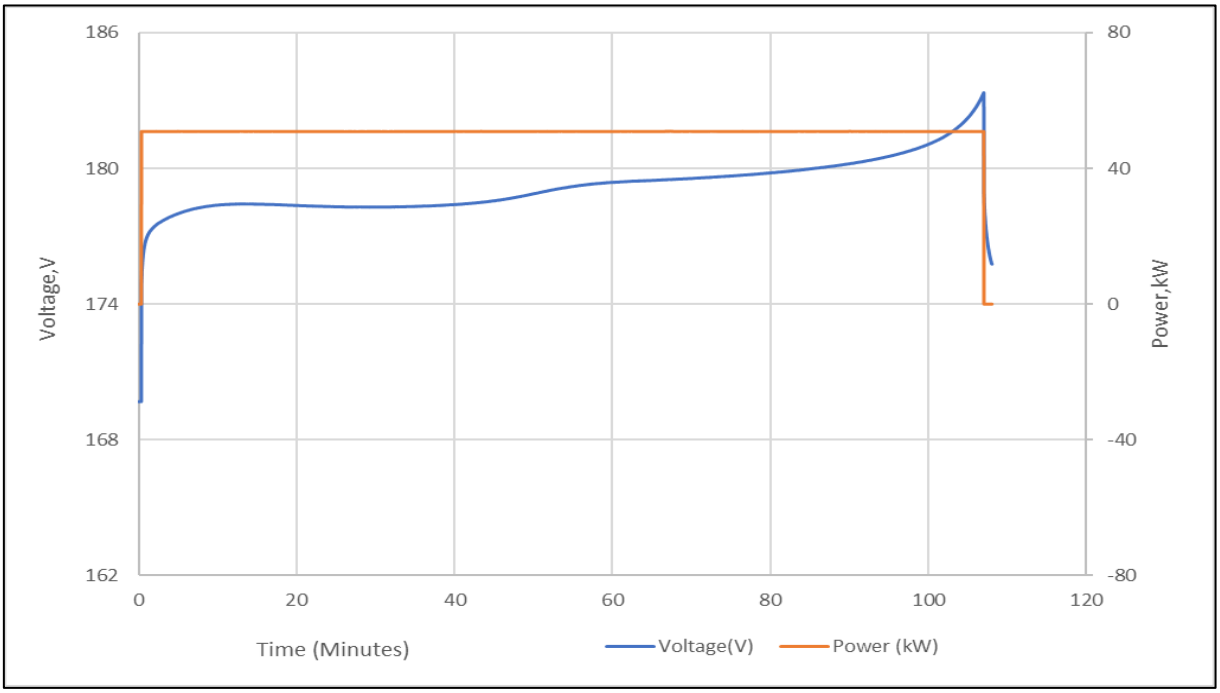


Figure 3: Initiating unit, module 3 charge to 100% SOC

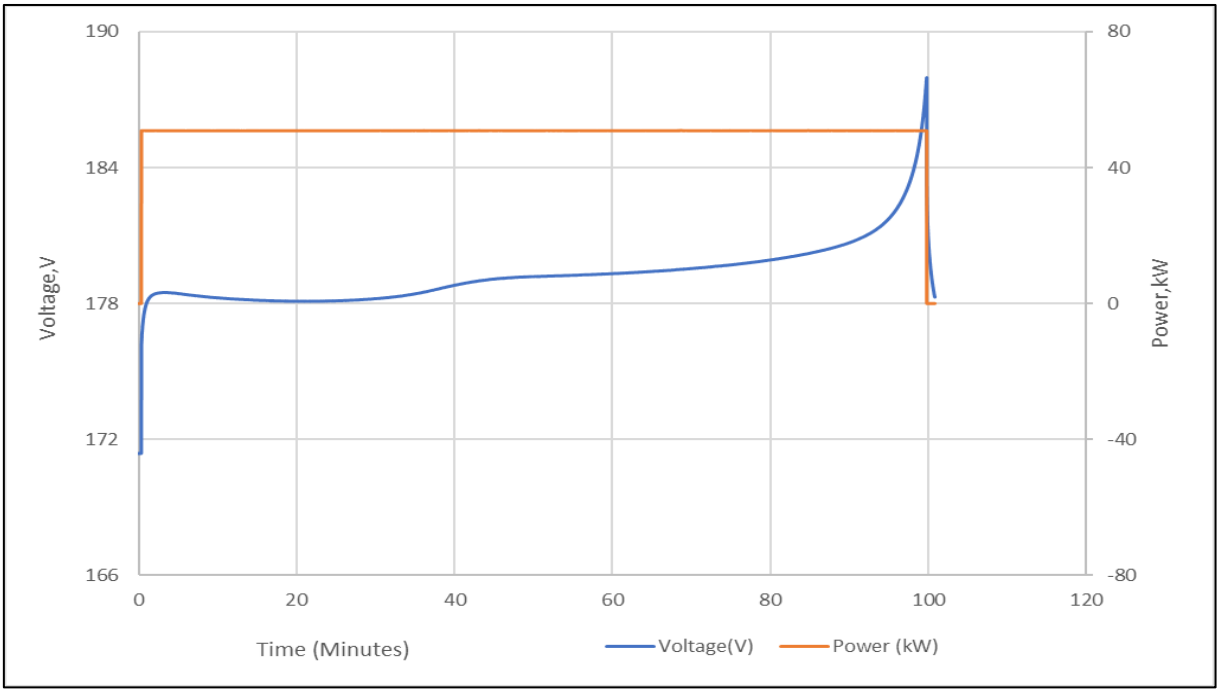


Figure 4: Initiating unit, module 4 charge to 100% SOC

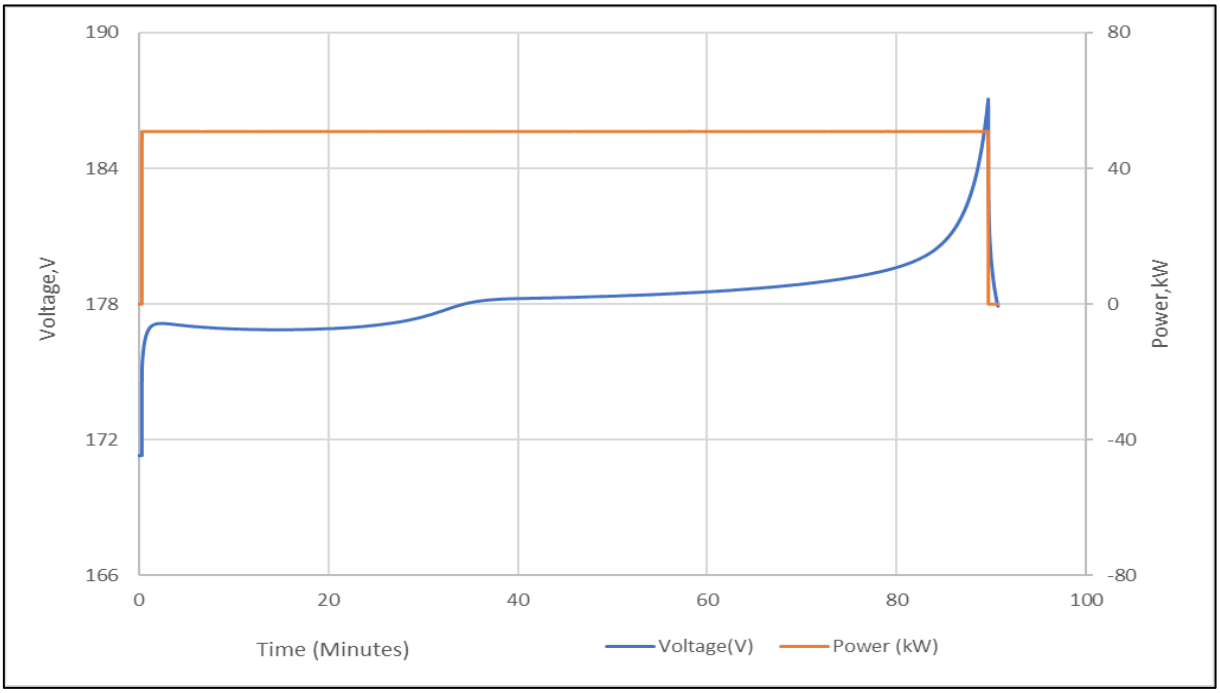


Figure 5: Initiating unit, module 5 charge to 100% SOC

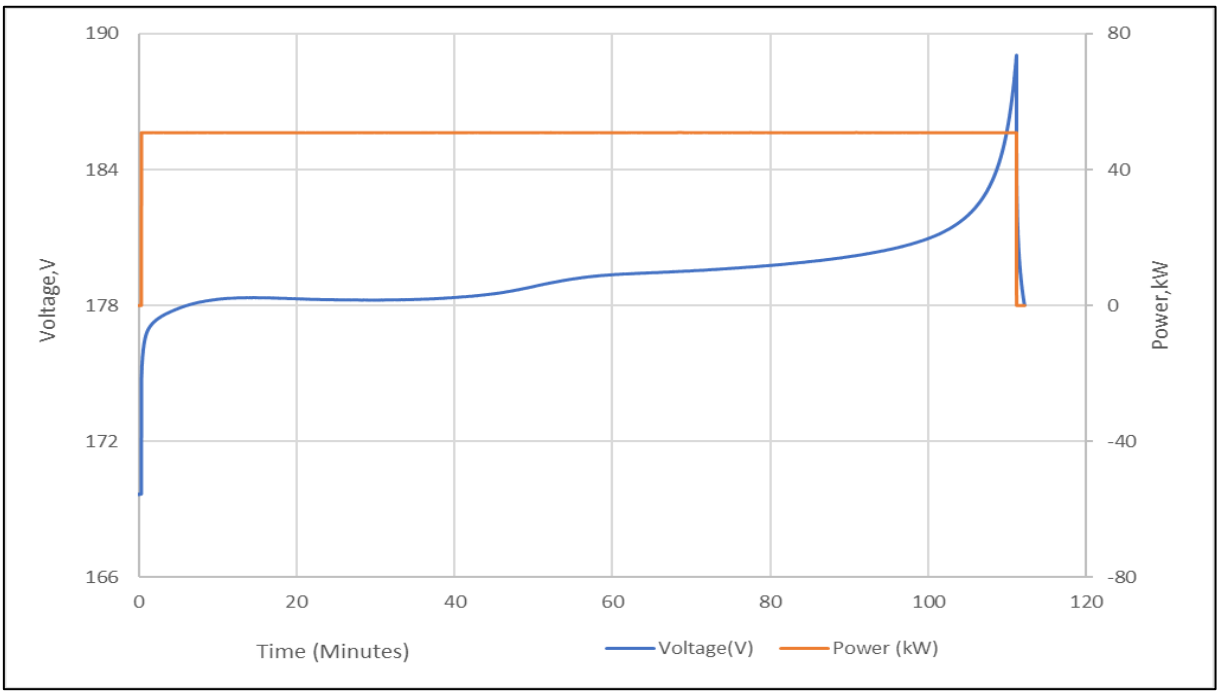


Figure 6: Initiating unit, module 6 charge to 100% SOC

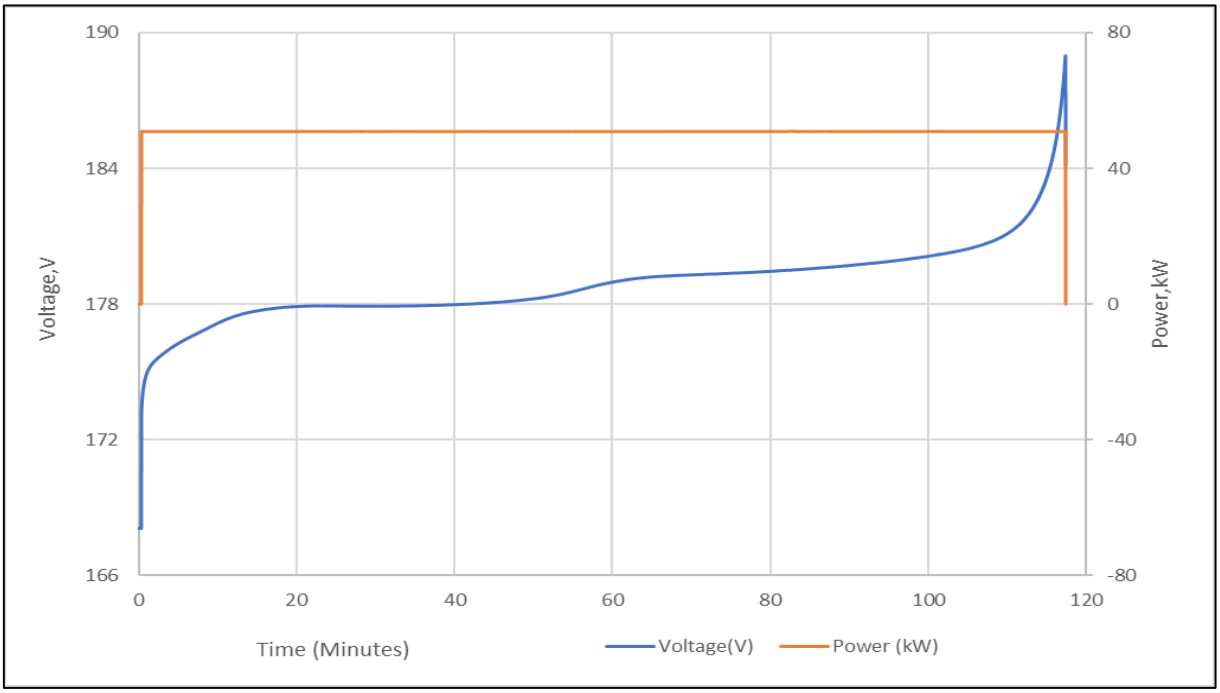


Figure 7: Initiating unit, module 7 charge to 100% SOC

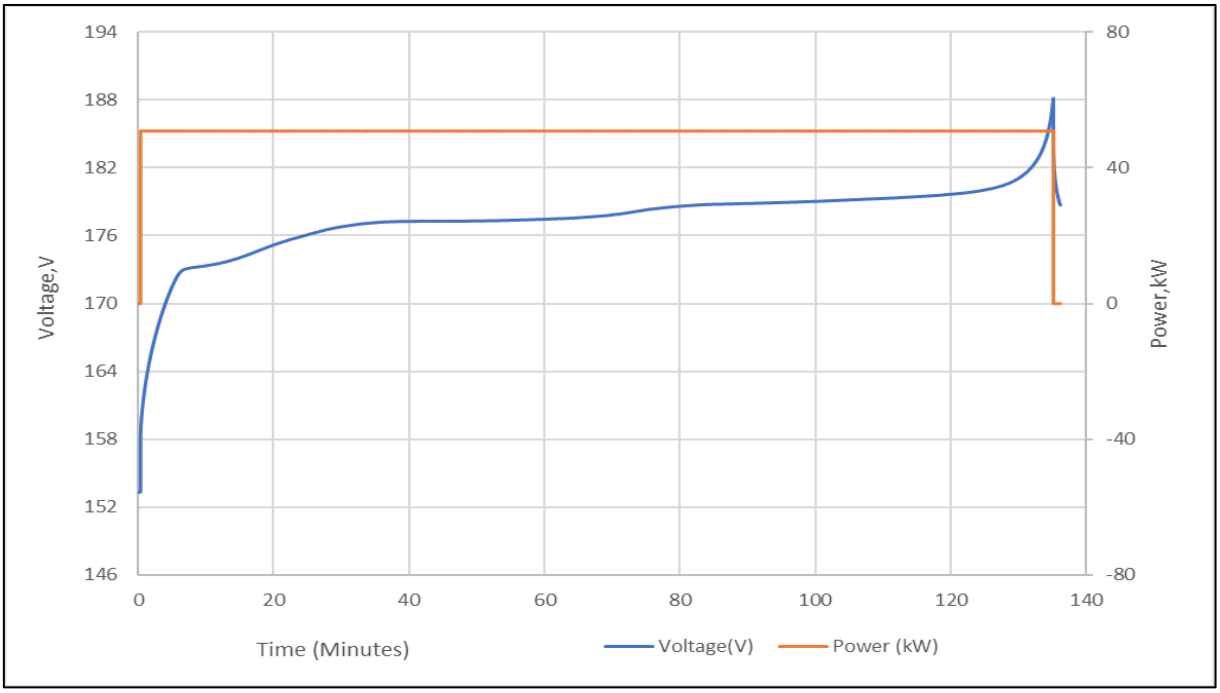


Figure 8: Initiating unit, module 8 charge to 100% SOC

Attachment B: BESS (including module and any integral fire detection and suppression systems) Construction Photos/Diagrams - (*Pages **31** through **31***)








BESS unit and module Construction Photos

Note: there is no fire detection and suppression systems in the Unit BESS.

Attachment C: BESS and Equipment Instrumentation and Test Installation Layout Photos/Diagrams - (*Pages **32** through **35***)

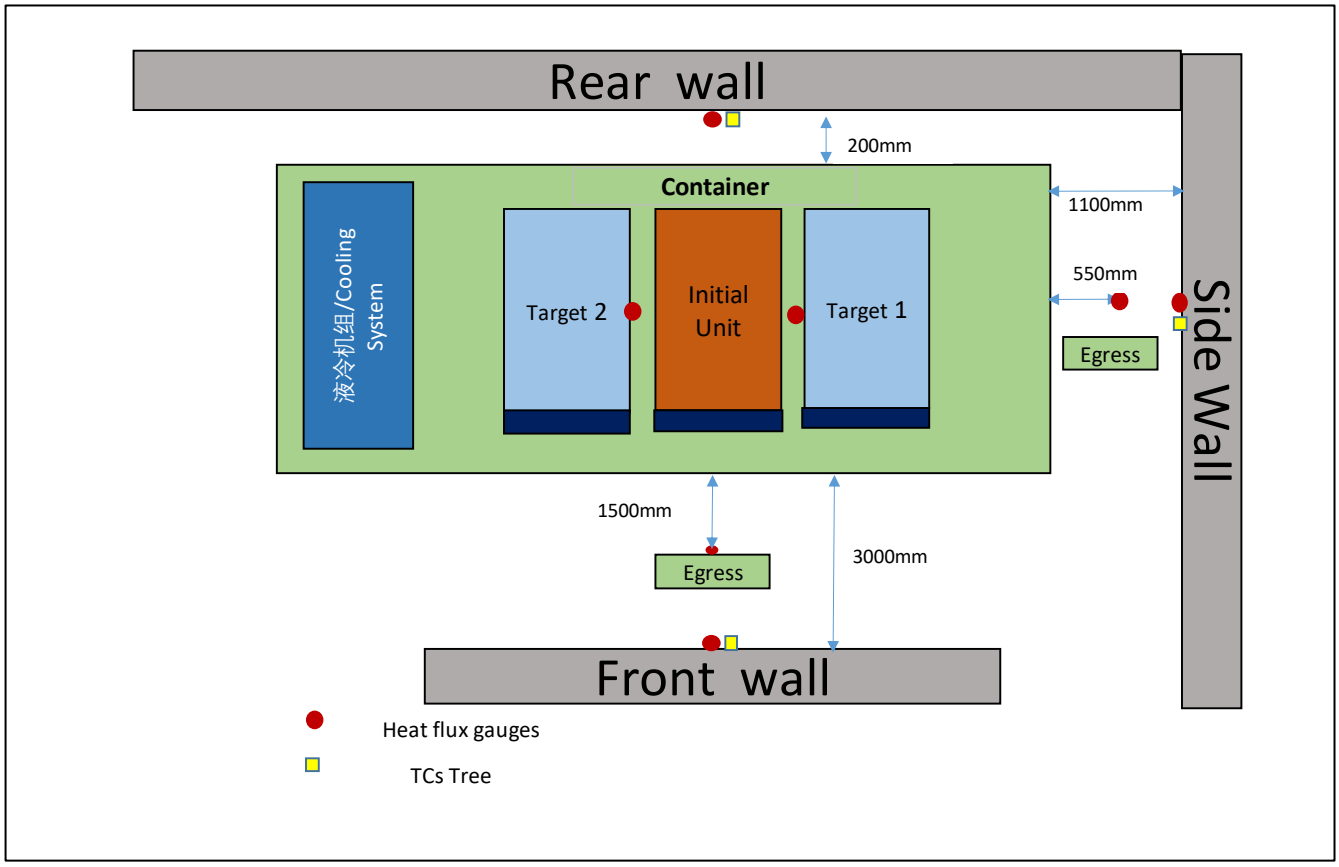
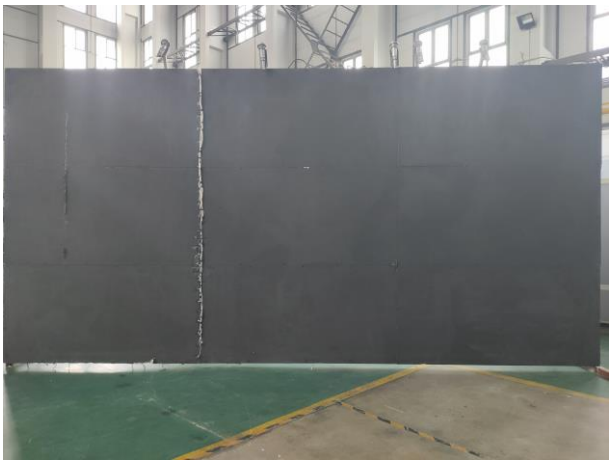


Figure 9: Test area layout



Front view - TC Location of front wall. From the bottom to up, TCs were FW-1 to FW-24



Side view - TC Location of side wall. From the bottom to up, TCs were SW-1 to SW-24



Rear view - TC Location of side wall. From the bottom to up, TCs were RW-1 to RW-24

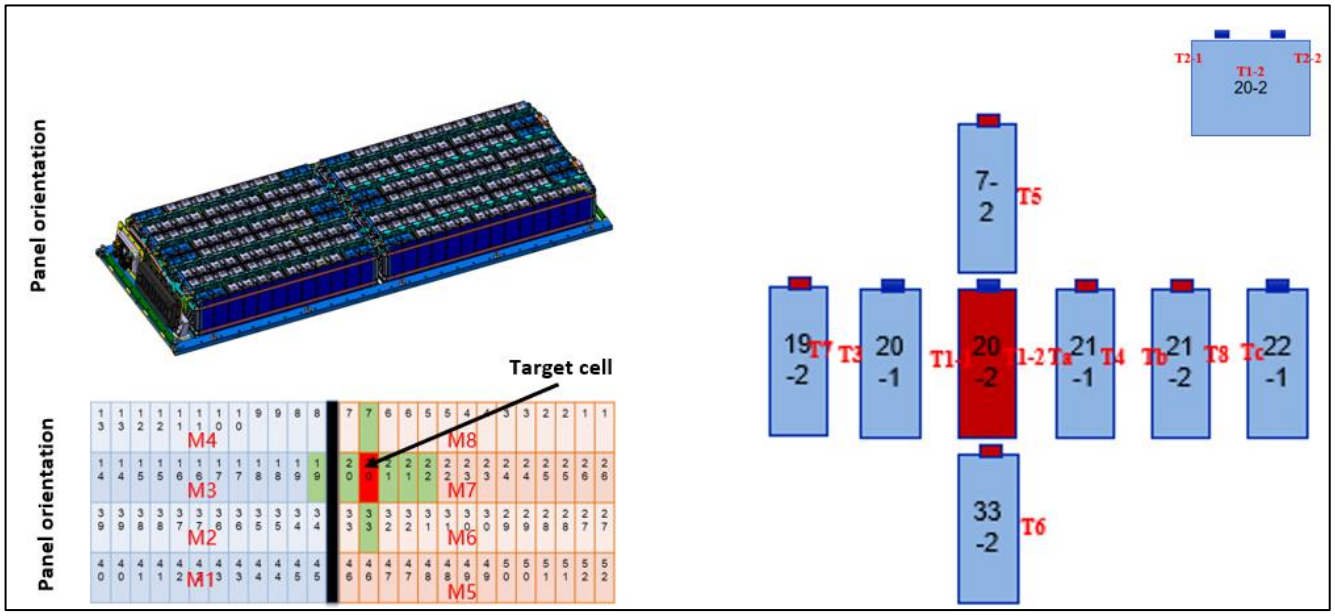


Figure 10: TC Location in the initiating module and above module. TCs were on the cells' large side body

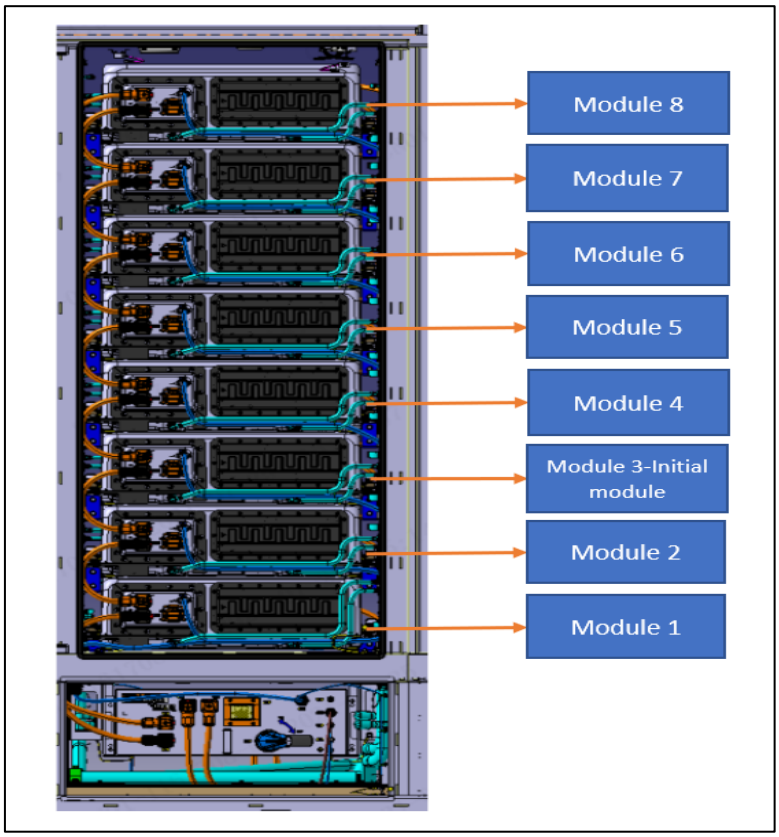


Figure 11: The initiating module 3 location in the initiating unit



Initiating unit	Target unit - 1	Target unit - 2

Figure 12: TC location in the initiating and target units, T16 series for target unit-1, T17 series for target unit-2

(Note: Except T15 affixed to the top frame of the initiating module, other T14 affixed to the middle height of the module frame.)

Attachment D: Temperature Profiles and Heat Flux Measurements During Testing (Initiating Cell and Module, Target Modules, Wall Surfaces, etc. - (*Pages **36** through **39***)

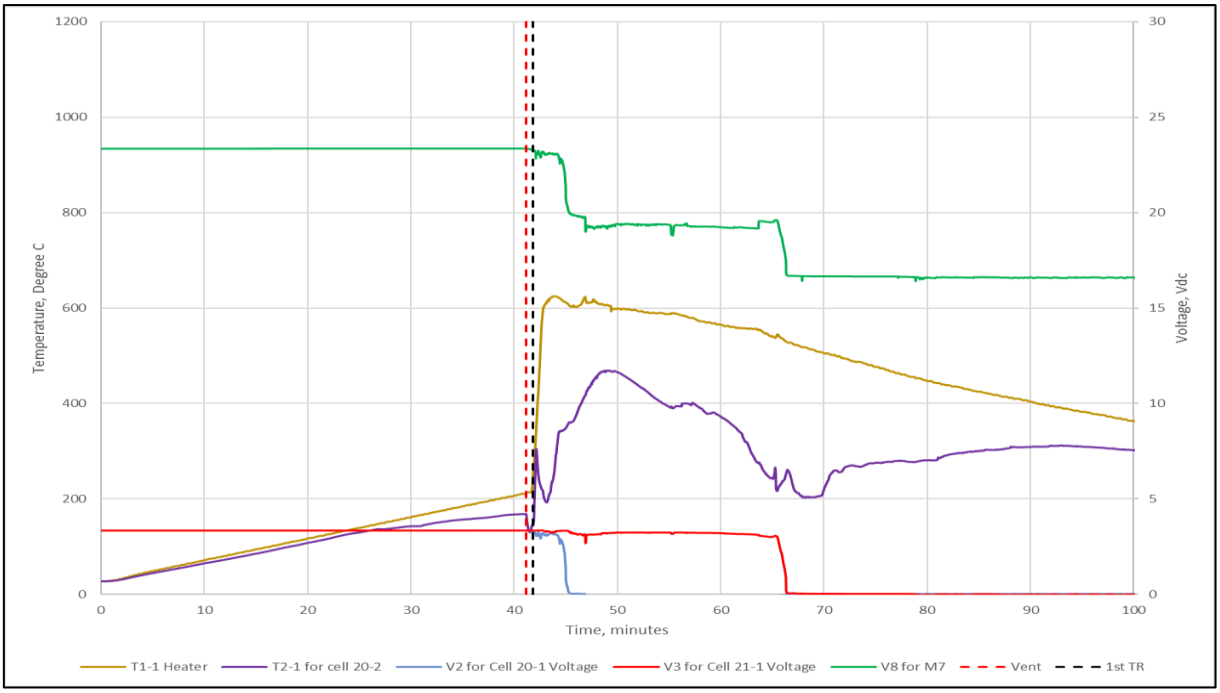


Figure 13: Initiating cells vent, Thermal runaway Initiating cell Temperature and Voltage Profiles During Testing

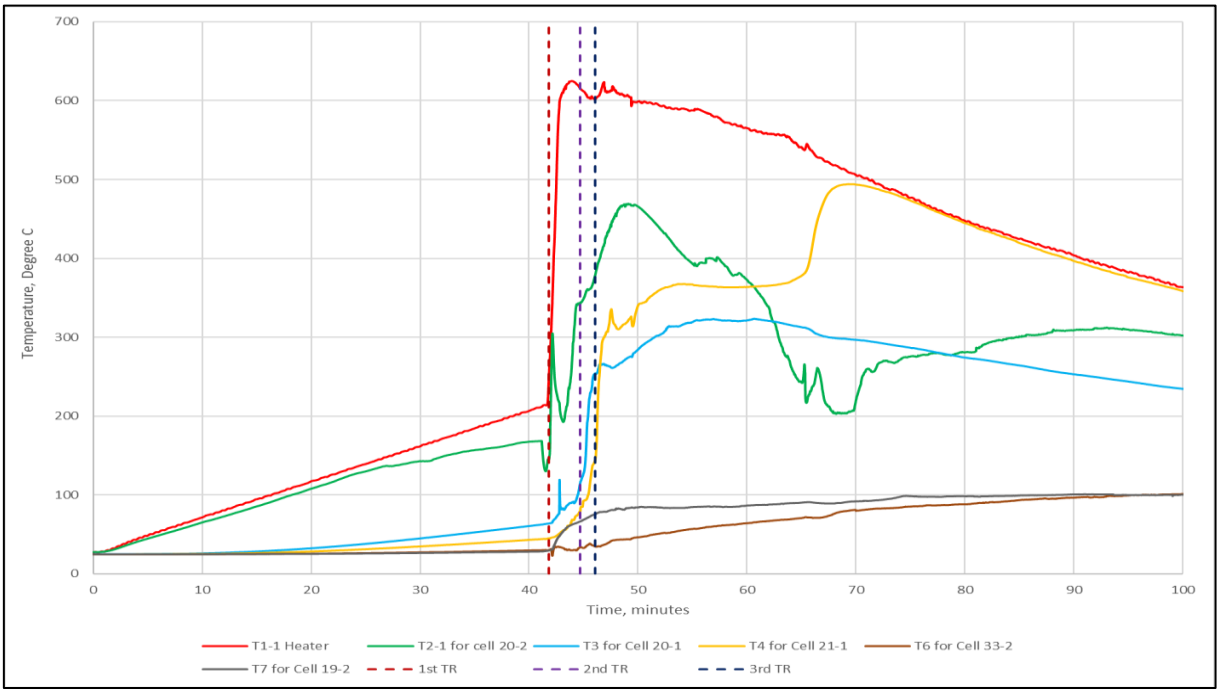


Figure 14: Initiating module temperature

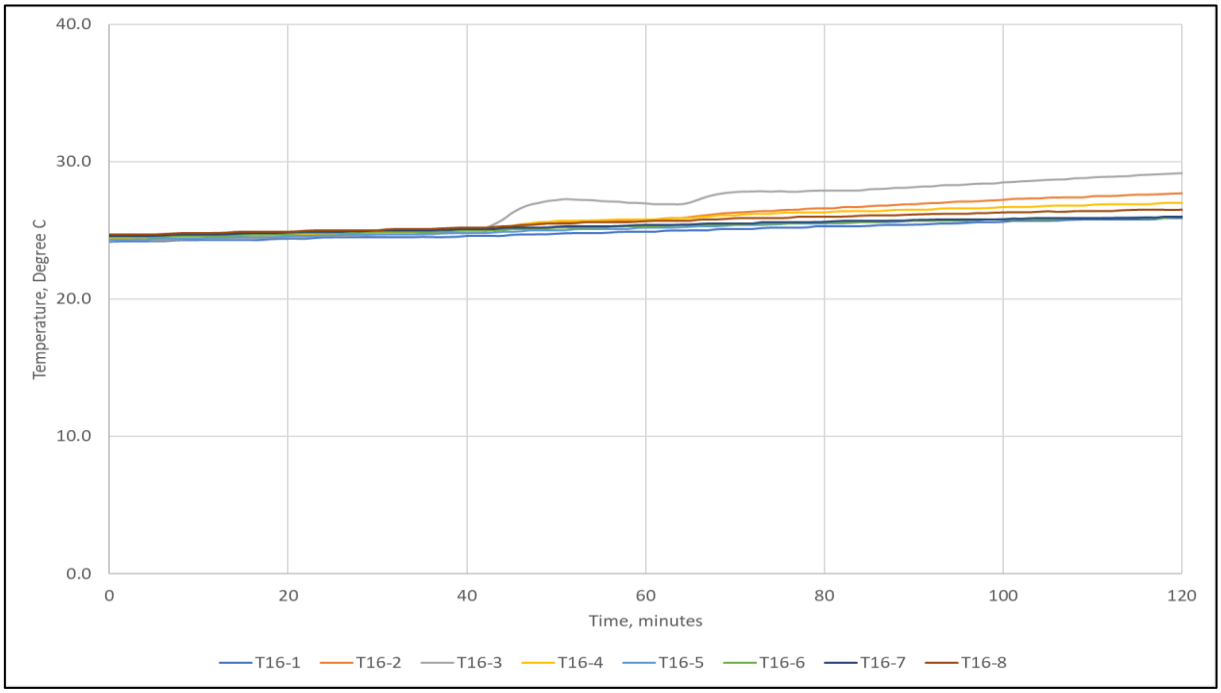


Figure 15: Target unit-1 temperature

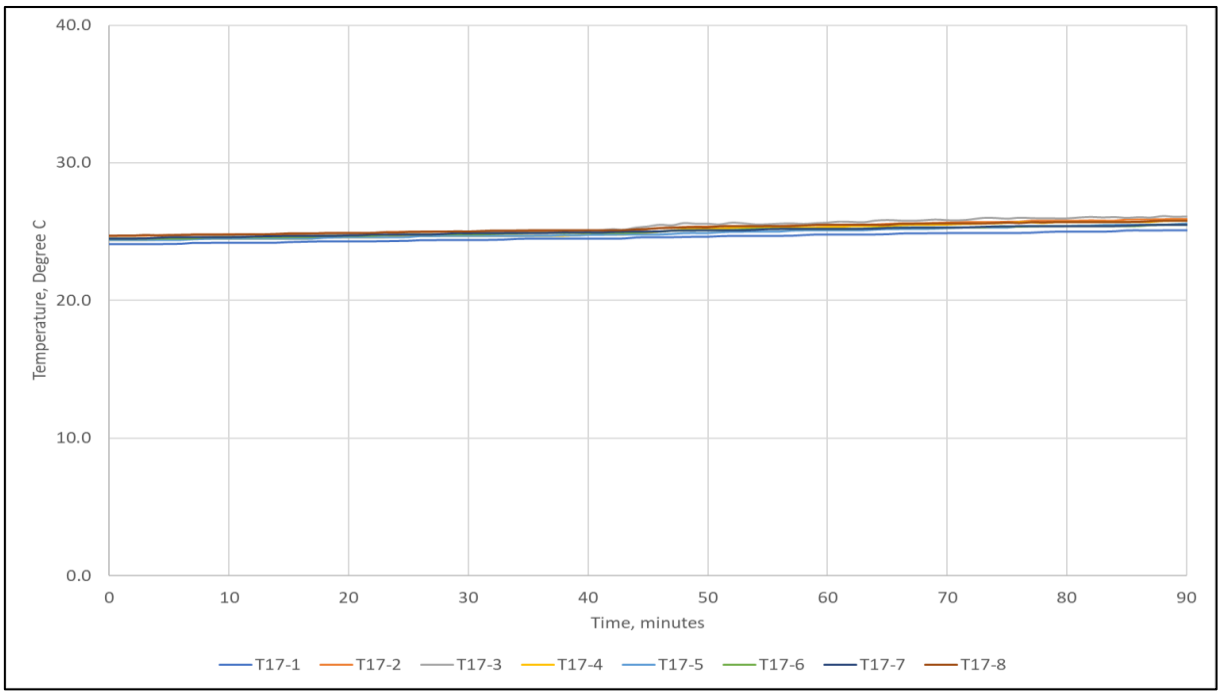


Figure 16: Target unit-2 temperature

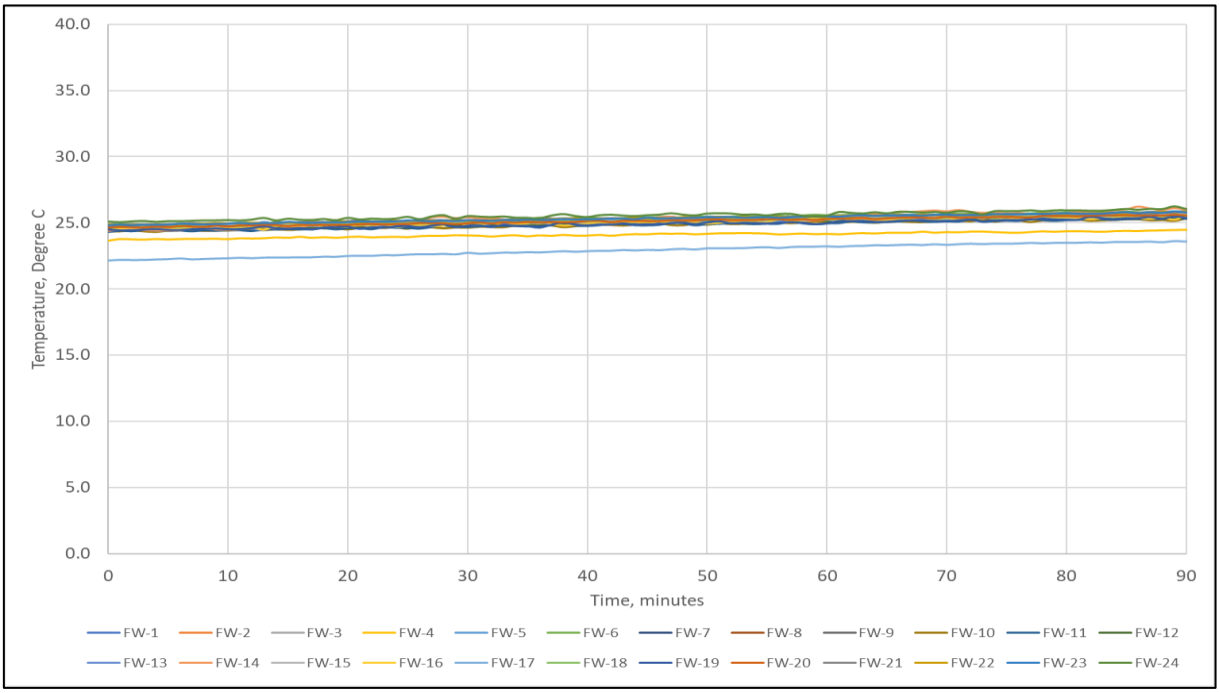


Figure 17: Front wall temperature

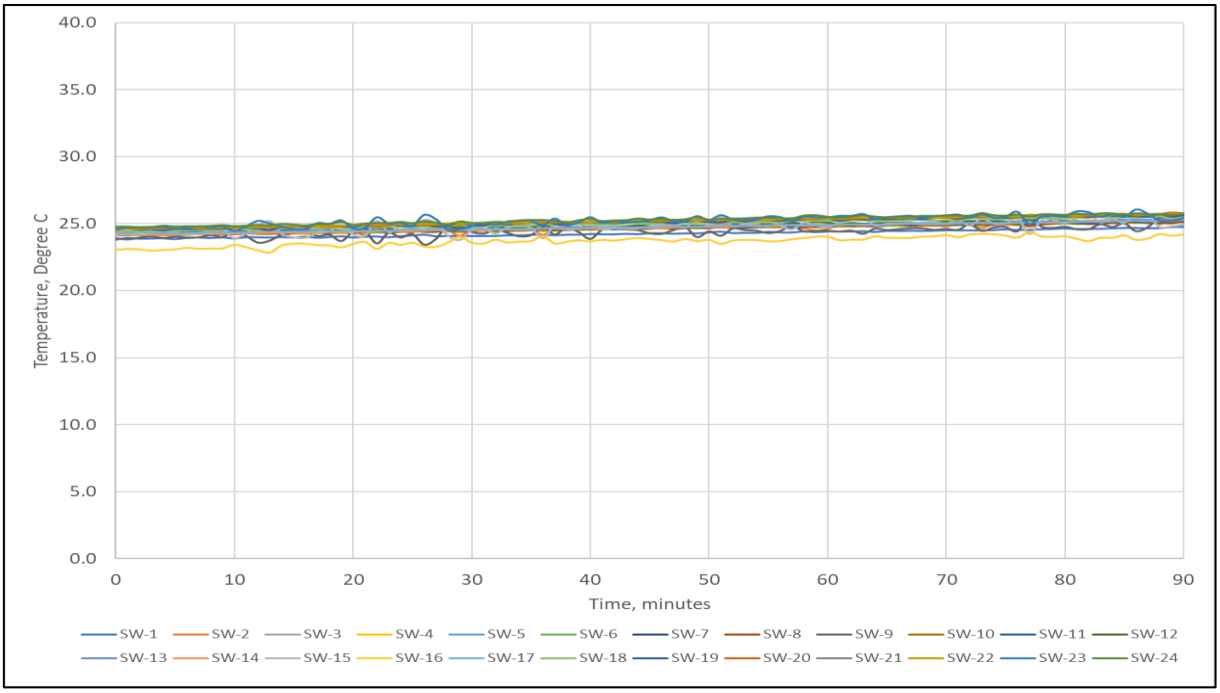


Figure 18: Side wall temperature

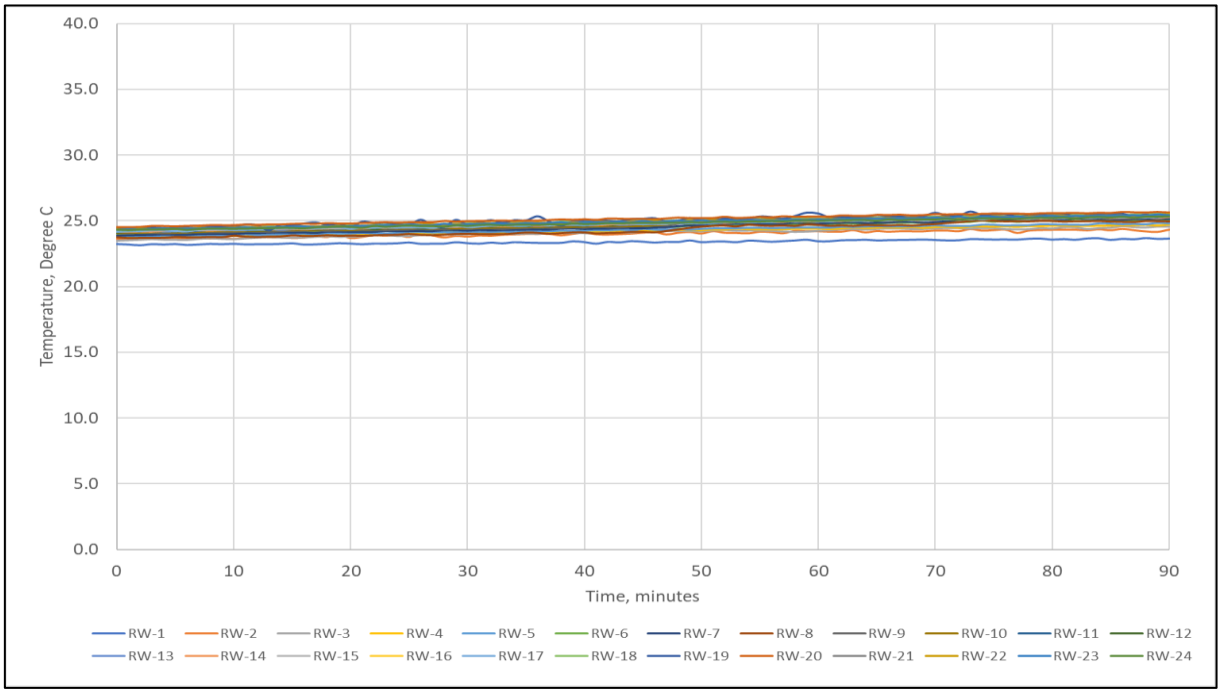


Figure 19: Rear wall temperature

Attachment E: BESS Unit Testing and Post Testing Photos - (*Pages **40** through **41***)



(a) Start Heating
[00:00:00]



(b) Vent initiating cell 20-2
[00:41:08]



(c) Initiating cell 20-2 Thermal runaway
[00:41:48]



(d) Cell 20-1 Thermal runaway
[00:44:40]



(e) Cell 21-1 Thermal runaway
[00:46:03]



(f) Thermal runaway of adjacent cell
Approximately [01:05:26]



(g) Test Termination
[01:25:00]

Figure 20: BESS Unit Testing Photos









Figure 21: BESS Unit Photos after test

Attachment F: BESS Unit Gas Flow Rate and Heat Release and Smoke Release Profiles - (*Pages **42** through **44***)

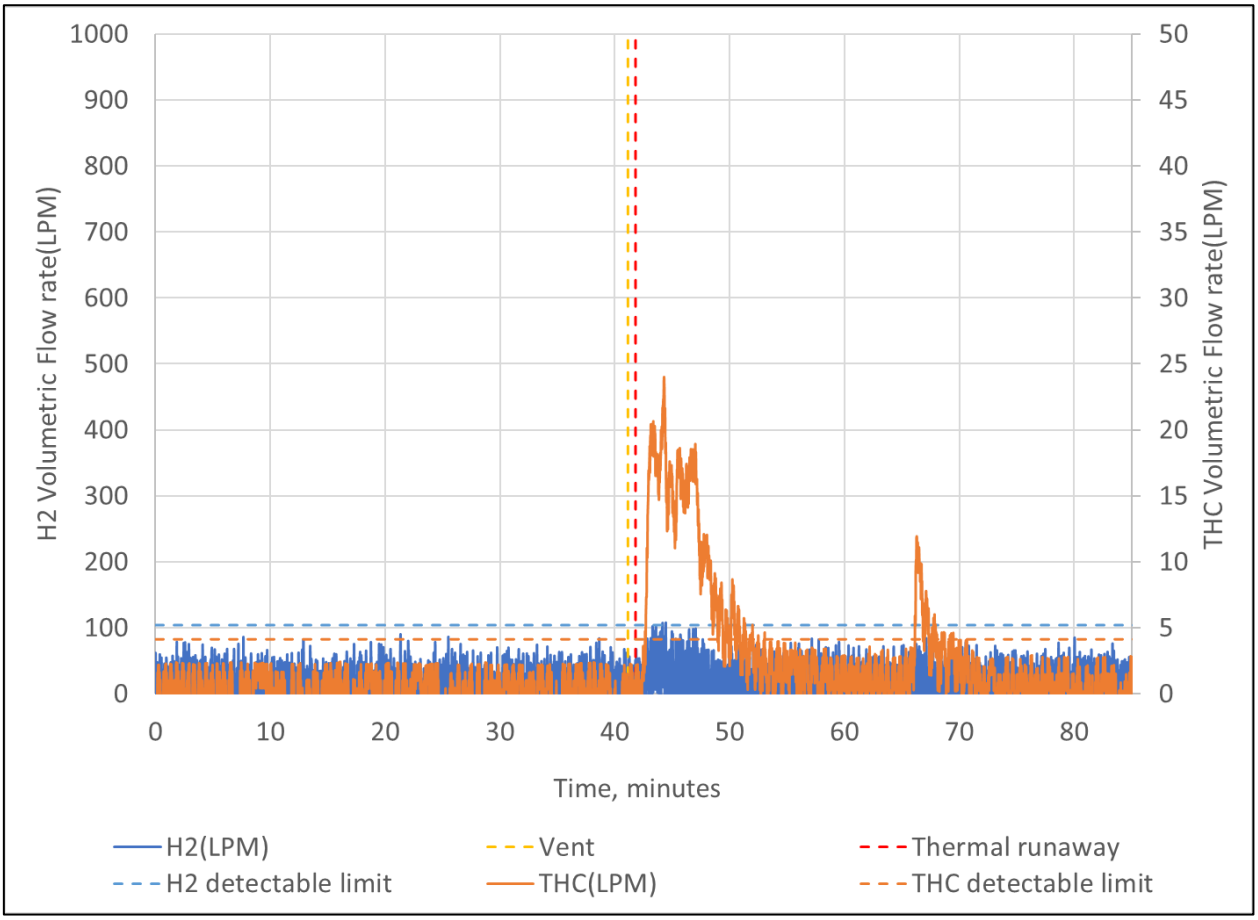


Figure 22: THC, H2 flow rates

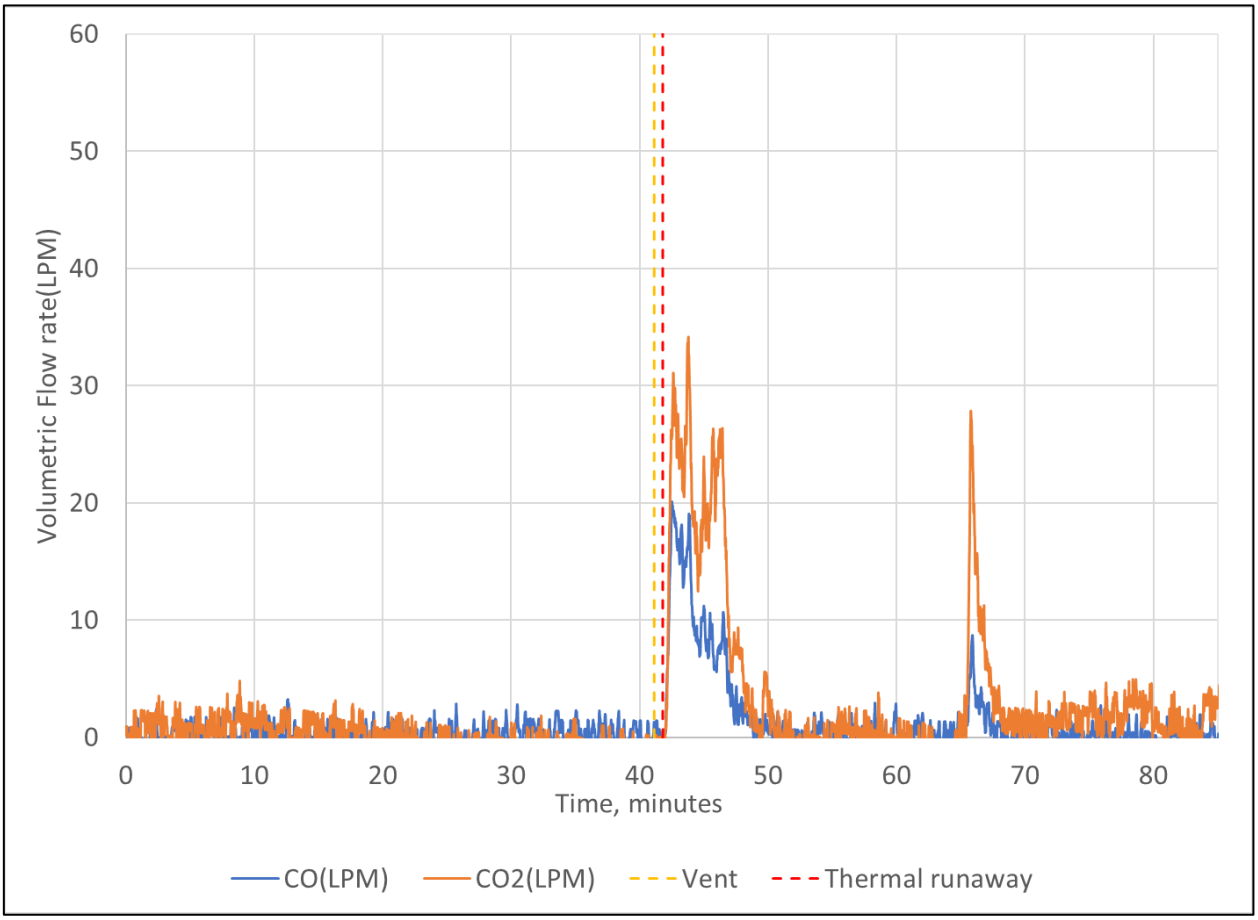


Figure 23: CO, CO2 flow rates

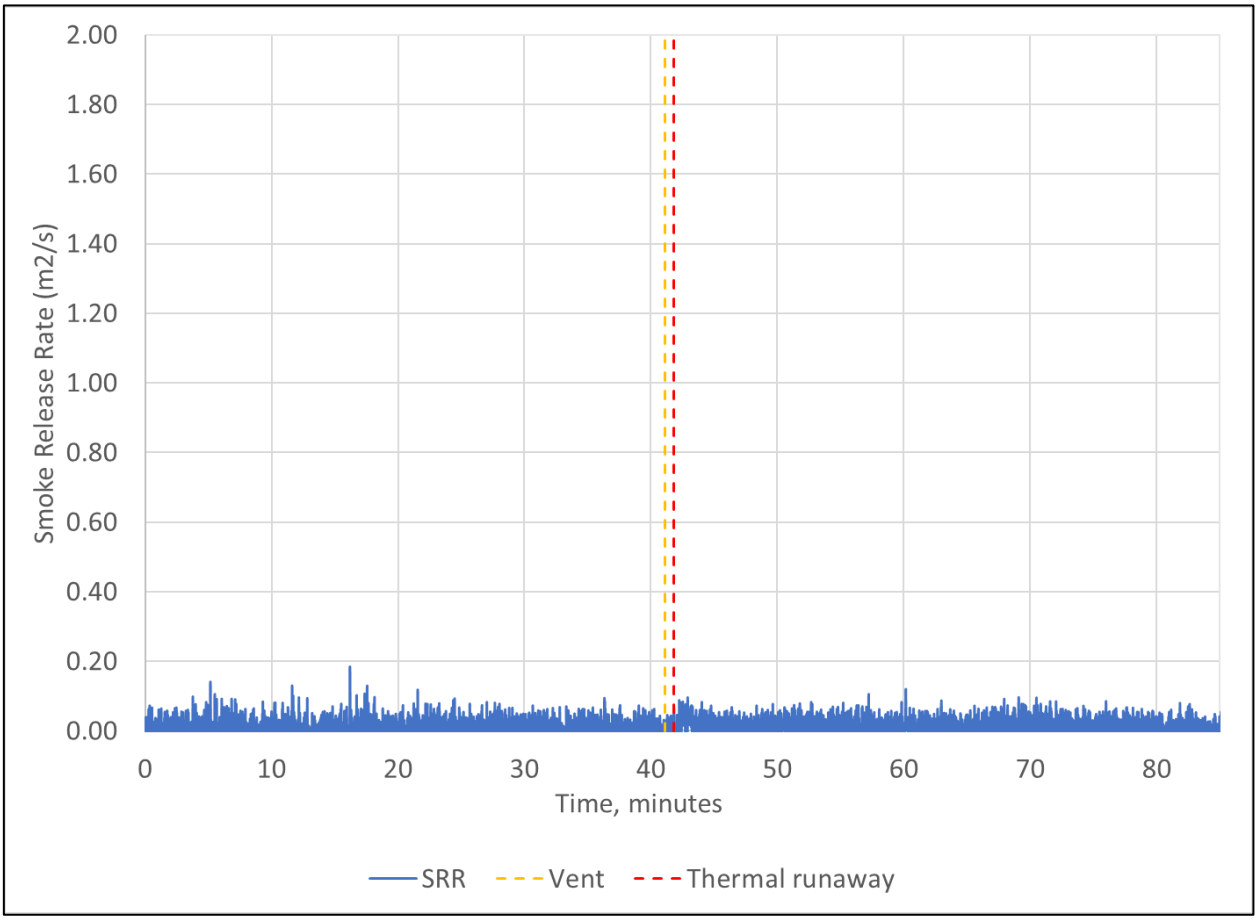


Figure 24: Smoke release rate

Appendix D

UL1973D Test Report

Prüfbericht-Nr.: *Test report no.:*	**CN23QV2N 001**	**Auftrags-Nr.:** *Order no.*:	244501240	Seite 1 von 125 *Page 1 of 125*
Kunden-Referenz-Nr.: *Client reference no.*:	2057436	**Auftragsdatum:** *Order date:*	2023-03-06	
Auftraggeber: *Client*:	**Contemporary Amperex Technology Co., Limited.** No. 2, Xingang Road, Zhangwan Town, Jiaocheng District,Ningde City, 352100 Fujian, P.R. China			
Prüfgegenstand: *Test item*:	Rechargeable Lithium-ion Battery System			
Bezeichnung / Typ-Nr.: *Identification / Type no.*:	C02306P05L01			
Auftrags-Inhalt: *Order content*:	TUV Bauart approval			
Prüfgrundlage: *Test specification*:	ANSI/CAN/UL 1973: 2022			

Wareneingangsdatum: *Date of sample receipt*:	2023-05-05
Prüfmuster-Nr.: *Test sample no:*	Engineering sample
Prüfzeitraum: *Testing period*:	2023-06-05 to 2023-08-12
Ort der Prüfung: *Place of testing*:	See page 4
Prüflaboratorium: *Testing laboratory:*	TÜV Rheinland (Shanghai) Co., Ltd.
Prüfergebnis*: *Test result**:	Pass



geprüft von: tested by:		**genehmigt von:** *authorized by*:	
Datum: *Date:* 2023-10-16	Wilson Zhou	**Ausstellungsdatum:** *Issue date:* 2023-10-16	Scola Chen
Stellung / Position:	Project Engineer	**Stellung** / Position:	Reviewer

Sonstiges / *Other*: See the following pages for General product information and comment for details.

Zustand des Prüfgegenstandes bei Anlieferung: *Condition of the test item at delivery*: Prüfmuster vollständig und unbeschädigt *Test item complete and undamaged*

* Legende:	P(ass) = entspricht o.g. Prüfgrundlage(n)	F(ail) = entspricht nicht o.g. Prüfgrundlage(n)	N/A = nicht anwendbar	N/T = nicht getestet
** Legend:*	*P(ass) = passed a.m. test specification(s)*	*F(ail) = failed a.m. test specification(s)*	*N/A = not applicable*	*N/T = not tested*

Dieser Prüfbericht bezieht sich nur auf das o.g. Prüfmuster und darf ohne Genehmigung der Prüfstelle nicht auszugsweise vervielfältigt werden. Dieser Bericht berechtigt nicht zur Verwendung eines Prüfzeichens.
This test report only relates to the above mentioned test sample. Without permission of the test center this test report is not permitted to be duplicated in extracts. This test report does not entitle to carry any test mark.
V05

Anmerkungen
Remarks

1	Alle eingesetzten Prüfmittel waren zum angegebenen Prüfzeitraum gemäß eines festgelegten Kalibrierungsprogramms unseres Prüfhauses kalibriert. Sie entsprechen den in den Prüfprogrammen hinterlegten Anforderungen. Die Rückverfolgbarkeit der eingesetzten Prüfmittel ist durch die Einhaltung der Regelungen unseres Managementsystems gegeben. Detaillierte Informationen bezüglich Prüfkonditionen, Prüfequipment und Messunsicherheiten sind im Prüflabor vorhanden und können auf Wunsch bereitgestellt werden. *The equipment used during the specified testing period was calibrated according to our test laboratory calibration program. The equipment fulfils the requirements included in the relevant standards. The traceability of the test equipment used is ensured by compliance with the regulations of our management system.* *Detailed information regarding test conditions, equipment and measurement uncertainty is available in the test laboratory and could be provided on request.*
2	Wie vertraglich vereinbart, wurde dieses Dokument nur digital unterzeichnet. Der TÜV Rheinland hat nicht überprüft, welche rechtlichen oder sonstigen diesbezüglichen Anforderungen für dieses Dokument gelten. Diese Überprüfung liegt in der Verantwortung des Benutzers dieses Dokuments. Auf Verlangen des Kunden kann der TÜV Rheinland die Gültigkeit der digitalen Signatur durch ein gesondertes Dokument bestätigen. Diese Anfrage ist an unseren Vertrieb zu richten. Eine Umweltgebühr für einen solchen zusätzlichen Service wird erhoben. Informationen zur Verifizierung der Authentizität unserer Dokumente erhalten Sie über folgenden Link: Einführung in digitale Signaturen *As contractually agreed, this document has been signed digitally only. TUV Rheinland has not verified and unable to verify which legal or other pertaining requirements are applicable for this document. Such verification is within the responsibility of the user of this document. Upon request by its client, TUV Rheinland can confirm the validity of the digital signature by a separate document. Such request shall be addressed to our Sales department. An environmental fee for such additional service will be charged. For information on verifying the authenticity of our documents, please visit the following link: Introduction to Digital Signature*
3	Prüfklausel mit der Note * wurden an qualifizierte Unterauftragnehmer vergeben und sind unter der jeweiligen Prüfklausel des Berichts beschrieben. Abweichungen von Prüfspezifikation(en) oder Kundenanforderungen sind in der jeweiligen Prüfklausel im Bericht aufgeführt. *Test clauses with remark of * are subcontracted to qualified subcontractors and descripted under the respective test clause in the report.* *Deviations of testing specification(s) or customer requirements are listed in specific test clause in the report.*
4	Die Entscheidungsregel für Konformitätserklärungen basierend auf numerischen Messergebnisen in diesem Prüfbericht basiert auf der "Null-Grenzwert-Regel" und der "Einfachen Akzeptanz" gemäß ILAC G8:2019 und IEC Guide 115:2021, es sei denn, in der auf Seite 1 dieses Berichts genannten angewandten Norm ist etwas anderes festgelegt oder vom Kunden gewünscht. Dies bedeutet, dass die Messunsicherheit nicht berücksichtigt wird und daher auch nicht im Prüfbericht angegeben wird. Zu weiteren Informationen bezueglich des Risikos durch diese Entscheidungsregel siehe ILAC G8:2019. *The decision rule for statements of conformity, based on numerical measurement results, in this test report is based on the "Zero Guard Band Rule" and "Simple Acceptance" in accordance with ILAC G8:2019 and IEC Guide 115:2021, unless otherwise specified in the applied standard mentioned on Page 1 of this report or requested by the customer. This means that measurement uncertainty is not taken in account and hence also not declared in the test report. For additional information to the resulting risk based of this decision rule please refer to ILAC G8:2019.*

TEST REPORT

ANSI/CAN/UL 1973

Batteries for Use in Stationary and

Motive Auxiliary Power Applications

Report reference No...... :	CN23QV2N 001
Date of issue .....:	see cover page
Total number of pages.....:	see cover page
Testing Laboratory.....:	TÜV Rheinland (Shanghai) Co., Ltd.
Address.....:	No. 177, Lane 777, West Guangzhong Road, Jing'an District, Shanghai 200072, P. R. China
Manufacture's name .....:	**Contemporary Amperex Technology Co., Limited.**
Address.....:	No. 2, Xingang Road, Zhangwan Town, Jiaocheng District,Ningde City, 352100 Fujian, P.R. China
Test specification:	
Standard.....:	ANSI/CAN/UL 1973: 2022
Test procedure .....:	cTUVus mark approval
Non-standard test method……..:	N/A
Test Report Form No. .....:	UL1973D
Test Report Form(s) Originator ....:	TÜV Rheinland (Shanghai)
Master TRF.....:	Dated 2022-03
Test item description.....:	Rechargeable Lithium-ion Battery system
Trade Mark.....:	CATL
Model/Type reference .....:	C02306P05L01
Ratings .....:	See model list on page 6 for details.

List of Attachments (including a total number of pages in each attachment):

Attachment 1: Photo documentation (13 pages);

Attachment 2: Critical Components List (18 pages)

Summary of testing:

Test items:

	Construction review
cl. 15	Overcharge Test
cl. 16	High Rate Charge
cl. 17	Short Circuit Test
cl. 18	Overload Under Discharge
cl. 19	Overdischarge Protection Test
cl. 20	Temperature and Operating Limits C heck Test
cl. 21	Imbalanced Charging Test
cl. 22	Dielectric Voltage Withstand Test
cl. 23	Continuity Test
cl. 24	Failure of Cooling/Thermal Stability S ystem
cl. 25	Working Voltage Measurements
cl. 26.2	Input
cl. 26.3	Leakage current
cl. 27	Electromagnetic Immunity Tests
cl. 31	Static Force Test
cl. 32	Impact Test
cl. 33	Drop Impact Test
cl. 34	Wall Mount Fixture/Support Structure/ Handle Test
cl. 40	Salt fog test
cl. 42	Single Cell Failure Design Tolerance

The DUT was complied with the requirements of ANSI/CAN/UL 1973:2022.

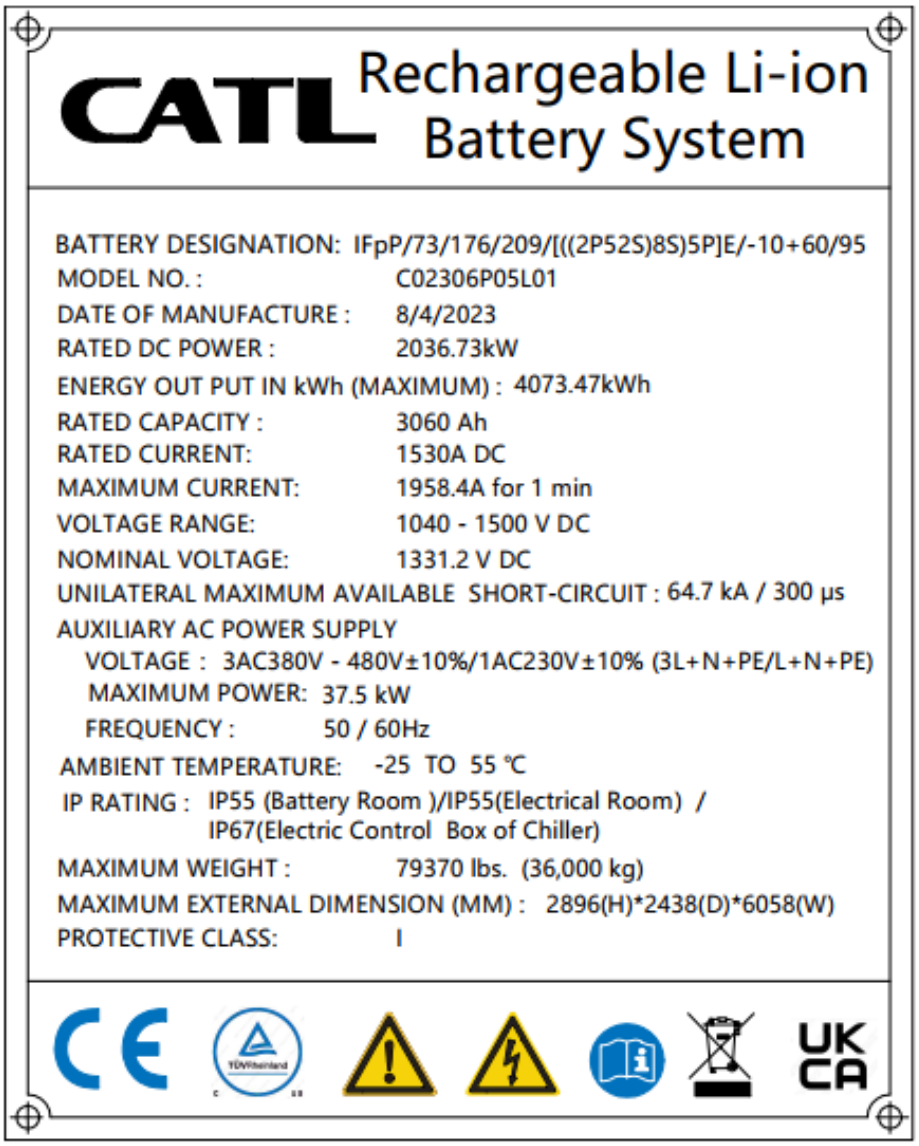
Test Location:

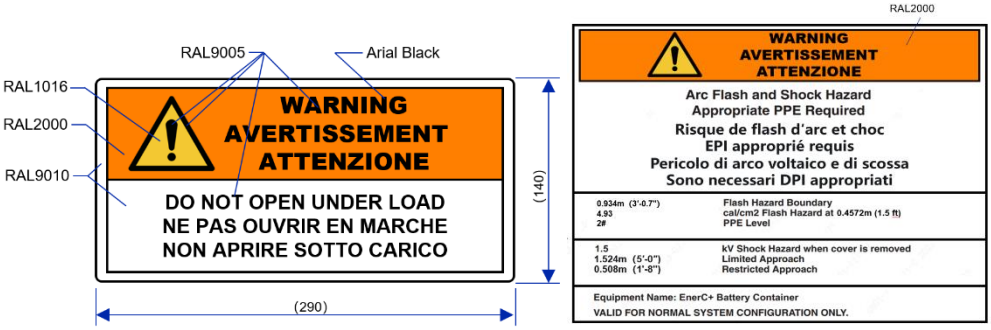
Test location :

Contemporary Amperex Technology Co., Limited.

No. 2, Xingang Road, Zhangwan Town, Jiaocheng District,Ningde City, 352100 Fujian, P.R. China

Copy of marking plate





Test item particulars:	
Information about the product needed to establish a correct test program, such as product mobility, type of power connections and similar.	(Test item particulars are selected by the TRF Originator base on the requirements in the standard)
Equipment application .....:	Stationary
Connection to the mains .....:	Permanent connection, not directly connected to the mains
Mains supply tolerance (%) or absolute mains supply values .....:	N/A
Cell/Battery Type.....:	Lithium-ion Cell Used
Battery Voltage Range.....:	See model list
Installation/Use environment .....:	outdoors
Overvoltage Category.....:	OVC II
Pollution Degree.....:	PD3(outside) PD2(inside)
IP protection class .....:	IP55(Battery room); IP55(Electrical room); IP67(Chiller control box)
Altitude during operation (m) .....:	4000
Possible test case verdicts:	
Test case does not apply to the test object .....:	N(/A)
Test object does meet the requirement:	P(ass)
Test object does not meet the requirement .....:	F(ail)
Testing:	
Date of receipt of test item .....:	see cover page
Date(s) of performance of tests ....:	see cover page
General remarks:	
This report shall not be reproduced, except in full, without the written approval of the testing laboratory. The test results presented in this report relate only to the object tested. "(see remark #)" refers to a remark appended to the report. "(see appended table)" refers to a table appended to the report. **Throughout this report a ☐ comma / ☒ point is used as the decimal separator.**	
Factory location:	
Contemporary Amperex Technology Co., Limited. No. 2, Xingang Road, Zhangwan Town, Jiaocheng District,Ningde City, 352100 Fujian, P.R. China	

Description of the product:

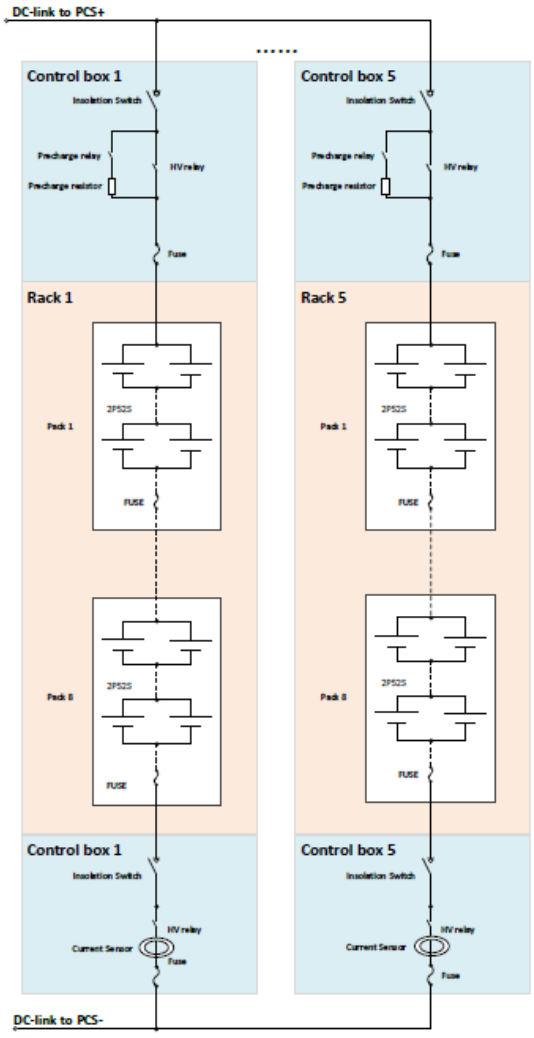
Product Description:

The model C02306P05L01-R Battery rack is the core unit in the energy storage sys-tem and acts as the equipment for storing electrical energy. It can be applied to many applications includ-ing renewable energy integration, frequency regulation, and voltage regulation.Battery rack includes battery , battery management system（BMS）, thermal management system (TMS),auxiliary distribution system, and fire suppression system (FSS).

The battery rack contains 8 battery modules. Each battery module is composed of 52 lithium iron cells (306Ah/3.2V) in series connection.The control box is for providing the auxiliary power for whole BMS control system and TMS liquid cooling system, and the battery system is composed of 416 battery cells. For safety protection, an internal high speed DC fuse is included.

The BMS functional safety was evaluated according to UL 60730-1 Annex H and UL 60730-1 Annex H by TÜV Rheinland.

Block diagram as below:



Item	Specifications			
Product name	Rechargeable Li ion Cell	Rechargeable Li ion Battery Module	Rechargeable Li ion Battery Rack	Rechargeable Li ion Battery System
Type/model	CBDD0	M02306P05L01	C02306P05L01-R	C02306P05L01
Nominal voltage	3.2V	166.4V	1331.2V	1331.2V
Rated capacity	306Ah	612Ah	612Ah	3060Ah
Voltage range	2.5-3.65	130~189.8V	1040~1500V	1040~1500V
Upper limit charging voltage	3.95V	-	-	-
Recommended charging current by manufacturer	153A	306A	306A	1530A
Recommended charging power by manufacturer	489.6W(max 195.84A)	50.91kW	407.34kW	2036.73kW
Maximum continuous charging current	153A	306A	306A	1530A
Recommended discharging current by manufacturer	153A	306A	306A	1530A
Recommended discharging power by manufacturer	489.6W(max 195.84A)	50.91kW	407.34kW	2036.73kW
Maximum continuous discharging current	195.9A	306A	306A	1530A
Standard temperature range for charging	0°C to 60°C	-	-	-
Standard temperature range for discharging	-20°C to 60°C	-	-	-
Operating ambient temperature range	-	-	-25°C to 55°C	-25°C to 55°C
Storage temperature range	-30°C to 60°C	-	-30°C to 60°C	-30°C to 60°C
Standard charging method by manufacturer	153A CC to 3.65V , CV to 15.3A	Charge at constant power 50.91kW until any cell voltage reaches 3.65V then derate until charge with 0.05P till 189.8V or	Charge at constant power 407.34kW until any cell voltage reaches 3.65V then derate until charge with	Charge at constant power 2036.73kW until any cell voltage reaches 3.65V then derate until charge with

		any cell voltage reaches 3.65V	0.05P till 1500V or any cell voltage reaches 3.65V	0.05P till 1500V or any cell voltage reaches 3.65V
Charging method for internal short-circuit test	153A CC to 3.65V , CV to 15.3A	-	-	-
Standard discharging method by manufacturer	153A DC to 2.5V	Discharge at constant power 50.91kW until 130V or any cell voltage reaches 2.5V	Discharge at constant power 407.34kW until 1040V or any cell voltage reaches 2.5V	Discharge at constant power 2036.73kW until 1040V or any cell voltage reaches 2.5V
Lower limit discharging voltage	2V	-	-	-
Over voltage protection value	-	-	max. cell voltage reaches 3.81V	max. cell voltage reaches 3.81V
Under voltage protection value	-	-	min. cell voltage reaches 2.32V	min. cell voltage reaches 2.32V
Overcurrent protection value	-	-	Max(I*135% , 10A)	Max(I*135% , 10A)
Over temperature protection value	-	-	57℃	57℃
Dimension	Width*Depth*Height: 174.7±0.8mm*71.6±0.8mm*207.3±0.8 mm	Width*Depth*Height: 830mm*2235mm *250mm	Width*Length*Height: 2252.5mm*936mm *2698mm	Width*Length*Height: 2,438mm*6,058mm *2,896mm
Weight	5500±300g	Approx.653±5kg	Approx.7200kg	Approx.36000kg
Configuration	-	2P52S	(2P52S)8S	((2P52S)8S)5P
Max.short circuit current declared by manufacturer	-	-	-12.94kA	-64.7kA
Duration at max.short circuit current declared by manufacturer	-	-	-300 μs	-300 μs

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict

INTRODUCTION			
1	**Scope**		**P**
2	**Components**		**P**
2.1	A component of a product covered by this standard shall comply with the requirements for that component. See Annex A for a list of standards covering components generally used in the products covered by this standard. A component shall comply with the CSA, UL, and/or ULC standards as appropriate for the country where the product is to be used.	See appended table Critical components.	P
3	**Units of Measurement**		**—**
4	**Undated References**		**—**
5	**Normative References**		**—**
6	**Glossary**		**—**
CONSTRUCTION			
7	**General**		**P**
7.1	Non-metallic materials		P
7.1.1	Polymeric materials employed for enclosures shall comply with the requirements as outlined in the Enclosure Requirements table, Table 4.1, Path III, of UL 746C except as modified by this standard. *Exception No. 1: Polymeric materials utilized for light electric rail (LER) enclosures for motive and VAP applications shall have a minimum flammability of V-1 or better, in accordance with UL 94 if intended for building into an enclosure or compartment within the train.* *Exception No. 2: LER enclosure parts for motive and VAP applications may alternatively be evaluated to the 20 mm end-product flame tests in accordance with UL 746C.*	Metal enclosure	N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
7.1.2	The factors taken into consideration when an enclosure is being judged are as follows. For a nonmetallic enclosure, all of these factors shall be considered with respect to thermal aging. Dimensional stability of a polymeric enclosure is addressed by compliance to the mold stress relief distortion test. a) Resistance to impact; b) Crush resistance; c) Abnormal operations; d) Severe conditions; and e) Mold-stress relief distortion.	Metal enclosure	N/A
7.1.3	The polymeric materials employed as enclosures and insulation shall be suitable for the anticipated temperatures encountered in the intended application. Pack enclosures shall have a Relative Thermal Index (RTI) with impact suitable for temperatures encountered in the application but no less than 80 °C (176 °F), as determined in accordance with UL 746B.		N/A
7.1.4	The pack enclosure materials intended to be exposed to sunlight in the end use application shall comply with the UV Resistance and the Water Exposure and Immersion tests in accordance with UL 746C.		N/A
7.1.5	Polymeric materials used as direct support for live parts other than those circuits determined nonhazardous (i.e. limited power circuits) shall comply with the insulation requirements of UL 746C. *Exception: Polymeric materials used as direct support for live parts that meet the requirements for "Safeguards Against Fire Under Normal Operating Conditions and Abnormal Operating Conditions," Clause 6.3, of UL 62368-1/CSA C22.2 No. 62368-1, or the requirements for "Safeguards Against Fire Under Single Fault Conditions," Clause 6.4, of UL 62368-1/CSA C22.2 No. 62368-1 are considered acceptable. Where specified in the reference document that components must meet the relevant IEC component standards, those components shall meet the applicable CSA or UL Standards.*		P
7.1.6	Polymeric tanks, piping and housings containing only electrolyte and sensors in flow batteries shall have a flammability rating of HB or better in accordance with UL 94.	No Such components.	N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
7.1.7	Printed wiring boards shall have a flammability rating of V-0 or V-1 in accordance with UL 94. *Exception: This requirement does not apply to printed wiring boards connected only in low-voltage, limitedenergy circuits (LVLE) where the deterioration or breakage of the bond between a conductor and the base material does not result in a risk of fire or electric shock.*		P
7.1.8	Gaskets and Seals relied upon for safety shall be determined suitable for the temperatures they are exposed to and other conditions of use. Compliance is determined by the applicable tests of UL 157.		P
7.2	Metallic parts resistance to corrosion		P
7.2.1	Metal pack enclosures shall be corrosion resistant. A suitable plating or coating process can achieve corrosion resistance. Additional guidance on methods to achieve corrosion protection can be found in UL 50E/C22.2 No. 94.2.	Corrosion resistant metal enclosure used.	P
7.2.2	Conductive parts in contact at terminals and connections shall not be subject to corrosion due to electrochemical action. Combinations above the line in Table D.1 of Annex D shall be avoided unless there is an evaluation that demonstrates that the potential for corrosion is negligible for the particular connection materials and design. See Annex D.		P
7.3	Enclosures		P
7.3.1	The enclosure of a battery system shall have the strength and rigidity required to resist the possible physical abuses that it will be exposed to during its intended use, in order to reduce the risk of fire or injury to persons. Compliance is determined by the tests of this standard.	Compliance checked by the tests. Also see clause 31, 32 and 33.	P
7.3.2	A tool providing the mechanical advantage of a pliers, screwdriver, hacksaw, or similar tool, shall be the minimum mechanical capability required to open the enclosure.	Not opened without a tool.	P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
7.3.3	Openings in the enclosure shall be designed to prevent inadvertent access to hazardous parts. Compliance is determined by the Tests for Protection Against Access to Hazardous Parts Indicated by the First Characteristic Numeral, Clause 12 of IEC 60529 or CAN/CSA-C22.2 No. 60529, for a minimum IP rating of IP2X or IPXXB, and C22.1, the Enclosure Selection Table for Nonhazardous Locations, Table 65. (Evaluation per IEC 60529 or CAN/CSA-C22.2 No. 60529, Clause 12, consists of the use of the IEC articulate probe applied with a force of 10 N ±10 %). *Exception: For battery systems intended for location in restricted access locations only per 6.51, hazardous parts may be contacted with the articulate probe, but shall be located or guarded to prevent unintended contact by service or other trained personnel. Such equipment shall be provided with installation instructions in accordance with 45.3 and marked in accordance with 44.14.*	Battery room: IP55; Electrical room: IP55 Chiller control box: IP67	P
7.3.4	Openings in the enclosure shall be constructed to prevent accumulation of flammable gases that could lead to a hazardous condition from concentrations of hydrogen gas due to electrolysis of aqueous electrolytes for applicable battery technologies, such as vented or valve regulated lead acid and nickel batteries and applicable electrochemical capacitor technologies, greater than 25 % of the LFL of hydrogen (equivalent to 1 % concentration in a volume of air). Ventilation openings shall have a minimum opening area of: $A = 0.005NC_5(cm^2)$ Where: A = Total cross sectional area of ventilation holes required (cm^2) N = Number of cells in battery C_5 = Capacity of battery at the 5-h rate (Ah) *Exception: The area of ventilation openings can be reduced if it can be demonstrated that there is sufficient ventilation within the battery to prevent hydrogen accumulations above 25 % of the LFL of hydrogen.*	Lithium ion battery technology used, where no hazards condition from concentrations of hydrogen gas occurs.	N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
7.3.5	Packs intended for installation where they may be exposed to moisture either through rain, splashing water or immersion shall be evaluated for their intended resistance to ingress of moisture in accordance with IEC 60529 or CAN/CSA-C22.2 No. 60529, or as outlined in NFPA 70, Article 110, or Section 2 of C22.1 for enclosure type designation and UL 50E/C22.2 No. 94.2, or NEMA 250. See also Section 39.	Battery room: IP55; Electrical room: IP55 Chiller control box: IP67	P
7.4	Wiring and terminals		P
7.4.1	General		P
7.4.1.1	Wiring shall be insulated and acceptable for the purpose, when considered with respect to temperature, voltage, and the conditions of service to which the wiring is likely to be subjected within the equipment.	For more detail of compliance of tests of this standard, see clause 20.	P
7.4.1.2	A wiring splice or connection shall be mechanically secure and shall provide electrical contact without strain on connections and terminals. Wiring shall be secured and routed away from sharp edges or parts exceeding insulation. Openings in compartments through which insulated wiring is routed shall be smooth and well-rounded or provided with protective insulating bushings or grommet to prevent abrasion. Wiring connections between various parts of a battery module/pack and accessories shall be routed and secured to prevent the potential for short circuit conditions to occur.	Wiring splice or connection checked	P
7.4.1.3	An uninsulated live part, including a terminal, shall be secured to its supporting surface by a method other than friction between surfaces so that it will be prevented from turning, shifting in position, or creating short circuit.	Terminal block designed to prevent hazardous construction.	P
7.4.1.4	An external battery terminal shall be designed to prevent inadvertent shorting. An external terminal shall be designed to prevent inadvertent misalignment or disconnection when installed in its end use application.	Terminal block designed to prevent hazardous construction.	P
7.4.1.5	External non-detachable cords and leads that are accessible in the end use installation shall be provided with strain relief that prevents strain to internal conductors under pull and push-back conditions. Compliance is determined by the tests of 26.4 and 26.5.	No such parts.	N/A
7.4.1.6	Plugs and receptacles shall be rated for the intended voltage, current, temperature, and if applicable, for disconnect under load conditions.	No such parts.	N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
7.4.1.7	Battery system cables shall be rated for their anticipated service including voltage, current, temperature and environment. External cords for hazardous voltage circuits shall be jacketed to prevent wear to internal conductors and rated and provided with insulation suitable for the intended applications.	Checked and found eligible for their anticipated service.	P
7.4.1.8	In multiway plugs and sockets, and wherever shorting could otherwise occur, means shall be provided to prevent contact between parts in SELV circuits or parts at hazardous voltage due to loosening of a terminal or breaking of a wire at a termination. Compliance is checked by inspection, by measurement and, where necessary, by the following test. A force of 10 N (2.25 lbf) is applied to the conductor near its termination point. The conductor shall not break away or pivot on its terminal to the extent that spacings are reduced below the values specified in 7.5.	No such parts.	N/A
7.4.1.9	Wiring compartments and wiring terminals provided for connection of the battery system to external circuits shall be constructed as outlined below: a) A field wiring compartment in which supply connections are to be made shall be located so that the connections will be accessible for inspection after the unit is installed as intended. b) A knockout in a sheet-metal enclosure shall be secured and shall be removable without undue deformation of the enclosure. The knockout shall be surrounded by a flat surface to accommodate seating of a conduit bushing or locknut of the appropriate size. c) An outlet box, terminal box, wiring compartment, in which field connections are made shall be free from any sharp edges including screw threads, a burr, a fin or moving part of the like that may abrade the insulation on conductor or otherwise damage wiring. d) A field wiring terminal or lead shall be rated for the connection of a conductor or conductors having a minimum ampacity rating of 125% of the rating of the unit. e) The distance between the end of the connection point of a field installed wire and the wall of the enclosure toward which the wire is to be directed, shall be in accordance with Table 312.6 (A) or (B) of NFPA 70.		P
7.4.2	Beads and ceramic insulators		N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
7.4.2.1	Beads and similar ceramic insulators on conductors shall: a) Be so fixed or supported that they cannot change their position in such a way that a hazard would be created; and b) Not rest on sharp edges or sharp corners.	No such parts.	N/A
7.4.2.2	If beads are located inside flexible metal conduits, they shall be contained within an insulating sleeve, unless the conduit is mounted or secured in such a way that movement in normal use would not create a hazard. Compliance is checked by inspection and, where necessary, by the following test. A force of 10 N (2.25 lbf) is applied to the insulators or to the conduit. The resulting movement, if any, shall not create a hazard in the meaning of this standard.		N/A
7.5	Spacings and separation of circuits		P
7.5.1	General		P
7.5.1.1	Electrical circuits within the pack at opposite polarity shall be provided with reliable physical spacing to prevent inadvertent short circuits (i.e. electrical spacings on printed wiring boards, physical securing of un-insulated leads and parts, etc.). Insulation suitable for the anticipated temperatures and maximum voltages shall be used where spacings cannot be controlled by reliable physical separation.		P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
7.5.1.2	Electrical spacings in circuits shall be based upon the grade of insulation required as outlined in the Insulation Materials and Requirements, Clause 5.4 of UL 62368-1/CSA C22.2 No. 62368-1, and shall comply with Clearances, Clause 5.4.2, and Creepage Distances, Clause 5.4.3, of UL 62368-1/CSA C22.2 No. 62368-1. For the appropriate pollution degree of the intended environment see 7.5.2 and 7.5.3. *Exception No. 1: As an alternative to these spacing requirements, the spacing requirements in UL 840, may be used. For determination of clearances, a dc source such as a battery does not have an overvoltage category as outlined in the section for Components of UL 840 unless charged through an ac mains connected rectifier, then the overvoltage category should be the same as that required for the rectifier unless the rectifier uses galvanic isolation. If galvanic isolation is employed, then the overvoltage category can be reduced to the next lower overvoltage category. The anticipated pollution degree is determined by the design and application of the battery system or subassembly under evaluation.* *Exception No. 2: As an alternative to the clearance values outlined in UL 62368-1/ CSA C22.2 No. 62368-1 the alternative method for determining minimum clearances in the Annex for Alternative Method for Determining Clearances for Insulation in Circuits Connected to an AC Mains not Exceeding 420 V peak (300 V RMS), Annex X, of UL 62368-1/CSA C22.2 No. 62368-1 may be applied.* *Exception No. 3: As an alternative to these spacing requirements, the spacing requirements of Table 7.1 may be applied instead. When using this table, maximum working voltages of circuits can be determined through the test of Section 23. See the note in Table 7.1 regarding adjustment for spacings where double or reinforced insulation is required.* *Exception No. 4: As an alternative, clearances and creepage distances per IEC 60664-1 can be applied instead.*	The electrical spacings for clearance and creepage, comply with UL 840	P
7.5.1.3	Conductors of circuits operating at different potentials shall be reliably separated from each other unless they are each provided with insulation acceptable for the highest potential involved.	Each circuit is separated from others.	P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
7.5.1.4	An insulated conductor shall be reliably retained so that it cannot contact an uninsulated live part of a circuit operating at a different potential. Some examples include clamping or routing of conductors, use of separating barriers of insulating material or other means that provides permanent separation of the parts.	Complied	P
7.5.1.5	There are no minimum spacings applicable to parts where insulating compound completely fills the casing of a compound or subassembly if the distance through the insulation, at voltages above SELV levels is a minimum of 0.4-mm (0.02-in) thick for supplementary or reinforced insulation, and passes the Dielectric Voltage Withstand Test. There is no minimum insulation thickness requirement for insulation of circuits at or below SELV levels for basic or functional insulation. Some examples include potting, encapsulation, and vacuum impregnation.	Complied	P
7.5.1.6	UL 840 shall not be used for clearances between an uninsulated live part and the walls of a metal enclosure, including fittings for conduit or armored cable. UL 840 shall not be used for the clearance and creepage distance at field wiring terminals	Considered	P
7.5.1.7	When determining the clearance for double or reinforced insulation in accordance with UL 840, the clearances of reinforced insulation shall be dimensioned corresponding to the rated impulse voltage, but choosing one step higher in the preferred series of values in the Minimum Clearances for Equipment table of UL 840 than that specified for basic insulation. If the impulse withstand voltage required for basic insulation, is other than a value taken from the preferred series, reinforced insulation shall be dimensioned to withstand 160 % of the impulse withstand voltage required for basic insulation.	Considered	P
7.5.1.8	When determining the creepage for double or reinforced insulation in accordance with UL 840, the creepage distances for reinforced insulation shall be twice the creepage distance required for the basic insulation as determined in UL 840.	Considered	P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
7.5.1.9	When determining the electrical spacing according to 7.5.1.1, a battery circuit that has no direct connection to a primary circuit and derives its power from a transformer or converter shall be considered a secondary circuit. The phase-to-ground rated system voltage used in the determination of mains transient voltage in UL 62368-1/CSA C22.2 No. 62368-1 or the rated impulse voltage in UL 840 shall be the rated supply voltage of the charging equipment for the battery.		P
7.5.1.10	For batteries intended for installation at high altitudes (i.e. 2000 m and above), see the Multiplication Factors for Clearances and Test Voltages table of UL 62368-1/CSA C22.2 No. 62368-1 or the Altitude Correction Factors for Clearance Correction table of IEC 60664-1 for multiplication factors to be applied to clearance values.	4000m	P
7.5.2	Overvoltage categories applied for electrical creepage and clearance determination		P
7.5.2.1	When determining the creepage and clearance requirements from 7.5.1.2, the overvoltage categories for the battery systems shall be determined based on how the batteries are connected to the supply mains. For equipment or circuits energized from the mains, four categories are considered: a) Category IV applies to equipment permanently connected at the origin of an installation (upstream of the main distribution board). Examples are electricity meters, primary overcurrent protection equipment and other equipment connected directly to outdoor open lines; b) Category III applies to equipment permanently connected in fixed installations (downstream of, and including, the main distribution board). Examples are switchgear and other equipment in an industrial installation; c) Category II applies to equipment not permanently connected to the fixed installation. Examples are appliances, portable tools and other plug-connected equipment; and d) Category I applies to equipment connected to a circuit where measures have been taken to reduce transient overvoltages to a low level.	OCV II used and considered.	P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
7.5.2.2	For stationary battery systems, Overvoltage Category III is applied. Overvoltage Category II may be applied for a stationary battery system that is isolated from an Overvoltage category III supply source (such as from an Overvoltage category III PCS) through an isolated transformer or protected in a manner that prevents transient overvoltage conditions. For vehicle auxiliary power batteries and on board LER batteries, Overvoltage Category II shall be applied.		P
7.5.3	Pollution degree for electrical creepage and clearance determination		P
7.5.3.1	With reference to 7.5.1.2, the following are conditions for determining the pollution degree to utilize when determining creepage and clearance distances. See also examples noted in Table 7.2. a) Pollution Degree 1 – No pollution or only dry, non-conductive pollution. Normally, this is achieved by having components and subassemblies adequately enclosed by enveloping or hermetic sealing so as to exclude dust and moisture. b) Pollution Degree 2 – Only non-conductive pollution that might temporarily become conductive due to occasional condensation. c) Pollution Degree 3 – Subject to conductive pollution, or to dry non-conductive pollution which could become conductive due to expected condensation. d) Pollution Degree 4 – Pollution that generates persistent conductivity through conductive dust or rain and snow.	PD3(outside) PD2(inside)	P
7.6	Insulation levels and protective grounding and bonding		P
7.6.1	Hazardous voltage circuits shall be insulated from accessible conductive parts and circuits as outlined in 7.6.2 through the following: a) Basic insulation and provided with a protective grounding system for protection in the event of a fault of the basic insulation; or b) A system of double or reinforced insulation; or c) A combination of (a) and (b).		P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
7.6.2	Safety extra low voltage (SELV) circuits as defined in 6.54 that are insulated from accessible conductive parts through functional insulation only are considered accessible.	Insulation checked for accessible part for SELV circuit.	P
7.6.3	Batteries that rely upon protective grounding, shall comply with 7.6.4 – 7.6.9.	Complied with 7.6.4 - 7.6.9.	P
7.6.4	Accessible non-current carrying metal parts of a battery system with hazardous voltage circuits, that could become live in the event of an insulation fault, shall be bonded to the equipment ground terminal.	Grounding system exists.	P
7.6.5	Parts of the protective grounding system shall be reliably secured in accordance with 7.4.1.2 and provided with good metal-to-metal contact. All connections shall be secured against accidental loosening and shall ensure a thoroughly good connection. The resistance between the protective conductive terminal of 7.6.8 and the accessible non-current carrying conductive parts outlined in 7.6.2 shall not exceed 0.1 Ω.	Measured resistance between the protective conductive terminal and accessible non-current carrying part: 0.014 Ω	P
7.6.6	With reference to 7.6.5, when connecting conductive parts to be bonded, paint or coatings in areas of contact shall be removed or paint piercing lock washers shall be used with securement bolts or screws to provide good metal to metal contact. Thread-locking sealants, epoxies, glues, or other similar compounds, and solder alone shall not be used as a securement means as these are not considered reliable. In addition, rivets, hinges (unless metal-to-metal piano type hinges), and parts that may be removed as a result of servicing shall not be relied upon as connections for ensuring continuity of the protective grounding and bonding system.		P
7.6.7	With reference to 7.6.5, methods of securement considered reliable and ensuring good metal-to-metal contact can consist of the following methods: a) Terminal blocks; b) Pressure connectors, grounding lugs and similar grounding and bonding equipment connectors; c) Exothermic welding processes; d) Machine screw-type fasteners that engage not less than two threads or are secured with a nut; and e) Thread-forming machine screws that engage not less than two threads in the enclosure.	d), e)	P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
7.6.8	The main ground terminal of the protective grounding system shall be identified by one of the following: a) A green-colored, not readily removable terminal screw with a hexagonal head; b) A green-colored, hexagonal, not readily removable terminal nut; c) A green colored pressure wire connector; or d) The word “Ground” or the letters “G” or “GR” or the grounding symbol (IEC 60417, No. 5019) or otherwise identified by a distinctive green color.	The main ground terminal of the protective grounding system complies with d).	P
7.6.9	Conductors, relied upon for the protective grounding and bonding system, shall be sized to handle intended fault currents and if insulated, the insulation shall be green or green and yellow striped in color. Grounding conductors shall be sized in accordance with Article 250.122 of NFPA 70 or Rule 10-810 of C22.1.	Grounding conductor color: green and yellow.	P
7.7	Transformers	No such parts.	N/A
7.7.1	Transformers shall be evaluated in accordance with UL 1562, UL 1310 or an equivalent standard for overload conditions, and shall have suitable insulation for the circuits they are connected to.		N/A
7.7.2	Transformers in low voltage circuits can alternatively be evaluated in accordance with 26.6.		N/A
7.7.3	Transformers shall be provided with overcurrent protection on the primary side of the transformer and sized in accordance with Article 450 of NFPA 70 or Section 26 of C22.1.		N/A
7.8	System safety analysis	Complied.	P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
7.8.1	A safety analysis consisting of a hazard identification, risk analysis and risk evaluation shall be conducted on the device under test. This safety analysis shall determine which parts of the system are safety related through an existing methodology such as outlined 7.8.2. This approach should determine the hazard scenarios and define mitigation mechanisms. This safety analysis shall identify safety circuits or software that address each hazardous condition and consider the performance of each safety circuit or software. The following conditions in (a) – (c) shall be considered unless sufficient justification (e.g. additional safety analysis) is provided by the manufacturer that these conditions are not hazardous. The following conditions in (a) – (c) shall be considered at a minimum, but are not limited to: a) Battery cell over-voltage and under-voltage; b) Battery over-temperature and under-temperature; and c) Battery over-current during charge and discharge conditions.	Evaluated according to UL 60730-1 Annex H.	P
7.8.2	Documents that can be used as guidance for the safety analysis include: a) IEC 60812; b) IEC 61025; c) MIL-STD-1629A; and d) IEC 61508, all parts.	See above.	P
7.8.3	The analysis of 7.8.1 is utilized to identify anticipated faults in the system which could lead to a hazardous condition and is validated by compliance with 7.9. The analysis shall consider the reliability of any monitoring components and systems and any communication systems providing information to the controls that can affect safety. The analysis shall consider single fault conditions in the protection circuit in addition to single faults elsewhere that could lead to a hazardous condition.	See above.	P
7.9	Protective circuit and controls		P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
7.9.1	Active protective devices shall not be relied upon for critical safety and shall comply with one of the following in (a) – (c) and comply with 7.9.2 and 7.9.3 as applicable. Refer to 6.49 and 6.50 for definitions of active and passive protective devices. a) They are provided with a redundant passive protective device; b) They are provided with redundant active protection that remains functional and energized upon loss of power to, or failure of the first level of active protection; or c) They remain fully operational or fail safe upon loss of power to, or under a single fault condition of the active circuit. *Exception : Active protective devices that comply with IEC 61508 (all parts), meeting minimum Safety Integrity Level (SIL) "2", ISO 13849 (all parts), meeting minimum performance level (PL) "c", or ISO 26262 (all parts), minimum of Automotive Safety Integrity Level (ASIL) "C" are permitted to be relied upon for critical safety. The SIL, PL, or ASIL for a safety function may be reduced if the manufacturer provides additional safety analysis, e.g. Layer of Protection Analysis (LOPA), showing that the required risk reduction level has been reduced by other measures used within the battery system.*		P
7.9.2	Active protective devices relied upon for safety as noted in 7.9.1, shall be evaluated in accordance with: a) The Failure-Mode and Effect Analysis (FMEA) requirements in UL 991 (Section 7); b) The Protection Against Internal Faults to Ensure Functional Safety requirements in UL 60730-1 or CAN/CSA E60730-1 (Clause H.27.1.2); or c) The Protection Against Faults to Ensure Functional Safety requirements (Class B requirements) in CSA C22.2 No. 0.8 (Section 5.5) to determine compliance and identify tests necessary to verify single fault tolerance.	Evaluated according to UL 60730-1 Annex H.	P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
7.9.3	With reference to 7.9.1, software relied upon for safety shall comply with: a) Software Class 1 requirements of UL 1998; b) Software Class B requirements of CSA C22.2 No. 0.8; or c) The Controls Using Software requirements (Software Class B requirements) in UL 60730-1 (Clause H.11.12) or CAN/CSA E60730-1.		P
7.9.4	Software and its associated hardware determined critical to safety that can be updated remotely shall meet the requirements outlined in UL 5500.		P
7.9.5	Battery systems shall be protected against all hazards identified in the safety system safety analysis of 7.8.		P
7.9.6	With reference to 7.9.5, if relied upon for maintaining the cells within their safe operating limits, the battery management system (BMS) shall maintain cells within the specified cell voltage and current limits to protect against overcharge and over-discharge. The BMS shall also maintain cells within the specified temperature limits providing protection from overheating and under temperature operation. When reviewing safety circuits to determine that cell operating region limits are maintained, tolerances of the protective circuit/component shall be considered in the evaluation. Components such as fuses, circuit breakers or other devices and parts determined necessary for safe operation of the battery system that are required to be provided in the end use installation, shall be identified in the installation instructions.		P
7.9.7	With reference to 7.9.5 and 7.9.6, if safe operating limits are exceeded, a protective circuit shall limit or shut down the charging or discharging to prevent excursions beyond these limits. When a hazardous scenario occurs, as determined in 7.8.1, the system shall continue to provide the safety function or go to a safe state (SS) or risk addressed (RA) state. If the safety function has been damaged, the system shall remain in the safe state or risk addressed state until the safety function has been restored and the system has been deemed safe to operate.		P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
7.9.8	Solid state circuits and software controls, relied upon as the primary safety protection, shall be evaluated and tested to verify electromagnetic immunity in accordance with Section 27. *Exception: Solid state circuits and software need not comply if it can be demonstrated that the solid state circuits and software are not relied upon as the primary safety protection.*	Complied. Evaluated according to UL 60730-1 Annex H.	P
7.9.9	Battery systems with hazardous voltage circuits, including outputs of 60 V or greater, shall either be provided with a manual disconnect device or be provided with installation instructions for the disconnect device to be provided during installation of the system. The disconnect device shall be located as near as possible to the battery system terminals and it shall be rated for the application including disconnect under load if applicable. The disconnect device shall disconnect both poles of the circuit. The manual disconnect shall not require the use of a special tool or equipment to be operated. The disconnect device shall consist of either a manually operated switch or circuit breaker. *Exception No. 1: A battery system having either a plug or receptacle or connector for connection to the output circuit may be provided without an additional disconnect means. The plug, receptacle and connectors used for this purpose shall be investigated in accordance with UL 1682 and rated for current interruption suitable for the circuit. The required spacing to the hazardous voltage circuits shall be maintained when the plug or receptacle or connector is disconnected.* *Exception No. 2: A flow battery that can be turned off such that no circuits remain at hazardous voltage are not required to have a manual disconnect device.*	Complied	P
7.9.10	Fuses provided for battery overcurrent protection including short circuit protection shall be evaluated for both short circuit and overload conditions. Fuses that are evaluated for short circuit conditions only (type aR fuses), shall be provided with supplementary protection (e.g. the BMS) to ensure protection under overcurrent conditions in ranges below those covered by these types of fuses.		P
7.9.11	Protective components of battery modules intended for series connection in battery systems shall be rated for the maximum voltage of the intended battery system.		P
7.10	Cooling/thermal management system		P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
7.10.1	Battery systems that rely upon integral thermal management systems to prevent overheating shall be designed to shutdown upon failure of the thermal management system unless is can be demonstrated, that the thermal management system failure does not result in a hazardous situation. Compliance is determined by the Failure of the Cooling/Thermal Stability System Test of Section 24.	Complied with Test of section 24	P
7.10.2	Piping, hose, and tubing used to contain liquid shall be resistant to chemical degradation from the liquid it contains, as well as other liquids reasonably likely to contact such parts during expected life of the equipment. It shall have the strength and material characteristics necessary to withstand the anticipated mechanical and environmental stresses. Compliance is determined as outlined in 7.11.1.	Complied	P
7.10.3	With reference to 7.10.2, piping containing fluids in accordance with the scope of ASME B31.3, shall comply with the applicable requirements of that code. ASME B31.3 applies to piping that contains toxic fluids, flammable fluids, fluids damaging to human tissue, and nonhazardous fluids at pressures greater than 15 psi (105 kPa) or temperatures lower than −29 °C (−20 °F) or greater than 186 °C (366 °F).	A mixture of Ethylene glycol and water for liquid cooling	P
7.10.4	Piping, hose, and tubing containing liquids, shall be routed and secured to prevent leakage that could result in a fire, explosion or shock hazard.		P
7.10.5	Fans or blowers utilized for air-cooling systems shall comply with the applicable requirements in UL 507. *Exception: Fans located in SELV or ELV dc circuits need not be evaluated if shown to comply with the test of 26.1.*		N/A
7.10.6	Battery systems that rely on integral heaters to maintain operating temperatures of the battery system, shall be designed to shutdown upon failure of the heaters unless it can be demonstrated through fault analysis and if necessary an abnormal operation test, that the heater failure does not result in a hazardous situation.	No such parts.	N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
7.10.7	Temperature controls for heaters used to maintain the operating temperature range of a battery system during cold ambient conditions shall be positioned such that they monitor the system temperature and are minimally affected by the outside ambient. For example, temperature controls or regulators should normally be located away from outside vents.	No such parts.	N/A
7.11	Electrolyte containment parts and parts subject to pressure	No such parts.	N/A
7.11.1	Parts that contain electrolyte, such as piping, hose, and tubing shall be resistant to chemical degradation from the electrolyte. Electrolyte containing parts shall have the strength and material characteristics necessary to withstand the anticipated mechanical and environmental stresses. Compliance is determined through review of material datasheets and where determined necessary, an immersion test (using the electrolyte as the test liquid) in accordance with the Volume Change Test after Immersion of UL 157 for elastomeric materials or the Test for Resistance of Polymeric Materials to Chemical Reagents in UL 746A for other than elastomeric materials, (same as ASMT D543, Test Method I), as applicable to the material and part being tested. Elastomeric parts in contact with electrolyte shall be subjected to the volume change and extraction test after 70-h immersion in the electrolyte in accordance with UL 157. The volume change shall be minus 1 to plus 25 % and extraction (change in weight) no greater than 10 %. Plastics other than elastomeric parts in contact with electrolyte shall be subjected to an immersion for 168 h at room temperature followed by a check for volume and weight change in accordance with ASTM D543, Procedure I method. The percentage of change of volume shall not be greater than 2 % of the original and the change in weight shall be no not increase more than 25 % or decrease more than 10 % of the original value. *Exception No. 1: See Annex C for material requirements for flowing electrolyte systems.* *Exception No. 2: Not applicable to individual cell or capacitor casings and materials that have been evaluated to appropriate component requirements per 7.12.*	Not applicable to Lithium Battery System	N/A
7.11.2	Piping, hose, and tubing containing electrolyte, shall be routed and secured to prevent leakage that could result in a fire, explosion or shock hazard.	Not applicable to Lithium Battery System	N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
7.11.3	Parts under pressure shall be acceptable for the maximum anticipated pressure as determined by the tests of Section 36. Exception: See Annex C for material requirements for flowing electrolyte systems.	Not applicable to Lithium Battery System	N/A
7.11.4	Relief valves or rupture members relied upon to relieve overpressure conditions in a battery system shall operate in accordance with their specifications for start to discharge (i.e. pressure at which the relief valve or rupture membrane starts to relieve pressure). Compliance is determined by the tests of Section 37. This requirement does not apply to relief valves or rupture members integral to a cell or monobloc battery such as a VRLA type battery. *Exception: Relief valves and ruptures members stamped with the ASME approval mark for the particular device in accordance with the ASME Boiler and Pressure Vessel Code need not be subjected to the tests of Section 37.*	Not applicable to Lithium Battery System	N/A
7.11.5	A pressure-relief device shall have its discharge opening located and directed so that operation of the device will not deposit moisture on bare live parts or on insulation or components that could be detrimentally affected by the discharge. It shall have a start to discharge (i.e. pressure at which the relief valve or rupture membrane starts to relieve pressure) rating adequate to relieve the pressure.	Not applicable to Lithium Battery System	N/A
7.11.6	The fill port of the electrolyte containment of a monobloc system shall be designed to prevent overfill and spillage of electrolyte during the electrolyte filling.	Not applicable to Lithium Battery System	N/A
7.11.7	Flow batteries shall be provided with a means for spill control such as a spill containment system to prevent electrolyte spills. The spill containment shall be sufficient to handle electrolyte spills for the size of the system. See Spill Containment Systems, Section C6, for means to determine compliance.	Not applicable to Lithium Battery System	N/A
7.11.8	Flowing electrolyte batteries shall be provided with a means of leak detection that shall identify when a leak occurs in the system and initiate controls to mitigate the leak condition.	Not applicable to Lithium Battery System	N/A
7.12	Cells (battery and electrochemical capacitor)		P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
7.12.1	Sealed nickel metal hydride cells shall comply with the cell tests of the Testing Required for Cells table of UL 2054 in addition to the requirements of this standard. Cells shall be provided with specifications for use (charging and discharging), installation, storage and disposal. *Exception No. 1: The overall dimensions of the projectile test aluminum test screen may be increased from those outlined in UL 2054 to accommodate large cells intended for stationary and LER applications, but the flat panels of the test screen shall not exceed a distance of 305 mm (12 in) from the cell in any direction.* *Exception No. 2: The overall external resistance for the short circuit test shall be less than or equal to 20 mΩ.* *Exception No. 3: The crush test shall be a bar crush test rather than a flat plate crush using a bar with a 15-cm (5.9-in) diameter if the flat plate crush test per UL 2054 is insufficient to create a crush condition in the cell as determined by (a) – (c) below. The force shall be applied until one of the following occurs:* *a) A voltage (OCV) drop of one-third of the original cell voltage occurs;* *b) A deformation of 15 % or more of initial cell dimension occurs; or* *c) A force of 1,000 times the weight of cell is reached.* *Exception No. 4: Nickel metal hydride or nickel cadmium cells that are sealed and formed as part of a monobloc battery, need only comply with the requirements of this standard as part of the assembled battery. If provided with a pressure release vent or flame arrester, the nickel battery shall comply with the requirements outlined in 7.12.8.* *Exception No. 5: Sample numbers tested for each test based upon UL 2054 test program may be reduced from 5 samples tested to 2 samples tested.* *Exception No. 6: During the heating test, the samples are held for 30 min at the maximum temperature rather than 10 min.*	Lithium ion cells used.	N/A
7.12.2	Secondary lithium cells shall comply with the requirements outlined in Annex E, and be marked as required in 44.15 and 44.16. Cells shall be provided with specifications as outlined in 45.7.	The Lithium ion cell has been tested and certified with standards UL1973: 2022.	P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
7.12.3	Secondary lithium cell design shall ensure sufficient safety measures to mitigate internal short circuits and other hazardous conditions during the life of the cells. Safety measures to maintain cell safety include, but are not limited to, the following: a) The appropriate choice and placement of insulation. IEEE 1625 and IEEE 1725 provide guidance on placement and application of insulation within cells and general cell design safety considerations; b) Sufficient sizing of the negative electrode active materials to cover the positive electrode active materials; c) Proper placement of insulation and separation of parts at opposite polarity including insulation and placement of tabs to prevent inadvertent short circuits during the life of the cell; d) The use of appropriate protection mechanisms such as separator shutdown, protective coatings and electrolyte additives, etc.; and e) The use of separators with sufficient strength, thermal properties and that are sized to prevent short circuit between the positive and negative electrodes during charge and discharge over the life of the cells.		P
7.12.4	With reference to 7.12.3, compliance to (a) – (e) is determined through a review of the cell construction as part of a tear down analysis, a review of documentation on the cell construction and components, and the cell tests of Annex E.		P
7.12.5	Sodium-beta cells and batteries shall comply with the cell tests outlined in Annex B. Cells shall be provided with specifications for use (charging and discharging), installation, storage and disposal.	Lithium ion cells used.	N/A
7.12.6	Flowing electrolyte stacks and battery systems shall comply with the requirements outlined in Annex C.	Lithium ion cells used.	N/A
7.12.7	With reference to 7.12.6, flowing electrolyte battery systems shall be designed to mitigate shunt currents. Imbalance conditions and the potential for corrosion of the electrolyte containment parts may occur as a result of excessive shunt currents in a flowing electrolyte battery system. The flowing electrolyte battery manufacturer shall demonstrate through analysis and data that shunt currents have been mitigated as a result of the system design.		N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
7.12.8	Batteries employing pressure release valves or flame arrestors shall comply with the pressure release test or the flame arrester test of UL 1989 in addition to the requirements of this standard. See Annex H for alternative criteria for vented or valve regulated lead acid or nickel cadmium batteries. Cells and multi-cell/monobloc batteries shall be provided with specifications for use (charging and discharging), installation, storage and disposal as outlined in Annex H.		P
7.12.9	Electrochemical capacitor cells and modules shall comply with the requirements outlined in UL 810A in addition to the requirements of this standard.	Lithium ion cells used.	N/A
7.12.10	Sodium ion cells (e.g. Prussian Blue cells or transition metal layered oxide cells) shall comply with Annex E, and be marked as required in 44.15 and 44.16. Cells shall be provided with specifications as outlined in 45.7.	Lithium ion cells used.	N/A
7.13	Repurposed cells and batteries		N/A
7.13.1	Batteries and battery systems using repurposed cells and batteries shall ensure that the repurposed parts have gone through an acceptable process for repurposing in accordance with UL 1974. See also 44.3.		N/A
PERFORMANCE			
8	**General**		**P**
8.1	Unless indicated otherwise the device under test (DUT) shall be at the maximum operational state of charge (MOSOC), in accordance with the manufacturer's specifications, for conducting the tests in this standard. After charging and prior to testing, the samples shall be allowed to rest for a maximum period of 8 h at room ambient. *Exception: For secondary lithium ion cells or batteries in which temperature is not a dependency on the test, the rest time may be extended to 36 h, but shall not be less than 90 % MOSOC.*	Complied	P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
8.2	Unless otherwise indicated, fresh samples (i.e. not more than 6 months old) representative of production shall be used for the system level tests described in Sections 15 – 42. The test program and number of samples to be used in each test is shown in Table 8.1. *Exception No. 1: At the agreement of the manufacturer, DUT samples may be re-used for more than one test if not damaged in a manner that would affect test results. Minor repairs can be made to samples such as replacement of fuses, etc. in order to reuse samples for multiple tests.* *Exception No. 2: For repurposed batteries and battery systems, the "repurposing manufacturing date" is the date of manufacture used to determine the 6 month threshold.*	Test conducted with fresh sample (within 6 months)	P
8.3	All tests, unless noted otherwise, are conducted in a room ambient 25 ±5 °C (77 ±9 °F). Tests shall be conducted with the DUTs heated to normal operating temperatures unless indicated otherwise in the test. For those tests that require the DUT to reach thermal equilibrium, thermal equilibrium is considered to be achieved if after three consecutive temperature measurements taken at intervals of 10 % of the previously elapsed duration of the test but not less than 15 min, indicate no change in temperature greater than ±2 °C (3.6 °F).	Unless otherwise specified, all tests conducted within a room ambient 25 °C ±5 °C (77±9°F).	P
8.4	Thermocouples shall be attached to the central component cell or module during the system level tests in Sections 15 – 42. Temperatures shall also be measured on any components affected by temperature in the control circuit during the tests of 9.1 and 9.2. Temperature shall be measured using thermocouples consisting of wires not larger than 24 AWG (0.21 mm^2) and not smaller than 30 AWG (0.05 mm^2) connected to a potentiometer-type instrument. Temperature measurements shall be made with the measuring junction of the thermocouple held tightly against the component/location being measured.		P
8.5	Unless noted otherwise in the individual test methods, the tests shall be followed by a 1-h observation time prior to concluding the test and temperatures shall be monitored in accordance with 10.2.		P
9	**Determination of Potential for Fire Hazard**		**P**

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
9.1	In addition to visible signs of fire, non-compliant test results for fire shall also include an evaluation for combustible vapor concentrations during testing if there is the potential for combustible vapor concentrations based upon the technology and design of the battery system. For detection of potential combustible vapor concentrations that may be emitted during testing, a gas monitor suitable for detecting 25 % of the lower flammability limit (LFL) of the evolved gases being measured. A minimum of two sampling locations where concentrations may occur such as at vent openings or vent ducts shall be used for taking measurements. *Exception: As an alternative to using gas detection measurement to determine if there are combustible vapor concentrations, non-compliant tests results for fire may include an evaluation for potential combustible vapor concentrations with the use of a minimum of two continuous spark sources. The continuous spark sources shall provide at least two sparks per second with sufficient energy to ignite natural gas and shall be located near anticipated sources of vapor such as vent openings or at the vent duct.*	No visible signs of fire, flammable concentrations of vapor during test.	P
9.2	Additional precautions shall be taken during tests requiring this analysis due to the potential for combustible vapor concentrations that may occur within the test room or chamber.		P
10	**Important Test Considerations**		**P**

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
10.1	The tests contained in this standard may result in explosions, fire and emissions of combustible and/or toxic vapors, leakage of hazardous chemicals as well as electric shock. It is important that personnel use extreme caution when conducting any of these tests and that they be protected from flying fragments, leaked electrolyte, explosive force, toxic vapors and chemicals and sudden release of heat and noise that could result from testing. To prevent injury, protective equipment and clothing should be utilized when handling batteries and when conducting testing. Short-circuiting can lead to very hazardous currents, and large format batteries may still be hazardous even in an uncharged condition. The test area shall be well ventilated to protect personnel from possible harmful vapors or gases and care should be taken to prevent exposure to leaked electrolyte. Test facilities shall be equipped to contain, mitigate, and exhaust toxic vapors and particulate matter, leaked electrolyte and other hazardous substances that may be generated during the tests of this standard including the External Fire Exposure Test of Section 41. See also 9.2.	Checked	P
10.2	As an additional precaution, the temperatures on surfaces of the DUT shall be monitored during the tests per 8.5. All personnel involved in the testing of battery systems shall be instructed to never approach the DUT until temperatures are falling and are at safe levels.	The temperature was monitored.	P
11	**Single Fault Conditions**		**P**
11.1	Where there is a specific reference to a single fault condition in the individual test methods, the single fault shall consist of a single failure (i.e. open, short or other failure means) of any component in the electrical energy storage system that could occur as identified in the system safety analysis of 7.8 and that could affect the results of the test.	Evaluated for functional safety criteria considering single fault conditions in accordance with 7.8.1.3	P
12	**Test Results**		**P**
12.1	Tests that result in one or more of the following conditions as noted in Table 12.1 and as defined in Section 6, shall be considered as non-compliant for the test. Additional details of passing results criteria are provided in the individual test methods.		P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
12.2	For the following tests, if the DUT is still operational after the test (a user replaceable fuse may be replaced or user resettable device such as an accessible circuit breaker, etc. reset), it shall be subjected to a minimum single charge/discharge cycle in accordance with the manufacturer's specifications. No noncompliant results as outlined in Table 12.1 shall occur during the charge/discharge cycle of a still operational DUT. a) Overcharge; b) Short Circuit; c) Overdischarge Protection; d) Imbalanced Charging; e) Failure of Cooling/Thermal Stability System; f) Electrostatic Discharge; g) Radio-Frequency Electromagnetic Field; h) Fast Transient/Burst Immunity; i) Surge Immunity; j) Radio-Frequency Common Mode; k) Power Frequency Magnetic Field; l) Operational Verification; m) Vibration; n) Shock; o) Impact or Drop Impact; p) Static Force; q) Thermal Cycling; r) Salt Fog; and s) Resistance to Moisture. NOTE: If the tests of (f) – (l) may be done on the battery management system only and not the whole battery system.	Observed as per the standard	P
13	**Determination of Toxic Emissions**		**P**

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
13.1	For those systems for which venting from cells or capacitors could result in the emission of toxic gases as determined by an analysis of the outgassed substances, the concentration of toxic gases during the destructive testing noted in Table 12.1 shall be monitored using one of the sampling methods noted below and as outlined in 13.2. Analysis of the outgassed substances can be obtained through review of MSDS sheets and/or analysis of the outgassed substances. If it can be determined through examination of the cells after testing that they did not vent as a result of the test, the system is in compliance with these criteria. a) ASTM D4490; b) ASTM D4599; c) OSHA Evaluation Guidelines for Air Sampling Methods Utilizing Spectroscopic Analysis; or d) NIOSH Manual of Analytic Methods.	No vent of the cell was occurred as a result of the test.	P
13.2	To determine the concentration of toxic emissions, testing shall be conducted in a closed test chamber of known volume large enough to contain the DUT. Results obtained from continuous sampling the emissions during testing shall be scaled to estimate the anticipated exposure and concentration of toxic materials within either the passenger compartment of a light electric rail (LER) or the anticipated smallest room in which the system can be installed. For walk-in units, continuous monitoring shall also be conducted in the interior of the system enclosure. The results for stationary applications shall be further scaled to consider a 0.5 air changes per hour (ACH) ventilation rate. The 0.5 ACH represents allowable low ventilation rated for construction. *Exception: Stationary systems intended for installation outdoors only and that are not walk-in units are exempted from this monitoring. Stationary systems and systems for LER applications are also exempted from these requirements if provided with a ventilation system or otherwise designed to prevent exposure to toxic vapor releases and vents vapors to a safe location.*	No vent of the cell was occurred as a result of the test.	P
14	**Measurement Equipment Accuracy**		**P**

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
14.1	Unless noted otherwise in the test methods, the overall accuracy of measured values of test specifications or results when conducting testing in accordance with this standard, shall be within the following values of the measurement range: a) ±1 % for voltage; b) ±3 % for current; c) ±4 % for watts; d) ±2 °C (±3.6 °F) for temperatures at or below 200 °C (392 °F), and ±3 % for temperatures above 200 °C (392 °F); e) ±0.1 % for time; f) ±1 % for dimension; g) ±3 % for Ah; h) ±4 % for Wh.		P
ELECTRICAL TESTS			
15	**Overcharge Test**		**P**
15.1	The purpose of this test is to evaluate a battery system's ability to withstand an overcharge condition.		P
15.2	A fully discharged DUT (i.e. discharged to the manufacturer's specified EODV) shall be subjected to an overcharge resulting from a single fault condition in the charging protection/control circuit of the system that could lead to an overcharge condition. See Section 11 for a description of a single fault condition. Single fault conditions can be applied to both passive and active protective devices. During test, the voltage of the cells shall be measured. The test supply equipment used for charging the DUT shall be sufficient to create an overcharge of the DUT to at least 110 % of the maximum specified charging voltage. The charging rate used shall be the manufacturer's specified maximum charging rate. *Exception No. 1: Overcharge testing on a subassembly may be conducted instead of the complete battery system if determined to be representative of the battery system.* *Exception No. 2: Components in circuits evaluated for reliability (i.e. evaluated for functional safety in accordance with 7.9) need not be subjected to single fault conditions.*	Test conducted with 110 % of the maximum specified charging voltage. Single fault condition not applied, it was considered in cl. 7.8 and 7.9. Tested on minimum subassembly battery system	P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
15.3	The test shall continue until ultimate results occur followed by an observation period per 8.5. Ultimate results are considered to have occurred when one of the following occurs: a) The sample charging is terminated by the protective circuitry whether it is due to voltage or temperature controls or if the DUT reaches 110 % of its maximum specified charging voltage limit. Exceeding the manufacturer's specified charging limit is considered a non-compliant result. The DUT is monitored per 8.5 and 10.2; or b) Battery system failure occurs as evidenced by explosion, fire or other identifiable non-compliant results per Table 12.1.	a)	P
15.4	During the test, detection methods as outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations if determined necessary. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the testing per Section 13.	No venting, leakage and rupture of the internal cell was occurred.	P
15.5	If the DUT is operational after the overcharge test it shall be subjected to a discharge and charging cycle in accordance with the manufacturer's specifications. See 12.2 for details regarding user resettable devices. An observation period per 8.5 is then conducted.	Operational and cycled, No non-compliant result.	P
15.6	At the conclusion of the observation period, the samples shall be subjected to an "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.	No rupture and no leakage after Dielectric Voltage Withstand Test.	P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
15.7	As a result of the overcharge test, the maximum charging voltage measured on the cells or modules shall not exceed their normal operating region. Also, the following in (a) – (h) are considered noncompliant results. For additional information on non-complying results refer to Table 12.1. a) E – Explosion; b) F – Fire; c) C – Combustible vapor concentrations; d) V – Toxic vapor release; e) S – Electric shock hazard (dielectric breakdown); f) L– Leakage (external to enclosure of DUT); g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3); h) P – Loss of protection controls.	No non-compliant result	P
16	**High Rate Charge**		P
16.1	The purpose of this test is to evaluate a battery system's ability to protect against a high rate charge condition at currents over the battery maximum charging current specification.		P
16.2	A fully discharged DUT (i.e. discharged to the manufacturer's specified EODV) shall be subjected to a high rate charge. There shall be a single fault condition on overcurrent charge protection devices or controls unless they have been evaluated for reliability (i.e. evaluated for functional safety in accordance with 7.9). During the test, the current and voltage of the cells shall be measured. The test supply equipment used for charging the DUT shall be sufficient to provide a current that is 20 % greater than the maximum specified charging rate for the batteries. *Exception: High rate charge testing on a subassembly may be conducted instead of the complete battery system if determined to be representative of the battery system.*	Test conducted with 120 % of the maximum specified charging current. The teat was interrupt by current protective. Single fault condition not applied, it was considered in cl. 7.8 and 7.9. Tested on minimum subassembly battery system	P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
16.3	The high rate charging of the DUT shall continue until ultimate results occur followed by an observation period per 8.5. Ultimate results are considered to have occurred when one of the following occurs: a) The sample charging is terminated by the protective circuitry whether it is due to current, voltage or temperature controls. The DUT is monitored per 8.5 and 10.2; or b) Battery system failure occurs as evidenced by explosion, fire or other identifiable non-compliant results per Table 12.1.	Ultimate results a) observed.	P
16.4	During the test, detection methods as outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations if determined necessary. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the testing per Section 13.		P
16.5	If the DUT is operational after the high rate charge test, it shall be subjected to a discharge and charging cycle in accordance with the manufacturer's specifications. See 12.2 for details regarding user resettable devices. An observation period per 8.5 is then conducted.		P
16.6	At the conclusion of the observation period, the samples shall be subjected to an "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.	No rupture and no leakage after Dielectric Voltage Withstand Test	P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
16.7	As a result of the high rate charge test, the battery protection circuit (e.g. BMS) shall detect the overcharging current and shall prevent the battery from being charged over the maximum battery charging current. The following in (a) – (h) are considered non-compliant results. For additional information on noncomplying results refer to Table 12.1. a) E – Explosion; b) F – Fire; c) C – Combustible vapor concentrations; d) V – Toxic vapor release; e) S – Electric shock hazard (dielectric breakdown); f) L – Leakage (external to enclosure of DUT); g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3); h) P – Loss of protection controls.	No non-compliant result	P
17	**Short Circuit Test**		**P**
17.1	This test shall be conducted on a fully charged DUT (MOSOC per 8.1) with parallel connected cells or modules to determine its ability to withstand an external short circuit. DUTs with only series connections (i.e. no parallel connections of cells or modules) are tested at the cell or module level if determined to be equivalent to testing at the system level. *Exception: Short circuit testing on a subassembly may be conducted instead of the complete battery system if determined to be representative of the battery system.*	Testing on the complete battery system and battery module	P
17.2	The sample shall be short-circuited by connecting the positive and negative terminals of the sample with a shorting device having resistance as low as practicable. In all cases the resistive circuit load shall have a maximum total resistance of 20 mΩ, as measured from the DUT terminals. For battery systems, the short circuit discharge profile at the terminals for current and time shall be recorded and compared with the manufacturer's specified value in 44.4.	The complete Battery System was short circuit with resistance of 19.561 mΩ	P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
17.3	The direct short circuit test shall also be conducted on the battery module if it is intended to be installed or replaced in the field. The output of the battery module sample shall be short-circuited with a shorting device having resistance as low as practicable with a maximum total resistance of 20 mΩ.	Battery module short circuit with resistance of 19.3 mΩ	P
17.4	Tests shall be conducted at room ambient. The samples shall reach thermal equilibrium temperature as outlined in 8.3 before the terminals are connected.	Tested at Room Ambient.	P
17.5	The sample shall be completely discharged (i.e. discharged until near zero state of charge/its energy is depleted), or protection in the circuit has operated and the temperature on the center module has peaked or reached a steady state condition and 7 h has elapsed, or a fire or explosion has occurred.	Protection in the circuit has operated.	P
17.6	During the test, samples supplied with protective devices shall be subjected to a single component fault using any single fault condition that may be determined to occur during discharge conditions. See Section 11 for details regarding single fault conditions. Single fault conditions can be applied to both passive and active protective devices. *Exception: Components in circuits evaluated for reliability (i.e. evaluated for functional safety criteria considering single fault conditions in accordance with 7.9) need not be subjected to single fault conditions.*	Single fault condition not applied, it was considered in cl. 7.8 and 7.9.	P
17.7	During the test, a detection method as outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations if determined necessary. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the testing per Section 13.	No venting, leakage and rupture of the internal cell was occurred.	P
17.8	If the DUT is operational after the short circuit test it shall be subjected to a charge and discharge cycle in accordance with the manufacturer's specifications. See 12.2 for details regarding user resettable devices. An observation period per 8.5 is then conducted.	Fuse open, DUT couldn't operation after test	N/A
17.9	At the conclusion of the observation period , the samples shall be subjected to the "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.	No rupture and no leakage after Dielectric Voltage Withstand Test.	P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
17.10	As a result of the short circuit test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1. a) E – Explosion; b) F – Fire; c) C – Combustible vapor concentrations; d) V – Toxic vapor release; e) S – Electric shock hazard (dielectric breakdown); f) L – Leakage (external to enclosure of DUT); g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3); h) P – Loss of protection controls. *Exception: For modules that do not have integral short circuit protection controls, the compliance criteria is (a) and (b) above only.*	No non-compliant result	P
17.11	For battery systems, the measured maximum short circuit current and duration at that maximum value shall not be greater than the specified value of 44.4.		P
18	**Overload Under Discharge**		P
18.1	This test shall be conducted on a fully charged DUT (MOSOC per 8.1) with parallel connected cells or modules to determine its ability to withstand an overload discharge condition. DUTs with only series connections (i.e. no parallel connections of cells or modules) may be tested at the cell or module level if determined to be equivalent to testing at the system level. *Exception: Overload under discharge testing on a subassembly may be conducted instead of the complete battery system if determined to be representative of the battery system.*		P
18.2	Condition 1 is the overload above the specified maximum discharge current of the battery, but below the BMS overcurrent protection (secondary protection) in accordance with 18.3 – 18.5.		N/A
18.3	With reference to 18.2, the positive and negative terminals of the DUT is to be connected to the external discharging equipment. The fully charged DUT shall then be discharged at a current equal to 90 % of the rated overcurrent protection value of the BMS (secondary protection).	Test conducted with 90 % of the rated overcurrent protection value of the BMS.	P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
18.4	With reference to 18.2, the test shall be continued until: a) The DUT has been completely discharged (i.e. discharged until near zero state of charge/its energy is depleted); b) The protection in the circuit has operated and the temperature on the center cell/module has peaked or reached a steady state condition and 7 h has elapsed; or c) A fire or explosion has occurred. *Exception: The overload condition 1 can be waived if the maximum discharge current of the battery is equal to or higher than 90 % of the overcurrent protection value of the BMS (secondary protection).*		N/A
18.5	With reference to 18.2, during the test, samples supplied with protective devices in the discharge circuit shall be subjected to a single component fault using any single fault condition that may be determined to occur during discharge conditions. See Section 11 for details regarding single fault conditions. Single fault conditions can be applied to both passive and active protective devices. *Exception: Overcurrent protection components in circuits evaluated for reliability (i.e. evaluated for functional safety criteria considering single fault conditions in accordance with 7.9) need not be subjected to single fault conditions.*		N/A
18.6	Condition 2 is the overload above the BMS overcurrent protection, but below the primary overcurrent protection in accordance with 18.7 – 18.9.	Considered in 18.2	N/A
18.7	With reference to 18.6, the positive and negative terminals of the DUT shall be connected to the external discharging equipment. The DUT shall then be discharged at a current equal to 135 % of the main fuse rating. *Exception No. 1: If the secondary overcurrent protection is a contactor, switch or similar disconnecting device, which has been investigated for an overload current higher than 135 % of the primary overcurrent protector rating, then the test shall be conducted at a discharge current of 150 % of the primary overcurrent protector rating.* *Exception No. 2: If the secondary overcurrent protection has be investigated for an overload current higher than 150 % of the primary overcurrent protector rating, then the condition 2 test can be waived.*		N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
18.8	With reference to 18.6, the test shall be continued until: a) The DUT has been completely discharged (i.e. discharged until near zero state of charge/its energy is depleted); b) The protection in the circuit has operated and the temperature on the center cell/module has peaked or reached a steady state condition and 7 h has elapsed; or c) A fire or explosion has occurred.		N/A
18.9	With reference to 18.6, during the test, samples supplied with protective devices in the discharge circuit shall be subjected to a single component fault using any single fault condition that may be determined to occur during discharge conditions. See Section 11 for details regarding single fault conditions. Single fault conditions can be applied to both passive and active protective devices. *Exception: Overcurrent protection components in circuits evaluated for reliability (i.e. evaluated for functional safety criteria considering single fault conditions in accordance with 7.9) need not be subjected to single fault conditions.*		N/A
18.10	During the test, a detection method as outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations if determined necessary. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the testing per Section 13.		N/A
18.11	If the DUT is operational after the short circuit test, it shall be subjected to a charge and discharge cycle in accordance with the manufacturer's specifications. See 12.2 for details regarding user resettable devices. An observation period per 8.5 shall then be conducted.		N/A
18.12	At the conclusion of the observation period, the samples shall be subjected to the "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.	No rupture and no leakage after Dielectric Voltage Withstand Test	N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
18.13	As a result of the overload test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1. a) E – Explosion; b) F – Fire; c) C – Combustible vapor concentrations; d) V – Toxic vapor release; e) S – Electric shock hazard (dielectric breakdown); f) L – Leakage (external to enclosure of DUT); g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3); h) P – Loss of protection controls.	No non-compliant result	N/A
19	**Overdischarge Protection Test**		**P**
19.1	This test shall be conducted on a fully charged sample (MOSOC per 8.1) to determine the DUT's ability to withstand an overdischarge condition and is conducted with all discharge protection circuitry for both temperature and minimum voltage connected to prevent irreparable cell damage. During the test, active protective devices shall be subjected to single fault conditions, unless the protection circuit has been tested for functionality in accordance with 7.9. During test, the voltage of the cells shall be measured. *Exception: Overdischarge protection testing on a subassembly may be conducted instead of the complete battery system if determined to be representative of the battery system.*	Single fault condition not applied, it was considered in cl. 7.8 and 7.9. Tested on minimum subassembly battery system	P
19.2	The DUT shall be subjected to a constant discharging current/power that will discharge a battery at the manufacturer's specified maximum discharge rate. The test will continue until the passive protection device(s) are activated, or the minimum cell voltage/maximum temperature protection is activated, or the DUT has been discharged for an additional 30 min after it has reached its specified normal discharge limit, whichever comes first.	The minimum cell voltage protection is activated.	P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
19.3	During the test, a detection method as outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations as determined necessary. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the testing per Section 13.	No venting, leakage and rupture of the internal cell was occurred.	P
19.4	If the DUT is operational after the overdischarge protection test it shall be subjected to a charge and discharge cycle in accordance with the manufacturer's specifications. See 12.2 for details regarding user resettable devices. An observation period per 8.5 is then conducted.	Operational and cycled, No non-compliant result.	P
19.5	At the conclusion of the observation period, the samples shall be subjected to the "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.	No rupture and no leakage after Dielectric Voltage Withstand Test.	P
19.6	As a result of the overdischarge protection test, the minimum discharge voltage measured on the cells shall not exceed their normal operating range. Also, the following in (a) – (h) are considered noncompliant results. For additional information on non-complying results refer to Table 12.1. a) E – Explosion; b) F – Fire; c) C – Combustible vapor concentrations; d) V – Toxic vapor release; e) S – Electric shock hazard (dielectric breakdown); f) L – Leakage (external to enclosure of DUT); g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3); h) P – Loss of protection controls.	No non-compliant result.	P
20	**Temperature and Operating Limits Check Test**		**P**

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
20.1	This test is conducted to determine whether or not the cells/modules of the DUT are being maintained within their specified operating limits (including voltage and current at specified temperature) during maximum charge and discharge conditions. During this test, it shall also be determined as to whether or not temperature sensitive safety critical components are being maintained within their temperature ratings based upon the maximum operating temperature specifications of the DUT as well as a determination that temperatures on accessible surfaces are not exceeding safe limits. *Exception: Temperature and operating limits check test on a subassembly may be conducted instead of a complete battery system if determined to be representative of the battery system.*	Test was conducted on the complete battery system.	P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
20.2	A fully discharged DUT (i.e. discharged to EODV) shall be conditioned within a chamber set to the upper limit charging temperature specifications of the DUT. After being stabilized at that temperature (refer to 8.3), the DUT shall be connected to a charging circuit input representative of anticipated maximum charging parameters. The DUT shall then be subjected to maximum normal charging while monitoring voltages and currents on modules until it reaches the manufacturer's specified fully charged condition. Temperatures shall be monitored on temperature sensitive components including cells. *Exception No. 1: If the DUT is unable to be tested in a chamber, it can be tested at an ambient temperature of 25 ±5°C (77 ±9°F). If tested at ambient temperatures during the test, the temperature measurement T shall not exceed:* $T \leq T_{max} - (T_{ma} - T_{amb})$ Where: T is the temperature of the given part measured under the prescribed test. T_{max} is the maximum temperature specified for compliance with the test. T_{amb} is the ambient temperature during the test. T_{ma} is the maximum ambient temperature permitted by the manufacturer's specification or 25 °C (77 °F), whichever is greater. *Exception No. 2: If the design of the DUT and its controls result in worse case normal charging conditions when testing at ambient (i.e. due to thermostats or other controls lowering the charge levels at elevated ambient), the test shall be conducted at ambient temperature of 25 ±5°C (77 ±9°F). Temperatures on temperature sensitive components shall not exceed T_{max}.*	Tested at room ambient 55 °C	P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
20.3	While still in the conditioning chamber, the chamber temperature shall be set to the upper limit discharging temperature specifications of the DUT if different from the charging temperature. The fully charged DUT (MOSOC per 6.1) shall then be discharged in accordance with the manufacturer's maximum rate of discharge down to the manufacturer's specified end of discharge condition while monitoring voltage and current on modules. Temperatures shall be monitored on temperature sensitive safety critical components including cells. Temperatures on accessible surfaces are also monitored. *Exception No. 1: If the DUT is unable to be tested in a chamber, it can be tested at an ambient temperature of 25 ±5°C (77 ±9°F). If tested at ambient temperatures during the test, the temperature measurement T shall not exceed:* $T \leq T_{max} - (T_{ma} - T_{amb})$ Where: T is the temperature of the given part measured under the prescribed test. T_{max} is the maximum temperature specified for compliance with the test. T_{amb} is the ambient temperature during the test. T_{ma} is the maximum ambient temperature permitted by the manufacturer's specification or 25 °C (77 °F), whichever is greater. *Exception No. 2: If the design of the DUT and its controls result in worse case normal discharging conditions when testing at ambient (i.e. due to thermostats or other controls lowering the discharge rate at elevated ambient), the test shall be conducted at ambient temperature of 25 ±5°C (77 ±9°F). Temperatures on temperature sensitive components shall not exceed T_{max}.*	Tested at 55 °C	P
20.4	The charge and discharge cycles are then repeated for a minimum of two complete cycles of charge and discharge. The DUT is then subjected to an observation period per 8.5.	Total 3 cycles applied.	P
20.5	At the conclusion of the observation period, the samples shall be subjected to the "as received" dielectric voltage withstand test in accordance with Section 22 if it anticipated that there has been deterioration of the insulation during the temperature test. The DUT shall be examined for signs of rupture and evidence of leakage.	No rupture and no leakage after Dielectric Voltage Withstand Test.	P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
20.6	The manufacturer's specified operating limits for cells/modules (voltage, current at specified temperatures) shall not be exceeded during the charging and discharging cycles. Temperatures measured on components shall not exceed their specifications. Temperatures measured on accessible surfaces shall not exceed allowed limits. See Table 20.1 and Table 20.2 for temperature limit tables. Additional non-compliant results during the temperature test are as noted below in (a) – (e). For additional information on non-complying results refer to Table 12.1. a) E – Explosion; b) F – Fire; c) C – Combustible vapor concentrations; d) V – Toxic vapor release; e) S – Electric shock hazard (dielectric breakdown); f) L – Leakage (external to enclosure of DUT); g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3); and h) P – Loss of protection controls.	No non-compliant result.	P
21	**Imbalanced Charging Test**		**P**
21.1	This test is to determine whether or not a battery system with series connected cells/modules can maintain the cells/modules within their specified operating parameters if it becomes imbalanced. *Exception No. 1: Testing may be conducted at a subassembly level if that is representative of the battery system.* *Exception No. 2: Testing may be conducted on an alternate configuration if it can be shown to be representative for the battery system.*	Single fault condition not applied, it was considered in cl. 7.8 and 7.9. Tested on minimum subassembly battery system	P
21.2	A fully charged DUT (MOSOC per 8.1) shall have all of its modules/cells with the exception of one discharged to its specified fully discharged condition. The undischarged module/cell shall be discharged to approximately 50 % of its specified state of charge (SOC) to create an imbalanced condition prior to charging.		P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
21.3	The sample shall then be charged in accordance with the manufacturer's maximum normal charging specifications. Charging shall continue until end of charge conditions and the DUT reaches thermal equilibrium. The voltage of the partially charged module/cell shall be monitored during the charging to determine if its voltage limits are being exceeded. During the test, active protective devices shall be subjected to single fault conditions, unless the protective circuit has been tested for functionality in accordance with 7.9.		P
21.4	During the test, a detection method as outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations as determined necessary. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the testing per Section 13.		P
21.5	If the DUT is operational after the test it shall be subjected to a discharge and charging cycle in accordance with the manufacturer's specifications. See 12.2 for details regarding user resettable devices. An observation period per 8.5 is then conducted.		P
21.6	At the conclusion of the observation period, the DUT shall be subjected to an "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.	No rupture and no leakage after Dielectric Voltage Withstand Test.	P
21.7	The maximum voltage limit of the module/cell shall not be exceeded when charging an imbalanced DUT. Also, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1. a) E – Explosion; b) F – Fire; c) C – Combustible vapor concentrations; d) V – Toxic vapor release; e) S – Electric shock hazard (dielectric breakdown); f) L – Leakage (external to enclosure of DUT); g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3); h) P – Loss of protection controls.	No non-compliant result.	P
22	**Dielectric Voltage Withstand Test**		**P**

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
22.1	This test is an evaluation of the electrical spacings and insulation at hazardous voltage circuits within the battery system.		P
22.2	Circuits exceeding 42.4 V peak or 60 Vdc shall be subjected to an electric strength test in accordance with UL 62368-1/CSA C22.2 No. 62368-1, Clause 5.4.9. *Exception: Semiconductors or similar electronic components liable to be damaged by application of the test voltage may be bypassed or disconnected.*		P
22.3	The test voltage shall be applied between the hazardous voltage circuits of the DUT and noncurrent carrying conductive parts that may be accessible and low voltage circuits separated from hazardous voltage circuits by reinforced or double insulation.	See table 22	P
22.4	The test voltage is also to be applied between the hazardous voltage charging circuit and the enclosure/accessible non-current carrying conductive parts of the DUT.		P
22.5	If the accessible parts of the DUT are covered with insulating material that may become live in the event of an insulation fault, then the test voltages are applied between each of the live parts and metal foil in contact with the accessible parts.		P
22.6	The test voltages shall be applied for a minimum of 1 min with the cells/modules disconnected to prevent charging during application of the voltage. Technologies that are required to be at an elevated operating temperature in order to be active, such as sodium-beta chemistries, shall be in a hot state prior to disconnection and applying the test potential.		P
22.7	The test voltages shall be applied for a minimum of 1 min between all the hazardous circuits of the battery and accessible parts or circuits. Technologies that are required to be at an elevated operating temperature in order to be active, such as sodium-beta chemistries, shall be in a hot state prior to disconnection and applying the test potential.		P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
22.8	If the battery system contains hygroscopic materials that may affect spacings, this test is repeated with the DUT or with the subassembly of the DUT containing the hygroscopic materials subjected to humidity conditioning of UL 62368-1/CSA C22.2 No. 62368-1, Clause 5.4.8. As a result of this testing, there shall be no dielectric breakdown as outlined in 22.7.	No hygroscopic material.	N/A
23	**Continuity Test**		**P**
23.1	This test evaluates the continuity of the protective grounding and bonding system of the battery system that is intended to provide an electrically conductive path from the point of a ground fault on a battery system or its representative parts or components through normally non-current-carrying conductors, equipment, or the earth to the electrical supply source.		P
23.2	An alternate test method outlined in 23.7 may be used if the construction of the protective grounding and bonding system adheres to the construction methods outlined in 7.6.5 – 7.6.7. If the connections means vary from that outlined in 7.6.6 and 7.6.7, the fault current method outlined in 23.3 – 23.6 is the default method for evaluating the suitability of the protective grounding system.	An alternate test method outlined in 21.7 conducted.	P
23.3	The grounding system of an battery system shall have no more than 0.1 Ω resistance between any two parts of the system that are measured in accordance with the continuity test of 23.4 and 23.5.		N/A
23.4	The voltage drop in a protective grounding system is measured after applying a test current of 200% of the rating of the overcurrent protection device rating, for a duration corresponding to 200% of the time-current characteristic of the overcurrent protection device. If the duration for 200% is not given, a point closest on the time-current characteristic shall be used. The overcurrent protective device limits the fault current in the protective grounding system, and is either provided in the battery system or external to the battery system and specified in the installation instructions. The supply used to provide the test current shall have a no load voltage not exceeding 60 Vdc.		N/A
23.5	The voltage drop measurement is made between any two conductive parts of the grounding system.		N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
23.6	The resistance shall be calculated from the measured voltage drop and current. The determined resistance shall be less than or equal to 0.1 Ω.		N/A
23.7	To check the continuity of the bonding connections, the resistance can be measured between two points on the bonding connections using a milli-ohmmeter. The measured resistance between any two bonding connections shall be less than or equal to 0.1 Ω.		P
24	**Failure of Cooling/Thermal Stability System**		P
24.1	The purpose of this test is to determine if the battery system can safely withstand a failure in the cooling/thermal stability system. *Exception: Testing may be conducted at a subassembly level if that is representative of the energy storage system.*	The product protected with over temperature.	P
24.2	The DUT shall be fully discharged to the manufacturer's end of discharge condition EODV and then conditioned at maximum specified operating ambient for a period of 7 h or until thermally stable per 8.3, whichever is shorter. While still in the conditioning chamber, the DUT, with its cooling/thermal stability system disabled shall then be charged at its maximum specified charge rate until completely charged or until operation of a protective device.		P
24.3	The DUT shall be fully charged (MOSOC per 8.1) and then conditioned at maximum specified operating ambient for a period of 7 h or until thermally stable per 8.3, whichever is shorter. While still in the conditioning chamber, the DUT, with its cooling/thermal stability system disabled shall then be discharged at the maximum discharge rate until it reaches its specified end of discharge condition or until operation of a protective device.		P
24.4	During the test, one of the detection methods outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the testing per Section 13.		P
24.5	If the DUT is operational after the test it shall be subjected to a discharge and charging cycle in accordance with the manufacturer's specifications. See 12.2 for details regarding user resettable devices. An observation period per 8.5 is then conducted.		P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
24.6	At the conclusion of the observation period, the DUT shall be subjected to an “as received” dielectric voltage withstand test per Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.		P
24.7	The test method of 24.2 – 24.6 shall be repeated with the DUT conditioned at the minimum specified operating ambient.		P
24.8	As a result of the failure of cooling/thermal stability test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1. a) E – Explosion; b) F – Fire; c) C – Combustible vapor concentrations; d) V – Toxic vapor release; e) S – Electric shock hazard (dielectric breakdown); f) L – Leakage (external to enclosure of DUT); g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3); h) P – Loss of protection controls.		P
25	**Working Voltage Measurements**		**P**
25.1	This test is to measure the working voltage of a battery system.		P
25.2	The working voltage between live parts of opposite polarity, live and dead metal parts, live parts and a metal enclosure, and live and ground connections under both normal charging and discharging conditions as specified by the manufacture is measured.	See table 25	P
25.3	The dead metal parts and metal enclosure shall be assumed to be connected to the negative terminal of the system for testing purpose.		P
25.4	The values obtained during the measurements outlined in 25.2 shall be used to verify electrical spacings criteria per 7.5.		P
26	**Tests on Electrical Components**		**N/A**
26.1	**Locked-rotor test for low voltage dc fans/motors in secondary circuits**		**N/A**

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
26.1.1	The purpose of this test is to determine if a low voltage dc fan or motor does not present a hazard in a locked rotor condition. Fans complying with UL 507 are considered to comply with this requirement without test.	No such components.	N/A
26.1.2	A sample of the fan or motor is placed on a wooden board, which is covered with a single layer of tissue paper, and the sample in turn is covered with a single layer of bleached cotton cheesecloth of approximately 40 g/m^2.		N/A
26.1.3	The sample is then operated at the voltage used in its application and with its rotor locked for 7 h or until steady conditions are established per 8.3, whichever is the longer.		N/A
26.1.4	There shall be no ignition of the tissue paper or cheesecloth.		N/A
26.2	**Input**		P
26.2.1	The input current draw of a control or accessory separate from the pack such as a mains supplied control or an accessory control evaluated independent from a system, shall be subjected to the input test of 24.2.2.		P
26.2.2	The current or watts input to an ac mains supplied unit, when connected to an ac supply adjusted to the test voltage specified in Table 24.1 shall not be more than 110% of the rated/specified value. The current or watts input draw of a dc supplied unit, when connected to a dc supply, shall not exceed the rated/specified value of the device.		P
26.3	**Leakage current**		P
26.3.1	For separate controls or other accessories of the system that are cord connected and supplied by ac mains circuits, the controls shall comply with the Protective Touch Voltage, Touch Current and Protective Conductor Current test of UL 62368-1/CSA C22.2 No. 62368-1, Clause 5.7.		P
26.4	**Strain relief test**		N/A
26.4.1	The purpose of this test is to determine if the strain relief means for a non-detachable accessible cord prevents damage or displacement upon being pulled.	No such parts.	N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
26.4.2	The battery system or accessory provided with a strain relief shall withstand without damage to the cord or conductors and without displacement, a direct pull of 156 N (35 lbf) applied to the cord for 1 min. Supply connections within the equipment shall be disconnected from terminals or splices during the test when applicable. If the strain relief is mounted in a polymeric enclosure or part, the test is conducted after the mold stress test after the part has cooled to room temperature.		N/A
26.4.3	As a result of the pull force, there was no damage or displacement of internal connectors. Inner conductors may not elongate more than 2 mm (0.08 in) from the pre-test position.		N/A
26.5	**Push-back relief test**		**N/A**
26.5.1	The purpose of this test is to determine if the strain relief of a non-detachable accessible cord provides adequate protection to connections and prevent hazardous displacement of internal wiring and connections as a result of push back.	No such parts.	N/A
26.5.2	A product shall be tested in accordance with 24.5.3 and 24.5.4 without occurrence of any of the following conditions: a) Subjecting the supply cord to mechanical damage; b) Exposing the supply cord to a temperature higher than that for which it is rated; c) Reducing spacings (such as to a metal strain-relief clamp) below the minimum required values; or d) Damaging internal connections or components.		N/A
26.5.3	The supply cord shall be held 25.4 mm (1 in) from the point where the cord or lead emerges from the product and is then to be pushed back into the product. When a removable bushing, which extends further than 25.4 mm (1 in) is present, the bushing shall be removed prior to the test.		N/A
26.5.4	When the bushing is an integral part of the cord, then the test shall be carried out by holding the bushing. The cord shall be pushed back into the product in 25.4-mm (1-in) increments until the cord buckles or the force to push the cord into the product exceeds 26.7 N (6 lbf).		N/A
26.5.5	The supply cord shall be manipulated to determine compliance with 24.5.1.		N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
26.5.6	If the strain relief is mounted in a polymeric enclosure or part, the test is conducted after the mold stress test after the part has cooled to room temperature.		N/A
26.6	**Low voltage transformer evaluation**		**N/A**
26.6.1	The purpose of this test is to determine that transformers located in low voltage circuits (i.e. ≤ 60 Vdc) do not present a fire hazard under overload conditions. Transformers complying with UL 1310 or equivalent standard and evaluated under overload conditions are considered to comply with these requirements without further testing.		N/A
26.6.2	If the tests in this section are conducted under simulated conditions on the bench, these conditions shall include any protection device that would protect the transformer in the complete equipment. Tests shall be conducted under ambient laboratory conditions. A sample of the transformer is placed on a wooden board, which is covered with a single layer of tissue paper, and the sample in turn is covered with a single layer of bleached cotton cheesecloth of approximately 40 g/m^2 (1.18 oz/yd^2).		N/A
26.6.3	If a transformer has more than one secondary winding or a tapped secondary winding, separate tests shall be conducted for each winding, or each section of a tapped winding, with the other windings loaded or unloaded as may occur in service unless it can be determined that one condition will produce the most unfavorable results.		N/A
26.6.4	A resistive load that will draw three times the normal input current or maximum obtainable output current, whichever is less, shall be connected directly to the transformer secondary winding with the transformer connected to the voltage of the circuit the transformer will be installed in. The transformer shall be operated continuously: a) Until ultimate conditions are observed, including opening of a thermal cutoff or a similar device; b) For 7 h if temperatures stabilize or cycling of an automatically reset protector occurs; or c) For 50 cycles of resetting a manually reset protector.		N/A
26.6.5	As a result of the overload test, there shall be no emission of molten metal or fire as evidenced by burning or charring of the cheesecloth indicator or tissue paper.		N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict

27	**Electromagnetic Immunity Tests**	**CN23NX0R 001**	**P**
27.1	**General**		**P**
27.1.1	Active protective devices (e.g. battery management systems, solid state circuits, software controls, etc.) relied upon as the primary safety protection in 7.8 – 7.9 shall demonstrate sufficient immunity to electromagnetic interference by complying with the tests specified in 27.2 – 27.7. Alternate test procedures and levels specified in other standards may be used, but only if they are equivalent or more severe than the test procedures and levels specified below.		**P**
27.1.2	Each test shall begin with an operational DUT. The DUT may consist of only the battery management system, if that is the only part of the battery system that will be impacted.		P
27.1.3	During specific tests as indicated in 27.2 – 27.7, the DUT shall be subjected to a charge/discharge cycle in accordance with the manufacturer's specification. No non-compliant results as outlined in Table 12.1 shall occur during the charge/discharge cycle. *Exception: It is acceptable if the charge/discharge cycle is not completed at the conclusion of the test.*		P
27.1.4	After each test in 27.2 – 27.7, the DUT shall be inspected to verify that it is still operational and in compliance with Table 12.1. This may require Operational Verification (27.8) of the DUT if it is not possible to determine that it is fully operational by inspection. If the DUT is no longer operational, a failure analysis shall be conducted to determine the reason for the failure and to verify that the DUT has failed safely in accordance with Table 12.1. A DUT that is no longer operational shall not be used on any remaining test.		P
27.1.5	In addition, after all tests in this section have been completed, all samples used during the tests specified in 27.2 – 27.7 shall comply with the Operational Verification in 27.8.		P
27.2	**Electrostatic discharge**		**P**
27.2.1	The DUT shall demonstrate immunity to electrostatic discharges in accordance with the test procedure specified in IEC 61000-4-2.		P
27.2.2	The following test levels shall be used: a) ±6 kV contact discharge; and b) ±8 kV air discharge.		P
27.2.3	After the test, the DUT shall comply with 27.1.4.		P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
27.3	**Radio-frequency electromagnetic field**		**P**
27.3.1	The DUT shall demonstrate immunity to radio-frequency electromagnetic fields in accordance with the test procedure specified in IEC 61000-4-3.		P
27.3.2	The following test levels shall be used: a) 10 V/m from 80 MHz to 1 GHz, 1 kHz (80 % AM); and b) 3 V/m from 1.4 GHz to 6.0 GHz, 1 kHz (80 % AM).		P
27.3.3	During the test, the DUT shall comply with 27.1.3.		P
27.3.4	After the test, the DUT shall comply with 27.1.4.		P
27.4	**Fast transient/burst immunity**		**P**
27.4.1	The DUT shall demonstrate immunity to electrical fast transients/bursts in accordance with the test procedure specified in IEC 61000-4-4.		P
27.4.2	The following test levels in (a) – (c) shall be used. If the DUT has a DC power input port connected to an AC/DC converter such as a power supply or charger that is an integral part of the battery pack, the test shall be conducted on the AC input of the AC/DC converter using the test level specified in (c). Otherwise, the test shall be conducted on the DC power input port of the DUT using the test level specified in (b). a) On signal/control ports intended to be connected to cables longer than 3 m (118 in), ±1 kV (5/50 ns, 5 kHz); capacitive clamp shall be used; b) On input and output DC ports, ±1 kV (5/50 ns, 5 kHz); and c) On input and output AC ports, ±2 kV (5/50 ns, 5 kHz).		P
27.4.3	After the test, the DUT shall comply with 27.1.4.		P
27.5	**Surge immunity**		**P**
27.5.1	The DUT shall demonstrate immunity to surges in accordance with the test procedure specified in IEC 61000-4-5.		P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
27.5.2	The following test levels in (a) – (c) shall be used. If the DUT has a DC power input port connected to an AC/DC converter such as a power supply or charger that is an integral part of the battery pack, the test shall be conducted on the AC input of the AC/DC converter using the test level specified in (c). Otherwise, the test shall be conducted on the DC power input port of the DUT using the test level specified in (b). a) For I/O signal/control ports intended to be connected to long-distance cables longer than 30 m (98.4 ft), which leave the building, and/or are for outdoor use, ±1 kV line-to-ground; b) For input and output DC ports, ±0.5 kV line-to-line, and ±1 kV line-to-ground; and c) For input and output AC ports, ±1 kV line-to-line, and ±2 kV line-to-ground.		P
27.5.3	After the test, the DUT shall comply with 27.1.4.		P
27.6	**Radio-frequency common mode**		**P**
27.6.1	The DUT shall demonstrate immunity to radio-frequency conducted disturbances in accordance with the test procedure specified in IEC 61000-4-6.		P
27.6.2	The following test levels in (a) – (c) shall be used. If the DUT has a DC power input port connected to an AC/DC converter such as a power supply or charger that is an integral part of the battery pack, the test shall be conducted on the AC input of the AC/DC converter using the test level specified in (c). Otherwise, the test shall be conducted on the DC power input port of the DUT using the test level specified in (b). a) For I/O signal/control ports intended to be connected to cables longer than 3 m (118 in), 10 V (150 kHz to 80 MHz, 1 kHz, 80 % AM); b) For input and output DC ports, 10 V (150 kHz to 80 MHz, 1 kHz, 80 % AM); and c) For input and output AC ports, 10 V (150 kHz to 80 MHz, 1 kHz, 80 % AM).		P
27.6.3	During the test, the DUT shall comply with 27.1.3.		P
27.6.4	After the test, the DUT shall comply with 27.1.4.		P
27.7	**Power-frequency magnetic field**		**P**
27.7.1	The DUT shall demonstrate immunity to power-frequency magnetic fields in accordance with the test procedure specified in IEC 61000-4-8.		P
27.7.2	The test level of 10 A/m shall be used.		P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
27.7.3	During the test, the DUT shall comply with 27.1.3.		P
27.7.4	After the test, the DUT shall comply with 27.1.4.		P
27.8	**Operational verification**		**P**
27.8.1	After the tests in 27.2 – 27.7 have been completed, all samples used during these tests shall comply with the following.		P
27.8.2	The manufacturer shall declare the anticipated performance of all safety functions performed by active protective devices.		P
27.8.3	The manufacturer shall provide test procedures to verify that each of the safety functions performed by active protective devices is working correctly. This may include, for example, execution of a full charge/discharge cycle, or verification of correct safety function performance by simulation.		P
27.8.4	The test procedures specified in 27.8.3 shall be performed with each DUT in the following conditions: a) Fully-charged; and b) Fully-discharged.		P
27.8.5	During the test procedures specified in 27.8.3 – 27.8.4, each DUT shall exhibit one of the following behaviors: a) No loss of safety functions; or b) Transition to an appropriate state to ensure safe operation of the DUT. This could include a DUT that has lost its ability to charge or discharge as long as safety is maintained.		P
27.8.6	If redundant methods of protection are provided for a safety function to comply with 7.9.1, each method of protection shall be evaluated to determine if it functions as intended.		P
MECHANICAL TESTS			
28	**Vibration Test (LER Motive Applications and VAP Applications)**		**N/A**
28.1	The purpose of this test is to determine the battery system's resistance to anticipated vibration in LER motive and VAP installations and applies only to those systems intended for installation in these applications.		N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
28.2	The sample shall be secured to the testing machine by means of a rigid mount, which supports all mounting surfaces of the sample. *Exception: The sample may be mounted within a mounting fixture representative of the intended end use application.*		N/A
28.3	The fully charged sample (MOSOC per 8.1) shall be subjected to a vibration test in accordance with the Simulated Long Life Testing at Increased Random Vibration Levels Tests of IEC 61373, for the appropriate Category and Class of equipment as determined by the intended rail installation. (Category and Class of equipment is defined in IEC 61373.) *Exception: Batteries intended for VAP applications shall be subjected to the Vibration Endurance Test of UL/ULC 2271 or UL/ULC 2580.*		N/A
28.4	The DUT shall be subjected to vibration in 3 mutually perpendicular directions. During the test the OCV of the DUT and temperatures on the center cell/module shall be monitored for information purposes.		N/A
28.5	During the test, one of the detection methods outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the testing per Section 13.		N/A
28.6	If the DUT is operational after the test it shall be subjected to a discharge and charging cycle in accordance with the manufacturer's specifications. See 12.2 for details regarding user resettable devices. An observation period per 8.5 is then conducted.		N/A
28.7	At the conclusion of the observation period, the DUT shall be subjected to an "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.		N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
28.8	As a result of the vibration test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1. a) E – Explosion; b) F – Fire; c) C – Combustible vapor concentrations; d) V – Toxic vapor release; e) S – Electric shock hazard (dielectric breakdown); f) L – Leakage (external to enclosure of DUT); g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3); h) P – Loss of protection controls.		N/A
29	**Shock Test (LER Motive Applications and VAP Applications)**		**N/A**
29.1	The purpose of this test is to determine the battery system's resistance to anticipated shock in LER motive and VAP installations and applies only to those systems intended for installation in these applications.	Battery system intended to be used in applications for stationary installation	N/A
29.2	The sample shall be secured to the testing machine by means of a rigid mount, which supports all mounting surfaces of the sample. During the test, temperatures on the center module are monitored for information purposes. Exception No. 1: This sample may be mounted within a mounting fixture representative of the intended end-use rail application. Exception No. 2: Batteries intended for VAP applications shall be subjected to the Shock Test of UL/ULC 2271 or UL/ULC 2580.		N/A
29.3	A fully charged sample (MOSOC per 8.1) shall be subjected to a shock test in accordance with IEC 61373 for the appropriate Category and Class of equipment as determined by the intended rail installation. (Category and Class of equipment is defined in IEC 61373.) *Exception: This test may be conducted at the module level if it can be shown that testing shall be representative of the battery system.*		N/A
29.4	Both positive and negative direction shocks shall be applied in each of 3 mutually perpendicular directions for a total of 18 shocks.		N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
29.5	During the test, one of the detection methods outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the testing per Section 13.		N/A
29.6	If the DUT is operational after the test it shall be subjected to a discharge and charging cycle in accordance with the manufacturer's specifications. An observation period per 8.5 is then conducted.		N/A
29.7	At the conclusion of the observation period, the DUT shall be subjected to an "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.		N/A
29.8	As a result of the shock test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1. a) E – Explosion; b) F – Fire; c) C – Combustible vapor concentrations; d) V – Toxic vapor release; e) S – Electric shock hazard (dielectric breakdown); f) L – Leakage (external to enclosure of DUT); g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3); h) P – Loss of protection controls.		N/A
30	**Crush Test (LER Motive Applications and VAP Applications)**		**N/A**
30.1	This test is conducted on a fully charged battery system intended for LER motive and VAP applications to determine its ability to withstand a crush that could occur during an accident and applies only to those systems intended for installation in these applications.	Battery system intended to be used in applications for stationary installation	N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
30.2	A sample shall be crushed between a fixed surface and a ribbed test platen in accordance with the test fixture described in SAE J2464, with the following exceptions as noted below. Packs with 3 axes of symmetry, are subjected to 3 mutually perpendicular directions of press. A different sample of the DUT may be used for each crush. *Exception No. 1: The maximum force applied to the DUT shall be 100 ±6 kN.* *Exception No. 2: Battery systems with only 2 axes of symmetry, such as cylindrical designs are subjected to 2 mutually perpendicular directions of press.* *Exception No. 3: The DUT may be installed in a protective framework representative of what is provided in the end use application.* *Exception No. 4: A subassembly may be tested instead of a complete battery system if it can be demonstrated to be equivalent to testing a complete battery system.*		N/A
30.3	A detection method as outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations within the sample. Venting of gases may occur, but shall not exceed ERPG-2 levels using the measurement methods outlined in Section 13. The sample shall be subjected to an observation period and the examined.		N/A
30.4	As a result of the crush test, the following in (a) – (d) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1. a) E – Explosion; b) F – Fire; c) C – Combustible vapor concentrations; d) V – Toxic vapor release;		N/A
31	**Static Force Test**		**P**
31.1	The purpose of this test is to determine if the enclosure has sufficient strength to safely withstand a static force that may be applied to it.		P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
31.2	The enclosure of a fully charged DUT (MOSOC per 8.1) shall withstand a steady force of 250 N ±10 N for a period of 5 s, applied in turn to the top, bottom and sides of the enclosure fitted to the DUT, by means of a suitable test tool providing contact over a circular plane surface 30 mm (1.2 inch) in diameter. However, this test is not applied to the bottom of an enclosure having a mass of more than 18 kg (39.7 lbs). If the DUT is operational after completion of the application of the static force, it shall be subjected to a discharge and charging cycle in accordance with the manufacturer's specifications. An observation period per 8.5 is then conducted.		P
31.3	If deemed necessary (i.e. due to design of system and anticipation of venting of cells), one of the detection methods outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the testing per Section 13.		P
31.4	After the observation period, the DUT shall be subjected to an "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.		P
31.5	As a result of the static force test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1. a) E – Explosion; b) F – Fire; c) C – Combustible vapor concentrations; d) V – Toxic vapor release; e) S – Electric shock hazard (dielectric breakdown); f) L – Leakage (external to enclosure of DUT); g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3); h) P – Loss of protection controls.		P
32	**Impact Test**		**P**
32.1	The purpose of this test is to evaluate the mechanical integrity of the enclosure and its ability to provide mechanical protection to the battery system contents.		P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
32.2	A fully charged sample (MOSOC per 8.1) shall be subjected to a minimum of three impacts of 6.8 J (5 ft-lb) on any surface that can be exposed to a blow during intended use. The impact shall be produced by dropping a steel sphere, 50.8 mm (2 inches) in diameter, and weighing 535 g (1.18 lb) from a height, H, of 1.29 m (50.8 in). For surfaces other than the top of an enclosure, the steel sphere shall be suspended by a cord and swung as a pendulum, dropping through the vertical height of 1.29 m (50.8 in), with the product being impacted placed against a restraining vertical wall. See Figure 32.1. A different sample may be used for each impact.		P
32.3	If the DUT is operational after the impacts it shall be subjected to a discharge and charging cycle in accordance with the manufacturer's specifications. An observation period per 8.5 is then conducted.		P
32.4	During the test, one of the detection methods outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the testing per Section 13.		P
32.5	After the observation period, the DUT shall be subjected to an "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.		P
32.6	As a result of the impact test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1. a) E – Explosion; b) F – Fire; c) C – Combustible vapor concentrations; d) V – Toxic vapor release; e) S – Electric shock hazard (dielectric breakdown); f) L – Leakage (external to enclosure of DUT); g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3); h) P – Loss of protection controls.		P
33	**Drop Impact Test**		**P**

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
33.1	Modules that are intended for field installation into rack mount or similar equipment are subjected to a drop impact test to determine that no hazard exists as a result of an inadvertent drop during installation or removal.		P
33.2	After being equilibrated at room temperature per 8.3, a fully charged module/component pack shall be dropped from a minimum height of 100 cm (39.4 in) for products weighing 7 kg (15.4 lbs) or less, 10 cm (3.9 in) for products weighing >7 kg (15.4 lbs), but less than 100 kg (220.5 lbs), and 2.5 cm (0.98 in) for products weighing > 100 kg (220.5 lbs), to strike a concrete or metal surface in the position most likely to produce adverse results and in a manner most representative of what would occur during maintenance and handling/removal of the battery system during installation and servicing. The orientation of the drop shall be determined by the testing personnel from an analysis of the installation and servicing instructions. If using a metal test surface, it should be provided with some manner of insulation such as insulating film that will prevent inadvertent short circuiting to the surface but will not affect test results.	660kg, 2.5cm	P
33.3	The sample shall be dropped a minimum of one time. However, if only one drop test is performed, it shall not be a flat drop. If one drop test is a flat drop, then at least one other test shall be performed that is not a flat drop.		P
33.4	The concrete surface shall be at least 76-mm (3-in) thick and the concrete or metal drop surface shall be large enough in area to cover the DUT.		P
33.5	After the drop, if the DUT is operational it shall be subjected to a discharge and charging cycle in accordance with the manufacturer's specifications. An observation period per 8.5 is then conducted.		P
33.6	At the conclusion of the observation period, an "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.	No rupture and no leakage after Dielectric Voltage Withstand Test	P
33.7	A spark ignition source or gas monitoring as outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations within the sample immediately after the drop and repeated in the instance of increasing temperatures.		N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
33.8	As a result of the drop impact test, the following in (a) – (g) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1. a) E – Explosion; b) F – Fire; c) C – Combustible vapor concentrations; d) S – Electric shock hazard (dielectric breakdown); e) L – Leakage (external to enclosure of DUT); f) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3); and g) P – Loss of protection controls.	No non-compliant result	P
34	**Wall Mount Fixture/Support Structure/Handle Test**		P
34.1	A wall mounting apparatus of a wall mounted battery system, a battery support structure such as a stationary battery system rack, the support structure for a flow batteries stack(s), or a handle(s) provided for handling of a field/rack installed module/pack, shall have sufficient strength to support the battery system or allow for carrying of module/pack. Compliance is determined by the test below. *Exception: This test can be waived for a battery rack complying with UL 2416 and rated for the intended weight of the batteries to be supported.*	Battery support structure was evaluated	P
34.2	The wall mounting apparatus or other support structure and battery system shall be installed in accordance with the manufacturer's specifications. A force equal to three times the weight of the battery system is additionally applied to the center of the mounting apparatus or support structure in a downward direction. The force shall be held for 1 min. For modules/packs with a carrying handle(s), the DUT shall be supported by the carrying handles and a force equal to three times the weight of the DUT is additionally applied in a downward direction. If more than one carrying handle is provided, the added weight shall be distributed between the handles.		P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
34.3	As a result of the applied force, there shall be no damage to the mounting apparatus or support structure and the securement means when testing the wall mounting fixture or supporting structure. As a result of the applied force, there shall be no damage to handles or the handle mounting/securement means of the DUT.		P
35	**Mold Stress Test**		**N/A**
35.1	The purpose of this test is to determine if an enclosure made from molded polymeric material can withstand an accelerated aging test without compromising the safety of the enclosure.	Metal enclosure used.	N/A
35.2	One complete fully discharged sample (discharged to the manufacturer's specified EODV) shall be placed in a full-draft circulating-air oven maintained at a uniform temperature of at least 10°C (18°F) higher than the maximum temperature of the enclosure measured during the Temperature and Operating Limits Check Test in Section 20, but not less than 70°C (158°F). The sample shall remain in the oven for 7 h.		N/A
35.3	After removal from the oven the DUT shall be subjected to an observation period per 8.5. After the observation period, the sample shall be subjected to an "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.		N/A
35.4	As a result of the mold stress conditioning, the sample shall show no evidence of mechanical damage, such as cracking of the enclosure exposing hazardous parts or reducing electrical spacings or leakage of electrolyte from the enclosure.		N/A
36	**Pressure Release Test**		**N/A**
36.1	The purpose of this test is to ensure that the resettable pressure relief valve operates to prevent damage to the battery system and its electrolyte containment. This test is applicable to valve regulated technologies such as valve regulated lead acid batteries and for nickel systems with resettable relief valves.	No such components.	N/A
36.2	A sample of the battery/cell shall be submerged in a container of mineral oil. For large batteries only the pressure relief valve needs to be submerged.		N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
36.3	A charging current shall be caused to flow at an increased rate (to be specified by the manufacturer) until bubbles are observed to rise from the pressure relief valve.		N/A
36.4	Results are acceptable if gas is released normally and the electrolyte containment system does not rupture or leak and the DUT's casing is not ruptured.		N/A
37	**Start-To-Discharge Test**		**N/A**
37.1	The purpose of this test is to determine the average start to discharge pressure of a resettable pressure relief valve not provided with an ASME stamp and rating.	No such components.	N/A
37.2	A calibrated pressure gauge having a range of at least 150% of the anticipated maximum working pressure of the pressure relief valve shall be installed to indicate pressures developed within the battery system during test.		N/A
37.3	To determine the start-to-discharge pressure setting of a pressure-relief valve, each of three samples of the valve shall be subjected three times to a gradually increasing air pressure. The pressure at which the valve begins to open shall be recorded. The start-to-discharge pressure setting of each sample is considered to be the average value of the three trials.		N/A
37.4	The start-to-discharge value mentioned in 37.3 is the highest average value for the three samples tested.		N/A
37.5	The start-to-discharge pressure shall be in the range of 90 – 100% of its assigned start-to-discharge pressure setting.		N/A
ENVIRONMENTAL TESTS			
38	**Thermal Cycling Test (LER Motive Applications and VAP Applications)**		**N/A**
38.1	This test determines the electrical energy storage system's ability to withstand temperature fluctuations that may be anticipated during the end-use application. This test is only applicable to LER motive applications and VAP applications.	Not used for LER Applications	N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
38.2	A fully charged battery system (MOSOC per 8.1) shall be placed in a test chamber and subjected to the following cycles in (a) – (e). At the conclusion of the cycling, the samples shall remain at room temperature, 25 ±5°C (77 ±9°F) for 24 h. a) Raising the chamber-temperature to 75 ±2°C (167 ±3.6°F) within 30 min and maintaining this temperature for 6 h. b) Reducing the chamber temperature to 20 ±2°C (68 ±3.6°F) within 30 min and maintaining this temperature for 2 h. c) Reducing the chamber temperature to minus 40 ±2°C (minus 40 ±3.6°F) within 30 min and maintaining this temperature for 6 h. d) Raising the chamber temperature to 20 ±2°C (68 ±3.6°F) within 30 min. e) Repeating the sequence for a further 9 cycles. *Exception No. 1: Temperatures may need to be held for longer periods for those larger systems where temperature stabilization may take longer. The time required in this case for systems that require longer exposures should be based upon the time it takes for the temperature on internal cells within the DUT to reach thermal equilibrium per 8.3 plus 1 additional hour. This time shall never be less than the exposure times noted in (a) – (d) above.* *Exception No. 2: Testing may be conducted at a subassembly level if that is representative of the energy storage system.*		N/A
38.3	If the DUT is operational after the test, it shall be subjected to a discharge and charging cycle in accordance with the manufacturer's specifications. An observation period per 8.5 is then conducted.		N/A
38.4	During the test, one of the detection methods outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the testing per Section 13.		N/A
38.5	At the conclusion of the observation period, the sample is then subjected to an "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.		N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
38.6	As a result of the thermal cycling test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1. a) E – Explosion; b) F – Fire; c) C – Combustible vapor concentrations; d) V – Toxic vapor release; e) S – Electric shock hazard (dielectric breakdown); f) L – Leakage (external to enclosure of DUT); g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3); h) P – Loss of protection controls.		N/A
39	**Resistance to Moisture Test**		P
39.1	The purpose of this test is to determine that the battery system can safely withstand exposure to moisture anticipated in the end use.		P
39.2	With the DUT in its normal operating orientation, it shall be subjected to a moisture resistance test based upon its IP rating in accordance with IEC 60529 or CAN/CSA-C22.2 No. 60529. The battery system shall be installed and connected as intended for this test for the end use application. For batteries located where they may be subjected to flooding conditions, the IP rating will need to minimally cover immersion. If the DUT is operational after the conditioning, it shall be subjected to a discharge and charging cycle in accordance with the manufacturer's specifications. An observation period per 8.5 is then conducted. *Exception No. 1: Enclosures with Enclosure Type Ratings as identified in NFPA 70, Article 110, or Section 2 of C22.1, are subjected to the environmental testing outlined in UL 50E/C22.2 No. 94.2, rather than the IP Code.* *Exception No. 2: Testing may be conducted at a subassembly level if that is representative of the energy storage system.*	Battery room: IP55; Electrical room: IP55 Chiller control box: IP67	P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
39.3	During the test, one of the detection methods outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations if venting of cells is anticipated. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the testing per Section 13.		P
39.4	At the conclusion of the observation period, the DUT shall be subjected to an “as received” dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.		P
39.5	As a result of the resistance to moisture test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1. a) E – Explosion; b) F – Fire; c) C – Combustible vapor concentrations; d) V – Toxic vapor release; e) S – Electric shock hazard (dielectric breakdown); f) L – Leakage (external to enclosure of DUT); g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3); h) P – Loss of protection controls.		P
40	**Salt Fog Test**		**P**
40.1	This test determines the electrical energy storage system’s ability to safely withstand anticipated exposure to a salt fog conditions due to use near marine environments, and would apply to those stationary systems installed near sea environments whose internal components may be exposed to deterioration from salt fog through openings in the enclosure. This test would not apply to those systems not intended to be installed near marine environments as indicated in the installation instructions or whose enclosure is designed to prevent ingress of moisture with protection against corrosion (e.g. UL/NEMA 4X).		P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
40.2	A fully charged electrical energy storage system (MOSOC per 8.1) shall be subjected to the test method per IEC 60068-2-52, with a severity level of 1 or 2 depending upon the application and location of installation. *Exception: A sample at the subassembly level that would be representative of the battery system may be used for this test.*		P
40.3	If the DUT is operational after the conditioning, it shall be subjected to a discharge and charging cycle in accordance with the manufacturer's specifications.		P
40.4	During the cycling, one of the detection methods outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations if venting of cells is anticipated. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the cycling per Section 13. An observation period per 8.5 is then conducted.		P
40.5	At the conclusion of the observation period, the DUT shall be subjected to an "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.		P
40.6	As a result of the salt fog test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1. a) E – Explosion; b) F – Fire; c) C – Combustible vapor concentrations; d) V – Toxic vapor release; e) S – Electric shock hazard (dielectric breakdown); f) L – Leakage (external to enclosure of DUT); g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3); h) P – Loss of protection controls.		P
41	**External Fire Exposure for Projectile Hazards Test**		**N/A**

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
41.1	The purpose of this test is to determine that a battery system will not explode as evidenced by projectiles landing beyond the test perimeter as a result of being exposed to a hydrocarbon pool fire simulating an external fire exposure that may occur. *Exception No. 1: The battery system may be subjected to the External Fire Exposure Test in UL/ULC 2580 instead of the method outlined in 41.3.* *Exception No. 2: Testing may be conducted on a representative subassembly rather than a complete battery system if determined that equivalent results to testing a battery system can be obtained.* *Exception No. 3: If the secondary lithium cells employed in the system comply with the projectile test of* *Section E9, the system is exempted from this test. This test is not applicable to systems employing lead acid or similar monobloc aqueous electrolyte batteries.* *Exception No. 4: This test does not apply to systems intended for outdoor use only that are mounted on a non-combustible surface such as*	Projectile test evaluated at cells level according to Annex E	N/A
41.2	This test shall be conducted in a controlled setting free from the effects of wind or other environmental factors that may affect the test. The ambient temperature during the testing is to be within the range of 0 °C to 46 °C (32 °F to 114.8 °F).		N/A
41.3	A fully charged DUT at normal operating temperature is subjected to a hydrocarbon pool fire for 20 min. The fuel used shall be heptane or similar hydrocarbon fuel.		N/A
41.4	The pan, which provides the fire containment, shall be constructed of steel of sufficient thickness to prevent warping during the course of the 20-min test. The pan shall be sized in relation to the DUT and to accommodate the fuel and water levels. The walls of the pan shall not project more than 8 cm (3.1 in) above the level of the fuel at the start of the test. The pan dimensions shall be sized to ensure that the sides of the tested-device are exposed to the flame. The pan shall exceed the horizontal projection of the DUT by 20 to 50 cm (7.9 to 19.7 in).		N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
41.5	There should be approximately 15.24 cm (6 in) of water in the pan prior to adding the hydrocarbon fuel to protect the fuel pan and to provide for consistent flame output during the test. The fuel shall be added as needed during the test to provide sufficient fuel for the test duration. The fire shall cover the whole area of the pan during whole fire exposure.		N/A
41.6	A suitable means to extinguish the fire in the fuel pan within 15 s, or remove the battery from above the fire, shall be provided. This may be accomplished by drawing a cover over the pan, or by moving the DUT from over the pan or removing the pan as putting the fire out may be difficult and should not be underestimated.		N/A
41.7	The DUT shall be fully supported and centered above the fire containment pan above the surface of the heptane. The DUT support structure shall be robust enough to withstand the weight of the DUT for the duration of the test without allowing the DUT to lean or topple. The pan shall be sized large enough to cover the dimension of the DUT, and shall be of a sufficient height so that the bottom surface of the DUT is approximately 50 cm (19.7 in) from the top fuel surface in the pan. See Figure 41.1 for details of set up.		N/A
41.8	During the test, the temperature of the cells or modules within the DUT may be monitored for information purposes.		N/A
41.9	After the 20-min fire exposure the fire shall be extinguished, and the DUT shall be subjected to a hose down in accordance with 41.10 to represent fire fighter response the system may be exposed to during a fire. At the conclusion of the hose down, there shall be a one hour observation period in accordance with 8.5.		N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
41.10	The battery shall be subjected to a low impact hose stream delivered through a 38 mm (1-1/2 in) fog nozzle set at a discharge angle of 30° with a nozzle pressure of 517 kPa (75 psi) and a minimum discharge of 4.7 L/s (75 gpm). The tip of the nozzle shall be a maximum of 1.5 m (5 ft) from the center of the exposed surface of the DUT. The minimum duration of the low impact hose stream test shall be 6.5 s/m2 (0.60 s/ft2). The outer surface of the DUT shall be identified as the exposed area, as the hose stream must traverse this area during its application. To prevent potential for exposure to projectiles, the technician conducting the hose down portion of the test shall do so behind a protective barrier.		N/A
41.11	To determine that an explosion hazard has resulted, the DUT with pan fire test set up shall be centered within a circular inner perimeter marked on the floor with paint or a similar marking material. The marking shall be no wider than 12 mm (0.47 in) and the size of the circular inner perimeter area marking shall be no greater than 1.0 m (3.3 ft) from the outer edge of the longest side of the DUT.		N/A
41.12	For protection from projectiles during the test, the DUT, test set up, and inner perimeter marking shall be enclosed within a protective test chamber that can contain the projectiles or within an outer perimeter consisting of a protective barrier wall of a noncombustible material such as masonry or concrete and wall thickness suitable for containing projectiles during the test. The walls of the test chamber or the outer perimeter shall be located a minimum of 1.5 m (4.95 ft) from the inner perimeter marking to prevent the possibility of projectiles bouncing off the walls and back into the inner perimeter.		N/A
41.13	As a result of this test, there shall be no explosion of the DUT that results in projectiles falling outside of the circular inner perimeter described in 41.11. See Table 12.1 for additional details.		N/A
42	**Single Cell Failure Design Tolerance**		**P**
42.1	**General**		**P**

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
42.1.1	There have been field incidents with various battery technologies that have been attributed to a cell failure, which led to a hazardous event. The cell failures in these incidents were the result of either manufacturing defects or insufficient cell or battery design or a combination of both. Since there is a possibility that a cell may fail within a battery system, the battery system shall be designed to prevent a single cell failure from propagating to the extent that there is fire external to the DUT or an explosion.	UL 9540A evaluated and satisfied with UL 1973 requirement.	P
42.1.2	The cell failure mechanism used for this testing shall reflect what is known or anticipated to occur in the field for a given technology. If the cell failure mechanism cannot be exactly replicated, a close simulation of what is known to occur in the field through the use of an external stress such as applied heating or mechanical force shall be utilized for the test. Examples of methods to simulate a single cell failure are outlined in Appendix F. Multiple tests and possible multiple failure methods may need to be conducted as part of the analysis before a final methodology for testing is determined.		P
42.2	**Single cell failure design tolerance (lithium ion)**		**P**
42.2.1	A lithium ion battery system shall be designed to mitigate a single cell failure leading to a thermal runaway of that cell. With lithium ion batteries, it is often the effects of propagation to surrounding cells due to the heating effect of the initial cell failure that leads to hazardous events. The DUT (e.g. battery pack or module) shall be designed to prevent a single cell thermal runaway failure from creating a significant hazard as evidenced by fire propagation outside of the DUT and/or an explosion.		P
42.2.2	Any number of methods can be used to produce a single cell thermal runaway failure. For example, thermal runaway in cells can be achieved through the use of heaters, nail penetration, overcharge, etc. The testing agency is responsible for selecting and demonstrating an appropriate method for inducing thermal runaway. It is recommended to evaluate a candidate method first using a small subassembly of cells to evaluate the cell failure and effects to surrounding cells. During an effort to establish a suitable failure method, temperatures should be taken on the cell casings, and voltages measured for information purposes. See Appendix F for guidance on several methods of inducing cell failure. The method chosen shall be agreed upon by the testing agency.	Heater used	P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
42.2.3	The details of the method used when analyzing the cell's reaction that can impact the results are to be documented. For example, if heating the cell to achieve failure: e.g. the type of heater and its dimensions, location on the cell where the heater is placed and how it is placed, maximum temperature attained including temperature ramp rate, length of time until reaction, temperatures on cell and voltage, state of charge of the cell at the beginning of the heating phase, etc. The test article shall be representative of the actual battery configuration and any modifications should not significantly impact the test results. For example, if overcharge is to be carried out, the heat conduction path between tabs shall not be hindered as that may reduce the severity of the test.		P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
42.2.4	Once a suitable method of cell failure has been determined, the fully charged DUT (MOSOC per 8.1) shall be subjected to the single cell failure tolerance test, which consists of inducing a fault in one internal cell that is within the DUT, until cell failure resulting in thermal runaway as defined in 6.58 occurs, and determining whether or not that failure produces a significant external hazard or whether or not that failure does not cause the failure of neighboring cells. If cascading occurs, the cascading shall not propagate beyond the DUT. Prior to choosing the specific cell to fail, an analysis of the DUT design to determine the cell location considered to have the greatest potential to lead to a significant external hazard shall be conducted, taking into consideration the cell's proximity to other cells and materials that may lead to potential for propagation. If it can impact the results, the sample shall be at the maximum specified temperature during charging and operation with some tolerance as necessary for movement of the sample outside of the chamber during testing, but within ±5°C (±9°F). Once the thermal runaway is initiated, the mechanism used to create thermal runaway is shut off or stopped and the DUT is subjected to a 24-h observation period. *Exception No. 1: Testing may be repeated on another sample with a cell in a different location within the DUT if it is not clear which location represents the worst case scenario. The location of the failed cell shall be documented for each test.* *Exception No. 2: Testing may be conducted on a representative subassembly consisting of one or more modules and surrounding representative environment, if it can be demonstrated that there is no propagation beyond the subassembly. When testing at the module or subassembly level, consideration needs to be made of the vulnerability to combustion of those components surrounding the module in the final assembly. Temperatures on DUT external surfaces and surfaces of parts in contact with or near the DUT in the final assembly, shall be monitored to determine if excessive temperature on these adjacent parts could result in a potential for propagation within the full battery system. If there are excessive temperatures on the surfaces that may lead to potential for propagation, testing shall be repeated with all adjacent components in place of a complete battery system.*	Heater used. Testing conducted on a subassembly battery module	P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
42.2.5	Temperatures on the failed cell and surrounding cells are to be monitored and reported for information purposes.		P
42.2.6	As a result of the testing of 42.2, there shall be no fire propagating from the DUT or explosion of the DUT.		P
42.3	**Single cell failure design tolerance (other technologies)**	**Lithium-ion cell.**	**N/A**
42.3.1	Other technologies such as lithium metal, sodium sulfur, sodium nickel chloride, and lead acid where there may not be enough field data regarding their tolerance to single cell failure events, are to be subjected to a single cell failure test method similar to 42.2, except as modified as noted below. The failure mechanism for these technologies may be different than that of lithium ion and thermal runaway may or may not result from the cell failure. Similar to lithium ion, when choosing a cell failure technique, it should be representative of what can occur in the field for the particular technology. The failure mechanism chosen shall consider failures due to potential cell manufacturing defects for that technology and/or cell and battery design deficiencies that could lead to latent failures of the cell, and that would not be evident under the individual cell safety testing.		N/A
42.3.2	For other technologies, similarly as with lithium ion, it is recommended to evaluate a candidate method first using a small subassembly of cells to evaluate the cell failure and effects to surrounding cells. During an effort to establish a suitable failure method, temperatures should be taken on the cell casings, and voltages measured for information purposes. See Appendix F for guidance on several methods of inducing cell failure. The method chosen shall be agreed upon by the testing agency.		N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
42.3.3	When a suitable worse case representative method for cell failure has been determined, the DUT is to be subjected to the internal cell failure occurring in the location within the DUT considered most vulnerable to the potential for propagation. The DUT shall be in a condition that reflects its operating parameters at the worst moment such a failure could occur. For example, the DUT shall be at its nominal operating temperature. During the test, temperatures shall be monitored in critical locations such as adjoining cells during the test to record the rise in temperature due to the internal failure. If no thermal runaway occurs as a result of the single cell failure, the test is stopped when the DUT temperature has stabilized or reaches ambient room temperature, and the DUT is subjected to a 24-h observation period. If a thermal runaway is initiated, the mechanism used to create thermal runaway is shut off or stopped and the DUT is subjected to a 24-h observation period. *Exception No. 1: Testing may be repeated on another sample with a cell in a different location within the DUT if it is not clear which location tested represented the worst case scenario. The location of the failed cell is to be documented for each test.* *Exception No. 2: Testing may be conducted on a representative subassembly consisting of one or more modules and surrounding representative environment, if it can be demonstrated that there is no propagation beyond the subassembly. When testing at the module or subassembly level, consideration needs to be made of the vulnerability to combustion of those components surrounding the modules in the final assembly.*		N/A
42.3.4	As a result of the testing per 42.3.3, there shall be no fire propagating from the DUT or explosion of the DUT.		N/A
42.3.5	Temperatures on the failed cell and surrounding cells, external enclosure surfaces of the DUT and the supporting surface are to be monitored and reported for information purposes. The number of cells that fail due to propagation from the triggering cell shall be documented.		N/A
MANUFACTURING AND PRODUCTION LINE TESTS			
43	**General**		**P**

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
43.1	Manufacturers of battery systems shall have documented production process controls in place that continually monitor the following key elements of the manufacturing process that can affect safety, and shall include corrective/preventative action to address defects found affecting these key elements: a) Supply chain control; and b) Assembly processes.		P
43.2	Battery systems shall be subjected to 100 % production screening to determine that any active controls utilized for safety are functioning. *Exception: This check of the safety controls can be conducted on subassemblies or components of the system before final assembly.*		P
43.3	An "as received" dielectric voltage withstand test as outlined in the Dielectric Voltage Withstand Test, Section 22 shall be conducted on 100 % production of Assemblies/packs with circuits exceeding 60 Vdc or 42.4 V peak as outlined in Section 22. *Exception: The time for the test may be reduced to 1 s if the test voltage values are increase by 2.4 times the values in Section 22 or as outlined in the routine test criteria of the Electric Strength Test of UL 62368-1/CSA C22.2 No. 62368-1, Clause 5.4.9.*		P
43.4	A continuity check of the grounding system using a milliohmmeter or other method, shall be conducted on 100 % production employing protective grounding. The continuity check shall determine that measurements made on any two points of the grounding system do not exceed 0.1 Ω.		P
43.5	Each resettable non-ASME coded pressure-relief valve shall be tested by the manufacturer for the start-to-discharge pressure by subjecting the pressure-relief valve to a gradually increasing air pressure until the valve begins to open. The start-to-discharge pressure shall be in the range of 90 – 100 % of its rated start-to-discharge pressure rating.		N/A
MARKINGS			
44	**General**		**P**

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
	Advisory Note: In Canada, there are two official languages. Therefore, it is necessary to have CAUTION, WARNING, and DANGER instructions and markings in both English and French. Annex G lists acceptable French translations of the CAUTION, WARNING, and DANGER instructions and markings specified in this Standard. When a product is not intended for use in Canada, instructions and markings may be provided in English only.		P
44.1	Required markings shall be permanent. Examples of permanent marking are ink stamping, engraving and if adhesive labels, compliance to UL 969 or CSA C22.2 No. 0.15 for the surface adhered and conditions of use. Markings required by this standard including nameplate markings per 44.2 and any cautionary markings shall be legible, provided in text color that contrasts with the background color and visible upon installation of the battery system.	The marking was printed on the sheet-metal on the enclosure	N/A
44.2	Batteries shall be marked with the manufacturer's name, trade name, trademark or other descriptive marking which may identify the organization responsible for the product, part number or Model number, and electrical ratings in volts dc and capacity in Ampere-hours or Watt-hours and chemistry. The battery system terminals shall be marked to indicate whether they are positive (+) or negative (-). The battery shall also be marked with its IP rating.		P
44.3	Batteries and Battery systems using repurposed batteries in accordance with 7.13, shall be marked “Repurposed” or “Second Life” and “UL 1974”.	No repurposed batteries used.	N/A
44.4	Battery systems shall be marked with the maximum short circuit current and duration (at maximum short circuit current) at the system output terminals.	Marked on the battery system label	N/A
44.5	Battery systems shall also be marked with the date of manufacture, which may be in the form of a code that does not repeat within 20 years.		P
44.6	A battery system intended for use with specific chargers shall be marked with the following or equivalent: "Use Only ( ) Charger".		P
44.7	A battery system evaluated for protection against ingress of moisture per 7.3.5, shall be provided with the appropriate IP Code rating.	Battery room: IP55； Electrical room: IP55 Chiller control box: IP67	P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
44.8	Systems shall be marked with a cautionary marking indicating to read all instructions before installation, operation and maintenance of the system. This marking may be in the form of the symbol(s) for example: ISO 7000, “caution” Symbol No. 434 (exclamation point inside triangle) followed by the “read instruction manual” Symbol No. 790 (open book). If using symbols, their meaning shall be explained in the instruction manual.	Symbol used.	P
44.9	Systems that must be operated in a certain orientation for safe operation, shall be provided with markings indicating the correction orientation of the system.		P
44.10	Systems shall be marked with a warning marking indicating risk of electrocution near hazardous voltage battery terminals.		P
44.11	Systems with replaceable fuses, shall be marked with rating and type of fuse for replacement. The marking shall be located near the fuseholder.		N/A
44.12	Separable accessories and controls which are intended for connection to the mains supply shall be provided with markings that include the manufacturer’s name, part number of the accessory and electrical ratings in voltage, frequency, phase if applicable, and current or watts.	See user manual	P
44.13	A ground terminal shall be marked as outlined in 7.6.8.		P
44.14	Additional warning markings for battery systems located in restricted access locations such as warnings regarding hazardous moving or electrical parts, hot surfaces, etc., to alert service or other trained personnel and prevent hazards, shall be provided on the battery systems in locations where they will be visible those persons having access to the location.	Rely on final system, See user manual and installation instruction.	N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
44.15	With reference to 7.12.2, a secondary lithium cell shall be legibly and permanently marked with: a) The manufacturer's name, trade name, or trademark or other descriptive marking by which the organization responsible for the product may be identified; b) A distinctive catalog, model or designation number or the equivalent; and c) The date or other dating period of manufacture not exceeding any three consecutive months. *Exception No. 1: The manufacturer's identification may be in a traceable code if the product is identified by the brand or trademark owned by a private labeler.* *Exception No. 2: The date of manufacture may be abbreviated; or may be in a nationally accepted conventional code or in a code affirmed by the manufacturer, provided that the code:* a) Does not repeat in less than 10 years; and b) Does not require reference to the production records of the manufacturer to determine when the product was manufactured.		P
44.16	With reference to 44.15, if a manufacturer produces a cell at more than one factory, each cell shall have a distinctive marking to identify it as the product of a particular factory.		P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
44.17	Required markings for single cells and multi-cell/monobloc vented and valve regulated lead acid and nickel cadmium batteries shall be legibly and permanently marked in accordance with 44.1 with the following included: a) The manufacturer's name, trade name or trademark, model designation, and month and year of manufacture; *Exception: The date of manufacture may be in the form of a code that does not repeat in 10 years.* b) The statement "Warning: Risk of fire, explosion, or burns. Do not disassemble, heat above XX °C (or °F), or incinerate." (Where XX is the cell or battery's maximum temperature specification.) *Exception: This statement may be included in the instructions provided with the cell or battery, rather than be marked on the battery.* c) Battery type (e.g. valve regulated lead-acid battery) and rated nominal voltage and capacity; and d) Positive and negative leads or terminals indicated by (+) and (−).		N/A
INSTRUCTIONS			
45	**General**		**P**
45.1	Components of a battery system shall be provided with a complete set of instructions for proper installation and use in a battery system. These instructions shall include normal operating specifications.		P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
45.2	Systems shall be provided with complete instructions for installation in the end use application. Installation instructions shall include the following along with any other instructions necessary for the safe and correct installation of the system and its accessories in the intended end use: a) Insulated tools, insulated gloves, personal protective equipment, and clothing and other measures necessary for safe installation of the battery system; b) The necessary housing requirements for protection against ingress of moisture and debris or access by persons; c) Ventilation requirements to prevent accumulation of hydrogen greater than 25 % of hydrogen LFL; d) Protective components and devices required in the end use installation such as fuses, circuit breakers, wiring, and other devices such as disconnect devices in accordance with NFPA 70 or C22.1. See 7.9.9; e) Circuit diagrams and instructions for proper connection of the system and any ancillary devices such as separate controllers, monitoring devices, etc.; f) Warnings and instructions regarding the battery electrolyte; g) Instructions regarding any commissioning tests and checks necessary before placing system into service; h) Table or list, etc. of symbols used and their meanings; i) The necessary information to complete an arc flash/blast analysis, including bolted fault current (IBF), 1/2 bolted fault current (1/2 IBF), protective device clearing time, and protective device current interrupt capability at a minimum, if applicable to the system; and j) If applicable, the manufacturer shall provide information on design considerations for maximum and minimum system configurations, such as number of modules installed in series, maximum resistance, and maximum inductance to prevent arc flash incident energy from exceeding the requirements of Personal Protective Equipment Category 4 per NFPA 70E or CSA Z462-15.		P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
45.3	Battery systems intended for installation in a restricted access location per 6.51 shall have installation instructions indicating this with instructions defining the type of location required, its restrictions, signage and other information to be provided.	Rely on Final System.	N/A
45.4	A system shall be provided with instructions for the proper use including charging and discharging, storage, recycling and disposal. These instructions shall include temperature limits, charging and discharging limits as well as instructions regarding the use of any controls or monitoring systems.		P
45.5	A system shall include the following statements or equivalent: a) An attention word, such as "DANGER," "WARNING," or "CAUTION." b) A brief description of possible hazards. c) A list of actions to take to avoid possible hazards regarding disposal of the system such as do not crush, disassemble, dispose of in fire, or similar actions.		P
45.6	The system shall be provided with a maintenance manual that includes a schedule for maintenance of the system and accessories including a check of wiring and connections, etc. The maintenance manual shall include necessary safety precautions regarding handling or conducting maintenance on the system and its connections and accessories.		P
45.7	Cells shall be provided with a complete set of instructions that include operating region specifications for charging and discharging including current temperature range and voltages, installation instructions, storage of batteries and disposal instructions. Guidance on cell specification information that should be provided on cells can be found in the Cell Specification Sheet, Annex E of IEEE 1625.		P
45.8	The installation instructions for vented and valve regulated lead acid and nickel cadmium batteries shall indicate that the batteries and components of the battery systems shall be installed in accordance with Article 480 or 706 of NFPA 70 or Section 64 of CSA C22.1.		N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
45.9	Installation instructions for vented and valve regulated lead acid and nickel cadmium batteries shall indicate that the charging system for these batteries shall prevent charging outside of the battery specifications through the use of voltage (and temperature for VRLA) monitoring and controls, or both current and temperature monitoring and controls. The system may also use current monitoring to prevent out of condition specifications. The instructions shall indicate that chargers shall comply with UL 1012, UL 1741, UL 60335-2-29/CSA C22.2 No. 60335-2-29, CAN/CSA C22.2 No. 107.2, or UL 62368-1/CSA C22.2 No. 62368-1. Instructions for the battery system shall provide information on a specific charger to be used with the battery system if the charger is relied upon to maintain the battery system safety.		N/A
45.10	The instructions for vented and valve regulated lead acid and nickel cadmium batteries shall indicate that battery systems exceeding 60 Vdc shall be provided with a disconnecting means for all ungrounded conductors in accordance with Article 480 of NFPA 70 or Section 64 of CSA C22.1.		N/A
45.11	Installation instructions for single cells and multi-cell/monobloc vented and valve regulated lead acid and nickel cadmium batteries shall be provided with instructions indicating that service disconnects shall be provided as applicable to the end product battery system in accordance with Article 480 of NFPA 70 or Section 64 of CSA C22.1.		N/A
45.12	Installation instructions for vented and valve regulated lead acid and nickel cadmium multibattery/cell systems shall include the short circuit current output from the battery system rather than the marking of 44.4.		N/A
45.13	Vented lead acid or nickel cadmium cell and battery installation instructions shall indicate the need for spill control in accordance with the building, fire and installation codes.		N/A
45.14	The instructions for vented and valve regulated lead acid and nickel cadmium cells and batteries shall indicate that ventilation to address any hydrogen off gassing shall be in accordance with the local fire and installation codes.		N/A
45.15	The instructions for open rack vented and valve regulated lead acid and nickel cadmium battery systems shall indicate that these racks shall be installed in restricted access locations or be installed within a protective enclosure that prevents access in accordance with the end use application.		N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
45.16	Instructions for vented and valve regulated lead acid and nickel cadmium cells and batteries shall indicate recommended wiring for battery connections, the minimum clearance between cells and batteries on the racks and any type of protection device.		N/A
45.17	Instructions for vented and valve regulated lead acid and nickel cadmium cells and batteries shall include maintenance instructions for maintaining the cells and batteries in safe operating condition through the life of the cell and battery including electrolyte maintenance if applicable, examination of terminals and casings for damage, etc.		N/A
45.18	If lead acid and nickel cadmium cells and batteries are intended for installation in an end use that utilizes protective grounding, the installation instructions shall recommend that the grounding and bonding system be checked after the completion of the assembly to ensure that the resistance is less than or equal to 0.1 Ω.		N/A
45.19	The instructions provided with lead acid and nickel cadmium cells and batteries shall indicate the maximum voltage of the end use system they can be installed in. If the voltage in the end use is exceeded, then the instructions shall recommend a repeat of the dielectric voltage withstand test of the assembly for the higher voltage.		N/A
Appendix A Standard for Components			
A1	**Standards for Components**		**P**
A1.1	The CSA Group and UL standards listed below are used for evaluation of components and features of products covered by this standard. Components shall comply with all the applicable CSA Group and UL component standards. These standards shall be considered to refer to the latest edition and all revisions published to that edition.	See appended table Critical components.	P
Appendix B Test program for sodium-beta battery cells			
B1	**General**		**N/A**
APPENDIX C Test program for flowing electrolyte batteries			
C1	**General**		**N/A**
APPENDIX D Metal compatibility table			
D1	**General**		**N/A**
D1.1	For combinations that fall above the line in Table D.1, an evaluation on the parts can be conducted to determine suitability. Protection methods such as coatings can be used, but will need to be evaluated.		N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
D1.2	The evaluation method shall consist of a comparison of the part to evaluate with a similar part using construction that is below the line of Table D.1, after corrosion conditioning such as a salt fog conditioning in accordance with ASTM B117, ISO 9227 or similar method. Measurements of the properties of the connection parts (design under consideration as well as comparison design) under test shall be made before and after conditioning with a comparison of the results. Properties to measure will depend upon the part being evaluated, but could include resistance, temperatures on the part during operation, or bond/mechanical strength as applicable to the type of connection.		N/A
D1.3	The deterioration of the devices under evaluation shall not result in unacceptable properties (i.e. reduced performance that would result in malfunction of the connection) nor shall the deterioration be greater than that of the comparison design.		N/A
D1.4	As another approach, a coating with known properties, such as one evaluated to UL 546, along with sealing the area to prevent moisture exposure can be used to establish acceptable protection against galvanic corrosion without additional evaluation.		N/A
APPENDIX E Cell Test Program			
E1	**General**	Certified Lithium ion cell used with UL1973: 2022	**N/A**
E1.1	The following shall be used to evaluate lithium ion cells or other secondary lithium cells.		N/A
E1.2	Samples used for testing shall be representative of production. The number of samples used for each test and the pass/fail criteria for testing is outlined in Table E.1. As an alternate, the lithium ion cell test program outlined in Sections E10 – E11 may be used		N/A
E1.3	Prior to conditioning in E1.4, two samples from the total set of samples as representative samples shall be subjected to the capacity check per E2.2 to confirm the capacity of the samples is correct.		N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
E1.4	Prior to testing, the samples shall be conditioned by first discharging them down to the manufacturer's specified end point voltage and then charging them to the manufacturer's specified upper limit charging voltage using the manufacturer's specified maximum charging current. Samples shall be charged at the upper temperature limit of the charging operating region and the lower limit of the charging operating region for those tests as identified in Table E.1. During charging, a minimum of one temperature is measured on the surface of the cell centered on the cell. For prismatic cells, this would be on the largest flat surface.		N/A
E1.5	Some lithium cells are capable of exploding when the tests described in this Annex are conducted. It is important that personnel be protected from the flying fragments, explosive force, sudden release of heat, and noise that results from such explosions. The test area shall be well ventilated to protect personnel from possible harmful fumes or gases.		N/A
E1.6	As an additional precaution, the temperatures on the surface of the cell casings shall be monitored in accordance with E1.7 during the tests described in this Annex. All personnel involved in the testing of lithium cells shall be instructed never to approach a lithium cell while the surface temperature exceeds 90 °C (194 °F) and not to touch the lithium cell while the surface temperature exceeds 45 °C (113 °F).		N/A
E1.7	In accordance with E1.6, the surface temperatures of the cell casing shall be measured as follows: a) By thermocouples consisting of wires not larger than 0.21 mm2 (24 AWG) and not smaller than 0.05 mm2 (30 AWG) and a potentiometer-type instrument; and b) The temperature measurements on the cells shall be made with the measuring junction of the thermocouple held tightly against the metal casing of the cell. *Exception: Placing the thermocouple on a thin piece of paper or label is an acceptable practice.*		N/A
E1.8	For protection, the Projectile Test in E9 shall be conducted in a room separate from the observer or within an appropriate containment chamber.		N/A
E2	**Preconditioning and Capacity Check**		**N/A**
E2.1	**Preconditioning**		**N/A**

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
E2.1.1	The charge/discharge cycling preconditioning in E2.1.2 shall be done before testing and conducted on secondary lithium metal (i.e. lithium metal anode) cells. Lithium ion cells need not be subjected to charge/discharge cycle preconditioning.		N/A
E2.1.2	Secondary lithium metal (i.e. lithium metal anode) cells shall be conditioned at 25 °C ±5 °C (77 °F ±9 °F). The cells shall be continuously cycled as specified by the manufacturer. The specification shall be such that the full rated capacity of the cell is utilized and the number of cycles accumulated shall be at least equal to 25 % of the advertised cycle life of the cell or cycled continuously for 90 days, whichever is shorter. Cycling shall be done either individually or in groups. Cells shall be recharged prior to testing.		N/A
E2.2	**Capacity check**		**N/A**
E2.2.1	Prior to conducting testing, the capacity of the lithium ion and lithium metal cells to be tested shall be checked in accordance with E2.2.2 – E2.2.5 by selecting two samples from the total set of samples.		N/A
E2.2.2	For secondary lithium metal (i.e. lithium metal anode) cells, this capacity check shall be conducted on preconditioned secondary lithium metal cells per E2.1. *Exception : For secondary lithium metal cells subjected to preconditioning per E2.1, the capacity check may be conducted during the preconditioning of these secondary lithium metal cells by checking the discharged capacity during the first few cycles. This capacity confirmation may be done in the manufacturer shipping inspection by checking the capacity discharge curve shipped with the samples.*		N/A
E2.2.3	The cell shall be discharged at 25 °C ±5 °C (77 °F ±9 °F) at a constant current of 0.2C rate, down to a specified end of discharge voltage. The cell shall then be charged in a room ambient temperature, 25 °C ±5 °C (77 °F ±9 °F), at charging parameters specified by the manufacturer until fully charged. The cell shall then be allowed to stabilize at room ambient per 6.52.		N/A
E2.2.4	With the cell in the fully charged condition, the cell shall be discharged at a constant current discharge in accordance with the cell manufacturer's specifications down to the end of discharge voltage. The duration of the discharge shall be monitored and the measured capacity of the cell shall be calculated to three significant figures.		N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
E2.2.5	For cells to be used for the test program outlined in this Annex, their measured capacity shall equal or exceed the rated specifications. All samples shall be subjected to the capacity check test if any representative sample does not meet this criteria. The cells not meeting this criteria shall be excluded from testing.		N/A
E3	**Short Circuit**		**N/A**
	Fully charged, conditioned cells are stored in an ambient temperature of 25 °C ±5 °C (77 °F ±9 °F) until their casing reaches ambient temperature, and then subjected to a short circuit condition using an external resistance of ≤ 20 mΩ. The external resistance shall be applied to the cell terminals for 7 h or until temperatures on the cell cool to within ±10 °C (18 °F) of ambient conditions.		N/A
	Compliance criteria: No fire, no explosion.		N/A
E4	**Cell Impact**		**N/A**
	Fully charged, conditioned cells shall be subjected to an impact test as outlined in E11.4. The cells shall be at an ambient temperature of 25 °C ±5 °C (77 °F ±9 °F) prior to testing.		N/A
	Compliance criteria: No fire, no explosion.		N/A
E5	**Drop Impact**		**N/A**
	Fully charged cells shall be dropped three times from a height of 1 m (3.3 ft) onto a flat concrete or metal surface. The cells shall be at an ambient temperature of 25 °C ±5 °C (77 °F ±9 °F) prior to testing.		N/A
	The cells shall be dropped in a manner that the impacts occur in random orientations. After completion of the impacts, the cells shall be subjected to a minimum one hour observation period before being examined.		N/A
	Compliance criteria: No fire, no explosion.		N/A
E6	**Heating**		**N/A**
	Fully charged, conditioned cells shall be subjected to a heating test as outlined in E11.7.		N/A
	Compliance criteria: No fire, no explosion.		N/A
E7	**Overcharge**		**N/A**

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
	Fully charged conditioned cells shall be discharged in accordance to manufacturer's specifications down to the specified end point voltage. The test is conducted in an ambient of 25 °C ±5 °C (77 °F ±9 °F) and with the cell casing at an ambient of 25 °C ±5 °C (77 °F ±9 °F) at the start of the test. The voltage and temperature of the cell shall be monitored during the test. The cells are charged with a constant current at the maximum specified charge current until the voltage of the cell reaches 120 % of the maximum specified charge voltage value or 130 % State of Charge (SOC), whichever is reached first. The charge is then terminated while the cell temperature continues to be monitored. The test is concluded when the cell temperature drops and returns to ±10 °C (18 °F) of the test ambient.		N/A
	Compliance criteria: No fire, no explosion.		N/A
E8	**Forced Discharge**		**N/A**
	Fully charged cells shall be discharged in accordance to manufacturer's specifications down to the specified end point voltage. The test is conducted in an ambient of 25 °C ±5 °C (77 °F ±9 °F). The discharged cells are subjected to a forced discharge at a constant current 1.0 It A for 90 min with the discharge voltage limit not to exceed the numerical value of the upper limit charging voltage specified for the cell. If the discharge voltage limit is reached before the 90 min, the cell shall be discharged at a constant voltage discharge equal to the manufacturer's determined low voltage cutoff, with the current decreasing as necessary until the 90 min time period is reached.		N/A
	Compliance criteria: No fire, no explosion.		N/A
E9	**Projectile**		**N/A**
	Two fully charged cells shall be subjected to the projectile test criteria as outlined in E11.10.		N/A
	As a result of the projectile test, the cells there shall not be an explosion of the cells resulting in projectiles with sufficient force to penetrate the test cage screen.		N/A
ALTERNATIVE TEST PROGRAM FOR SECONDARY LITHIUM CELLS			
E10	**General**		**N/A**

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
E10.1	This cell test program may be used to evaluate secondary lithium cells for use in battery systems that comply with this standard instead of the test program outlined in Sections E1 – E9. Samples used for testing shall be representative of production. The number of samples used for each test and the pass/fail criteria for testing shall be as outlined in Table E.2.		N/A
E10.2	Some lithium cells are capable of exploding when the tests described below are conducted. It is important that personnel be protected from the flying fragments, explosive force, sudden release of heat, and noise that results from such explosions. The test area shall be well ventilated to protect personnel from possible harmful fumes or gases.		N/A
E10.3	As an additional precaution, the temperatures on the surface of the cell casings shall be monitored in accordance with E10.4 during the tests described below. All personnel involved in the testing of lithium cells shall be instructed never to approach a lithium cell while the surface temperature exceeds 90 °C (194 °F) and not to touch the lithium cell while the surface temperature exceeds 45 °C (113 °F).		N/A
E10.4	In accordance with E10.3, the surface temperatures of the cell casing shall be measured as follows: a) By thermocouples consisting of wires not larger than 0.21 mm2 (24 AWG) and not smaller than 0.05 mm2 (30 AWG) and a potentiometer-type instrument; and b) With the measuring junction of the thermocouple held tightly against the metal casing of the cell. *Exception: Placing the thermocouple on a thin piece of paper or label is an acceptable practice.*		N/A
E10.5	For protection, the Projectile Test in E11.10 shall be conducted in a room separate from the observer or within an appropriate containment chamber.		N/A
E10.6	Secondary lithium metal (i.e. lithium metal anode) cells shall be conditioned in accordance with E2.1 prior to the testing.		N/A
E10.7	The capacity of the samples for all lithium chemistries shall be confirmed in accordance with E2.2 prior to testing.		N/A
E11	**Tests**		**N/A**
E11.1	**Short-circuit test**		**N/A**

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
	Each test cell shall be short-circuited by connecting the positive and negative terminals with a resistance load of less than or equal to 20 mΩ. The temperature of the cell case shall be recorded during the test. The short circuit shall be applied until the cell case temperature has returned to ±10 °C (±18 °F) of ambient temperature. Tests shall be conducted at 55 ±5 °C (131 ±9 °F). The samples shall reach equilibrium at 55 ±5 °C (131 ±9 °F), as applicable, before the terminals are connected.		N/A
	Compliance criteria: No fire, no explosion.		N/A
E11.2	**Overcharge test**		**N/A**
	A cell shall be subjected to a constant current charge at the maximum specified charging current until the cell reaches 120 % of its maximum specified charge voltage limit or it reaches 130 % SOC, whichever comes first.		N/A
	Compliance criteria: No fire, no explosion.		N/A
E11.3	**Crush test**		**N/A**
	A cell shall be subjected to a bar crush using a bar with a 15-cm (5.9-in) diameter. The force for the crushing shall be applied by a hydraulic ram or similar force mechanism. The force shall be applied until one of the following in (a) – (c) occurs. Once the maximum force has been obtained, the force shall be released. a) A voltage (OCV) drop of one-third of the original cell voltage occurs; b) A deformation of 15 % or more (in the direction of the crush) of initial cell dimension occurs; or c) A force of 1000 times the weight of cell is reached. A cylindrical, pouch or prismatic cell shall be crushed with its longitudinal axis parallel to the crushing apparatus. Each sample shall be subjected to a crushing force in only one direction and the crush shall be conducted only on the wide side of a pouch or prismatic cell. Separate samples shall be used for each test.		N/A
	For other than pouch cells, the crush shall be applied in the center of the cells.		N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
	For pouch type cells, the crushing force shall be applied on the casing near where the cell tabs exit. If the positive and negative tabs are on opposite sides, the crush force shall be applied on the casing near where the negative tab exits.		N/A
	Compliance criteria: No fire, no explosion.		N/A
E11.4	**Impact test**		**N/A**
	A cell shall be placed on a flat surface. A 15.8 ±0.1-mm (5/8 ±0.004-in) diameter bar shall be placed across the center of the sample. A 9.1 ±0.46-kg (20 ±1-lb) weight shall be dropped from a height of 610 ±25 mm (24 ±1 in) onto the sample. The cell shall be impacted with its longitudinal axis parallel to the flat surface and perpendicular to the longitudinal axis of the 15.8-mm (5/8-in) diameter curved surface lying across the center of the test sample. For prismatic and pouch cells, only the wide side shall be impacted. Each sample shall be subjected to only a single impact. Separate samples shall be used for each test.		N/A
	Compliance criteria: No fire, no explosion.		N/A
E11.5	**Shock test**		**N/A**
	The cell shall be secured to the testing machine by means of a rigid mount which supports all mounting surfaces of the cell. Each cell shall be subjected to a total of three shocks of equal magnitude. The shocks shall be applied in each of three mutually perpendicular directions unless it has only two axes of symmetry in which case only two directions shall be tested. Each shock shall be applied in a direction normal to the face of the cell. For each shock, the cell shall be accelerated in such a manner that during the initial 3 ms the minimum average acceleration is 75 g (where g is the local acceleration due to gravity). The peak acceleration shall be between 125 and 175 g. Cells shall be tested at a temperature of 25 ±5 °C (77 ±9 °F).		N/A
	Compliance criteria: No venting, no leakage, no rupture, no fire, and no explosion.		N/A
E11.6	**Vibration test**		**N/A**

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
	A cell shall be subjected to simple harmonic motion with an amplitude of 0.8 mm (0.03 in) [1.6 mm (0.06 in) total maximum excursion]. The frequency shall be varied at the rate of 1 Hz/min between 10 and 55 Hz, and return in not less than 90 nor more than 100 min. The cell shall be tested in three mutually perpendicular directions. For a cell that has only two axes of symmetry, the cell shall be tested perpendicular to each axis. At the end of the vibration conditioning, the open circuit voltage (OCV) of the cell is measured and compared with the pre-test value.		N/A
	Compliance criteria: No venting, no leakage, no rupture, no fire, no explosion, and no OCV change. Note: No "OCV" change would be a drop in the open circuit voltage after testing of less than 10 % of the before test value.		N/A
E11.7	**Heating test**		**N/A**
	A cell shall be heated in a gravity convection or circulating air oven with an initial temperature of 25 ±5 °C (77 ±9 °F). The temperature of the oven shall be raised at a rate of 5 ±2 °C (9 ±3.6 °F) per minute to a temperature of 130 ±2 °C (266 ±3.6 °F) and remain for 10 min. For cells specified for temperatures above 100 °C (212 °F), the conditioning temperature shall be increased from 130 ±2 °C (266 ±3.6 °F), to 30 ±2 °C (86 ±3.6 °F) above the manufacturers maximum specified temperature. *Exception: For cells whose weight is greater than 500 g (1.1 lbs), the maximum temperature of the heating test shall be held for 30 min rather than 10 min.* The sample shall return to room temperature, 25 ±5 °C (77 ±9 °F), and then be examined.		N/A
	Compliance criteria: No fire, no explosion.		N/A
E11.8	**Temperature cycling test**		**N/A**

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
	The cells shall be placed in a test chamber and subjected to the following cycles: a) Raising the chamber-temperature to 85 ±2 °C (185 ±3.6 °F) or T_{max} + 10 °C (T_{max} is the manufacturer's maximum specified temperature) within 30 min and maintaining this temperature for 4 h; b) Reducing the chamber temperature to 25 ±5 °C (77 ±9 °F) within 30 min and maintaining this temperature for 2 h; c) Reducing the chamber temperature to minus 40 ±2 °C (minus 40 ±3.6 °F) within 30 min and maintaining this temperature for 4 h; d) Raising the chamber temperature to 25 ±5 °C (77 ±9 °F) within 30 min; e) Repeating the sequence for a further 9 cycles; and f) After the 10th cycle, storing the cells for a minimum of 24 h, at a temperature of 25 ±5 °C (77 ±9 °F) prior to examination. At the end of the cycling, the open circuit voltage (OCV) of the cell is measured and compared with the pre-test value.		N/A
	Compliance criteria: No venting, no leakage, no rupture, no fire, no explosion, and no OCV change. Note: No "OCV" change would be a drop in the open circuit voltage after testing of less than 10 % of the before test value.		N/A
E11.9	**Low pressure (altitude simulation) test**		**N/A**
	Sample cells shall be stored for 6 h at an absolute pressure of 11.6 kPa (1.68 psi) and a temperature of 25 ±5 °C (77 ±9 °F). At the end of the conditioning, the open circuit voltage (OCV) of the cell is measured and compared with the pre-test value.		N/A
	Compliance criteria: No venting, no leakage, no rupture, no fire, no explosion, and no OCV change. Note: No "OCV" change would be a drop in the open circuit voltage after testing of less than 10 % of the before test value.		N/A
E11.10	**Projectile test**		**N/A**

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict
	Each test sample cell shall be placed on a flat screen that covers a 102-mm (4-in) diameter hole in the center of a platform table. The flat screen cover shall be constructed of steel wire mesh having 20 openings per square 25.4 mm (1 in) area and a wire diameter of 0.43 mm (0.017 in). The screen shall be mounted 38 mm (1-1/2 in) above a Meker type burner. The fuel and air flow rates shall be set to provide a bright blue flame that causes the supporting screen to glow a bright red. An eight-sided covered wire cage, 610-mm (24-in) across and 305-mm (12-in) high, made from metal screening shall be placed over the test sample. See Figure E.2. The metal screening shall be constructed from 0.25-mm (0.010-in) diameter aluminum wire with 16 – 18 wires per square 25.4 mm (1 in) in each direction. *Exception No. 1: The overall dimensions of the projectile test aluminum test screen may be increased from those outlined above to accommodate large cells intended for EV applications but the flat panels of the test screen shall not exceed a distance of 305 mm (12 in) from the cell in any direction.* *Exception No. 2: The projectile test cage may be replaced by a visible circular perimeter marking on the supporting surface located 0.5 m (19.7 in) from the longest side of the cell. The marking shall be no greater than 5-mm (0.2-in) thick. The test set-up shall be located within a protective enclosure/room with noncombustible surfaces located a distance from the test perimeter marking where any projectiles that fall beyond the test perimeter marking can be safely contained.*		N/A
	The sample shall be heated and shall remain on the screen until it explodes or the cell has ignited and burned out. It is not required to secure the sample in place unless the sample is at risk of falling off the screen before the test is completed. When required, the sample shall be secured to the screen with a single wire tied around the sample.		N/A
	Compliance criteria: No projectile. Note: Those cells not complying with the Projectile Test of E11.10 can only be used in batteries that comply with the Thermal Exposure for Explosion Hazards Test of Section 41.		N/A
E12	**Test Samples and Results Criteria**		**N/A**
E12.1	**General**		**N/A**

<table>
<tr><th colspan="4">UL 1973</th></tr>
<tr><td>Clause</td><td>Requirement + Test</td><td>Result - Remark</td><td>Verdict</td></tr>
<tr><td></td><td>The test samples and results criteria for the tests in this annex shall be in accordance with Table E.2. Test results compliance criteria are defined in E12.2</td><td></td><td>N/A</td></tr>
<tr><td>E12.2</td><td>Test results compliance criteria</td><td></td><td>N/A</td></tr>
<tr><td></td><td>Venting is determined by evidence of mass loss as noted in Table E.3 below.
Table E.3 Venting and Leakage Mass Loss Criteria
<table>
<tr><td colspan="2">Mass of cell</td><td>Maximum mass percent loss</td></tr>
<tr><td>g</td><td>(oz)</td><td>%</td></tr>
<tr><td>≤ 1.0</td><td>(≤ 0.035)</td><td>0.5</td></tr>
<tr><td>>1.0, ≤ 5.0</td><td>(> 0.035, ≤0.176)</td><td>0.2</td></tr>
<tr><td>> 5.0</td><td>(> 0.176)</td><td>0.1</td></tr>
</table></td><td>Mass of cell > 5.0 g, Mass percent of loss ≤ 0.1%</td><td>N/A</td></tr>
<tr><td></td><td>Leakage is determined by evidence of visible liquid electrolyte on the external case of the cell or mass loss criteria as outlined in Table E.3.</td><td></td><td>N/A</td></tr>
<tr><td></td><td>Rupture is determined by a tear in the cell case at a location other than at the designed vent.</td><td></td><td>N/A</td></tr>
<tr><td></td><td>Fire is determined by evidence visible flames or of charging and burning of the cell and its contents.</td><td></td><td>N/A</td></tr>
<tr><td></td><td>Explosion is determined by evidence of disassembly of the cell and its contents beyond a rupture of the case.</td><td></td><td>N/A</td></tr>
<tr><td colspan="4">APPENDIX F Cell Failure Methods</td></tr>
<tr><td colspan="4">APPENDIX G Safety Marking Translations</td></tr>
</table>

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict

Refference	English	French
44.3	"Repurposed"	« Réutilisé »
44.3	“Second Life”	« deuxième vie »
44.3	"UL 1974"	« UL 1974 »
44.6	"Use Only ( ) Charger"	« Utiliser Uniquement ( ) Chargeur »
44.8	"caution"	« attention »
44.8	"read instruction manual"	« Lire le manuel d'instruction »
44.17(b)	“Warning: Risk of fire, explosion, or burns. Do not disassemble, heat above XX °C (or °F), or incinerate." (Where XX is the cell or battery’s maximum temperature specification.)	« Mise en garde : Risque d’incendie, d'explosion ou de brûlures. Ne pas démonter, chauffer à plus de XX °C (ou °F) ou incinérer. » (XX correspond à la température maximale que peut supporter une pile ou une batterie)
45.5	"DANGER," "WARNING," or "CAUTION."	« DANGER », « AVERTISSEMENT » ou « ATTENTION ».
16.1	“Corrosive fluid inside, only maintained by the manufacturer”	« Fluide corrisif à l’intérieur, seul le fabricant doit s’occuper de l’entretien »
16.2	“Indoor Use Only”	« Pour utilisation intérieure seulement »
16.3	“No User Serviceable parts, only mechanically recharged or refueled by authoriz	« Aucune des pièces ne peut être réparée par l’utilisateur; recharger mécaniquement ou ravita

French Required in Canada. P

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict

		ed service personnel”	iller par un personnel d’entretien qualifié uniquement. »		
	17.1	“ Do not use a cell stack/anode metal plate if it has been dropped, as it may result in a hazardous condition.”	« Ne pas utiliser un assemblage de cellules ou une plaque anode métallique s’ils ont été échappés, car une situation dangereuse pourrait en résulter. »		
APPENDIX H Alternative Approach for Evaluating Valve Regulated or Vented Lead Acid or Nickel Cadmium Batteries					
H1	**General**				**N/A**
APPENDIX I Test Program for Mechanically Rechargeable Metal-Air Batteries					
I1	**General**				**N/A**

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict

Cl. 2.1	Table: Critical Components				P
Object/part No.	**Manufacturer/ trademark**	**Type/Model**	**Technical Data**	**Standard**	**Marks of Conformity** [1)]
-	-	-	-	-	-

[1)] Components shall comply with all the applicable CSA Group and UL component standards. License available upon request.

-See attachment CDF for details.

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict

Cl. 15	TABLEL: Overcharge Test			P
Sample No.	OCV of DUT before test, Vdc	Device single faulted	Test Voltage applied to DUT, V	Charging curent, A
Battery 1#	150.51	-	189.8*1.1=208.78	306
-	-	-	-	-

Max Temp Measured, °C	Max Voltage Measured of DUT in Charging, V	The tested DUT, Operational / Inoperational	Dielectric Voltage Test, Brk / No Brk	Results
36.8	185.71	Operational	No Brk	Pass
-	-	-	-	-

Supplementary information:

☐ Testing on the complete battery system
☒ Testing on a subassembly as representative of the battery system
☐ Others:

Results:

As a result of the overcharge test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1.

a) E – Explosion;
b) F – Fire;
c) C – Combustible vapor concentrations;
d) V – Toxic vapor release;
e) S – Electric shock hazard (dielectric breakdown);
f) L– Leakage (external to enclosure of DUT);
g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3);
h) P – Loss of protection controls.

Remark: No non-compliant results. No venting, leakage and rupture of the internal cell was occurred.

Cl. 16	TABLEL: High Rate Charge			P
Sample No.	OCV of DUT before test, Vdc	Device single faulted	Max Charging curent, A	Test Voltage applied to DUT, V
Battery 1#	161.81	-	367.21	189.8
-	-	-	-	-

Max Temp Measured, °C	Max Voltage Measured of DUT in Charging, V	The tested DUT, Operational / Inoperational	Dielectric Voltage Test, Brk / No Brk	Results
32	171.33	Operational	No Brk	Pass
-	-	-	-	-

Supplementary information:

☐ Testing on the complete battery system
☒ Testing on a subassembly as representative of the battery system
☐ Others:

Results:

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict

As a result of the overcharge test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1.

a) E – Explosion;
b) F – Fire;
c) C – Combustible vapor concentrations;
d) V – Toxic vapor release;
e) S – Electric shock hazard (dielectric breakdown);
f) L– Leakage (external to enclosure of DUT);
g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3);
h) P – Loss of protection controls.

Remark: No non-compliant results. No venting, leakage and rupture of the internal cell was occurred.

Cl. 17	TABLEL: Short circuit test – test on battery module						P
Sample No.	OCV before test, Vdc	Measured External Short Circuit Resistance, mΩ	Device single faulted	Maximum short circuit current, A	Maximum short circuit duration	Specified short circuit current, A	Specified short circuit duration
Battery 1#	170.5	19.3	-	6452	375ms	-	-
-	-	-	-	-	-	-	-

Max Temp. Measured, °C	Maximum drawed discharging current, A	OCV of discharged DUT after test, V	The tested DUT, Operational / Inoperational	Dielectric Voltage Test, Brk /No Brk	Results
29.1	-	0	Inoperational	No Brk	Pass
-	-	-	-	-	-

Supplementary information:

☐ Testing on the complete battery system
☐ Testing on a subassembly as representative of the battery system
☒ Others: Battery module

Results:

As a result of the Short Circuit Test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1.

a) E – Explosion;
b) F – Fire;
c) C – Combustible vapor concentrations;
d) V – Toxic vapor release;
e) S – Electric shock hazard (dielectric breakdown);
f) L– Leakage (external to enclosure of DUT);
g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3);
h) P – Loss of protection controls.

Remark: No non-compliant results. No venting, leakage and rupture of the internal cell was occurred.

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict

Cl. 17	TABLEL: Short circuit test – test on complete battery system						P
Sample No.	OCV before test, Vdc	Measured External Short Circuit Resistance, mΩ	Device single faulted	Maximum short circuit current, A	Maximum short circuit duration	Specified short circuit current, A	Specified short circuit duration
Rack 1#	1396.3	19.561	-	12840	300μs	12940	300μs
Rack 5#	1396.3	19.561	-	12940	300μs	12940	300μs

Max Temp. Measured, °C	Maximum drawed discharging current, A	OCV of discharged DUT after test, V	The tested DUT, Operational / Inoperational	Dielectric Voltage Test, Brk /No Brk	Results
29	-	0	Inoperational	No Brk	Pass
-	-	-	-	-	-

Supplementary information:

☒ Testing on the complete battery system
☐ Testing on a subassembly as representative of the battery system
☐ Others:

Results:

As a result of the Short Circuit Test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1.

a) E – Explosion;
b) F – Fire;
c) C – Combustible vapor concentrations;
d) V – Toxic vapor release;
e) S – Electric shock hazard (dielectric breakdown);
f) L– Leakage (external to enclosure of DUT);
g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3);
h) P – Loss of protection controls.

Remark: No non-compliant results. No venting, leakage and rupture of the internal cell was occurred.

Cl. 18	TABLEL: Overload Under Discharge			P
Sample No.	OCV before test, Vdc	Device single faulted	Measured discharging current, A	Passive device rating, A
Battery 1#	171.11	-	306	-

Max Temp. Measured in test, °C	The minimum cell voltage, V	The tested DUT, Operational / Inoperational	Dielectric Voltage Test, Brk/No Brk	Results
28	2.437	Operational	No Brk	Pass

Supplementary information:

☐ Testing on the complete battery system
☒ Testing on a subassembly as representative of the battery system
☐ Others:

Results:

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict

As a result of the Overdischarge Protection Test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1.

a) E – Explosion;
b) F – Fire;
c) C – Combustible vapor concentrations;
d) V – Toxic vapor release;
e) S – Electric shock hazard (dielectric breakdown);
f) L– Leakage (external to enclosure of DUT);
g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3);
h) P – Loss of protection controls.

Remark: N/A

Cl. 19	TABLEL: Overdischarge Protection Test			P
Sample No.	OCV before test, Vdc	Device single faulted	Measured discharging current, A	Passive device rating, A
Battery 1#	171.11	-	306	-

Max Temp. Measured in test, °C	The minimum cell voltage, V	The tested DUT, Operational / Inoperational	Dielectric Voltage Test, Brk/No Brk	Results
35	2.437	Operational	No Brk	Pass

Supplementary information:

☐ Testing on the complete battery system
☒ Testing on a subassembly as representative of the battery system
☐ Others:

Results:

As a result of the Overdischarge Protection Test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1.

a) E – Explosion;
b) F – Fire;
c) C – Combustible vapor concentrations;
d) V – Toxic vapor release;
e) S – Electric shock hazard (dielectric breakdown);
f) L– Leakage (external to enclosure of DUT);
g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3);
h) P – Loss of protection controls.

Remark: No non-compliant results. No venting, leakage and rupture of the internal cell was occurred.

Cl. 20	TABLEL: Temperature and Operating Limits Check Test			P
Sample No.	Maximum Charging Current, A	Maximum Charging Voltage, Vdc	End of Charging Current, A	Ambient Temperature, °C
Container 1#	1613	1447.9	-	55.1

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict

Maximum Charging Rate, W	End of discharge voltage, Vdc	Maximum Discharging Rate, W	Charging and Discharging Cycle	Dielectric Voltage Test, Brk/No Brk	Results
2020280	-	2079660	3	No Brk	Pass

Max charging current of Cell in Cycle, A	Max Voltage of Cell in cycle, V	Max discharging current of Cell in Cycle, A	Minimum Voltage of Cell in cycle, V
322.6*	3.621	364.2*	2.494

Supplementary information:

☒ Testing on the complete battery system
☐ Testing on a subassembly as representative of the battery system
☐ Others:

Results

Additional non-compliant results during the temperature test are as noted below in (a) – (e). For additional information on non-complying results refer to Table 12.1.

a) E – Explosion;
b) F – Fire;
e) S – Electric shock hazard (dielectric breakdown);
f) L– Leakage (external to enclosure of DUT);
g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3);

Remark: No non-compliant results. No venting, leakage and rupture of the internal cell was occurred.

Notes : * The max charging/discharging current of cell is under the pulse current of the constant power cell(979.2W) of 2 parallel.

Cl. 20	TABLEL: Temperature and Operating Limits Check Test		P
Work condition.....:		Charging and discharging	
Ambient T_{amb} (°C) .....:		55 °C	
Max operating Temp. T_{ma} (°C) ....:		55 °C	
Measuring location		Max. Measured Temp. [ºC]	Max. Temp. Limit [°C]
Top of cluster 1, 4# electrical box upper cover		35.52	90
Cluster 1, 4# electrical box at CSC center		53.80	125
High voltage wiring harness on the positive bus side		91.25	125
Positive bus bar		84.55	125
Positive bus and insulator joint		66.39	135
Insulating paper		69.76	140
Sealing gasket for the outlet hole of the positive high voltage cable		58.17	80
Air switch		59.31	70
relay		62.27	75
Terminal strip		57.15	105

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict

transformer	81.00	155
AC-DC	62.40	70
DC-DC	58.90	70
PCB of IMM chip accessories (need to open the IMM shell	57.64	130
IMM optocoupler (need to open the IMM shell and lay corresponding	58.55	85
Fire protection system - Control panel center	55.23	65
Isolation switch - ring temperature (Cluster 1 main control box)	72.19	75
Contactor/relay - Ring temperature (Cluster 1 main control box)	73.87	85
Hall Sensor - Ring temperature (Cluster 1 main control box)	73.53	85
Copper bus base body (Cluster 1 main control box)	64.54	100
Fuse- Ring temperature (Cluster 1 main control box)	86.67	100
Fan-ring temperature (Cluster 1 main control box)	70.42	75
Prefilled relay - Ring temperature (Cluster 1 main control box)	69.08	85
SBMU High Voltage Connector body (Cluster 1 main control box)	64.90	125
SBMU isolation chip body (in SBMU of Cluster 1 main control box)	71.89	85
Ambient	55	Ref.

Supplementary information:
The test was conducted at ambient temperature 55°C, Operation mode: Constant power 2036.73kw. The cooling system is continuous working during the test.

Cl. 21	TABLEL: Imbalanced Charging Test				P
Sample No.	Initial OCV of 50% discharged module/cell, Vdc	OCV of the complete battery system, Vdc	Device single faulted	Measured Maximum charging current, A	Measured Maximum charging voltage, Vdc
Battery1# & Battery 2#	172.9	337.6	-	297.4	366.1

Measured Maximum Voltage on 50% discharged module/cell, Vdc	Measured Maximum Temp. on 50% discharged module/cell, °C	The tested DUT, Operational / Inoperational	Dielectric Voltage Test, Brk / No Brk	Results
3.65	30	Operational	No Brk	Pass

Supplementary information:

☐ Testing on the complete battery system
☒ Testing on a subassembly as representative of the battery system
☐ Testing on a altenate configuration as representative of the battery system
☐ Others:

Results:

As a result of the Imbalanced Charging Test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1.

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict

a) E – Explosion;
b) F – Fire;
c) C – Combustible vapor concentrations;
d) V – Toxic vapor release;
e) S – Electric shock hazard (dielectric breakdown);
f) L– Leakage (external to enclosure of DUT);
g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3);
h) P – Loss of protection controls.

Remark: No non-compliant results. No venting, leakage and rupture of the internal cell was occurred.

Cl.22	**Table: Dielectric Voltage Withstand Test**				**P**
Sample No.	Battery1#				
Test voltage applied between:	Voltage RMS (V)	Voltage Peak (V)	Voltage shape (Surge, Impulse, AC, DC, etc.)	Test voltage (Vdc)	Breakdown Yes / No
Battery Rack					
Battery system HV (+) to PE (BI)	-	-	-	DC 4414	No
Battery system HV (-) to PE (BI)	-	-	-	DC 4414	No
Battery system HV (+) to Communication circuit (RI)	-	-	-	DC 6000	No
Battery system HV (-) to Communication circuit (RI)	-	-	-	DC 6000	No
Container					
Busbar HV (+) to PE (BI)	DC 4414	-	-	DC 4414	No
Busbar HV (-) to PE (BI)	DC 4414	-	-	DC 4414	No
AC input to PE (BI)	DC 2120	-	-	DC 2120	No
Cooling system AC input to Communication circuit (RI)	DC 4240	-	-	DC 4240	No

Supplementary information:

Results:

As a result of the Dielectric Voltage Withstand Test, the following (e) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1.

e) S – Electric shock hazard (dielectric breakdown);

Remark: No non-compliant results. No venting, leakage and rupture of the internal cell was occurred.

Note(s): N/A

Cl. 25	**Table: Working Voltage Measurements**	**P**

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict

Sample No.	Container 1#		
Location	RMS voltage (V)	Peak voltage (V)	Comments
Battery power circuit (+) to (-)	1437	1500	-
-	-	-	-
Remark:			

Cl.23	**Table: Continuity Test**			**P**
Sample No.	Battery 1#			
Part	Tested current	Tested voltage	Measured Resistance	Result
Grounding point of electric compartment to electric compartment door handle	-	-	0.019 Ω	≤ 0.1Ω
-to grounding point of the left door of the electrical compartment	-	-	0.014 Ω	≤ 0.1Ω
-to grounding point of the right door of the electrical compartment	-	-	0.028 Ω	≤ 0.1Ω
-to grounding point of the 1# door of the battery compartment	-	-	0.017 Ω	≤ 0.1Ω
-to grounding point of the 3# door of the battery compartment	-	-	0.018 Ω	≤ 0.1Ω
-to grounding point of the 4# door of the battery compartment	-	-	0.018 Ω	≤ 0.1Ω
-to grounding point of the 5# door of the battery compartment	-	-	0.018 Ω	≤ 0.1Ω
-to grounding point of the 1# main control box	-	-	0.021 Ω	≤ 0.1Ω
-to grounding point of the 2# main control box	-	-	0.022 Ω	≤ 0.1Ω

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict

-to grounding point of the 3# main control box	-	-	0.022 Ω	≤ 0.1Ω
-to grounding point of the 4# main control box	-	-	0.047 Ω	≤ 0.1Ω
-to grounding point of the 5# main control box	-	-	0.024 Ω	≤ 0.1Ω
-to grounding point of the cooling system	-	-	0.019 Ω	≤ 0.1Ω
Grounding point of the 1# main control box to grounding point of 1# rack's 8# module	-	-	0.014 Ω	≤ 0.1Ω
Grounding point of the 2# main control box to grounding point of 2# rack's 8# module	-	-	0.014 Ω	≤ 0.1Ω
Grounding point of the 3# main control box to grounding point of 3# rack's 8# module	-	-	0.014 Ω	≤ 0.1Ω
Grounding point of the 4# main control box to grounding point of 4# rack's 8# module	-	-	0.024 Ω	≤ 0.1Ω
Grounding point of the 5# main control box to grounding point of 5# rack's 8# module	-	-	0.015 Ω	≤ 0.1Ω
Remark:				

Cl. 42	TABLEL: Single Cell Failure Design Tolerance					P
Sample No.	Initial OCV, V	Location of Failed Cell	Max Temp Measured on Failed cell, °C	Maximum Temp on Adjacent Cells °C	Maximum Temp on DUT enclosure, °C	Results
Battery 2#	173.2	Near module center	579.3	516.7	-	P
Result Key						
Supplementary information: **Results:** 1 – Thermal runaway did occur but fire did not propagate outside of the DUT and it did not explode.						

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict

2 –Thermal runaway did not occur, there was no explosion or fire outside of the DUT
3 – Thermal runaway occurred and fire propagated outside of the DUT.
4 – Thermal runaway occurred and the sample exploded.
5 - Other
Remark: External heater used to create a thermal runaway. Thermal runaway occured to the adjacent cell.

E2.2	**TABLEL: Capacity check**				**N/A**
Sample No.	OCV before Capacity check discharging, V	Discharging current, A	Discharged duration, h	Measured capacity, Ah	Results
(1) Measured capacity equal or exceed the rated specifications.					
(2) Measured capacity less than the rated specifications.					
(3) Others (explain)					
Remark:					

E3 / E11.1	**TABLEL: Short-Circuit Test**				**N/A**
Sample No.	Ambient Temp. °C	Initial OCV, V	Total load resistance of circuit, mΩ	Maximum Temperature of Cell Case, °C	Results
Result:					
(1) Sample remained intact (i.e. did not vent, Leakage, Rupture, catch on fire or explode)					
(2) Sample bulged					
(3) Sample vented					
(4) Leakage					
(5) Rupture					
(6) Sample caught on fire					
(7) Sample exploded					
(8) Sample smoldered without flame					
(9) Other (explain)					
Remark:					

E4 / E11.4	**TABLEL: Cell Impact**	**N/A**

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict

Sample No.	OCV of cell before test, V	Impact from height, m	Maximum Temperature on Cell Casing, °C	Results

Result:

(1) Sample remained intact (i.e. did not vent, Leakage, Rupture, catch on fire or explode)

(2) Sample bulged

(3) Sample vented

(4) Leakage

(5) Rupture

(6) Sample caught on fire

(7) Sample exploded

(8) Sample smoldered without flame

(9) Other (explain)

Remark:

E7 / E11.2	TABLEL: Overcharge test	N/A

Sample No.	OCV of Cell before Test, V	Max Charging current, A	Total Charging duration, h	Maximum charging Voltage in Test, V	Maximum Temp. of Cell in Test, ºC	Results

Result:

(1) Sample remained intact (i.e. did not vent, Leakage, Rupture, catch on fire or explode)

(2) Sample bulged

(3) Sample vented

(4) Leakage

(5) Rupture

(6) Sample caught on fire

(7) Sample exploded

(8) Sample smoldered without flame

(9) Other (explain)

Remark:

E8	TABLEL: Forced Discharge	N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict

Sample No.	OCV before applying reverse charging, V	Target Voltage , V	Measured Reverse Charge Current It, A	Total Time for Reversed Charge Application, min	Results

Result:

(1) Sample remained intact (i.e. did not vent, Leakage, Rupture, catch on fire or explode)

(2) Sample bulged

(3) Sample vented

(4) Leakage

(5) Rupture

(6) Sample caught on fire

(7) Sample exploded

(8) Sample smoldered without flame

(9) Other (explain)

Remark:

E9 / E11.10	TABLEL: Projectile test		N/A
Sample No.	OCV before test, V	OCV after test, V	Results

Result:

(1) Cell did not explode.

(2) Cell exploded but no part of the cell casing penetrated the wire screen.

(3) Cell exploded such that particles from the casing penetrated the wire screen.

(4) Cell vented without exploding.

(5) Cell caught on fire without explosion

(6) Other.

Remark:

E11.3	TABLEL: Crush test		N/A
Sample No.	OCV before test, V	Thickness before test, mm	Weight, kg

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict

Pressure applied, kN	OCV after test, V	Thickness after test, mm	Results

Result:

(1) Sample remained intact (i.e. did not vent, Leakage, Rupture, catch on fire or explode)

(2) Sample bulged

(3) Sample vented

(4) Leakage

(5) Rupture

(6) Sample caught on fire

(7) Sample exploded

(8) Sample smoldered without flame

(9) Other (explain)

Remark:

E11.5	TABLEL: Shock test				N/A
Sample No.	OCV before test, V	Mass before test, kg	OCV after test, V	Mass after test, kg	Results

Result:

(1) Sample remained intact (i.e. did not vent, Leakage, Rupture, catch on fire or explode)

(2) Sample bulged

(3) Sample vented

(4) Leakage

(5) Rupture

(6) Sample caught on fire

(7) Sample exploded

(8) Sample smoldered without flame

(9) OCV changed (a drop in the open circuit voltage after testing of more than 10% of the before test value)

(10) Other (explain)

Remark:

E11.6	TABLEL: Vibration test	N/A

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict

Sample No.	OCV before test, V	Mass before test, kg	OCV after test, V	Mass after test, kg	Results

Result:

(1) Sample remained intact (i.e. did not vent, Leakage, Rupture, catch on fire or explode)

(2) Sample bulged

(3) Sample vented

(4) Leakage

(5) Rupture

(6) Sample caught on fire

(7) Sample exploded

(8) Sample smoldered without flame

(9) OCV changed (a drop in the open circuit voltage after testing of more than 10% of the before test value)

(10) Other (explain)

Remark:

E11.8	TABLEL: Temperature cycling test				N/A
Sample No.	OCV before test, V	Mass before test, kg	OCV after test, V	Mass after test, kg	Results

Result:

(1) Sample remained intact (i.e. did not vent, Leakage, Rupture, catch on fire or explode)

(2) Sample bulged

(3) Sample vented

(4) Leakage

(5) Rupture

(6) Sample caught on fire

(7) Sample exploded

(8) Sample smoldered without flame

(9) OCV changed (a drop in the open circuit voltage after testing of more than 10% of the before test value)

(10) Other (explain)

Remark:

UL 1973			
Clause	Requirement + Test	Result - Remark	Verdict

E11.9	TABLEL: Low pressure (altitude simulation) test				N/A
Sample No.	OCV before test, V	Mass before test, kg	OCV after test, V	Mass after test, kg	Results

Result:

(1) Sample remained intact (i.e. did not vent, Leakage, Rupture, catch on fire or explode)

(2) Sample bulged

(3) Sample vented

(4) Leakage

(5) Rupture

(6) Sample caught on fire

(7) Sample exploded

(8) Sample smoldered without flame

(9) OCV changed (a drop in the open circuit voltage after testing of more than 10% of the before test value)

(10) Other (explain)

Remark:

--End of Report-

Appendix E

CATL EnerC+ 306 Container Product Specifications



EnerC+ 306 Container Product Specification

地址：福建省宁德市蕉城区漳湾镇新港路 2 号 ADD: No.2 Xin'gang Road, Zhangwan Town, Jiaocheng District, Ningde City, Fujian, PRC 352100
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Version	Date	Changes
1.0	Nov. 30, 2022	First Release
1.1	Apr. 24, 2023	Updated some descriptions
1.2	Jun.30, 2023	Updates some descriptions
2.0	Aug. 07, 2023	Updates some descriptions (Auxiliary, weight, fire protection system, aerosol as an option, etc.)
2.1	Oct. 11, 2023	Updates some descriptions (Update of SOC precision algorithm, short circuit current, etc)
2.2	Dec.01,2023	Update the input voltage of auxiliary power and the power of ventilation fan
2.3	Feb.22.2024	Add low voltage limit caution

Contents

Tables I
Figures II
1 General Introduction 1
1.1 Confidentiality 1
1.2 Purpose of Document 1
1.3 Definitions and Abbreviations 1
1.3.1 Definitions 1
1.3.2 Abbreviations 2
2 System Description 4
2.1 Application 4
2.2 Overview 4
2.2.1 Battery 5
2.2.2 BMS 5
2.2.3 FSS 6
2.2.4 TMS 6
2.3 Advantages 6
3 System Specifications 8
3.1 Power and Energy 8
3.2 Electrical Specifications 8
3.3 Mechanical Specifications 9
3.4 Environmental Specifications 9
3.5 Certification Standard 10
4 Battery Management System(BMS) 12
4.1 BMS Overview 12
4.2 BMS Architecture 12
4.3 BMS Function 13
4.3.1 Battery Status Monitoring 14
4.3.2 Charging/Discharging Management 14
4.3.3 Thermal Management 15
4.3.4 Program Refreshing 15
4.3.5 High Voltage Safety Monitoring 15

4.3.6 Peripheral Monitoring and Control Management 15
4.3.7 Fault Diagnosis Management 16
5 Fire Suppression System(FSS) 17
5.1 FSS Overview 17
5.2 FSS Function 17
5.2.1 Detection System 17
5.2.2 Explosion-Proof System 19
5.2.3 Fire Extinguishing System 20
6 Thermal Management System(TMS) 23
6.1 TMS Overview 23
6.2 TMS architecture 23
6.3 TMS Specification 25
7 User Interface 26
7.1 PCS Requirements 26
7.2 Fuse Matching 26
7.3 Common Mode Voltage 27
7.4 Communication 28
8 Appendix 30

Tables

Table 1 Power and Energy of EnerC+ 8

Table 2 Electrical specifications of EnerC+ 8

Table 3 Mechanical Data of EnerC+ 9

Table 4 Environmental Specifications of EnerC+ 9

Table 5 Certification Standard 10

Table 6 Detailed Performance Parameters of BMS 13

Table 7 Detector Type and Position Description 18

Table 8 The Parameters of the Inlet 20

Table 9 The Parameters of the Exhaust Port 20

Table 10 The Paraments of The Flange 21

Table 11 The Parameters of the Nozzle 21

Table 12 Main Feature of Thermal Management System 25

Table 13 Power Consumption of Thermal Management System 25

Figures

Figure 1 EnerC+ Liquid Cooling Energy Storage Container – Sideview 4

Figure 2 EnerC+ Liquid Cooling Energy Storage Container – Sideview Without Door 5

Figure 3 Three-Level BMS Architecture for One Container 12

Figure 4 Three-level BMS Architecture for Two Containers in Parallel 13

Figure 5 The Interactive Interface of FSS 17

Figure 6 Type and Location of Detectors 19

Figure 7 Smoke exhaust ventilation system 19

Figure 8 Dry Pipe System 21

Figure 9 Overview of the cooling unit of EnerC+ 23

Figure 10 Architecture of Thermal Management System 24

Figure 11 PCS Matching 26

Figure 12 Fuse Matching 27

Figure 13 One PCS for One Transformer 28

Figure 14 Multiple PCSs for One Transformer 28

Figure 15 The Communication Architecture of the System with two containers in parallel 29

Figure 16 The Front View and Dimensions of EnerC+ 30

Figure 17 The Side View and Dimensions of EnerC+ 30

Figure 18 The Top View and Dimensions of EnerC+ 31

Figure 19 Case1 containers installation layout 31

Figure 20 case 2 containers installatiuon layout 32

1 General Introduction

1.1 Confidentiality

This product specification is intended to be seen only by persons directly involved in this project. Transfer to other parties, especially to partners without the approval of CATL, has to be coordinated by the person in charge of this project in CATL and is governed by declarations relating confidentiality in the development contract.

1.2 Purpose of Document

This document is a product specification formulated by Contemporary Amperex Technology Company Limited (CATL) for Battery Energy Storage System developed by CATL. It describes and stipulates the performance index, basic functions, interface and communication, key parameters, safety characteristics, this product, as well as matters needing attention of users and relevant legal statements.

The specifications and parameters of the products are provided in this document. If the contract parties find any inadequacies, they shall inform us so as to develop better products.

CATL possesses the right to update and clarify this document.

1.3 Definitions and Abbreviations

1.3.1 Definitions

BESS: Battery Energy Storage System, using electrochemical cells to storage electrical energy.

Frequency Modulation: The grid should work under stable frequency while other uncontrol events will disturb the frequency. So, the active power shall be supplied to modulate the frequency of grid. The BESS shall provide the active power for the grid.

Voltage Modulation: The grid should work under stable voltage while other uncontrol events, especially the inductive load and capacitive load will disturb the voltage. So, the reactive power shall be supplied to modulate the voltage of grid. The BESS shall provide the reactive power for the grid.

Peak shaving and Valley filling: When the power plants generate more energy than the demand, the containers shall absorb the excess energy which called peak shaving. When the power plants generate less energy than the demand, the containers shall release the lack of energy which called Valley filling.

PV: Photovoltaic power generation.

Wind power: Power get from the rotation blade driven by wind.

Modbus TCP: The Modbus protocol including three kinds of messages: ASCII, RTU, TCP. Modbus TCP is a kind of communication protocol which is widely used in the industrial field.

Container: The container for the battery energy storage system.

Module: A mechanically integrated arrangement of cells connected in series and/or parallel, complete with packaging, thermal management, output DC connections, and associated cell sensing.

Cell: The smallest non-divisible component of the EnerC+ System, assembled into a battery module in series and parallel arrays.

RTE: Round-trip Efficiency, defined as discharging of the system from 100% SOC to 0% SOC immediately followed by charging the system from 0% SOC to 100% SOC. The Round-trip DC-DC energy efficiency shall be measured at the DC terminals of the container.

1.3.2 Abbreviations

BMS: Battery Management System.

TMS: Thermal Management System.

CAN: Controller Area Communication.

FSS: Fire Suppression System.

PCS: Power Conversion System.

BOL: Beginning of Life.

EOL: End of Life.

SOC: State of Charge.

SOH: State of Health.

CSC: Cell Supervision Circuit， the base unit of battery management.

SBMU: Slave Battery Management Unit, collects and analyses the data from CSC, and uploads to the MBMU.

MBMU: Main Battery Management Unit. The core control unit of the container.

EMS: Energy Management System. Monitoring and manage the charge and discharge of the BESS.

Sub Control Box: Including the SBMU fuse isolation switch and other components.

Master Control Box: Including the IMM, MBMU ETH fiber conversion module.

Distribution Box: Including auxiliary power system, UPS and other components.

2 System Description

2.1 Application

The EnerC+ container is a modular fully integrated product , consisting of rechargeable lithium-ion batteries, with the characteristics of high energy density, long service life, high efficiency. It can provide stable energy release for over 2h when the batteries are fully charged. The EnerC+ Energy Storage product is capable of various on-grid applications, such as frequency regulation, voltage support, arbitrage, peak shaving and valley filling, and demand response.In addition, EnerC+ container can also be used in black start, backup energy, congestion managemet, microgrid or other off-grid scenierios.

2.2 Overview

The overview of the container is shown in Figure 1. The detailed information can be found in the following chapters.



Figure 1 EnerC+ Liquid Cooling Energy Storage Container – Sideview



Figure 2 EnerC+ Liquid Cooling Energy Storage Container – Sideview Without Door

The EnerC+ container consists of following parts: batteries, BMS, FSS and TMS, which are integrated together to keep the normal working of the container.

2.2.1 Battery

The capacity of cell is 306Ah, 2P52S cells integrated in one module, 8 modules integrated into one rack, 5 racks integrated into one container. As the core of the energy storage system, the battery releases and stores energy.

2.2.2 BMS

BMS adopts the distributed scheme, through the three-level (CSC--SBMU--MBMU) architecture to control the BESS, to ensure the stable operation of the energy storage system. It can manage energy absorption and release, the thermal management system and low voltage power supply according to the detected information: battery voltage, current and temperature. It can monitor high voltage DC/AC security, diagnosis and analysis faults according information from various detectors and dry-contacts. And it can keep communication with PCS and EMS through CAN. The BMS is the most important control unit of EnerC+ container. The BMS possesses the UPS to keep normal function when facing the temporary out of power.

2.2.3 FSS

FSS consists of smoke detectors, heat detectors (optional), H2 detectors, the fire control panel, aerosol , the dry pipe(optional), the smoke exhaust ventilation system and the UPS. FSS undertakes functions : monitor the thermal run-away risks of container through the detectors, extinguish the thermal run away, especially the flame fire, control the loss to minimum. The control panel will control and record information for the fire suppression system. The FSS is independent with any other system and it is the security guard of EnerC+ container.

2.2.4 TMS

TMS consists of one powerful chiller, the PTC heater and the liquid cooling pipe distributed in each battery module. The TMS will control and keep the temperature of battery within reasonable range. The battery will work at best state and reach longest life under the thermal management system.

2.3 Advantages

Our EnerC+ container possesses the advantages below:

1) **Standard design.** The 20ft design is very convenient for the transportation. The standard design can be installed one-stop.

2) **New generation Cell.** EnerC+ container integrates the LFP 306Ah cells from CATL, with more capacity, slow degradation, longer service life and higher efficiency.

3) **High integrated.** The cell to pack and modular design will increase significantly the energy density of the same area. The system is highly integrated, and the area energy density is over 270 kWh/m^2.

4) **Extreme safety.** The system supports three levels of safety:

   Firstly, the cell safety, the highly stable lithium iron phosphate is used in the EnerC+ container. LFP is a kind of safety material especially for the BESS.

   Secondly, the electrical safety: a) E-Stop design; b)multiple fuse protection design; c) insulation monitor voltage monitor; d) multi-channel isolation design; e) lightning protection design.

   Thirdly, the fire protection design, CATL has four-level fire control strategy. The first-level is the alarm. The second-level is ventilation and smoke exhausting to prevent deflagration. The third-level is aerosol to extinguish initial fire, and the fourth-level is the dry pipe sprinkle fire protection to prevent fire spread.

5) **Adaptive thermal management.** EnerC+ integrated single-cluster water pump, temperature control

strategy automatically adjusted with battery status, prolonging battery life.

6) **Easy extension.** It is very convenient for the augmentation of containers or racks. Furthermore, the EnerC+ support one PCS connected to 2 containers; this will decrease the covered area significantly.

7) **Independent UPS.** EnerC+ container have integrated two UPS system, one is for FSS monitoring system which available capacity is 24 hours, another one is for BMS which available capacity is 20 minutes

3 System Specifications

In this chapter, the systems specifications will be introduced in detail. For the BESS, the system specifications included the power and energy, electrical specifications, the environmental specifications, the mechanical specifications and certification standards. The product model is C02306P05L01.

3.1 Power and Energy

Table 1 Power and Energy of EnerC+

DC Side Data		
Product Model	**C02306P05L01**	**Remark**
P-Rate	0.5P	
Cell		
Cell type	LFP	
Cell capacity	306Ah	
Cell Voltage range	2.5-3.65V	should not be less than 2.5 V in any case
Cell rated Energy	979.2Wh	
System		
Configuration	5P2P416S	
Rated Energy	4073.47kWh	
Rated Voltage	1331.2VDC	
Voltage Range	1040 ~ 1500VDC	
Rated Charging Current	1530A	
Maximum Charging Current	1958.4A	For 1 minutes
Rated Charging Power	2036.73kW	
Rated Discharging Current	1530A	
Maximum Discharging Current	1958.4A	For 1 minutes
Rated Discharging Power	2036.73kW	

3.2 Electrical Specifications

For the auxiliary power supply, the standard configuration is 2 auxiliary power circuit. Auxiliary 1 and auxiliary 2 is listed in Table 2. The UPS for the BMS components is include in the auxiliary power circuit. The optional configuration is 1 auxiliary power circuit and the detailed configurations can be consulted to CATL.

Table 2 Electrical specifications of EnerC+

Auxiliary Power & Communication		
Product Model	**C02306P05L01**	**Remark**

P-Rate		0.5P	
Auxiliary Power 1	**Voltage Range**	3AC+N+PE 480V(380…480V) ±10%，50/60HZ	
	Power	Max. 37.0kW	For reference
	Inrush Current	≤67.5A， ＜5S	
Auxiliary Power 2	**Voltage Range**	1AC230V(L+N) or 2AC480V(380…480V)	
	Power	Max. 0.5kW (Continuous)	
	Inrush Current	5A	
UPS	**Capacity**	DC24V. 7Ah capacity.@25℃	The UPS is only used to supply power to BMS components. The UPS is included in the Aux power supply
Communication Protocol		CAN, Modbus/TCP	

3.3 Mechanical Specifications

Table 3 Mechanical Data of EnerC+

Mechanical Data		
Product Model	**C02306P05L01**	**Remark**
Transportation	Land or sea transportation	
Size	2896mm(H)*2438mm(D)*6058mm(W)	
Weight	~36.0t	
Color	RAL7042 （Optional RAL 9003）	
IP Level	IP55 (Battery Room)	
	IP55 (Electrical Room)	
	IP67(Electric control box of Chiller)	

3.4 Environmental Specifications

Table 4 Environmental Specifications of EnerC+

Environment condition		
Specifications	**Range**	**Remark**
Charge Temperature Range	-25℃…+55 ℃	It is necessary to inform CATL for professional evaluation if temperature beyond range
Discharge Temperature Range	-25℃…+55 ℃	

Storage Temperature Range	-30℃…+60℃	
Application Altitude	≤2000m （no derating）	
Relative Humidity	0 ~ 95 % (non-condensing)	
Degree of Anti-corrosion of Battery Unit	C4, (optional C5)	
Seismic Level	IEEE 693-2018 Moderate design level	

3.5 Certification Standard

Table 5 Certification Standard

Standards & Certificates		
Cell	UN38.3	UN Transportation Testing for Lithium Batteries
	UL1973	Batteries for Use in Light Electric Rail (LER) Applications and Stationary Applications
	IEC62619	Safety requirements for secondary lithium cells and batteries, for use in industrial applications
	UL9540A	Energy Storage Systems and Equipment
Container	UL1973	Batteries for Use in Light Electric Rail (LER) Applications and Stationary Applications
	NFPA855	Standard for the Installation of Stationary Energy Storage Systems
	UL9540A	Energy Storage Systems and Equipment
	IEC 62477	Safety requirements for power electronic converter systems and equipment – Part 1: General
	IEC 62619	Secondary cells and batteries containing alkaline or other non-acid electrolytes – Safety requirements for secondary lithium cells and batteries, for use in industrial applications

	IEC 62933-5-2	Electrical energy storage (EES) systems – Part 5-2: Safety requirements for grid-integrated EES systems – Electrochemical-based systems
	IEC 61000-6-2	Generic standards – Emission standard for industrial environments
	IEC61000-6-2/4	Electromagnetic compatibility (EMC) –Part 4-6: Testing and measurement techniques – Immunity to conducted disturbances, induced by radio-frequency fields

4 Battery Management System(BMS)

4.1 BMS Overview

BMS is used in energy storage system, which can monitor the battery voltage, current, temperature, managing energy absorption and release, thermal management, low voltage power supply, high voltage security monitoring, fault diagnosis and management, external communication with EMS and ensure the stable operation of the energy storage system.

4.2 BMS Architecture

BMS includes three-level constructure, composed of 1 unit of MBMU, 1 unit of IMM, 1 unit of ETH, 1 unit of optical fiber (optional), 5 units of SBMUs, 40 units of CSCs. This is the architecture that one PCS connected to one container (Figure 3). What's more, the system can also support one PCS match 2 containers (Figure 4).

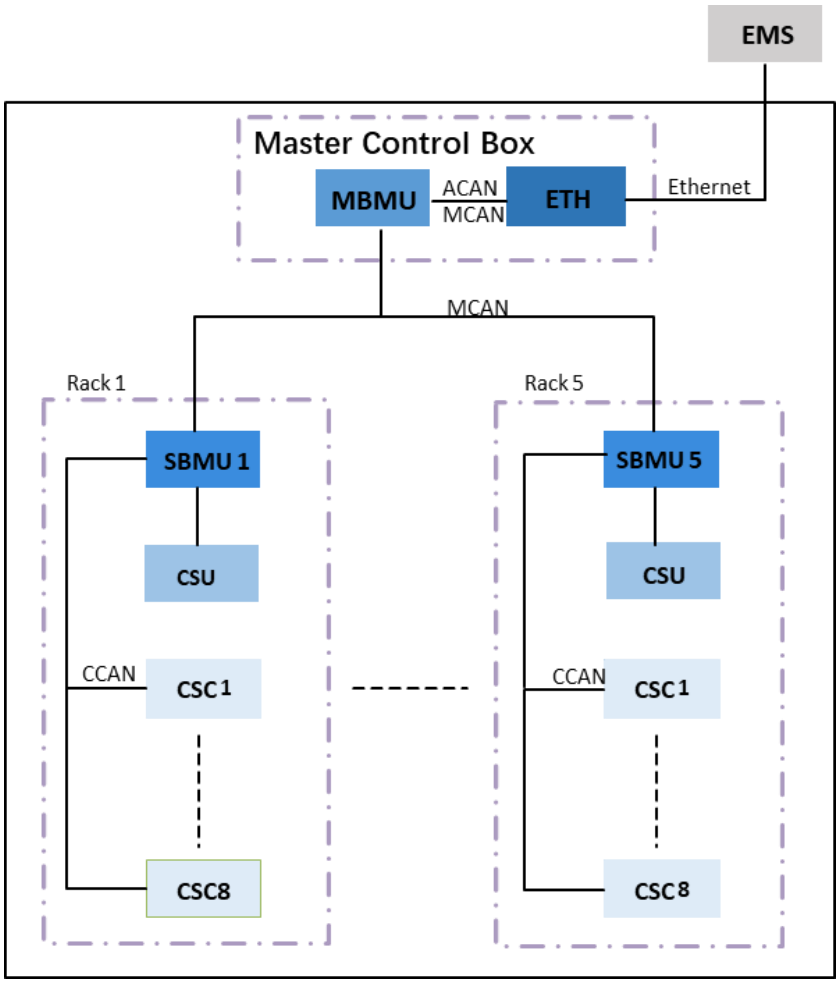


Figure 3 Three-Level BMS Architecture for One Container

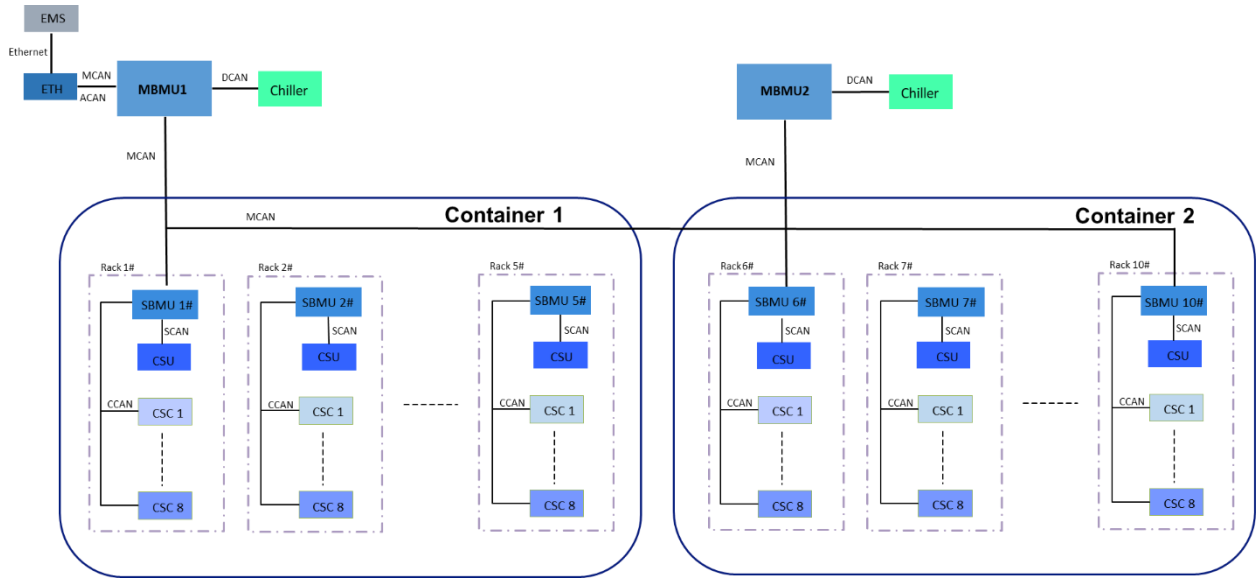


Figure 4 Three-level BMS Architecture for Two Containers in Parallel

4.3 BMS Function

The detailed information of BMS can be seen in Table 6. The parameters including: Cell voltage sampling, Cell temperature sampling, Current sampling, HV sampling, Ambient temperature detection, Insulation detection and other important parameters.

Table 6 Detailed Performance Parameters of BMS

Item	Performance Parameters	Value	Note
Working voltage	Range	20V~26V	
Cell voltage sampling	Range	1V~4.85V	
	Accuracy	±5mV	0℃ ~ +60℃
		±10mV	-40℃ ~ 0℃or60℃ ~ 85℃
Cell temperature sampling	Range	-40℃ ~ +125℃	
	Accuracy	±2℃	-20℃ ~+60℃
		±3℃	-40℃~-20℃&+60℃~+85℃
Current sampling	Range	± 500A	
	Accuracy	<1%FSR	-40℃ ~ 85℃
HV sampling	Range	0V ~ 1500V	
	Accuracy	1%FSR	
Cell balance	Current	100mA@3.2V	Opened in all channels
SOC	Static calibration	≤ 2%	Stay 1 h below 25% and Static voltage<3.26V

			SOC with current ≤ 2A.
	Pseudo-static Calibration	≤8%	Stay 3 min below 25% Static voltage<3.26V SOC with current ≤ 3A.
	Full charge Calibration	≤ 1%	Reach 100% SOC for 2 sec
SOH	Accuracy	＜± 5%	After calibratio
Ambient temperature detection	Range	-40℃ ~ +85℃	
	Range	±3℃	
Insulation detection	Range	0 ~ 10MΩ	
	Accuracy	-30% ~ 0%	
	Detection Time	≤10s	Y capacitor<0.47μF (for single side)

4.3.1 Battery Status Monitoring

1) BMS monitors the battery's parameters, including cell voltage, module temperature, battery module current and total battery module voltage.

2) BMS detects the battery status such as State of Charge (SOC) accurate to within 5%, SOH and the accurate to within 5%.

3) BMS functions as a safety management system in such cases as under voltage, over discharge, over voltage, over temperature, and over current of the battery. In case of failure, the system will give an alarm to the supervisory equipment, limit the charge and discharge current or power, and control the disconnection of all HV contactors. This can protect the battery while safeguarding the power systems security.

4) BMS shall provide battery information (including data recording and fault waveform recording) to EMS.

4.3.2 Charging/Discharging Management

1) BMS controls and monitors the high voltage main contactors, auxiliary relays and low voltage coils.

2) BMS has pre-charge control within the parallel connection among racks.

3) BMS works in the management of charge and discharge. It will calculate the charge and discharge power limit according to the existing status of the battery (temperature, SOC) and actual

performance of electrical components and then report to EMS which has the function of controlling to these limits.

4) BMS has the function of balance management to extend the reliability of the battery system.

4.3.3 Thermal Management

1) BMS has the function of sample collecting of battery cell temperature and chiller operating status.
2) BMS controls the liquid cooling TMS system based on cell & coolant's temperature.

4.3.4 Program Refreshing

BMS can flash programs on site, which supports the flashing of MBMU, SBMU, IMM, CSC and ETH by using the host computer through MCAN. BMS has the function of remote software flash, which enables to update BMS from a remote client via Ethernet. Furthermore, the system supports the BMS program refreshing through EMS.

4.3.5 High Voltage Safety Monitoring

1) BMS has the function of system insulation detection.
2) BMS has the function of high voltage sampling (collecting data of the main positive voltage).
3) BMS supports the detection of the dry contact of MSD, Fuse and Switch, as well as the auxiliary contact of the primary loop contactor.

4.3.6 Peripheral Monitoring and Control Management

1) BMS has the function of ambient temperature sampling and humidity sampling, which matches according to project requirements
2) BMS has multiple high-side drivers and can drive and control peripheral devices according to project requirements.
3) BMS has multiple dry contact interfaces and can monitor external signals according to project requirements.

4.3.7 Fault Diagnosis Management

1) BMS stores information such as operational parameters and historical alarms that can be viewed by ESS host computer.

2) BMS enables storage of latest historical alarms.

5 Fire Suppression System(FSS)

5.1 FSS Overview

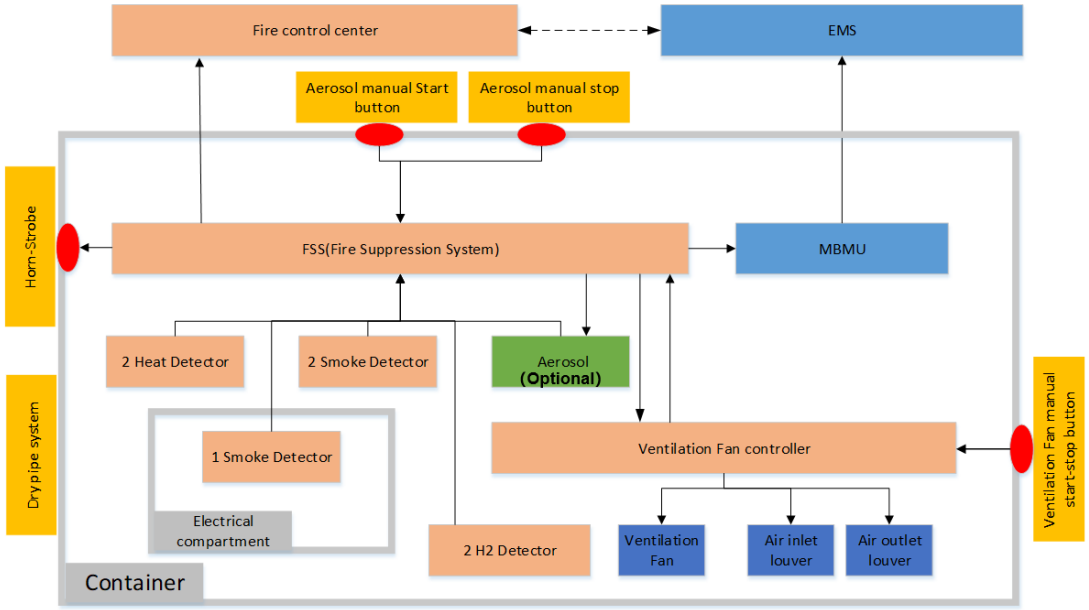
As an outdoor non-walk-in battery energy storage system, EnerC + provides a perfect set of fire suppression system solutions with detection, explosion control and fire extinguishing functions. The fire extinguishing control strategy is divided into four levels:

- **First level, alarm warning;**
- **Second level, ventilation and smoke exhaust to prevent deflagration;**
- **Third level, aerosol is released to extinguish the initial fire;**
- **Fourth level, dry pipe spraying to control the spread of fire.**

5.2 FSS Function

The fire suppression system is divided into three parts: detection system, explosion-proof system and fire extinguishing system. The information of the interactive interface is shown in the following Figure 5.

Figure 5 The Interactive Interface of FSS



5.2.1 Detection System

The detection system has three types of detectors, number and installation positions of which are shown in

Table 7 and Figure 6. All detection signals are received and processed by the fire control panel, and the hydrogen(H_2) detector can be linked with the smoke exhaust ventilation system system.

Table 7 Detector Type and Position Description

No	type	quantity	Configuration	remarks
1	Heat detector	2	standard	Detection of temperature, in the battery room
2	Smoke detector	2+1	standard	Detection of smoke particles, two in the battery room, and one in the electrical room
3	H_2 detector	2	standard	Detection of H_2, in the battery room
4	Fire control panel	1	standard	Receive detector signals and control fire extinguishing system and explosion-proof system, in the electrical room
5	Aerosol	7	**Optional**	When activated, aerosol power will be released rapidly to extinguish thermal runaway
6	Dry pipe system	1	**Optional**	As the last line of defense, the dry pipe system can effectively control the spread of fire.

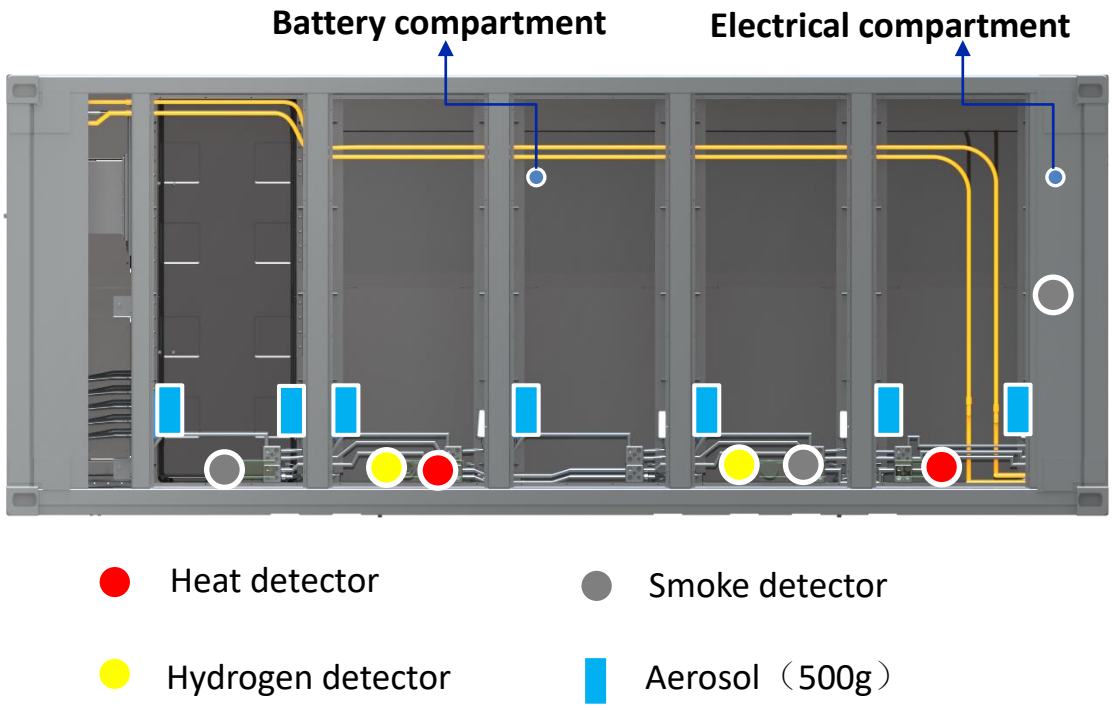


Figure 6 Type and Location of Detectors

5.2.2 Smoke exhaust ventilation System

Smoke exhaust ventilation system system meets NFPA855 (NFPA 69) standard, which is shown in Figure 7



Figure 7 Smoke exhaust ventilation system

The air inlet electric louver receives the alarm signal sent by the hydrogen(H_2) detector and opens the electric louver. When one of these two signals is received, the air inlet electric louver automatically closes. One signal comes from the hydrogen (H2) detector, indicating that the combustible gas concentration is within a reasonable threshold range, and the other signal is a secondary alarm signal. The parameters of the Inlet are shown in Table 8.

Table 8 The Parameters of the Inlet

Item	Specification
Supply voltage	24V DC
Rated power	60W
Position	Integrate in Rack

The air outlet electric louver will turn on the smoke exhaust ventilation system and releases the combustible gas in the battery room after receiving the alarm signal from the hydrogen(H_2) detector. The smoke exhaust ventilation fan will automatically turn off when the concentration of combustible gas falls within the reasonable threshold. The parameters of the exhaust port are shown in Table 9.

Table 9 The Parameters of the Exhaust Port

Item	Specification
Supply voltage	230V AC
Rated power	128W
Position	Integrate in Rack
Maximum air volume	820CFM

5.2.3 Fire Extinguishing System

5.2.3.1 Aerosol

When an initial fire occurs in the battery room, a fire alarm signal will occur, and the fire extinguishing system will automatically control the release of aerosol, which can also be triggered manually. The fixed position of aerosol is shown in Figure 6.

5.2.3.2 Dry pipe

As the last line of defense, the dry pipe system can effectively control the spread of fire, which is shown in Figure 8.

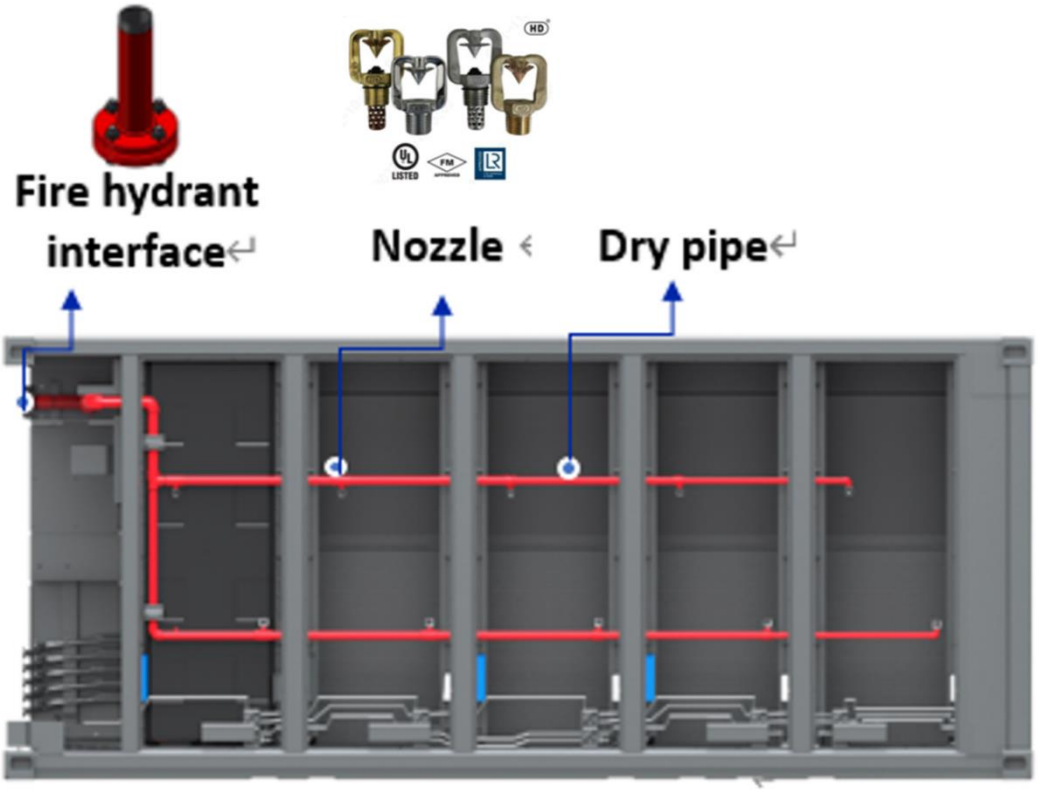


Figure 8 Dry Pipe System

The flange is installed at the entrance of the dry pipe fire protection system, for the connection between the pipes. The parameters of the flange are shown in Table 10.

Table 10 The Paraments of The Flange

Item	Specification
Model	DN65(maximum flow rate~19.3L/s)
Standard	EN1092-1
Material	ASTM A105
Class	PN 16
Flange type	TYPE 01 Plate flange for welding TYPE 05 Blind flange
End connection	Integrate in Rack

The HD Medium Velocity Water Spray Nozzles are open type (non-automatic) nozzles with rubber plug, designed for directional spray application in fixed fire protection system. The parameters of the nozzle are shown in Table 11.

Table 11 The Parameters of the Nozzle

Item	Specification
Model	MV-A Brass Material
Type	MV-A
Maximum working pressure	12bar（175 psi）
End connection	NPT 1/2 ''
Heat Sensor Position	Integrate in Rack

6 Thermal Management System(TMS)

6.1 TMS Overview

The TMS system of EnerC+ is liquid cooling, which main function is to maintain the temperature of the battery system to an allowable operating temperature range. Thus, the battery shall work at the best conditions, adsorb and release the maximum energy, slow degradation the SOH and maintain the longest life.

The Thermal management system is composed with the high-efficiency liquid cooling unit, the liquid cooling pipe under the bottom of battery and the PTC heater. The TMS works under the control of BMS. BMS sends the start up or shut down signals to the cooling unit, then the cooling unit and the PTC heater will work together to change the temperature of circulating coolant liquid for heat exchange in the cooling pipe. The circulating liquid will exchange the heat with the battery through the pipe. Thus, the temperature of battery will increase or decrease into appropriate range.

For example, the cooling unit will be started if the BMS detect the battery temperature over the setting value. The cooling mode will be activated to decrease the temperature of circulating liquid until reaching the setting value. When the BMS detects the battery temperature less than the setting value, the heat mode will be activated to increase the temperature of circulating liquid until the setting value. Detailed information will be described below.

6.2 TMS architecture



Figure 9 Overview of the cooling unit of EnerC+

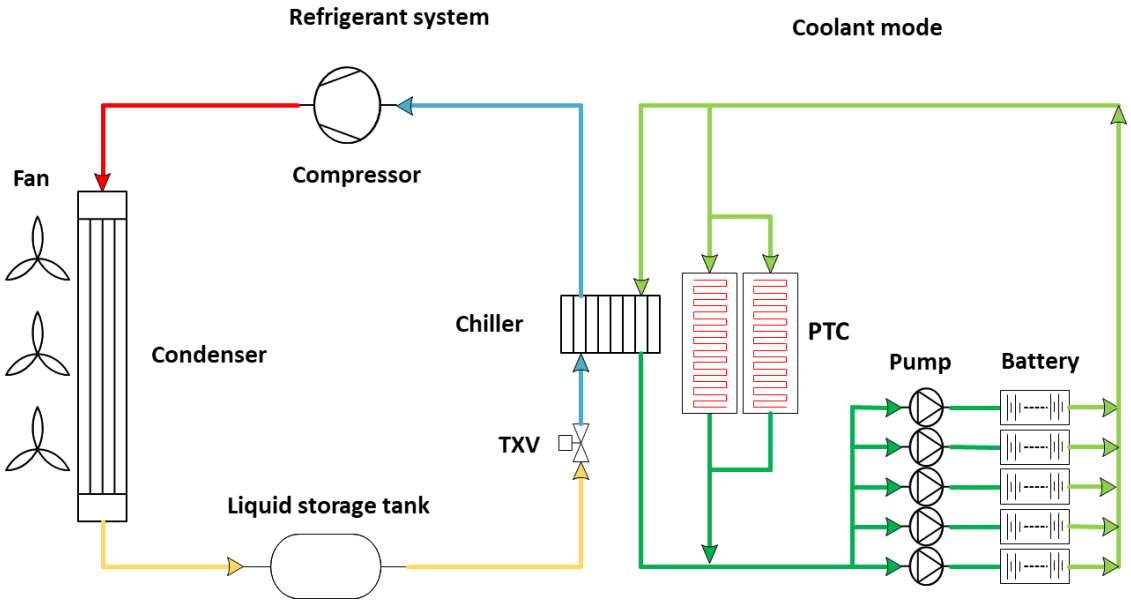


Figure 10 Architecture of Thermal Management System

The overview of cooling unit has been listed in Figure 9. EnerC+ own one high power cooling unit at the side of the container. TMS architecture can be described above (Figure 10). The composites parts are listed below:

a) **Compressor.** The function of compressor is to compress the low temperature and low pressure refrigerant gas into high temperature and high pressure refrigerant gas. Then the gas flow to the condenser through the pipe.

b) **Condenser.** The function of condenser is condensing the high temperature and high pressure refrigerant gas into ambient temperature and high pressure refrigerant liquid. Excess liquefaction heat will be taken away by the fan. Then the liquid flow to the chiller through the pipe.

c) **Chiller.** The function of chiller is to exchange the heat from the refrigerant liquid with the coolant. The ambient temperature and high pressure refrigerant liquid will evaporate into low temperature and low pressure refrigerant gas. The heat will transfer from the coolant to the refrigerant liquid. The low temperature coolant will flow to the cooling plate to cool the batteries while the refrigerant gas return to the compressor. The circle process will continue and the heat of battery will be taken away.

d) **PTC Heater**. The positive temperature co-efficiency resistance. The PTC will heat the coolant when the TMS get signals that the temperature of coolant is below the setting value. Then the coolant will be heated until the temperature increases to the setting value. The battery will be warmed up by the coolant.

e) **Pump.** The pump will force the coolant into circulating in the pipe.

6.3 TMS Specification

Table 12 Main Feature of Thermal Management System

	Coolant: 50%Ethylene glycol,50% Deionized water
	Max. ambient temperature: 55°C
	Power supply: 3AC 380…480V
	40kW Cooling capacity for 0.5P System
	Cooling capacity is auto-adjustable according to ambient temperature & discharge/charge status

The main features of TMS are listed above, which is shown in Table 12. The TMS will work under the ambient temperature range from -25℃ to 55℃. The cooling power is auto-adjustable according to ambient temperature & discharge/charge status. There are four operating modes for the TMS, including shutdown mode, cooling mode, heating mode and self-circulation mode.

Table 13 Power Consumption of Thermal Management System

Type of EnerC+	**0.5P System**
Cooling Capacity	40kW
Maximum Heating Power	17.6kW
Maximum Cooling Power	27.5kW
EER	≥2.76 (18℃ TMS liquid , @35℃ ambient)

7 User Interface

7.1 PCS Requirements

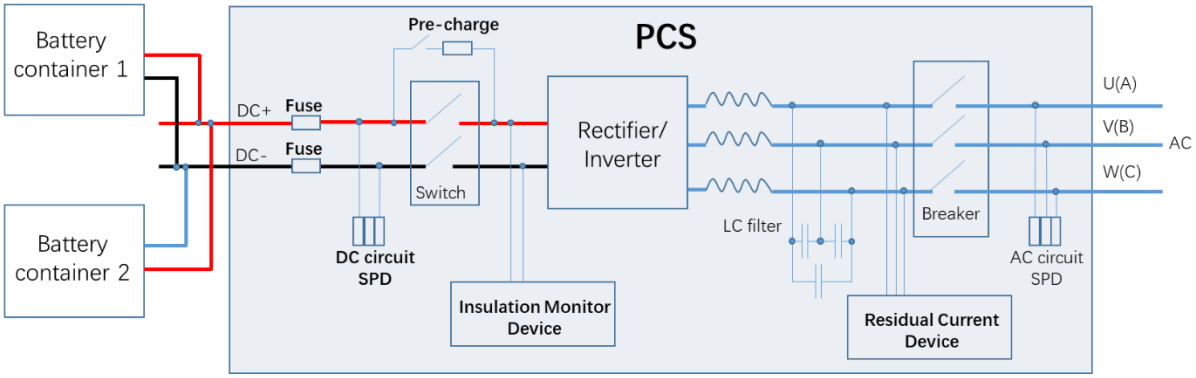


Figure 11 PCS Matching

- Please make sure to use one single copper Busbar for two parallel battery containers cable connection for positive or negative pole in PCS side.
- Please make sure to use Fuse(F) for DC circuit in PCS. The Fuse breaking time in PCS should less than the breaking time of fuse in battery container when short circuit occurs.
- Please make sure PCS have pre-charge circuit.
- Please make sure the PCS has a main circuit switch on the DC side .
- One PCS can match up to 2 battery containers.
- PCS should have SPD in DC high voltage bus.
- PCS should have SPD in AC side.
- PCS should have insulation monitor device. BMS monitor the insulation of DC bus before battery DC relay is closed. PCS monitor the insulation of DC bus after battery DC relay is closed.
- PCS should have residual current device to monitor the leakage current on AC side.
- When the battery is in a low SOC state after discharge, the grid cannot charge the battery in time and needs short-term storage. In this scenario, it is necessary to ensure that PCS is disconnected from the battery to prevent the battery from being over discharged.

7.2 Fuse Matching

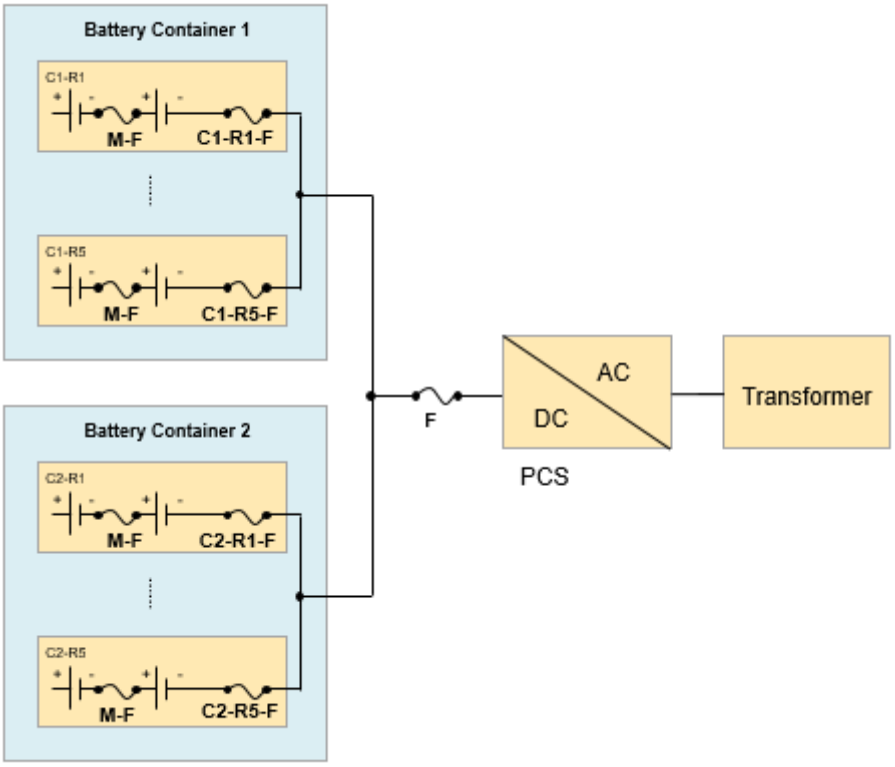


Figure 12 Fuse Matching

- The principle of fuse matching：
- Fuse Breaking Time: F<C-R-F<M-F. the F fuse means the fuses at the DC side of PCS. The C-R-F fuses means the fuses installed in the main control boxes. The M-F fuses means the fuses installed in the packs. The breaking time of F fuse is the minimum value of these three.
- Voltage Level：1500V
- **Fuse-F breaking ability in a single container：>64.7kA**

1. One PCS can connect two battery containers. Every container has 5 racks .
2. PCS DC side fuse is **Fuse F**.
3. Battery rack fuse is C-R-F.
4. Module fuse is M-F.

7.3 Common Mode Voltage

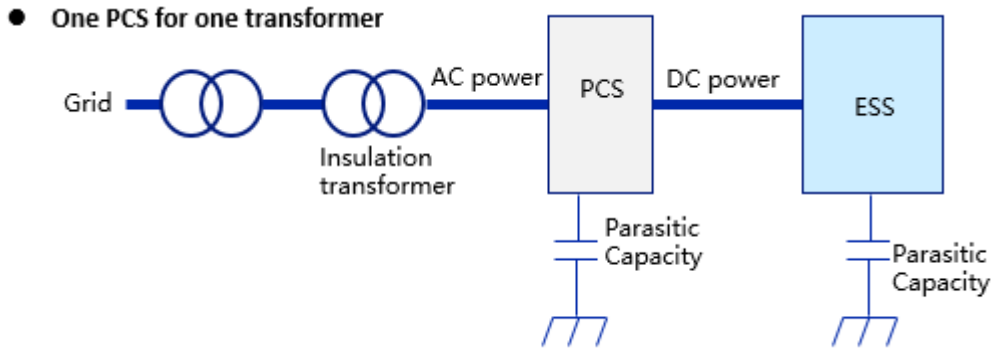


Figure 13 One PCS for One Transformer

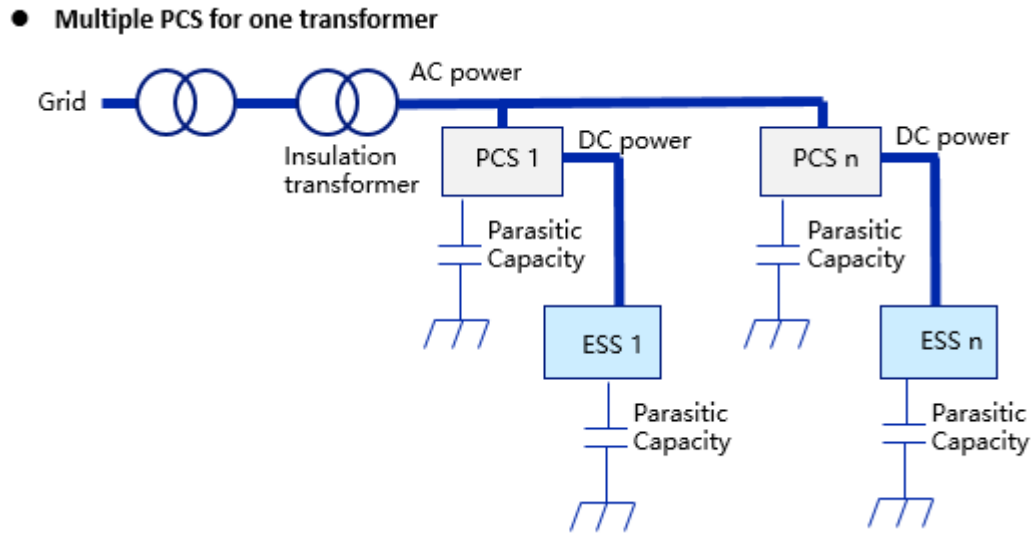


Figure 14 Multiple PCSs for One Transformer

The common mode voltage or current will affect the BESS reliability and personal safety. PCS will generate the common mode voltage and current due to the converter theory. Due to parasitic capacitance, the PCS should improve the insulation resistance isolation.And it is recommended to use insulation transformer. When multiple PCS are parallel connected, make sure that the switching of IGBT inside each PCS will not affect the other PCS to reduce the common mode voltage. The carrier synchronization should be considered in PCS control.

Common mode voltage value in DC side <100VAC, <15kHz

Make sure not to mix the AC and DC power cables, not to mix input and output cables, not to mix power cables and control cables.

7.4 Communication

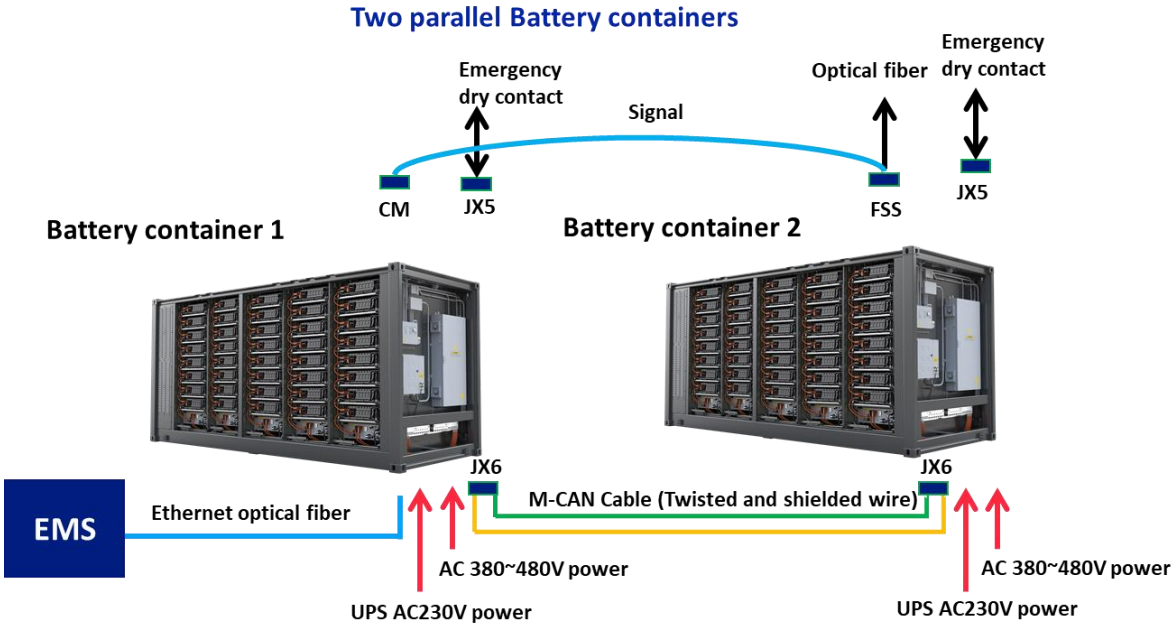


Figure 15 The Communication Architecture of the System with two containers in parallel

PCS should respond within 1s after BMS sending out the requirement.

PCS should respond within 1s after BMS sending out the emergency requirement by emergency dry contact.

PCS operation power should not exceed battery power limitation.

PCS should derating power to 0 W within 2s once receiving BMS limit to ZERO current requirement.

When the length of CAN communication loop exceeds to 30m, it is necessary to add CAN bridge to enhance communication signal.

It is recommended to use Ethernet optical fiber to communicating with EMS.

The A-CAN Bus or 485 Bus can be optional. If using the A-CAN Bus or 485 Bus, the Ethernet optical fiber will be not used.

8 Appendix

The attached is the triple view and the dimensions of EnerC+. The front view, the side view, the top view. The detailed installation information can be found in the users' manual.

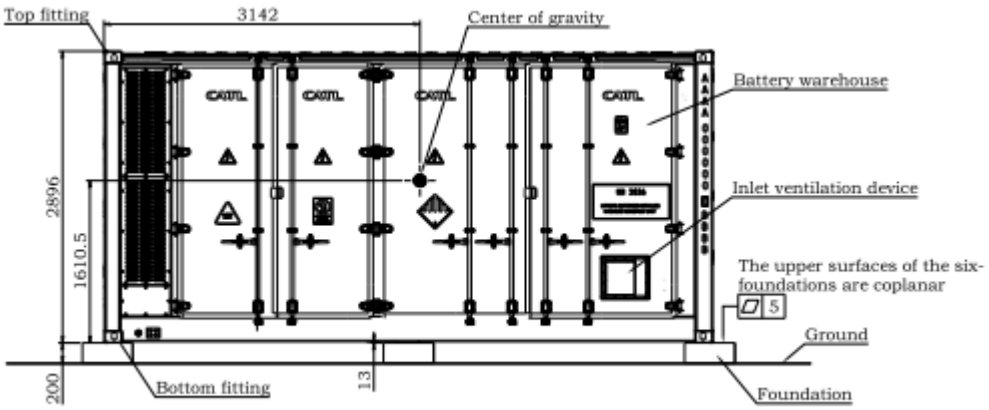


Figure 16 The Front View and Dimensions of EnerC+

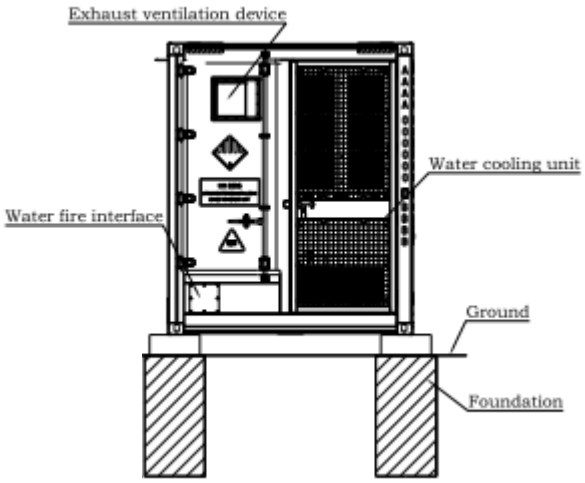


Figure 17 The Side View and Dimensions of EnerC+

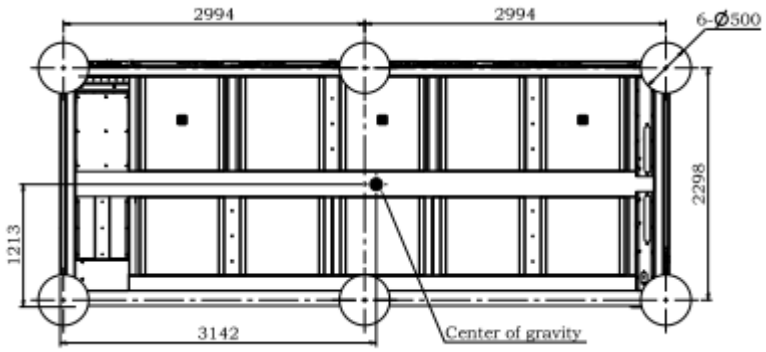


Figure 18 The Top View and Dimensions of EnerC+

There are two kinds of installation layout recommended. First case layout is listed below at Figure 19. Second Case layout is listed below at Figure 20.

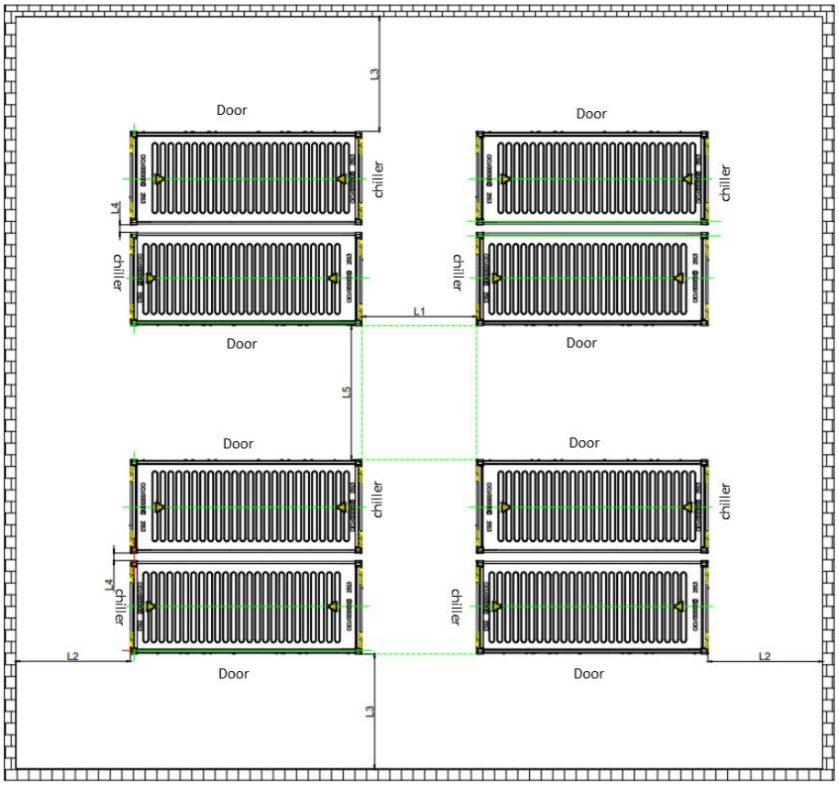


Figure 19 Case1 containers installation layout

For case 1. to avoid the hot air interaction for two containers ,and to maintain the container, the minimum distance must be followed :

L1 : 3.0m

L2 : 3.0m

L3 : 3.00m （Recommend 3.5m）

L4 : 0.90m（C5 or above），0.20m（C4 or below）

L5 : 3.00m （Recommend 3.5m）

Note that back-to-back two containers have opposite Wiring direction and need to control the length of the high-voltage cable to the PCS.

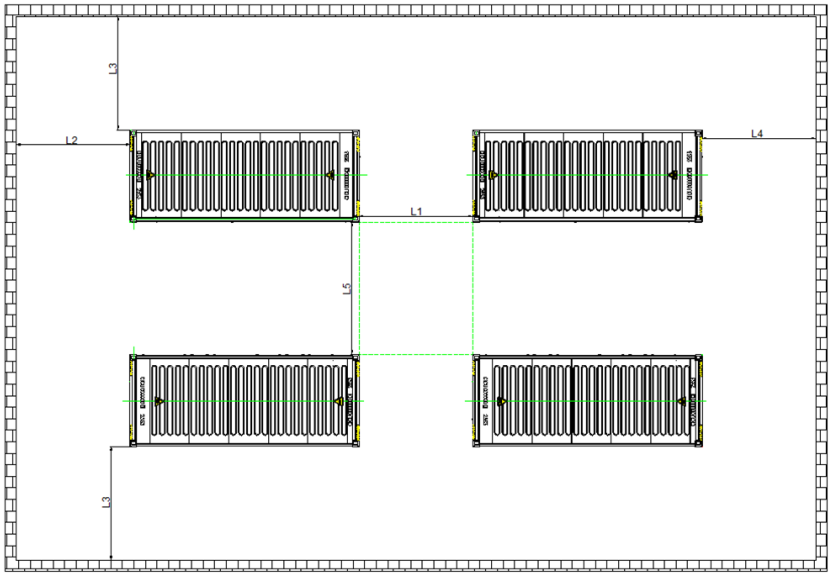


Figure 20 case 2 containers installatiuon layout

For case 2. to avoid the hot air interaction for two containers ,and to maintain the container， the minimum distance must be followed :

L1 : 3.00m （Recommend 3.5m）

L2 : 3.00m

L3 : 3.00m（Recommend 3.5m）

L4: 1.10m (For the distance from the electrical compartment surface to the wall or other containers.)

L5 : 3.00m （Recommend 3.5m）

Note: Orientation of water cooling unit and door in the drawing.

Contact us

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www.catl.com

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Appendix F

UL9540 Certificate

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Contemporary Amperex Technology
Co., Limited
No.2, Xingang Road,
Zhangwan Town, Jiaocheng District
352100 Ningde City Fujian
P.R. China
Attn: Sandy Lv

Re. : CU US + Canada Certificate

Type of Equipment : Rechargeable Lithium-ion Battery System
Model Designation : See Certificate
Certificate No. : CU 72302693 0001
File No. : CN23J9GR 001
Engineer/Contact : Wilson Zhou
Standard(s) : ANSI/CAN/UL 9540:2020

Dear Ms. Sandy Lv,

Enclosed, please find the TUV Rheinland Certificate of Approval No. CU 72302693 0001 as requested.

The equipment will be held by the manufacturer for reference purposes.

Call the TUV hotline at 1-TUV-Rheinland (1-888-743-4652) to get answers for all your compliance needs.

If we can be of any further assistance to you, please do not hesitate to contact us.

Sincerely yours,
Certification Body

Weichun Li

Enclosure

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TÜV Rheinland (China) Ltd.
莱茵检测认证服务（中国）有限公司

Room 301, 3F and Room 1203,12F, Building 4, No.15, Ronghua South Road, Beijing Economic-Technological Development Area Beijing (Yizhuang group in high-end industrial area of Beijing Pilot Free Trade Zone), P.R.China,100176

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邮编：100176

Tel: 86 10 8524 2222
Fax: 86 10 8524 2200
e-mail: info@bj.chn.tuv.com
Internet: http://www.chn.tuv.com

Certificate

Certificate no. CU 72302693 01

License Holder:
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No.2, Xingang Road,
Zhangwan Town, Jiaocheng District
Ningde City
352100 Fujian
P.R. China

Manufacturing Plant:
Contemporary Amperex Technology Co., Limited
No.2, Xingang Road,
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Ningde City
352100 Fujian
P.R. China

Test report no.: USA-Zhouwils CN23J9GR 001 **Client Reference:** Sandy lv

Tested to: ANSI/CAN/UL 9540:2020

Certified Product: Rechargeable Lithium-ion Battery System

License Fee - Units

Type Designation: C02306P05L01 — 10
Nominal voltage : 1331.2V
Rated capacity : 3060Ah
Trademark : CATL
Other Data : See Appendix (Construction Data Form)

10

Appendix: 1, 1-42

Licensed Test mark:

Date of Issue (day/mo/yr)
21/11/2023

Appendix G

UL 1973 Certification

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Contemporary Amperex Technology
Co., Limited
Zhangwan Town, Jiaocheng District
352100 Ningde City Fujian
P.R. China
Attn: Sandy Lv

Re. : CU US + Canada Certificate

Type of Equipment : (Rechargeable Lithium-ion Battery System)
Model Designation : See Certificate
Certificate No. : CU 72302694 0001
File No. : CN23QV2N 001
Engineer/Contact : Wilson Zhou
Standard(s) : ANSI/CAN/UL 1973:2022

Dear Ms. Sandy Lv,

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邮编：100176

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Certificate

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352100 Fujian
P.R. China

Manufacturing Plant:
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Co., Limited
No.2, Xingang Road,
Zhangwan Town, Jiaocheng District
Ningde City
352100 Fujian
P.R. China

Test report no.: USA-Zhouwils CN23QV2N 001 **Client Reference:** Sandy lv

Tested to: ANSI/CAN/UL 1973:2022

Certified Product: (Rechargeable Lithium-ion Battery System) **License Fee - Units**

Type Designation: C02306P05L01 10
Nominal voltage : 1331.2V
Rated capacity : 3060Ah
Trademark : CATL
Other Data: See Appendix (Construction Data Form)

10

Appendix: 1, 1-125

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Date of Issue (day/mo/yr)
23/10/2023

Appendix H

Condensed Aerosol Fire Extinguishing System JAD300-U01

Appendix H

Condensed Aerosol Fire Extinguishing System

Model: JAD300-U01

DESIGN, INSTALLATION, OPERATION AND MAINTENANCE MANUAL

Hubei Jiandun Fire Technology Co., Ltd.

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Manual No.JAD M230507 Version 1.0, 05-07-2023

Manual Revision Table

Manual No.	Version	Revise Page	Revise Content	Revise Date
JAD M230507	1.0	-	Original	2023.5.7

Content

1 Forward 1

2 Introduction 1

3 System Description 2

3.1 General 2

3.2 Fire Extinguishing Agent 4

3.3 Component Description 5

3.3.1 Component Composition 5

3.3.2 Technical Parameters 6

3.3.3 Electric Initiator 7

4 System Design and Limitations 8

4.1 General 8

4.2 Application 8

4.2.1 Calculate the total mass of aerosol-forming compound required to protect the hazard. 8

4.2.2 Calculate the number of aerosol generators required. 9

4.2.3 Precautions for other facilities/systems 10

4.2.4 Placement of JAD300-U01 aerosol fire extinguishing system 10

4.2.5 Operating/Temperature Range 12

5 Installation 13

5.1 General 13

5.2 Installation of Fire Extinguishing system 13

5.2.1 Installation of Single Generator System 14

5.2.2 Installation of Multiple Generator System 15

5.3 Post Installation Checkout 16

6 Operation 16

6.1 General 16

6.2 Operating Procedures 16

6.2.1 Automatic Control of Fire Extinguishing Process 16

6.2.2 Manual Control of Fire Extinguishing Process 19

6.2.3 System Isolate Switch 20

6.3 Post Fire Operation 20

6.4 Post Fire Maintenance 21

7 Maintenance 23

7.1 General 23

7.2 Preventive Maintenance 23

7.3 Inspection Procedures 24

7.3.1Monthly 24

7.3.2 Annual 24

7.3.3 Replacement/Removal from Service 24

8 System Components 25

9 Limited Warranty Statement 25

10.Limitation of Liability 25

Appendix 26

Appendix A Safety/Information Bulletins 26

Appendix B Material Safety Data Sheet 33

1 Forward

This manual is a guiding document for the design, installation and maintenance of condensed aerosol fire extinguishing system, which should be strictly followed in the process of design, installation and maintenance. This manual is written by the designers of Hubei Jiandun Fire Technology Co., Ltd. (hereinafter referred to as JAD). It contains basic information about the design, installation, operation and maintenance of condensed aerosol fire extinguishing system.

Important tips

JAD assumes no responsibility for application of any systems other than those addressed in this manual. The technical data in this manual is limited strictly for information purposes only. JAD believes this data to be accurate, but it is published and presented without any guarantee or warranty whatsoever, JAD disclaims any liability for any use that may be made of the data and information contained herein by any and all other parties.

JAD300-U01 condensed aerosol fire extinguishing system is to be designed, installed, inspected, maintained, and tested by qualified and trained personnel in accordance with the following:

- NFPA 2010 Standard for Fixed Aerosol Fire Extinguishing Systems and the National Fire Code of Canada; and any other applicable NFPA Standards.
- EN15276-2 Fixed firefighting systems - Condensed aerosol extinguishing systems Part 2: Design, installation and maintenance.
- All instructions, limitations, etc. contained in this manual.
- Storage, handling, and transportation shall be performed by qualified and trained personnel in accordance with DOT requirements.

Questions about the information provided in this manual or more detailed information presented in this manual should be addressed to:

Hubei Jiandun Fire Technology Co., Ltd.

No.199 Huaxi Road, Biological Industrial Park, China (Hubei) Free Trade Zone Yichang Area，Yichang City, Hubei Province, China

Tel: 0717-6741877 Mail: development@jad119.com

2 Introduction

JAD300-U01 condensed aerosol fire extinguishing system is designed for total flooding fire extinguishing application based on established design criteria. Application methods, design criteria, and limitations are contained in this manual. In any situation not specifically covered by this manual, the application and installation of the system must be

in accordance with the appropriate and/or applicable standards. All installations must meet the requirements of the local authority having jurisdiction.

JAD300-U01 Condensed Aerosol Fire Extinguishing System with ultra-high extinguishing efficiency and reliability is one of the company's innovative products. The system is small-sized and zero-pressure stored. It generates rapid extinguishing system with safe and reliable, non-toxic , harmless and environmentally friendly materials. It has been widely used in electrical cabinets, cold chain cabinets, communication rooms, battery boxes, energy storage cabinets, engine compartments or other similar enclosure space.

Since differences still exist between this fire extinguishing system and other fire extinguishing systems, the system designer must become thoroughly familiar with the design criteria contained in this manual in order to properly input design data and parameters. There are a number of limitations, which must be considered in entering parameters for accurate results. Users and operators must thoroughly read and understand the design standards and parameters in this manual, and they must be well trained before operation, so as to achieve the maximum utilization rate and the highest fire extinguishing ability to reduce property damage.

3 System Description

3.1 General

JAD300-U01 aerosol fire extinguishing system is total flooding application system, suitable for extinguishing the fire in protected enclosures. It is designed for Fires listed in table 3.1,

Table 3.1 Classification of fires

Classification of fires			
NFPA 10		Europe: CEN Standard EN2	
CLASS "A"	Fire in ordinary combustible materials such as wood, cloth, paper, rubber and many plastics.	CLASS "A"	Fire involving solid materials, usually of an organic nature (such as paper, wood, plastics and so on), in which combustion normally takes place with the formation of glowing embers.

CLASS "B"	Fires in flammable liquids, oil, greases, tars, oilbase paints, lacquers and flam mable gases.	CLASS "B"	Fires involving flammable liquids or liquefiable solids such as paraffin, petrol, oil and so on.
CLASS "C"	Fire which involve energized electrical, non-conductivity of the extinguishing media is of importance. (When electric al equipment is de-energized, extinguishers for Class "A" or "B"fires may be used safely).	CLASS "C"	Fire involving flammable gases such as propane,butane,methane and so on.
CLASS "D"	Fires in combustible metals such as magnesium, titanium, zirconium, sodium, lithium and potassium.	CLASS "D"	Fire involving metals such as aluminium, magnesium, titanium and so on.
CLASS "K"	Fire involving cooking grease, fats and oils.	CLASS "E"	Fires involving electrical apparatus
		CLASS "F"	Fire involving cooking oils and fat and such like.

Note：Class K,Class E, Class F fires are not tested.

JAD300-U01 aerosol fire extinguishing system can be used in the following fields,

Electric power industry: cable tunnel(including underground), cable well, control room, computer room, relay room, transformer distribution room, switchgear, high-voltage switchgear, low-voltage switchgear, fully sealed high-voltage box-type substations etc.;
Transportation industry: diesel locomotives, electric locomotives, railway engineering vehicles etc.;
New energy industry: wind turbines, wind power transformers, electrical cabinets, power distribution cabinets, cold chain cabinets, energy storage boxes, photovoltaic power generation transformers, electrical equipment rooms, electrical cabinets ,etc.;
Manufacturing industry: machining equipment, hydraulic equipment, CNC machine tools , etc.
Communication industry: communication equipment room, signal base station,etc.

JAD300-U01 aerosol fire extinguishing system shall not be used on fires involving the following materials,

a)Certain chemicals or mixtures of chemicals,such as cellulose nitrate and gunpowder, that are capable of rapid oxidation with a combination of air;
b) Reactive metals such as lithium, sodium, potassium, magnesium, titanium, zirconium, uranium, and plutonium;
c) Self-decomposition compounds, such as certain peroxides, hydrazine, etc;
d) Metal hydrides, such as potassium hydride, sodium hydride;
e) Spontaneously combustible substances, such as phosphorus;
f) Strong oxidants, such as nitrogen oxides, fluorine;
g) Deep-seated fires in Class A materials.

The extinguishing generators are **not suitable** for the following places:
Commercial, catering services, entertainment and other normally occupied spaces.

The generator is also not for use in hazardous (classified) locations.

3.2 Fire Extinguishing Agent

JAD300-U01 aerosol fire extinguishing system produces a large number of fire extinguishing media, which are mainly composed of ultra-fine potassium salt particles and inert gas. After a long period of continuous verification and application, potassium salt has been recognized as one of the most effective fire extinguishing agents. Its main fire-fighting mechanisms can be divided into four categories: isolation, suffocation, cooling and chemical suppression. Several fire-fighting mechanisms interact and combine to suppress the fire, without any negative impact on the environment. Both the Ozone Depletion Potential (ODP) and Global WarmingPotential (GWP) are zero. Because of the ultra-fine particle size（≤2μm）there is a dramatic increase in the surface area interaction between the agent and the fire. Aerosol has been shown to be a highly effective alternative to other extinguishing agents.

Different from other conventional fire extinguishing agents, aerosol will not decompose in case of fire and will not be extinguished due to the lack of oxygen. Therefore, it is especially suitable for normally unoccupied places .

When used at the normal design concentration required to extinguish most types of fires, aerosol is non-toxic to human body; However, when applying and handling the generator, there is a high shielding coefficient, and some safety restrictions and related standards and specifications should be observed. Exposure to aerosols should be minimized and unnecessary particle contact should be avoided.

Toxicity: The extinguishing agent discharged by JAD300-U01 aerosol fire extinguishing system can be suspended for a long time (up to one hour), providing excellent protection against re-ignition and minimizing cleaning work. When used at the normal design concentration required to put out most fires, aerosol is considered to be non-toxic to human body; Although the components of aerosol are not considered toxic at normal concentration level, ingestion of ultrafine particles may cause short-term

discomfort, therefore unnecessary contact should be avoided.

Corrosiveness: Extensive tests show that JAD300-U01 aerosol fire extinguishing system is non-corrosive and harmless to various materials, including structural metals, plastics, electrical components, complex materials used in aviation, films and tapes. If the system is not cleaned in time after discharging, aerosol may cause slight surface discoloration to some metal alloys, but this is a non-progressive event and will not affect the function.

Conductivity: Residue not cleaned after discharging will absorb moisture. If left untreated, caking may absorb moisture and may lead to non-progressive surface discoloration of unprotected metal surfaces. If agglomerated mass is formed on the PCB, it may lead to short circuit of electronic components on the PCB due to the moisture and metal particles contained in the agglomerated mass.

Cleanliness: The fire extinguishing agent discharged by condensed aerosol fire extinguishing system can remain suspended for a long time and can be easily discharged by fan or air treatment; A small amount of aerosol deposited on the floor or other horizontal surfaces can be cleaned by vacuuming, blowing, brushing or washing . Small amounts of residue or agglomerated mass that have not been removed during the ventilation process must be cleaned with contact cleaner spray thoroughly.

The above cleaning work should be completed within 24 hours after discharging.

Other safety considerations: The temperature of aerosol discharged into the hazard area after actuating the generator is relatively low. However, the aerosol flow leaving the generator is higher than 100℃ within a short distance from the generator discharge port. JAD300-U01 aerosol fire extinguishing system has a required installation clearance distance. Measures must be taken to ensure the generator placement meets this installation requirement.

The temperature of the generator casing after discharging will not exceed 150℃. The generators will remain quite warm to the touch for a time after actuation. When treating the generator after discharging before it is cooled to ambient temperature, be careful ! Aerosol generators must be mounted in such a way as to have an unobstructed discharge path and must not discharge at close range onto walls, ceiling, or equipment.

Storage: Temperature range (-40℃ ~+54℃) and humidity (maximum 95% relative humidity) have been evaluated. The accelerated aging test shows that JAD300-U01 aerosol fire extinguishing system has a 15 years' useful time.

3.3 Component Description

3.3.1 Component Composition

JAD Aerosol Fire Extinguishing system with self-generated aerosol fire extinguishing agent, is one of the most efficient Halon Alternative products. The condensed aerosol extinguishing generator is composed of stainless steel casing, initiator, aerosol-forming compound ,coolant ,mounting bracket and other elements. The coolant is used to cool the

aerosol fire extinguishing agent before it is discharging. The initiator is electrically activated with a secure two-wire connector.

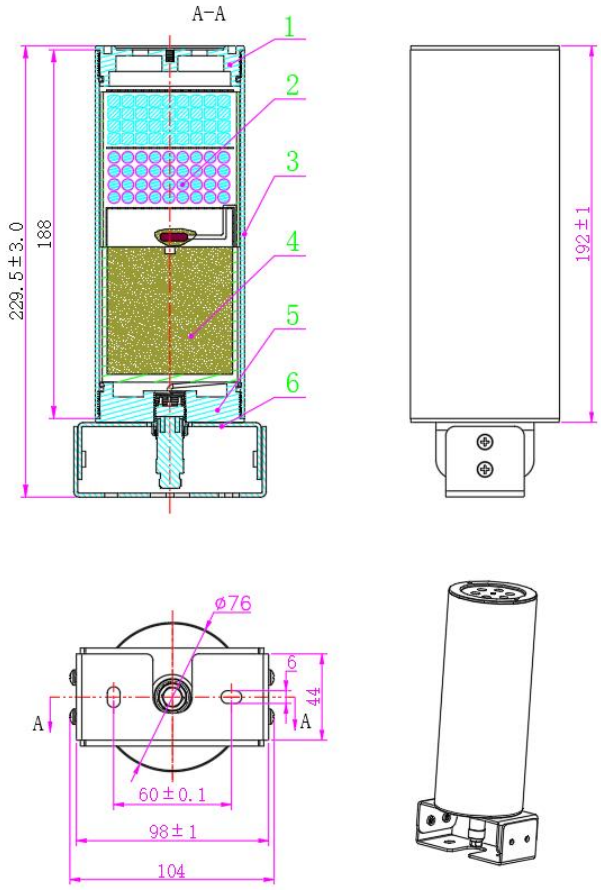


Figure 3.1 Drawing of JAD300-U01 aerosol fire extinguishing generator.

1. Front cover
2. Coolant
3. Casing
4. Aerosol-forming Compound
5. Back Cover
6. Mounting Bracket.

3.3.2 Technical Parameters

3.3.2.1 End-use: Total Flooding , normally unoccupied areas

3.3.2.2 Size: φ76mm(±0.2mm)×192mm (±1mm)(without bracket)

3.3.2.3 Weight: 2320g（±2%）

3.3.2.4 Discharge Time: 12.5S (±2.5S)

3.3.2.5 Thermal Clearance (discharge port)

a)The aerosol agent discharge temperature shall not exceed 75°C (167°F) at the minimum safe distance between the aerosol generator discharge ports and personnel. The minimum distance is130cm.

b)The aerosol agent discharge temperature shall not exceed 200°C (392°F) at the minimum safe distance between the aerosol generator discharge ports and combustible materials. The minimum distance is 70cm.

3.3.2.6 Thermal Clearance (generator casing)

a)The temperature shall not exceed 75°C (167°F) during and after discharge at the minimum safe distance between the generator casing and personnel. The minimum distance is 2cm.

b)The temperature shall not exceed 200° C (392° F) during and after discharge at the minimum safe distance between the generator casing and combustible materials. Since the temperature of the generator casing will not exceed 150℃(302° F), it is not applicable(N/A).

3.3.2.7 Operating temperature range: -40℃~+54℃

3.3.2.8 Mass of aerosol-forming compound: 300g(±6g)

3.3.2.9 Actuation method: Electrical

3.3.2.10 Initiator safe current: 600mA(±2mA) ,300s no action

3.3.2.11 Initiator rated current: 2A/5ms

3.3.2.12 Class of Fires and Density: see Table 3.2

Table 3.2 Class of Fires and Density

UL/ULC2775	
Class of Fire	Minimum design application density
Class“A”	105.3 g/m³
Class“B”	78 g/m³
Fuel combination:	105.3 g/m³
Class of Fire	Minimum design application density
EN15276	
Class“A”	105.3 g/m³
Class“B”	78 g/m³
Class“C”	105.3 g/m³
Fuel combination:	105.3 g/m³

3.3.2.13 Useful Time: 15 years

3.3.3 Electric Initiator

Electric Initiation: The JAD300-U01 aerosol fire extinguishing system is designed to be actuated by double-bridge electric initiator.

The specification of the electric initiator,

Initiator Model: WS-XPSS201

Initiator resistance: 1.0Ω ±0.2Ω

Initiator Minimum rated current: 900mA, It can be actuated 100% instantaneously. (it is normal when the current is between safe current to 900mA the initiator is actuated.)

Initiator Safe current: 600mA（±2mA）,300s no action

Initiator Rated current: 2A/5ms

Working voltage: 24V DC

For series connected generators below data should be noted,

power supply :24Vdc

maximum 10 JAD300-U01 generators connect in series

the maximum line resistance is 1Ω

4 System Design and Limitations

4.1 General

System design is based on the applicable requirements of the National Fire Protection Association (NFPA) Standard 2010, the EN15276-2 Fixed firefighting systems - Condensed aerosol extinguishing systems Part 2: Design, installation and maintenance, manufacturer's design data, and the authority having jurisdiction.

4.2 Application

The following steps must be taken to design and calculate the application of JAD300-U01 aerosol fire extinguishing system,

Determine how the protected area is used and whether the floor, ceiling and walls are fire-proof.

Determine the classification of hazard fires.

Determine the appropriate design density according to the fire classification.

Determine the geometric dimensions (volume, total area, height) of the protected area (the volume of protected equipment is not deducted from the total volume).

Determine whether there are any big obstacles in the hazard.

4.2.1 Calculate the total mass of aerosol-forming compound required to protect the hazard.

4.2.1.1 Protected area

Protected areas should be divided into fixed single closed spaces. The area and volume of a protected area should not be greater than 500m^2 and 2000m^3 respectively.

The area of unclosable openings in the protected area enclosure shall be kept to a minimum.If a protect area enclosure is designed with openings that cannot be closed, the non-sealing degree of the protected area should not be greater than 0.6%. Before the fire extinguishing system is actuated, the ventilation and ventilation facilities in the protected

area should be automatically closed, and the production operations that may affect the fire extinguishing effect should be stopped.

4.2.1.2 Protected Volume

When calculating the mass of aerosol-forming compound, the protection volume should be subtracted from the volume of permanently existing substances in the protection area that cannot be penetrated by the fire extinguishing agent.

$$W=K_1 \cdot K_2 \cdot C_1 \cdot V$$

where

W =design total mass of aerosol-forming compound (kg)

K_1=the compensation coefficient based on the non-uniformity of aerosol distribution and the height of the protected area.

When the height of the protected area is ≤2.4 m, K_1 = 1.00；

Consult Manufacturer for height of enclosure > 2.4m.

K_2=the leakage rate based on the calculated protected volume, that is, the ratio of the total opening to the total area of the outer surface of the protected area.

When the leakage rate of the protected area is< 0.3%, K_2 = 1.00；

When the leakage rate of the protected area is 0.3% ~ 0.6%, K_2 = 1.10；

Consult Manufacturer for the leakage rate of enclosure > 0.6%.

C_1=design application density (g/m³), the minimum mass of the designated aerosol generator in the unit enclosed space volume required for the design of the total flooding system, multiplied by a safety factor of 1.3.

V = protected volume (m³)

Consult Manufacturer for the volume of enclosure> 5m^3 .

4.2.2 Calculate the number of aerosol generators required.

The following formula is used to calculate the number of aerosol generators required for fire extinguishing systems:

N = W/m (when only one size generator is used)

where:

N= the number of generators required. If the value of N is a decimal, it is rounded to an integer.

W= the total mass of aerosol-forming compound required.

m= mass of aerosol-forming compound of a single aerosol generator.

4.2.3 Precautions for other facilities/systems

4.2.3.1 Obstacles affecting the distribution of chemicals

If the fixed equipment accounts for a large proportion of the total volume, or the position of the protected equipment hinders the free flow and distribution of aerosol in the whole area, which will affect the total flooding fire extinguishing ability of JAD300-U01 aerosol fire extinguishing system. It is better to use more small aerosol generators in hazard areas. If general mass is ≤500g, it will allow the strategic layout of aerosol generators and improve the distribution characteristics of the whole area. Resulting in the achievement of higher fire extinguishing energy efficiency.

4.2.3.2 Total flooding fire extinguishing in normally unoccupied areas where personnel may be present.

Note: For total flooding installations in normally unoccupied spaces where personnel may be present, a 30 second time delay shall be reserved to ensure egress time in prior to system discharge. In occupied and normally unoccupied areas, a system isolate switch shall be installed outside the hazard area to ensure that activation of the system is “manual only” when personnel are present.

4.2.3.3 Shutdown of Air Handling and Power Supply

After fire is detected by the system, the ventilation system and all openings (such as fire doors, cooling vents, air conditioning outlets, etc.) in the protected area must be closed to ensure the required application density, because the fire will be aggravated when the oxygen concentration in the protected area increases. Besides that, the power supply of the protected equipment must be turned off, in order to avoid short circuit of equipment and aggravate the fire.

4.2.4 Placement of JAD300-U01 aerosol fire extinguishing system

4.2.4.1 Installation

JAD300-U01 aerosol fire extinguishing system is suitable to be installed on the side wall and center of the protected area. It can be installed on walls, beams and structural columns, where the unit can be firmly fixed. It’s suggested to be installed on its unobstructed discharge path, which will not affect the positions of personnel, equipment and combustible materials located in the protected area. See Table 4.1 for aerosol streams characteristics. The position of the generator must also leave enough clearance between the structural material and the generator casing. See Table 4.2 generator casing clearance.

Table 4.1 Characteristics and Installation Limitations of Aerosol Discharge Flow

model	Distance at 75℃ of discharge port (m)	Installation Height (m)	Maximum Area Coverage (m^2)	Minimum Area Coverage height (m)	Maximum Area Coverage height (m)	Maximum volume(m^3)
300g	1.3	0~2.4	2.24*2.24	1	2.4	5

Distance at 75°C of discharge port: refers to the distance where the instantaneous peak temperature of blowout will not exceed 75 °C The generator must also be equipped with a clear discharge path as long as possible to reduce the possibility of caking with the consumption of fire extinguishing agent.

Table 4.2 Generator Casing Clearance

model	Required Clearance from Combustible and Structural Materials	
	mm	Inch
300g	13	0.50

4.2.4.2 Installation Height

Generally , JAD300-U01 aerosol fire extinguishing system should be installed at the bottom of the protected area or in a room close to the bottom of the protected area, and installed horizontally in the center of the bottom of the protected area to ensure the three-dimensional distribution of aerosol. The installation angles of systems with different installation heights are different, so it is only necessary to ensure that the discharge port of the system keeps an angle of 45 with the bottom of the protection area. In a large volume (≥100m^3), the installation method of aerosol generator must have a clear discharge path, and it must not be discharged to obstacles or equipment, which will lead to agglomeration and reduce efficiency, and it will also affect the fluidity and dispersity of aerosol fire extinguishing agent. The generators used for total flooding must be set on multiple levels.

When multiple fire extinguishing generators are installed in a unified protected area or the protected space is large (generally 30m^3-100m^3), their installation positions should be at multiple levels (tiers), and each level (tier) should meet the installation height limit and the maximum area coverage limit. This will ensure that the aerosol is completely evenly distributed throughout the hazard area.

JAD300-U01 aerosol fire extinguishing system generally used underfloor should be installed horizontally. For the same reason, aerosol fire extinguishing systems with less mass should be used for underfloor applications (generally, the generator of the system is ≤ 500g).

4.2.4.3 Aerosol Stream

The aerosol fire extinguishing agent should be distributed as evenly as possible around the hazard area to ensure that fire extinguishing agent can quickly flow and disperse to the fire source in the protected space. To ensure the fire extinguishing effect of

the fire extinguishing system. JAD300-U01 aerosol fire extinguishing system shall not be placed in the position where they are directly discharged from each other, leading to the aggregation of aerosol particles, reducing the fluidity and dispersion of fire extinguishing media and thus reducing the fire extinguishing effect. The location of the aerosol generator in total flooding application should also ensure that the aerosol flow does not directly hit the side of obstacles or protected equipment.

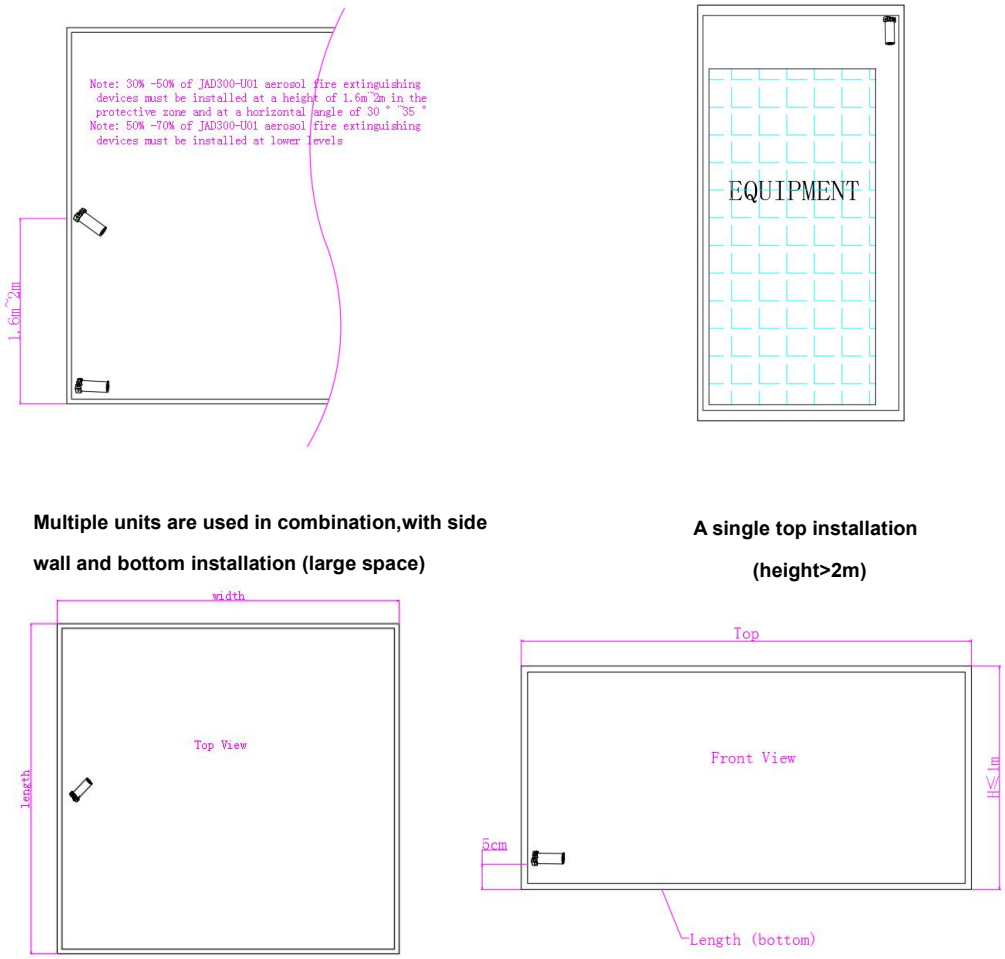


Figure 4.1 Placement of JAD300-U01 aerosol fire extinguishing system.

Note: 30% -50% of JAD300-U01 aerosol fire extinguishing systems must be installed at a height of 1.6m~2m in the protective zone and at a horizontal angle of 30 °~35 °

Note: 50% -70% of JAD300-U01 aerosol fire extinguishing systems must be installed at lower levels

Note: the space should be even unless there is an obstacle.

4.2.5 Operating/Temperature Range

JAD300-U01 aerosol fire extinguishing system has been evaluated for temperature range(-40℃ ~+54℃) and humidity (maximum 95% relative humidity). The accelerated

aging test shows that JAD300-U01 aerosol fire extinguishingsystemhave a 15 years' useful life.

5 Installation

5.1 General

Please read this manual carefully and be familiar with it before installing the equipment, so as to ensure the correct operation, inspection, testing and any other possible maintenance. During the installation, the equipment shall not be damaged by any mechanical, chemical or other damage that may cause operation failure. Equipment must be installed in strict accordance with all applicable standards and manuals.

WARNING

WHEN HANDLING, INSTALLING AND MAINTAINING THE EQUIPMENT, THE OPERATION MUST BE CARRIED OUT IN STRICT ACCORDANCE WITH THE INSTRUCTIONS IN THIS MANUAL. FAILURE TO FOLLOW THESE INSTRUCTIONS MAY LEAD TO FALSE START-UP, WHICH WILL LEAD TO NORMAL POTENTIAL INJURIES AND PROPERTY DAMAGE.

5.2 Installation of Fire Extinguishing system

When installing the fire extinguishing system in the protected area, the installation instructions must be carried out in strict accordance with the following order to prevent potential personal injury or property loss caused by misoperation.

Installation requirements for screws and nuts: 304 stainless steel

The installation tightening force meets the requirements of table 5.1,

Table 5.1

Bolt strength level	yield strength (N/mm^2)	Bolt nominal diameter (mm)							
		6	8	10	12	14	16	18	20
		Tightening torque (N.m)							
4.6	240	4-5	10-12	20-25	36-45	55-70	90-110	120-150	170-210
5.6	300	5-7	12-15	25-32	45-55	70-90	110-140	150-190	210-270
6.8	480	7-9	17-23	33-45	58-78	93-124	145-193	199-264	282-376
8.8	640	9-12	22-30	45-59	78-104	124-165	193-257	264-354	376-502
10.9	900	13-16	30-36	65-78	110-130	180-201	280-330	380-450	540-650
12.9	1080	16-21	38-51	75-100	131-175	209-278	326-434	448-597	635-847

WARNING

TO PREVENT POTENTIAL PERSONAL INJURY, PLEASE DE-ENERGIZE ALL ELECTRICAL CONNECTIONS PRIOR TO GENERATOR INSTALLATION. THE

DESIGN AND INSTALLATION OF AEROSOL GENERATOR SHOULD BE CARRIED OUT BY QUALIFIED PERSONNEL IN FIRE EXTINGUISHING SYSTEM TECHNOLOGY.

5.2.1 Installation of Single Generator System

1. Take JAD300-U01 aerosol fire extinguishing system out of the shipping container and check the integrity it. If the system is damaged or parts are missing, please do not install it. Use ohmmeter to check the completeness of initiator. Adjust the gear of the ohmmeter to 200Ω, and connect the two wires of the initiator of the system with the wires of the ohmmeter. If the figure exceeds the range of 1.0±0.2 Ω, do not install it.

2. To determine the installation location, it is necessary to ensure that the JAD300-U01 aerosol fire extinguishing system is discharged and released unimpededly when it is actuated. Attention must be paid to prevent the fire extinguishing system from directly discharging near the vertical surface of equipment ceiling in the hazard area, and to ensure that the fire extinguishing system will not be accidentally damaged. After the position is selected, locate and fix the mounting bracket 1.

3. Connect JAD300-U01 aerosol fire extinguishing system firmly to the mounting bracket 1, and make sure that there is no risk of actuation during the installation process, and all bolts are firmly screwed in place.

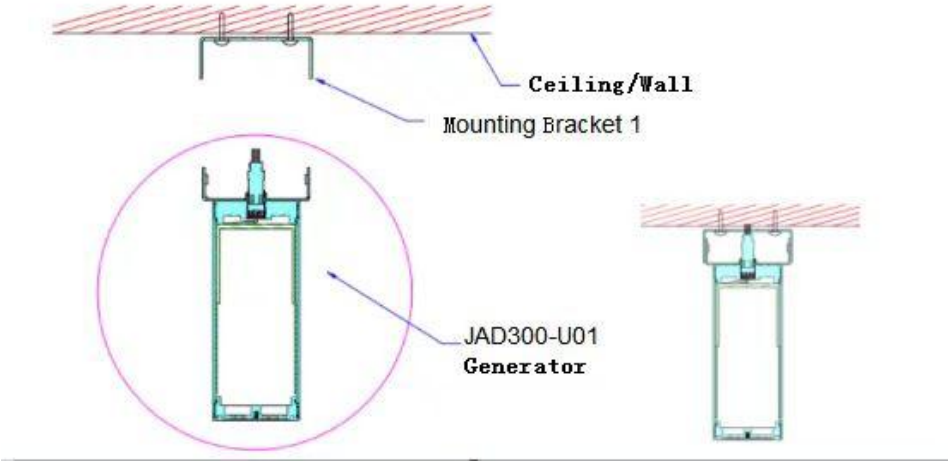


Figure 5.1 Single Generator System Installation

Attention: Ensure that the power supply is turned off, and connect the wire to the initiator connector at the bottom of the fire extinguishing system.

WARNING

TO PREVENT PERSONNEL INJURY, DE-ENERGIZE ALL ELECTRICAL CONNECTIONS PRIOR TO GENERATOR INSTALLATION. MAKE SURE THAT NO BODY PART IS PLACED DIRECTLY IN FRONT OF THE GENERATOR EXIT PORTS DURING INSTALLATION.

5.2.2 Installation of Multiple Generator System

1. Take JAD300-U01 aerosol fire extinguishing system out of the shipping container and check the integrity . If the system is damaged or parts are missing, please do not install it. Use ohmmeter to check the completeness of initiator. Adjust the gear of the ohmmeter to 200Ω, and connect the two wires of the initiator of JAD300-U01 aerosol fire extinguishing system with the wires of the ohmmeter. If the figure exceeds the range of 1.0±0.2Ω, do not install it.

2. To determine the installation location, it is necessary to ensure that the JAD300-U01 aerosol fire extinguishing system is discharged and released unimpeded when it is actuated. Attention must be paid to avoid direct discharging of fire extinguishing systems near the vertical surface of the equipment ceiling in the hazard area, and to ensure that the fire extinguishing systems will not be accidentally damaged. The location of the fire extinguishing systems must promote the circulating flow and mixing of aerosols from multiple fire extinguishing systems. Fire extinguishing systems shall not be placed in the position where they are directly discharged from each other, which will lead to the accumulation of aerosol fire extinguishing media and reduce the fire extinguishing effect of aerosol. After the position is selected according to the above principles, locate and fix the mounting bracket 1.

3. Connect JAD300-U01 aerosol fire extinguishing system firmly to the mounting bracket 1, and pay attention to ensure that there is no risk of actuation during the installation process, and all bolts are firmly screwed in place.

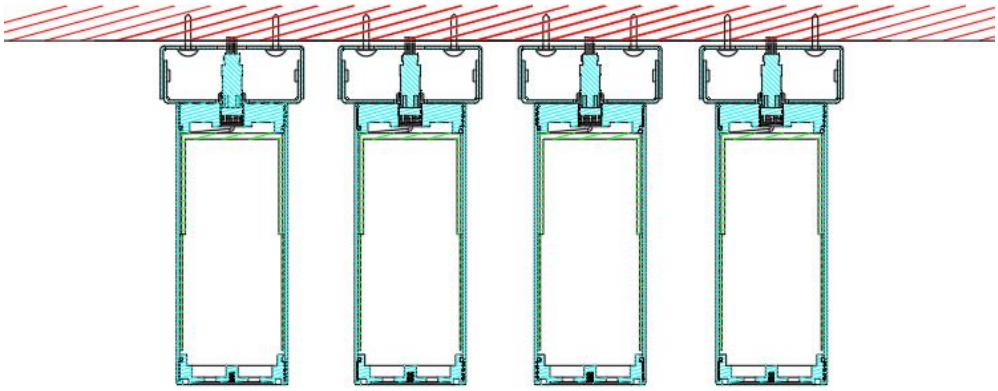


Figure 5.2 Multiple Generator System Installation

Attention: Ensure that the power supply is turned off, and connect the wire to the initiator connector at the bottom of the fire extinguishing system.

5.3 Post Installation Checkout

After installing the JAD300-U01 aerosol fire extinguishing system and connecting it to the detection/control system, perform the following inspections and tests.

1. Confirm that the fire extinguishing system with the correct size and model is installed as required.
2. Verify that the fire extinguishing system mounting bracket is correctly installed and all accessories are fastened.
3. Confirm that all electrical connections have been completed, and use an ohmmeter (electrical only) to test electrical continuity.
4. Verify that the positions of all fire extinguishing systems are correct. Check whether there are obstacles in the path of aerosol discharge flow. Fire extinguishing systems must be installed to ensure that they will not cause personal injury when they are actuated. The aerosol discharge flow shall not impact the ceiling or the vertical surface of the equipment at close range.
5. The isolation lighting must be installed correctly, easily accessible and clearly marked.
6. Verify the delay function and integrity.
7. All acceptance testing shall be in accordance with this manual, any applicable standards, and the authority having jurisdiction.

6 Operation

6.1 General

When the fire detection system detects a fire, the fire detection system transmits a actuation signal to the initiator of JAD300-U01 aerosol fire extinguishing system and actuate the aerosol generator. After the generator being actuated, a large amount of fire extinguishing media is generated, which is discharged into the protected area from the port of the system after passing through the coolant to extinguish the fire.

6.2 Operating Procedures

JAD300-U01 aerosol fire extinguishing system can be used with both automatic and manual control systems.

Note: If it is intended to be operated with automatic control system. All components must be UL/ULC listed as compatible with the aerosol generators under the UL Listing.

6.2.1 Automatic Control of Fire Extinguishing Process

For automatic aerosol fire extinguishing system, the fire extinguishing control mode of the protected area is fully automatic. In this state, when the system receives the fire signal

detected by two or more detectors in the same protected area, the controller in the protected area will send a signal to actuate the JAD300-U01 fire extinguishing system, and then the fire extinguishing system will perform the following procedures and operations,

a) According to the program setting, the controller of the protected area firstly sends out audible and visual alarm in the area, and simultaneously sends out the emergency evacuation signal of personnel;

b) After the above operations are completed, the countdown will be performed according to the delay time set by the program (the delay time can be adjusted according to the actual application scene and place);

c) During the delay period, all openings, fire doors, heat dissipation vents, air conditioning outlets and other openings that may affect the fire extinguishing effect will be automatically closed according to the design requirements and program settings;

d) Sending a feedback signal to the fire control system or monitoring system to monitor whether all programs or actions are running normally ;

e) After the delay period is over, immediately issue a fire extinguishing actuation command to the aerosol fire extinguishing generator;

f) After the generator being actuated, a large amount of fire extinguishing media (aerosol agent) will be generated and discharged into the protected area to extinguishing the fire;

g) At the same time, the aerosol-forming compound reacts, in the meantime a feedback signal will be transmitted to the fire control system. The controller sends a linkage signal to light up the gas discharge indicator light set at the entrance of the protection area, warning the personnel not to enter the area;

h) After the fire in the protected area is extinguished, the enclosure is to be quickly ventilated and the protected area shall be cleaned up.

The generator can be separately connected back to the control equipment or connected in series in a loop(see Figure 6.1 and Figure 6.2).

Control Process of JAD300-U01 Fire Extinguishing (single generator)

a)The current is directly input from the gaseous controller panel (see Figure 6.1)

b)The minimum actuation current of the aerosol fire extinguishing system is 900mA, and the minimum actuation voltage is 1.5Vdc. Attention should be paid to observing the maximum current required and the voltage drop from the power supply of the aerosol fire extinguishing system.

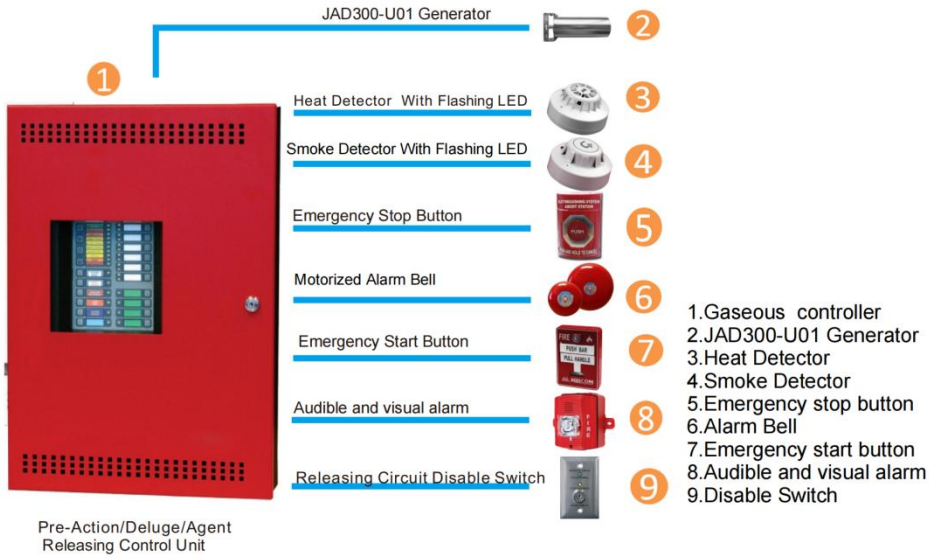


Figure 6.1 Single JAD300-U01 generator control progress

Control of Fire Extinguishing Process (series connected generators)

a)Automatic actuation mode achieved through fire detection systems (heat, smoke, or gas detectors). Connect to Gaseous fire suppression controller through heat, smoke or gas detector(see Fig6.2).

b)The minimum actuation current of the aerosol fire extinguishing system is 900mA, and the minimum actuation voltage is 1.5Vdc. Attention should be paid to observing the maximum current required and the voltage drop from the power supply to the aerosol fire extinguishing system.

c)Automatically connected to fire detection and control panels through heat, smoke, or gas detectors.

d)When the rated actuation voltage is DC24V, 10 series connected aerosol fire extinguishing generators can be actuated.

e)At a rated actuation voltage of DC24V (15.6V) of 65%, 10 series connected aerosol fire extinguishing generators can be actuated.

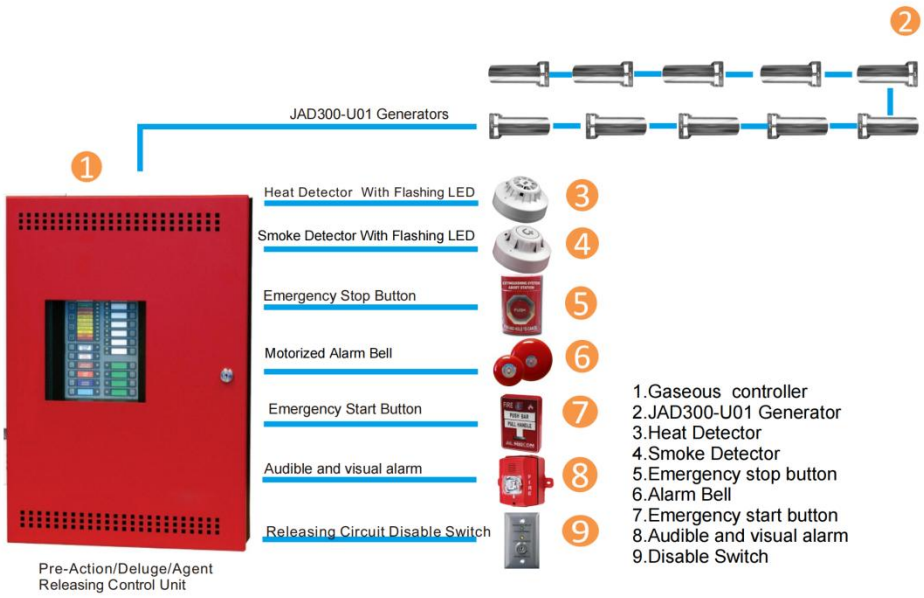


Figure 6.2 Series Connected JAD300-U01 generators control progress

Note：Fire Alarm Control Panels must be UL/ULC Listed as compatible with the aerosol generators under the UL Listing.

6.2.2 Manual Control of Fire Extinguishing Process

a) For manual aerosol fire extinguishing system, the fire control system only receives the fire signal detected by the fire detector, according to the program setting, the controller of the protected area first sends out audible and visual alarm in the area, and simultaneously sends out the emergency rescue signal of personnel.

b) In this state, even if the fire signal detected by two or more detectors in the same protected area is received, the fire extinguishing linkage signal will not be sent to the aerosol generator.

c) When it is necessary to actuate the JAD300-U01 aerosol generator in this state, the on-site operator can manually press the isolate switch set at the entrance of the protected area.

d) After the aerosol generator is actuated manually, fire extinguishing will be conducted as the same progress of autonomic aerosol fire extinguishing system.

e) This manual operation method is also effective when the fire extinguishing control mode is in the automatic state even if the fire detector has not detected the fire in the protected area. The control subsystem satisfies "manual override".

6.2.3 System Isolate Switch

The automatic operation of the system shall be prevented by means of a system isolate switch (located outside the protected area) when personnel are present in the hazard area. The operation of the system shall be manual only when personnel are present. While the system isolate switch is active the automatic activation of the system is inhibited but the fire detection and alarm system shall remain functional. The system shall return to full automatic control when the switch is reactivated.

The operation of the system isolate switch shall be electrically isolated and each conductor of the generators wires and initiate a visual indicator of status at the Control Station.

6.2.4 Flow Chart of Fire Extinguishing Control

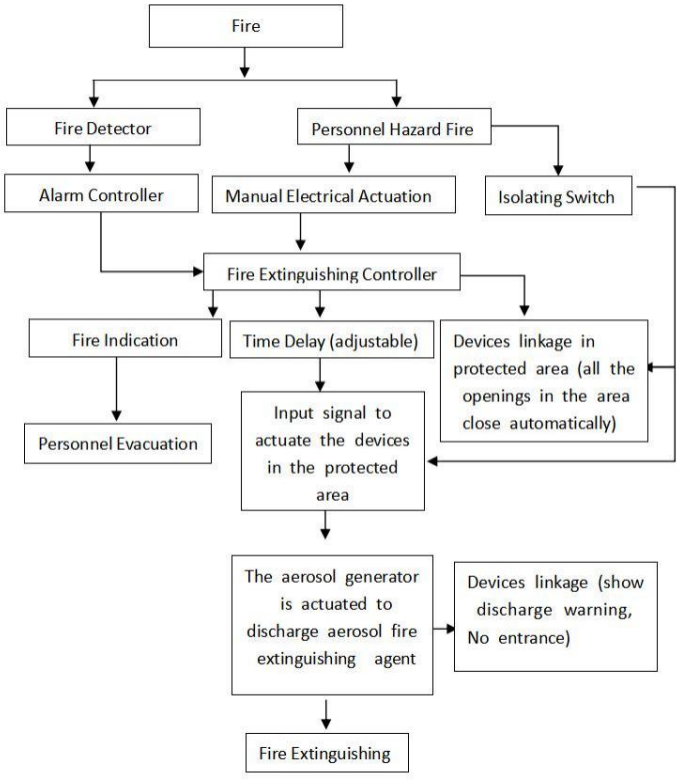


Figure 6.3 Flow chart of fire extinguishing control

6.3 Post Fire Operation

After the JAD300-U01 aerosol fire extinguishing system is discharged, trained professionals must carry out post-fire maintenance, post-treatment of the system and equipment must be performed according to the relevant provisions of this manual, and strictly abide by all warnings in this manual and relevant standards and specifications during operation and maintenance. Especially when entering the dangerous area, relevant safety technical disclosure and strict maintenance and treatment scheme must be specified.

WARNING

DO NOT ENTER A HAZARD AREA WITH AN OPEN FLAME OR LIGHTED CIGARETTE. THE POSSIBLE PRESENCE OF FLAMMABLE VAPORS MAY CAUSE RE-IGNITION OR EXPLOSION.

WARNING

ENSURE FIRE IS COMPLETELY EXTINGUISHED BEFORE VENTILATING AREA. BEFORE PERMITTING ANYONE TO ENTER THE HAZARD AREA, VENTILATE AREA THOROUGHLY OR USE SELF-CONTAINED BREATHING APPARATUS.

6.4 Post Fire Maintenance

The following operation procedures must be followed to maintain and re-commission the fire extinguishing system:

1. After JAD300-U01 aerosol fire extinguishing system is discharged, allow a minimum holding time of 10 minutes, during which ventilation or opening of relevant openings (doors, windows, fire doors, etc.) is not allowed in the protected area.

2. Ensure that there is a spare portable fire extinguisher in hand for use in case of re-ignition during the whole operation process.

3. Vent the area thoroughly by operating the ventilation system, by fan extraction, or by opening doors and windows. To avoid unwanted inhalation of fire by-products and aerosol, a protective breathing apparatus or mask should be worn if it is necessary to enter prior to complete ventilation of the hazard area.

4. Inspect the area to insure the fire is completely extinguished and that there are no localized hot spots or other sources of re-ignition present.

5. Clean any minor amounts of residue, which may have not been removed during ventilation, by thoroughly vacuuming, blowing, brushing, or washing away (with a water alcohol mixture) as appropriate. Check to make sure that there is no agglomeration due to discharge too close to equipment, walls etc. Any agglomeration exists must be wiped or washed clean.

6. If the residue after discharge is not treated, it may absorb moisture and may lead to non-gradual surface discoloration of unprotected metal surface. If caking is formed on the PCB, it may lead to short circuit of electronic components on the PCB due to the moisture and metal particles contained in the caking. The change of room temperature during a fire event or discharge will affect the humidity, so it is very important to reduce the humidity of the casing as soon as possible after discharge.

7. Remove the spent JAD300-U01 aerosol fire extinguishing system. The casing temperature of the fire extinguishing system after discharge is high. Be sure to wear gloves or take other hand protection measures when removing the spent system.

8. Dispose of spent systems according to applicable federal, state, and local

regulations.

9. Contact your distributor to replace the system immediately.

WARNING

BEFORE PERFORMING POST FIRE MAINTENANCE PROCEDURES, REFER TO THE MATERIAL SAFETY DATA SHEETS AND SAFETY BULLETINS IN THE APPENDIX OF THIS MANUAL.

NOTE

Aerosol fire extinguishing agent refers to a kind of gaseous colloidal mixed substance (particle size reaches 10^{-5}μm ∽ 10^{-1}μm) formed by physical or chemical action. The substance with gas fluidity, which can be spread around obstacles and has certain fire extinguishing function is aerosol fire extinguishing agent.

The extinguishingmedia and particles produced after JAD300-U01 aerosol fire extinguishing system is actuated are very easy to float and suspend in the protected area. Due to the characteristics of aerosol fire extinguishing agent, it can be suspended for a long time (up to one hour) and will not start to settle in a short time, so aerosol gas and particles are very easy to be discharged from the protected area, and only a very small amount of particles may be deposited on the equipment. Usually, there is almost nothing to do except extracting air from the protected area through fans or air handling systems. Then purge with compressed air. Because the particle size of aerosol deposited on the horizontal plane is 10^{-5} μm-10^{-1} μm, and no continuous layer will be formed, the gap between particles is also large, so the problem of conductivity will not occur.

However, as a preventive measure, it is always important to thoroughly inspect and clean the site after discharge. Although the aerosol itself is very "clean", environmental factors are also worthy of consideration. The actual fire is unknown and may produce harmful by-products, which may also expose great risks to sensitive equipment.

Because of the possible unknowns after the fire and the unreliable factors of the environment, we suggest thoroughly cleaning the impurities in the protected area to ensure the elimination of harmful substances in the protected space and avoid secondary injuries and economic losses. For example, on-site maintenance and housekeeping may be lax, resulting in dust accumulation in the protected area. During the discharge process, any dirt in the protected area will be blown to the surrounding area, and any dirt will be deposited in the protected area. Therefore, it is necessary to maintain the protected area and carry out subsequent ventilation and clean after the fire.

In addition, in rare cases, the discharging direction and equipment position of JAD300-U01 aerosol fire extinguishing system may be changed, resulting in the system being directly discharged onto the wall or equipment surface incorrectly. This may lead to the deposition of small, localized and highly concentrated particles on the surface. If left

untreated, caking may absorb moisture and may lead to non-progressive surface discoloration of unprotected metal surfaces. Therefore, it is very important to clean any agglomerated particles with contact cleaner spray within 24 hours after discharge.



Figure 6.4 Recommended contact cleaner spray

7 Maintenance

WARNING

BEFORE PERFORMING MAINTENANCE PROCEDURES, REFER TO THE MATERIAL SAFETY DATA SHEETS AND SAFETY BULLETINS IN THE APPENDIX OF THIS MANUAL.

7.1 General

Although JAD300-U01 aerosol fire extinguishing system needs much less maintenance than other fire extinguishing systems operating under pressure, it is necessary to establish a detailed regular maintenance plan for the system to ensure the continuous and correct operation of JAD300-U01 aerosol fire extinguishing system.

At a minimum, the log must record:

1.inspection interval,

2.inspection procedure performed,

3.maintenance performed, if any, as a result of inspection, and

4.the name of the responsible person performing the operation.

7.2 Preventive Maintenance

Perform preventive maintenance according to the preventive maintenance/replacement schedule in Table 7.1.

Table 7.1 Preventive Maintenance/Replacement Schedule

Schedule	Requirement
Monthly	Visual examination of the operating condition of the generators.
	Visual inspection of components
Annual	Check/test all system components.
	Test electrical continuity
	Check the bracket & position of the generators.
15 years	Remove from service

7.3 Inspection Procedures

7.3.1Monthly

1. Check all electrical connections to ensure that JAD300-U01 aerosol fire extinguishing system can operate normally in case of fire.

2. Conduct a comprehensive visual inspection of all JAD300-U01 aerosol fire extinguishing systems to see if there are any damaged or missing parts.

3. Ensure that JAD300-U01 aerosol fire extinguishing system is not obstructed and meets the required clearance.

7.3.2 Annual

1. Make a general visual inspection of all JAD300-U01 aerosol fire extinguishing systems for damaged or missing parts.

2. Ensure that the access to hazard areas and exits is unobstructed and the isolate switch is normal, and there are no obstacles that inhibit the normal operation of fire extinguishing systems or aerosol distribution in case of fire.

3. Inspect whether JAD300-U01 aerosol fire extinguishing system has physical damage, such as cracks, dents, deformation or corrosion. If damage is found, please replace it in time and re-install and debug it according to the operation instructions in this manual.

4. Inspect the mounting bracket and related hardware for loose, damaged or broken parts. Replace damaged parts and tighten all loose hardware.

5. Inspect whether the isolate switch outside the protection area is damaged, broken, dirty or deformed. Replace if necessary.

6. Inspect all electrical connections and conduct the electrical continuity test with an ohmmeter. Repair or replace the connections if necessary.

7. Ensure that the generator is not obstructed and the required clearance has been met.

7.3.3 Replacement/Removal from Service

JAD300-U01 aerosol fire extinguishing system has an installed useful life of 15 years. The production date and expiration date will be indicated on the product label. If the expiration date is exceeded, please contact the supplier for replacement.

8 System Components

Table 8.2 JAD300-U01 Aerosol Generator Assembly

Model	Capacity	P/N	Remarks
JAD300-U01	300g	JAD300-U01-C-00	The system is an integral structure that cannot be disassembled, and there are no spare parts.

Table 8.3 JAD300-U01 Mounting Brackets

Model	P/N
300g mounting bracket	JAD300-U01-C-0005

9 Limited Warranty Statement

Hubei Jiandun Fire Technology Co., Ltd. represents that this product is free from defects in materials and workmanship, and any products or parts proved to be defective in workmanship or materials can be repaired or replaced within 18 months from the first delivery date of our factory. Please return the defective products to the factory:

Manufacturer: Hubei Jiandun Fire Technology Co., Ltd.

Address: No.199 Huaxi Road, Biological Industrial Park, China (Hubei) Free Trade Zone Yichang Area，Yichang City, Hubei Province, China

Tel: 0717-6741877

E-mail:development@jad119.com

Delivery expenses caused by return the products with defects shall be borne by Hubei Jiandun Fire Technology Co., Ltd.

10.Limitation of Liability

This warranty does not cover systems damaged during transportation or caused by misuse, accident or negligence, or systems that have been repaired or changed by others. In any case, JAD will not be liable for special or indirect damages, such as damage or loss of systems, loss of profits or income, cost of capital, cost of purchasing or replacing goods, or claims made by customers of the original buyers. In this agreement, the remedies of the original buyer and all other buyers shall not exceed the price of the provided systems.

This warranty completely and explicitly replaces all other warranties, whether express or implied, including the warranties of merchantability or fitness.

Appendix

Appendix A Safety/Information Bulletins

JAD300-U01 aerosol fire extinguishing system uses pyrotechnic technology. Personnel responsible for the installation and maintenance of JAD300-U01 aerosol fire extinguishing system must be aware of the potential hazards associated with improper handling, installation or maintenance of this equipment.

Maintenance personnel of JAD300-U01 aerosol fire extinguishing system must be fully trained in proper handling, installation and maintenance, and the hardware of JAD300-U01 fire extinguishing system, and follow the instructions in this manual and the safety bulletin contained in this appendix. And JAD has provided appropriate warnings and precautions in the full text of this manual. These warnings and precautions must always be observed. Failure to do so may result in potential injury to personnel.

Safety Bulletin 1

Environmental Issues

Both Ozone Depletion Potential (ODP) and Global Warming Potential (GWP) are zero. There are no environmental issues associated with the use of JAD300-U01 aerosol fire extinguishing system.

Toxicity and Health Issues

Condensed aerosol fire extinguishing agent is non-corrosive and harmless to various materials, and JAD300-U01 aerosol fire extinguishing system will not do harm to health in its benign state, because the constituent chemicals are pressed into a very stable solid form, even when the working temperature rises. The stored chemicals will not cause harm to the environment or health.

Different fire extinguishing agents have different fire extinguishing mechanisms.The fire extinguishing mechanisms of general fire extinguishing agents mainly include isolation method, suffocation method, cooling method and chemical inhibition method. The fire extinguishing mechanism of condensed aerosol is mainly reflected in two aspects: on the one hand, it is the cooling effect of endothermic decomposition, on the other hand, it is the chemical inhibition effect of gas phase and solid phase, which play a synergistic role with each other. In addition, the gas phase components in aerosol fire extinguishing agent products also played a certain auxiliary role.

Aerosol extinguishing agent itself is composed of solid and gas combustion products. The solid phase is composed of highly dispersed alkali metal salts and oxide particles, which is not harmful to human health at normal design concentration. The gas phase may contain a small amount of carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NOx) and ammonia (NH_3). The amount of these gases is very small due to the pharmaceutical formula, pharmaceutical raw materials and processing flow.

Under the limited accidental exposure of normal design concentration, aerosol will not

cause harm to health. Exposure to aerosols is usually less than exposure to decomposition products of fire. Accidental exposure within five minutes is usually considered safe. However, certain safety restrictions should always be observed. Contact with aerosols should be avoided, as ingestion of ultra-fine particles may cause short-term discomfort. Aerosol emission also has a high shielding coefficient. Therefore, the following installation requirements must be observed.

System Installation Requirements:

The total flooding fire extinguishing of JAD300-U01 aerosol fire extinguishing system can only be used in normally unoccupied areas. The system needs to be equipped with an isolate switch to ensure the evacuation of personnel before the system is discharged, and it is only actuated manually when personnel may present in the protected area.

Safety Bulletin 2

Subject: Safety Handling Procedure of JAD300-U01 Aerosol Fire Extinguishing System

Personnel must be trained in proper handling, installation and maintenance before handling the JAD300-U01 aerosol fire extinguishing systems.

The instructions in this manual and the safety bulletin contained in this appendix must be strictly followed.

JAD has provided appropriate warnings and precautions in the full text of this manual. These warnings and precautions must be strictly observed. Failure to do so may result in potential injury to personnel.

Before dealing with JAD300-U01 aerosol fire extinguishing system, all personnel must be fully trained to know how to operate the fire extinguishing system safely and be familiar with the correct procedures of installation, disassembly, transportation and disposal.

Read, understand and always follow the operation and maintenance manuals, user manuals, etc. attached to each system.

The following safety procedures must always be observed:

Moving the systems: The fire extinguishing system shall be compactly transported in an upright manner in the provided packaging. They must be properly fixed in place and are not allowed to roll or fall off the tailgate of the vehicles. **Dropped systems are not to be installed.**

Rough handling: the fire extinguishing system shall not fall or be violently strook. **Dropped and Strook systems are not to be installed.**

Storage: Containers must be stored standing upright where they are not exposed to extreme environmental conditions or are subject to being knocked over.

Safety Bulletin 3

Subject: Post Fire Disposal of JAD300-U01 aerosol fire extinguishing system.

Recycling of JAD300-U01 aerosol fire extinguishing system after discharge

In most cases, the discharged JAD300-U01 aerosol fire extinguishing system can be disposed of in any landfill that treats industrial wastes. However, relevant local laws and regulations must be researched and observed. Each discharged JAD300-U01 aerosol fire extinguishing system will contain the following materials:

1. All stainless steel casings and front and back covers.
2.All installation mounting brackets.
3. Stainless steel aviation plug.
3. Ignition wristband and gasket inside the fire extinguishing system.
4. Silica and alumina (ceramic balls): 125g
5. Teflon wire: ø0.8mm×400mm
6. Thermal insulation silicone rubber
8. Trace chemicals: potassium carbonate (water-soluble particles remaining in the system during discharge).

If you have any questions about the above contents, please contact us.

Manufacturer: Hubei Jiandun Fire Technology Co., Ltd.

Address: No.199 Huaxi Road, Biological Industrial Park, China (Hubei) Free Trade Zone Yichang Area，Yichang City, Hubei Province, China.

Tel: 0717-6741877

E-mail:development@jad119.com

Safety Bulletin 4

Equipment Exposure Issues of JAD300-U01 Aerosol Fire Extinguishing system

JAD300-U01 aerosol fire extinguishing system has made relevant tests and strict material selection for the structure, including the structure, aviation composite materials and materials commonly used in electronics and circuit boards. In the case of this research and test, it is shown that JAD300-U01 aerosol fire extinguishing system has no harmful effect on the operation of the equipment.

Fire extinguishing mechanism:

Generation of aerosol fire extinguishing agent;

Chemical reaction to produce aerosol fire extinguishing agent

$K_{0.692}C_{1.197}N_{1.55}O_{2.188}H_{1.53} \rightarrow 0.346K_2O + 0.775N_2 + 1.197CO_2 + 0.765H_2O$

① Aerosol fire extinguishing agent generator: KNO_3 and O_2 are oxidants, $C_3H_6N_6$ is reductant/combustible agent, and C48H42O7 is adhesive/combustible agent.

② Aerosol fire extinguishing agent: K_2O provides potassium free radicals to play the main fire extinguishing role (endothermic decomposition and cooling, chemical inhibition), while N_2 and CO_2 dilute oxygen on the surface of combustible materials (oxygen dilution).

Note: The above reaction formula is theoretical. Because the formula is negative oxygen balance and the reaction is incomplete, the actual product is different from it. When the oxidant is insufficient, gas products such as CO and NH_3 may be produced. K_2O in the product may also be further reacted to generate carbonate/bicarbonate, etc.

Table A.1 Composition Table of Aerosol Fire Extinguishing Agent

	Gas composition（%）							Solid composition（%）			
ingredient	CO_2	N_2	NO_2	H_2O	O_2	CO	other	K_2CO_3	C	$KHCO_3$	other
content	30.79	47.96	7.38	6.44	6.37	0.28	0.78	81.61	15.28	0.25	2.86

Combustion reaction inhibition process:

The fire extinguishing process includes three stages:

（1）The fire spreads through the combustion reaction groups (O, H, OH) in the flame chain; （2）The tiny particles generated by aerosol have great surface area and surface energy, which attract the combustion reaction groups and have chemical action;（3）After the tiny particles enter the fire, they dissociate the potassium free radical (K) at the high temperature of the fire, participate in the combustion chain reaction, and have many chain reactions, which inhibit or interrupt the combination of combustion reaction groups and oxygen.

$K_2O+2\cdot H \rightarrow 2KOH$

$KOH+\cdot OH \rightarrow KO\cdot+H_2O$

$KO\cdot+\cdot H \rightarrow KOH$

$K\cdot+\cdot OH \rightarrow KOH$

$K\cdot+\cdot O \rightarrow KO\cdot$

$KOH+\cdot OH \rightarrow KO\cdot+H_2O$

$2K\cdot+\cdot O \rightarrow K_2O$

The combustion reaction groups react chemically with fine particles, which inhibits the

combustion reaction. The tiny particles dissociate at the high temperature of the fire, and the dissociated potassium radical (K) reacts with OH and O to generate KOH and KO, which further consumes H and OH, and finally generates KOH, K_2O and other products. As KOH and K_2O further react with CO_2 and H_2O in the air, substances such as K_2CO_3 and $KHCO_3$ are generated.

Aerosol characteristics:

Aerosol fire extinguishing agent refers to a kind of gaseous colloidal mixed substance (particle size reaches 10^{-5} μm~10^{-1} μm) formed by physical or chemical action. The substance with gas fluidity, which can spread around obstacles and has certain fire extinguishing function is aerosol fire extinguishing agent.

The extinguishingmedia and particles produced after JAD300-U01 aerosol fire extinguishing system is actuated are very easy to float and suspend in the protected area. Because of the characteristics of aerosol fire extinguishing agent, it can be suspended for a long time (up to one hour) and will not start to settle in a short time, so aerosol gas and particles are very easy to be discharged from the protected area, and only a very small amount of particles may be deposited on the equipment. Usually, there is almost no need to do anything except to extract air from the protected area through fans or air handling systems. Then purge with compressed air. Because the particle size of aerosol deposited on the horizontal plane is 10^{-5} μm~10^{-1} μm, and no continuous layer will be formed, the gap between particles is also large, so the problem of conductivity will not occur.

However, as a preventive measure, it is always important to thoroughly inspect and clean the site after discharge. Although the aerosol itself is very "clean", environmental factors are also a factor worthy of consideration. The actual fire is unknown and may produce harmful by-products, which may also pose great risks to sensitive equipment.

Due to the possible unknowns after the fire and the unreliable factors of the environment, we suggest thoroughly cleaning the impurities in the protected area to ensure the elimination of harmful substances in the protected space and avoid secondary injuries and economic losses. For example, on-site maintenance and housekeeping may be lax, resulting in dust accumulation in the protected area. During the discharge process, any dirt in the protected area will be blown to the surrounding area, and any dirt will be deposited in the protected area. Therefore, we think it is necessary to maintain the protected area and carry out subsequent ventilation and cleaning after the fire.

In addition, in rare cases, the spraying direction and equipment position of JAD300-U01 aerosol fire extinguishing system may be changed incorrectly, resulting in the JAD300-U01 aerosol fire extinguishing system being directly discharged onto the wall or equipment surface incorrectly. This may lead to the deposition of small, localized and highly concentrated particles on the surface. If left untreated, caking may absorb moisture and may lead to non-progressive surface discoloration of unprotected metal surface. If caking is formed on PCB, it may lead to short circuit of electronic components on PCB due to moisture and metal particles contained in caking.

The extinguishing agent discharged by JAD300-U01 aerosol fire extinguishing system can remain suspended for a long time and can be easily discharged by fan or air treatment. A small amount of aerosol deposited on the floor or other horizontal surfaces

can be cleaned by vacuuming, blowing, brushing or washing . Small amounts of residue or agglomerated mass that have not been removed during the ventilation process must be cleaned up with contact cleaner spray thoroughly.

The above cleaning work should be completed within 24 hours.

Summary

Combined with the study of aerosol characteristics and chemical composition of JAD300-U01 aerosol fire extinguishing system, it is shown that the correctly installed JAD300-U01 aerosol fire extinguishing system will not damage electronic equipment, nor will it adversely affect the effective life of equipment exposed to the fire extinguishing system protection area.

Generally speaking, JAD300-U01 aerosol fire extinguishing system should be installed at the bottom of the protected area or in a room close to the bottom of the protected area, and installed horizontally in the center of the bottom of the protected area to ensure the three-dimensional distribution of aerosol. The installation angles of systems with different installation heights are different, so it is only necessary to keep the angle of 45°（±5°）between the discharge port of JAD300-U01 aerosol fire extinguishing system and the bottom of the protected area. In a large volume (≥100m^3), the installation method of JAD300-U01 aerosol fire extinguishing system must have a clear discharge path, and it must not be discharged to obstacles or equipment, because it will lead to agglomeration, reduce efficiency and affect the liquidity of aerosol fire extinguishingmedia. The aerosol fire extinguishing system used for total flooding must put the fire extinguishing system on multiple levels.

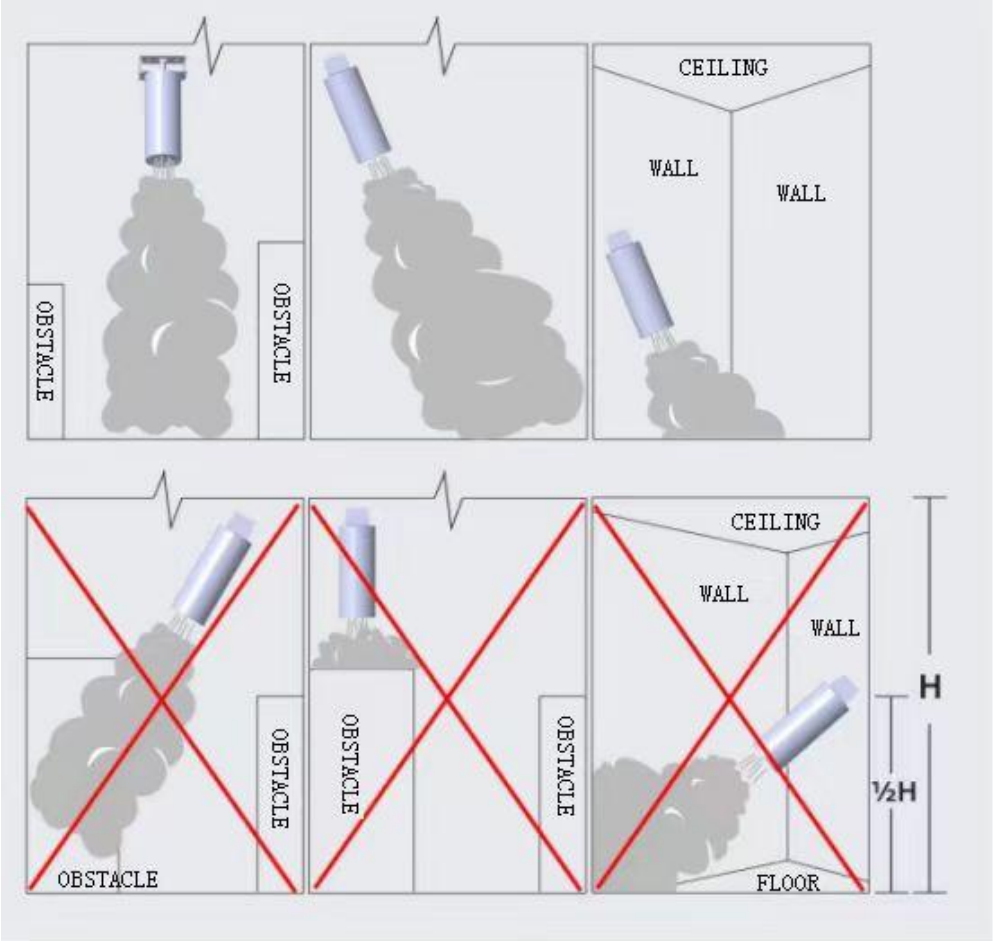


Figure A.1 Schematic Diagram of Discharge

It is very important to install JAD300-U01 aerosol fire extinguishing system to ensure proper aerosol flow and distribution. The aerosol fire extinguishing agent should be distributed as evenly as possible around the hazard area to ensure that the aerosol fire extinguishing agent can quickly flow and disperse to the fire source in the protective space. Ensure the fire extinguishing effect of the fire extinguishingsystemJAD300-U01 aerosol fire extinguishing system shall not be placed in the position where they are directly discharged from each other, which will lead to the aggregation of aerosol particles, reduce the fluidity and dispersion of fire extinguishing media and thus reduce the fire extinguishing effect of aerosol. For the same reason, the location of the aerosol generator in total flooding application should also ensure that the aerosol flow does not directly hit the side of obstacles or protected equipment. Always check whether there are obstacles in the path of aerosol discharge flow. The installation of JAD300-U01 aerosol fire extinguishing systems must ensure that they will not cause personal injury when actuating.

Appendix B

Material Safety Data Sheet

Material Safety Data Sheet

For reference only: Please contact us for details.No.199 Huaxi Road, Biological Industrial Park, China (Hubei) Free Trade Zone Yichang Area，Yichang City, Hubei Province, China.Tel: 0717-6741877 E-mail:development@jad119.com

Section1 Identification of the Substance/Company

Commodity	JAD300-U01 Aerosol Fire Extinguishing System Agent
Manufacturer	Hubei Jiandun Fire Technology Co., Ltd.
Address	No.199 Huaxi Road, Biological Industrial Park, China (Hubei) Free Trade Zone Yichang Area，Yichang City, Hubei Province, China.
Tel:	+86-717-6741877
Fax:	+86-717-6211484
Website/E-mail	development@jad119.com

Section 2 Component/ Information on Ingredients

Component	CAS#	Notes:
potassium nitrate	7757-79-1	The related raw materials are mixed and pressed into a highly stable and consistent grain. The grain is coated with silica gel and then assembled into a sealed stainless steel casing-it will not be exposed to the environment.
Melamine	108-78-1	
Phenolic resin	9003-35-4	
Appearance and smell:	Beige to white, no odor.	
Spontaneous combustion temperature:	350℃	
Water solubility:	Slightly Soluble	

Section 3 Hazard identification

Aerosol Generating Compound	Aerosol Fire Extinguishing Agent
flammable	Possible exposure to aerosol extinguishing agent if system is actuated. May cause temporary, very mild irritation of mucous membrane.

Section 4 First Aid Measures

Contact Method	Aerosol-Generating Compound	Aerosol Extinguishing Agent
Inhalation	N/A	Remove to fresh air
Eye Contact	Hold eyes open and flush with water	Remove to fresh air and flush with water.
Skin contact	Change clothing and shoes, wash with soap and water.	Wash with soap and water.

Section 5 Fire Fighting Measures

Aerosol-Generating Compound	Aerosol Extinguishing Agent
In the event of a fire, evacuate the area and inform emergency services. Ignition of JAD300-U01 aerosol fire extinguishing system to produces a fire extinguishing aerosol. Water may be used as an additional extinguishing agent.	N/A

Section 6 Accidental Release Measures

Aerosol-Generating Compound	Aerosol Fire Extinguishing Agent
N/A	Keep ventilate till aerosol drop away, clean up the discharge residue.

Section 7 Handling and Storage

Handing Precautions	Keep away from combustion source, high temperature and keep ventilate and dry.
Storage Precautions	Keep away from combustion source, high temperature and keep ventilate and dry.
Storage Class	9

Section8 Exposure Controls and Personal Protection

Exposure	Keep ventilate during manufacture and operation.
Personal Protection	Protective gloves, goggles and anti-static clothing should be worn during a production and spilled material clean up procedure. Fire proof and heat insulation clothing ,helmeted and shoe cover shall be worn during fire extinguishing procedure.

Section 9 Physical and Chemical Properties

Appearance	Steel Cylinder length:Φ76×192mm (excluding mounting bracket)

Section10 Stability and Reactivity

Stability	The system is extremely stable under normal temperature conditions
Conditions to Avoid	Avoid sources of fire, sources of electrical power, shock, and high temperatures
Hazardous Reaction Products	Combustion products potentially infinitesimal hazardous carbon monoxide CO and nitrogen oxides NOx
The agent in the system is extremely stable below 125℃	

Section 11 Toxicological Information

The TLV's (Threshold Limit Values) of the chemicals released in the aerosol phase are applicable only in case of long, as long as a complete professional life, exposure. This is not the case of a real life situation.		
Product		
The potential damage is not caused by the product mixture composition, but by the fact that it can be inhaled. The TLV's apply in case of long exposure over many years, contrasted to this application where exposure would be once only and short (in case of accidental discharge when evacuation does not take place on time).		
Components		
Potassium Nitrate	Toxicity	Acute oral toxicity(LD50):901mg/kg(rabbit)750mg/kg(rat)
Melamine	Toxicity	Toxic Dose LD50:3248mg/kg(oral,rat)
Phenolic resin	Toxicity	Not available

Section12 Ecological information

Present no ecological hazards, ODP(Ozone depletion potential)=0 GWP(Global warming potential)=0 ALT(Atmospheric life time)=Low

Section 13 Disposal Considerations

Comply with all local, state, and federal/international regulations.

Section 14 Transport Information

Proper shipping name	Safety systems
Hazard Class or Division	9
UN No.	3268
Packing Introduction	NULL

Division 9 articles present no significant hazard as packaged for transport.

Section 15 Regulatory Information

For the Following Components: The EU classification and R&S phrases, referred to the components of the Solid bound compound related only to the single components considered as separate chemical entities. Once mixed in the production of the solid bound compound, the risk sentences of the single components are not applicable being the solid bound compound a separate chemical entity.			
Potassium Nitrate	EU Classification	Oxidizer	
	R Phrase S Phrase	8 16 41	Contact with combustible material may cause fire Keep away from sources of ignition-No smoking in case of fire and /or explosion, do not breathe fumes.
Melamine	EU Classification	Oxidizer	
	R Phrase S Phrase	22 36 37	Harmful if swallowed Wear suitable protective clothing Wear suitable gloves

Phenolic resin	EU Classification R Phrase	No available 24/25 34	Toxic in contact with skin and if swallowed Causes burns
Limit Value for Exposure EINECS Status Restrictions on Marking and Use		None listed All components are included in EINECS inventories None	

Section16 Other Information

Comply with manufacturer’s installation and maintenance procedures.

Disclaimer:
The information contained herein is accurate to the best knowledge and belief of Hubei Jiandun Fire Technology Co., Ltd., and is intended to describe the product for health, safety, and environmental requirements only. It is not intended and should not be construed as a warranty. Consult Hubei Jiandun Fire Technology Co., Ltd.for further information.

Appendix I

ACTI FIRE Certificate of Conformity

CSIRO Verification Services
Clayton, Victoria, Australia
+61 13 0036 3400
https://activfire.csiro.au

Certificate of Conformity

Certificate num.	Registration date	Version Number	Version Issue date	Valid until	Page 1 of 3
afp - 3838	15-Sep-2023	1	15-Sep-2023	30-Apr-2025	

Product designation

Jiandun, Model JAD300-U01, aerosol fire extinguishing system

(Refer to the Schedule/enclosures for further specified details)

Agent/distributor

Hubei Jiandun Fire Technology Co., Ltd.
No. 199, Huaxi Road, Biological Industrial Park, Yichang Free Trade Zone, YICHANG DISTRICT, HUBEI, CHINA

Registrant

Hubei Jiandun Fire Technology Co., Ltd.
No. 199, Huaxi Road, Biological Industrial Park, Yichang Free Trade Zone, YICHANG DISTRICT, HUBEI, CHINA

Producer

Hubei Jiandun Fire Technology Co., Ltd.
No. 199, Huaxi Road, Biological Industrial Park, Yichang Free Trade Zone, YICHANG DISTRICT, HUBEI, CHINA

Conformance criteria and evaluation

The Jiandun, Model JAD300-U01, aerosol fire extinguishing system has been evaluated and verified as conforming with the relevant requirements of the following criteria.

1. CSIRO Technical Specification TS-016, Version 1,15-Sep-2023, 'Conformity verification of condensed aerosol fire extinguishing systems'.
2. Australian Standard AS 4487-2013, 'Condensed aerosol fire extinguishing systems—Requirements for system design, installation and commissioning and test methods for components'.
3. Underwriters Laboratories Standard UL 2775, 'Outline of Investigation for Fixed Condensed Aerosol Extinguishing System Units'.
4. Underwriters Laboratories - Evaluation and listing, 'UL listing'.

This certification is issued within the scope of CSIRO Verification Services – Rules governing ActivFire Scheme and is valid only for the product(s) as submitted for evaluation and verification of conformity, subject to the following conditions.

- Reference to details, limitations and requirements, where documented as a schedule/enclosure with this certificate.
- The Registrant is responsible for their attestation of conformity and ensuring that on-going production complies with the conformance criteria defined in this certificate.
- This certificate will not be valid if any changes or modifications are made to the product which have not been notified and validated by CSIRO Verification Services.
- This certificate is subject to periodical re-validation upon verification that all requirements, as determined by the conformity assessment body, continue to be satisfactorily met by the Registrant.
- This certificate may only be reproduced in its published form, without modification and inclusive of all schedules/enclosures.
- Any changes, errors or omissions, must be submitted in writing and if necessary or requested, substantiated with relevant evidence.
- Any representations, such as advertising or other marketing related activities or articles shall reflect the correct contents of this certificate and conform with all relevant trade practices .and consumer protection legislation and regulations.
- Any terms or conditions of use as applicable to content and documentation as published or accessed through web sites administered by the CSIRO Verification Services.

Issued by

Kai Loh
Executive Officer – ActivFire Scheme

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This certificate remains the property of CSIRO and may be subject to amendment, suspension or withdrawal at any time.
The validity and authenticity of this certificate can be verified by the certification register located at https://activfire.csiro.au

Schedule to
Certificate of Conformity

Certificate num.	Registration date	Version		Valid until	Page **2** of **3**
		Number	Issue date		
afp - 3838	15-Sep-2023	1	15-Sep-2023	30-Apr-2025	

Limitations/conditions of conformance

Limitations/conditions of conformance, where identified on this certificate, are derived from qualifications from evaluation(s) for conformity and/or other related technical documentation. All details with respect to design, assembly and installation instructions and restrictions should be checked against the producer's current technical manual/data sheets and the requirements of the Authority having Jurisdiction.

Specified limitations/conditions, determined from the evaluation for conformity, include the following.

i. Systems, installation and maintenance shall be installed in accordance with Hubei Jiandun Fire Technology Co., Ltd Model JAD300-U01 Aerosol Fire Extinguishing System design, installation, operation and maintenance manual JAD M230507 Version 1, 05-07-2023, including correct usage and maintenance and the requirements of AS 4487 and authorities having jurisdiction.

ii. Detection, actuation and control systems shall be design and installed in accordance with the requirements of AS 4487 and authorities having jurisdiction.

iii. System is not used to extinguish fires arising from:

   a. Chemicals or mixtures of chemicals, such as cellulose nitrate and gunpowder, that are capable of rapid oxidation with a combination of air.
   b. Reactive metals, such as lithium, sodium, potassium, magnesium, titanium, zirconium, uranium, and plutonium.
   c. Chemicals capable of undergoing auto thermal decomposition, such as some organic peroxides and hydrazine.
   d. Metal hydrides, such as potassium hydride, sodium hydride.
   e. Spontaneously combustible substances, such as phosphorus.
   f. Strong oxidants, such as nitrogen oxides, fluorine.
   g. Reactive hydrides, or metal amides, some which may react violently with a gaseous extinguishant.
   h. Deep-seated fires in Class A materials
   i. Class “C” fires involving gasses.

iv. System is not installed into marine applications.

v. System is not installed in occupiable areas and environment rated hazardous.

vi. The limiting aerosol characteristics are described in the table below:

Distance at 75 °C of discharge port (m)	Installation height (m)	Maximum area coverage (m)	Minimum area coverage height (m)	Maximum area coverage height (m)	Maximum volume (m^3)
1.3	0 – 2.4	2.24 × 2.24	1	2.4	5

Producer's description

The Jiandun, Model JAD300-U01, aerosol fire extinguishing system is a Halon alternative product. The system is composed of an initiator, aerosol -forming compound, coolant, mountain bracket and sealed casing.

The generators, combined with actuating mechanisms and other accessory equipment (detection, alarm, control equipment etc.), form the aerosol extinguishing system.

During a fire, the detection system transmits the actuation signal to the initiator of the aerosol generator after detecting the fire. The aerosol-forming compound will then be pyrotechnically actuated and produce aerosol extinguishing agent that flows through the coolant within the device prior to exiting through discharge port(s) into the protected space.

Schedule to
Certificate of Conformity

Certificate num.	Registration date	Version		Valid until	Page **3** of **3**
		Number	Issue date		
afp - 3838	15-Sep-2023	1	15-Sep-2023	30-Apr-2025	

Technical specification

The following details are a representative extract of the technical specification for the Jiandun, Model JAD300-U01, aerosol fire extinguishing system and may be subject to change. Complete and current details should be determined from the designated producer's technical manual/data sheets.

Schedule of variant designations

The following is a schedule of validated variant designations of the certified/listed equipment.

Variant		
Type	**Ident.**	**Description**
Model no.	JAD300-U01	300 g condensed aerosol fire extinguishing system

Schedule of properties/characteristics

The following schedule is an extract of physical and operational properties/characteristics of the certified/listed equipment.

Item	**Specifications**
Application density:	
• Class A fuels:	• 105.3 g/m^3
• Class B fuels:	• 78 g/m^3
Discharge time:	12.5 s (± 2.5 s)
Size:	Ø76 mm (±0.2 mm) × 192 mm (±1 mm) (without bracket)
Safe clearance distance to personnel	
• Discharge port	• 75 °C at 1300 mm
• Generator casing	• 75 °C at 20 mm
Safe clearance distance to combustibles	
• Discharge port	• 200 °C at 700 mm
• Generator casing	• N/A (casing does not exceed 150 °C)
Operating temperature:	-40 °C to +54 °C
Mass of aerosol-forming compound:	300 g ± 2%
Actuation method:	Electrical
Initiator safe current:	600 mA ± 2 mA, 300 s no action
Initiator rated current:	2 A

Supplementary information

Schedule of relevant articles

The following schedule is an extract of articles significant and/or related as evidence of conformity.

Reference			Date issued (or date validated)	Source
Ident. type	**Ident.**	**Title / description**		
Report No.	CSBA0056/R1	Verification of Conformity of the Hubei Jiandun Fire Technology Co., Ltd Model JAD300-U01 Aerosol Fire Extinguishing System to AS 4487:2013 in accordance with CSIRO Technical Specification TS-016 v01	15-Sep-2023	CSIRO, Fire Systems Laboratory, AU
Certificate No.	UL-CA-2328906-0	Certificate of Compliance Report reference EX26592-20230814 Date 16-Aug-2023 (EX26592-20230814-CertificateofCompliance.pdf)	15-Sep-2023	Underwriters Laboratories Inc, US
Fire ref.	FWSA.EX26592	Fixed Condensed Aerosol Extinguishing System Units Hubei Jiandun Fire Technology Co., Ltd. Aerosol-generating extinguishing system unit JAD300-U01 (ul_w3_FWSA.EX26592_JAD300-U01_v_20230915.pdf)	15-Sep-2023	Underwriters Laboratories Inc, US; Product IQ™
Manual	JAD M230507	Manual No. JAD M230507 Version 1, 05-07-2023 Condensed Aerosol Fire Extinguishing System Model: JAD300-U01 DESIGN, INSTALLATION, OPERATION MAINTENANCE MANUAL Hubei Jiandun Fire Technology Co., Ltd. (01-JAD300-U01 design, installation, maintenance manual No JAD M230507.pdf)	11-Aug-2023	Hubei Jiandun Fire Technology Co., Ltd., CN

Appendix J

SMA MV Power Station Model 4200-S2

MV POWER STATION
4000-S2 / 4200-S2 / 4400-S2 / 4600-S2

MVPS-4000-S2 / MVPS-4200-S2 / MVPS-4400-S2 / MVPS-4600-S2



Robust
- Station and all individual components type-tested
- Optimally suited to extreme ambient conditions

Easy to Use
- Plug and play concept
- Completely pre-assembled for easy set-up and commissioning

Cost-Effective
- Easy planning and installation
- Low transport costs due to 20-foot skid

Flexible
- One design for the whole world
- DC-Coupling Ready
- Numerous options

MV POWER STATION 4000-S2 / 4200-S2 / 4400-S2 / 4600-S2

Turnkey Solution for PV Power Plants and large-scale storage systems

With the power of the new robust central inverters, the Sunny Central UP or Sunny Central Storage UP, and with perfectly adapted medium-voltage components, the new MV Power Station offers even more power density and is a turnkey solution available worldwide. Being the ideal choice for the new generation of PV power plants operating at 1500 VDC, the integrated system solution is easy to transport and quick to assemble and commission. The MVPS and all components are type-tested. The MV Power Station combines rigorous plant safety with maximum energy yield and minimized deployment and operating risk. The MV Power Station is prepared for DC coupling.

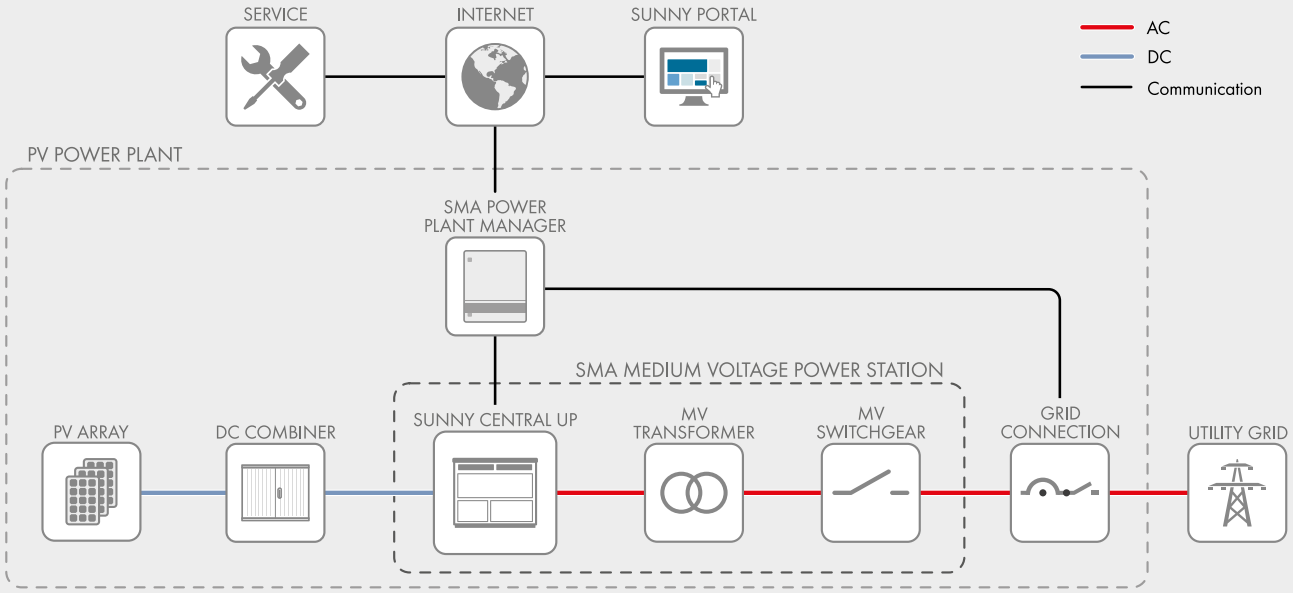
MV POWER STATION
4000-S2 / 4200-S2 / 4400-S2 / 4600-S2

Technical Data	MVPS 4000-S2	MVPS 4200-S2
Input (DC)		
Available inverters	1 x SC 4000 UP or 1 x SCS 3450 UP or 1 x SCS 3450 UP-XT	1 x SC 4200 UP or 1 x SCS 3600 UP or 1 x SCS 3600 UP-XT
Max. input voltage	1500 V	1500 V
Number of DC inputs	dependent on the selected inverters	
Integrated zone monitoring	○	
Available DC fuse sizes (per input)	200 A, 250 A, 315 A, 350 A, 400 A, 450 A, 500 A	
Output (AC) on the medium-voltage side		
Rated power at SC UP (at -25°C to + 35°C / 40°C optional 50°C)[1)]	4000 kVA / 3600 kVA	4200 kVA / 3780 kVA
Rated power at SCS UP (at -25°C bis +25°C / 40°C optional 50°C)[1)]	3450 kVA / 2930 kVA	3620 kVA / 3075 kVA
Charging power at SCS UP-XT (at -25°C bis +25°C / 40°C optional 50°C)[1)]	3590 kVA / 3000 kVA	3770 kVA / 3150 kVA
Discharging power at SCS UP-XT (at -25°C bis +25°C / 40°C optional 50°C)[1)]	4000 kVA / 3400 kVA	4200 kVA / 3570 kVA
Typical nominal AC voltages	10 kV to 35 kV	10 kV to 35 kV
AC power frequency	50 Hz / 60 Hz	50 Hz / 60 Hz
Transformer vector group Dy11 / YNd11 / YNy0	● / ○ / ○	● / ○ / ○
Transformer cooling methods	KNAN[2)]	KNAN[2)]
Transformer no-load losses Standard / Eco Design 1 / Eco Design 2	● / ○ / ○	● / ○ / ○
Transformer short-circuit losses Standard / Eco Design 1 / Eco Design 2	● / ○ / ○	● / ○ / ○
Max. total harmonic distortion	< 3%	
Reactive power feed-in (up to 60% of nominal power)	○	
Power factor at rated power / displacement power factor adjustable	1 / 0.8 overexcited to 0.8 underexcited	
Inverter efficiency		
Max. efficiency[3)] / European efficiency[3)] / CEC weighted efficiency[4)]	98.8% / 98.6% / 98.5%	98.8% / 98.7% / 98.5%
Protective devices		
Input-side disconnection point	DC load-break switch	
Output-side disconnection point	Medium-voltage vacuum circuit breaker	
DC overvoltage protection	Surge arrester type I	
Galvanic isolation	●	
Internal arc classification medium-voltage control room (according to IEC 62271-202)	IAC A 20 kA 1 s	
General Data		
Dimensions (W / H / D)	6058 mm / 2896 mm / 2438 mm	
Weight	< 18 t	
Self-consumption (max. / partial load / average)[1)]	< 8.1 kW / < 1.8 kW / < 2.0 kW	
Self-consumption (stand-by)[1)]	< 370 W	
Ambient temperature -25°C to +45°C / -25°C to +55°C / -40°C to +45°C	● / ○ / ○	
Degree of protection according to IEC 60529	Control rooms IP23D, inverter electronics IP54	
Environment: standard / harsh	● / ○	
Degree of protection according to IEC 60721-3-4 (4C1, 4S2 / 4C2, 4S4)	● / ○	
Maximum permissible value for relative humidity	95% (for 2 months/year)	
Max. operating altitude above mean sea level 1000 m / 2000 m	● / ○	
Fresh air consumption of inverter	6500 m³/h	
Features		
DC terminal	Terminal lug	
AC connection	Outer-cone angle plug	
Tap changer for MV-transformer: without / with	● / ○	
Shield winding for MV-Transformer: without / with	● / ○	
Monitoring package	○	
Station enclosure color	RAL 7004	
Transformer for external loads: without / 10 / 20 / 30 / 40 / 50 / 60 kVA	● / ○ / ○ / ○ / ○ / ○ / ○	
Medium-voltage switchgear: without / 1 feeder / 3 feeders 2 cable feeders with load-break switch, 1 transformer feeder with circuit breaker, internal arc classification IAC A FL 20 kA 1 s according to IEC 62271-200	● / ○ / ○	
Short circuit rating medium voltage switchgear (20 kA 1 s / 20 kA 3 s / 25 kA 1s)	● / ○ / ○	
Accessories for medium-voltage switchgear: without / auxiliary contacts / motor for transformer feeder / cascade control / monitoring	● / ○ / ○ / ○ / ○	
Integrated oil containment: without / with	● / ○	
Industry standards (for other standards see the inverter datasheet)	IEC 60076, IEC 62271-200, IEC 62271-202, EN50588-1, CSC Certificate	
● Standard features ○ Optional features – Not available		
Type designation	MVPS-4000-S2	MVPS-4200-S2

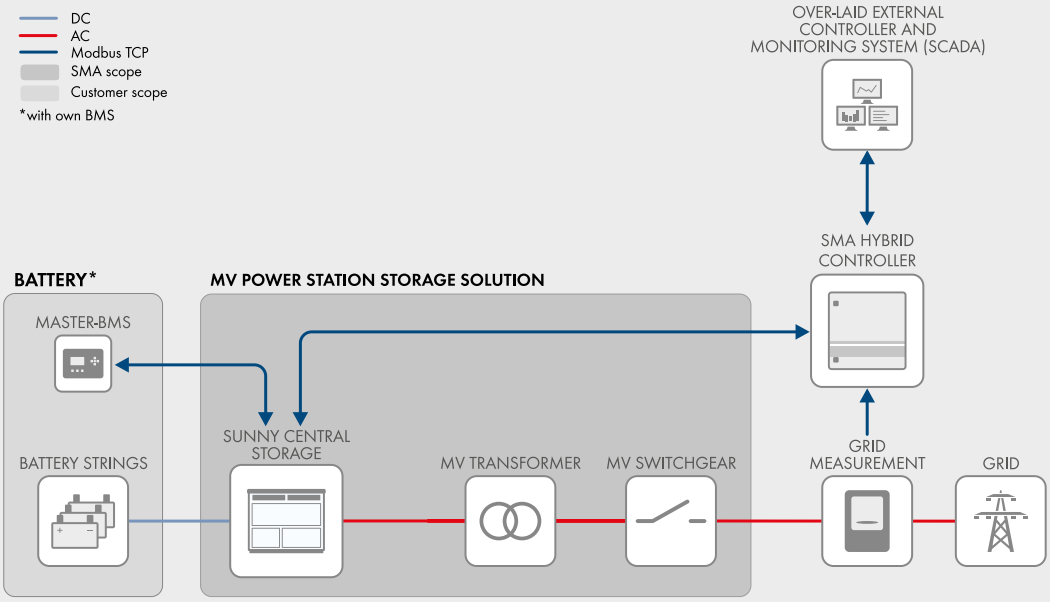
1) Data based on inverter. Further details can be found in the data sheet of the inverter.
2) KNAN = Ester with natural air cooling
3) Efficiency measured at inverter without internal power supply
4) Efficiency measured at inverter with internal power supply

Technical Data	MVPS 4400-S2	MVPS 4600-S2
Input (DC)		
Available inverters	1 x SC 4400 UP or 1 x SCS 3800 UP or 1 x SCS 3800 UP-XT	1 x SC 4600 UP or 1 x SCS 3950 UP or 1 x SCS 3950 UP-XT
Max. input voltage	1500 V	1500 V
Number of DC inputs	dependent on the selected inverters	
Integrated zone monitoring	○	
Available DC fuse sizes (per input)	200 A, 250 A, 315 A, 350 A, 400 A, 450 A, 500 A	
Output (AC) on the medium-voltage side		
Rated power at SC UP (at -25°C to + 35°C / 40°C optional 50°C)[1]	4400 kVA / 3960 kVA	4600 kVA / 4140 kVA
Rated power at SCS UP (at -25°C bis +25°C / 40°C optional 50°C)[1]	3800 kVA / 3230 kVA	3960 kVA / 3365kVA
Charging power at SCS UP-XT (at -25°C bis +25°C / 40°C optional 50°C)[1]	3950 kVA / 3300 kVA	4130 kVA / 3455 kVA
Discharging power at SCS UP-XT (at -25°C bis +25°C / 40°C optional 50°C)[1]	4400 kVA / 3740 kVA	4600 kVA / 3910 kVA
Typical nominal AC voltages	10 kV to 35 kV	10 kV to 35 kV
AC power frequency	50 Hz / 60 Hz	50 Hz / 60 Hz
Transformer vector group Dy11 / YNd11 / YNy0	● / ○ / ○	● / ○ / ○
Transformer cooling methods	KNAN[2]	KNAN[2]
Transformer no-load losses Standard / Eco Design 1 / Eco Design 2	● / ○ / ○	● / ○ / ○
Transformer short-circuit losses Standard / Eco Design 1 / Eco Design 2	● / ○ / ○	● / ○ / ○
Max. total harmonic distortion	< 3%	
Reactive power feed-in (up to 60% of nominal power)	○	
Power factor at rated power / displacement power factor adjustable	1 / 0.8 overexcited to 0.8 underexcited	
Inverter efficiency		
Max. efficiency[3] / European efficiency[3] / CEC weighted efficiency[4]	98.8% / 98.7% / 98.5%	98.8% / 98.7% / 98.5%
Protective devices		
Input-side disconnection point	DC load-break switch	
Output-side disconnection point	Medium-voltage vacuum circuit breaker	
DC overvoltage protection	Surge arrester type I	
Galvanic isolation	●	
Internal arc classification medium-voltage control room (according to IEC 62271-202)	IAC A 20 kA 1 s	
General Data		
Dimensions (W / H / D)	6058 mm / 2896 mm / 2438 mm	
Weight	< 18 t	
Self-consumption (max. / partial load / average)[1]	< 8.1 kW / < 1.8 kW / < 2.0 kW	
Self-consumption (stand-by)[1]	< 370 W	
Ambient temperature -25°C to +45°C / -25°C to +55°C / -40°C to +45°C	● / ○ / ○	
Degree of protection according to IEC 60529	Control rooms IP23D, inverter electronics IP54	
Environment: standard / harsh	● / ○	
Degree of protection according to IEC 60721-3-4 (4C1, 4S2 / 4C2, 4S4)	● / ○	
Maximum permissible value for relative humidity	95% (for 2 months/year)	
Max. operating altitude above mean sea level 1000 m / 2000 m	● / ○	
Fresh air consumption of inverter	6500 m³/h	
Features		
DC terminal	Terminal lug	
AC connection	Outer-cone angle plug	
Tap changer for MV-transformer: without / with	● / ○	
Shield winding for MV-Transformer: without / with	● / ○	
Monitoring package	○	
Station enclosure color	RAL 7004	
Transformer for external loads: without / 10 / 20 / 30 / 40 / 50 / 60 kVA	● / ○ / ○ / ○ / ○ / ○ / ○	
Medium-voltage switchgear: without / 1 feeder / 3 feeders 2 cable feeders with load-break switch, 1 transformer feeder with circuit breaker, internal arc classification IAC A FL 20 kA 1 s according to IEC 62271-200	● / ○ / ○	
Short circuit rating medium voltage switchgear (20 kA 1 s / 20 kA 3 s / 25 kA 1s)	● / ○ / ○	
Accessories for medium-voltage switchgear: without / auxiliary contacts / motor for transformer feeder / cascade control / monitoring	● / ○ / ○ / ○ / ○	
Integrated oil containment: without / with	● / ○	
Industry standards (for other standards see the inverter datasheet)	IEC 60076, IEC 62271-200, IEC 62271-202, EN50588-1, CSC Certificate	
● Standard features ○ Optional features – Not available		
Type designation	MVPS-4400-S2	MVPS-4600-S2

System diagram with Sunny Central UP



System diagram with Sunny Central Storage UP



MVPS-S2-SC4xxxUP-DS-en-13 SMA and Sunny Central are registered trademarks of SMA Solar Technology AG. FSC-certified paper.
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Appendix K

SMA Inverter Model SCS 3600 UP

/ SCS 3450 UP / SCS 3600 UP / SCS 3800 UP / SCS 3950 UP



Sunny Central Storage UP

Battery inverter for large-scale storage systems

Efficient
- Up to 4 inverters can be transported in one standard shipping container
- Higher power density

Robust
- Intelligent air cooling system OptiCool for efficient cooling
- Suitable for outdoor use in all climatic ambient conditions worldwide

Flexible
- One device for all applications
- Stand-alone device or turnkey solution with SMA medium-voltage system

Versatile
- Integrated battery communication
- Customized monitoring and control of inverters
- Grid management functions for dynamic grid support
- Integrated voltage supply for internal consumption and external loads

With an output of up to 3960 kVA and system voltages up to 1500 V DC, the SMA Sunny Central Storage allows for more efficient and flexible system design for battery power plants.

A separate voltage supply and additional space are available for the installation of customer equipment. The intelligent cooling system OptiCool ensure smooth operation even in extreme ambient temperature.

SUNNY CENTRAL STORAGE UP

Technical Data	SCS 3450 UP	SCS 3600 UP
Battery side (DC)		
Operating DC voltage range V_{DC}	880 V to 1500 V	921 V to 1500 V
Max. DC current $I_{DC, max}$	4750 A	
Fuse characteristic for battery connection - pre-arcing integral limit single DC busbar / split DC busbar [12) 14)]	10.75 MA^2s / 8.0 MA^2s	
Single DC busbar 36 connections per pole / split DC busbar 12/12/12 connections per pole / fused single DC busbar 22 connections per pole [15)]	● / ○ / ○	
DC connection	with terminal lug	
Grid side (AC)		
Nominal AC power at 1200 Vdc and cos φ =1.0 (at 25°C)	3450 kW	3620 kW
AC apparent power at 1200 Vdc (at 25°C / at 40°C / at 50°C)[3) 13)]	3450 kVA / 3140 kVA / 2930 kVA	3620 kVA / 3290 kVA / 3075 kVA
Max. AC current $I_{AC, max}$ (at 25°C / at 40°C / at 50°C)	3320 A / 3020 A / 2820 A	3320 A / 3020 A / 2820 A
Max. total harmonic distortion	< 3% at nominal power	
Nominal AC voltage / AC voltage range[1) 8)]	600 V / 480 V to 720 V	630 V / 504 V to 756 V
AC power frequency / range	50 Hz / 47 Hz to 53 Hz 60 Hz / 57 Hz to 63 Hz	
Min. short-circuit ratio at the AC terminals[9)]	> 2	
Cos Phi at rated power / displacement Cos Phi adjustable[8) 10)]	1 / 0.0 overexcited to 0.0 underexcited	
AC connection	with busbar system (three busbars, one per line conductor)	
Efficiency		
Max. efficiency[2)]	98.8%	
Protective Devices		
Input-side disconnection point	DC load break switch	
Output-side disconnection point	AC circuit breaker	
DC overvoltage protection	Surge arrester, type I	
AC overvoltage protection (optional)	Surge arrester, class I	
Lightning protection (according to IEC 62305-1)	Lightning Protection Level III	
Insulation monitoring	●	
Degree of protection: electronics / air duct / connection area (as per IEC 60529)	IP54 / IP34 / IP34	
General Data		
Dimensions (W / H / D)	2815 / 2318 / 1588 mm (110.8 / 91.3 / 62.5 inch)	
Weight	< 3700 kg / < 8200 lb	
Self-consumption (max.[4)] / partial load[5)] / average[6)])	< 8100 W / < 1800 W / < 2000 W	
Self-consumption (standby)	< 370 W	
Internal (8.4 kVA transformer) / external auxiliary power supply	● / ○	
Noise emission[7)]	65.0 dB(A)	
Operating temperature range (optional)[8)]	(−40°C) −25°C to 60°C / (−40°F) −13°F to 140°F	
Temperature range (standby)	−40°C to 60°C / −40°F to 140°F	
Temperature range (storage)	−40°C to 70°C / −40°F to 158°F	
Max. permissible value for relative humidity (condensing / non-condensing)	95% to 100% (2 month/year) / 0% to 95%	
Maximum operating altitude above MSL[8)] 1000 m / 2000 m[11)]	● / ○	
Fresh air consumption	6500 m^3/h	
Features		
Grid forming / black start ready	○ / ○	
Communication	Ethernet, Modbus Master, Modbus Slave	
Communication with SMA string monitor (transmission medium)	Modbus TCP / Ethernet (FO MM, Cat-5)	
Enclosure / roof color	RAL 9016 / RAL 7004	
Supply transformer for external loads	○ (2.5 kVA)	
Standards and directives complied with	CE, IEC / EN 62109-1 / -2, AR-N 4110 / 4120, Arrêté du 23/04/08	
EMC standards	IEC 61000-6-2, EN 55011, CISPR11, FCC Part 15 Class A	
Quality standards and directives complied with	VDI/VDE 2862 page 2, DIN EN ISO 9001	
Type designation	SCS 3450 UP	SCS 3600 UP

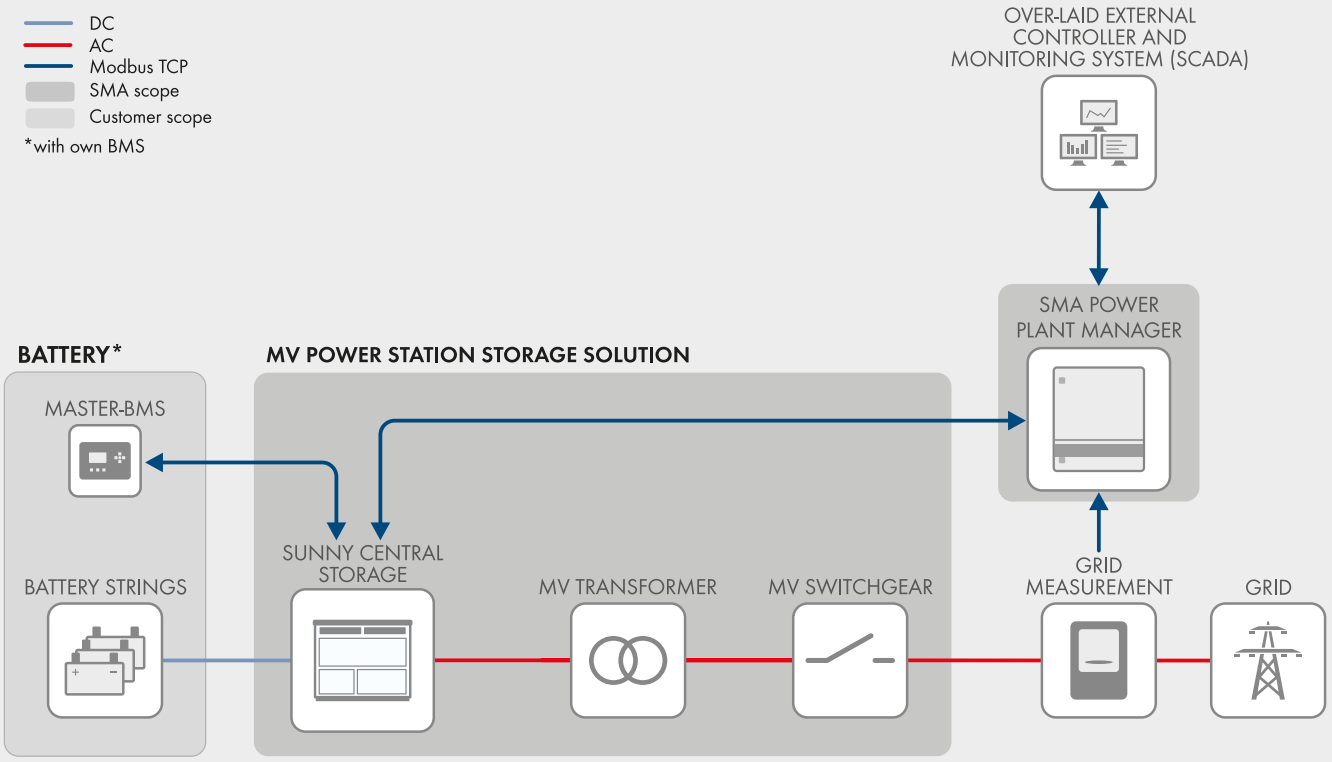
● Standard features ○ Optional – Not available

Technical Data	SCS 3800 UP	SCS 3950 UP
Battery side (DC)		
Operating DC voltage range V_{DC}	962 V to 1500 V	1003 V to 1500 V
Max. DC current $I_{DC, max}$	4750 A	
Fuse characteristic for battery connection - pre-arcing integral limit single DC busbar / split DC busbar [12) 14)]	10.75 MA²s / 8.0 MA²s	
Single DC busbar 36 connections per pole / split DC busbar 12/12/12 connections per pole / fused single DC busbar 22 connections per pole [15)]	● / ○ / ○	
DC connection	with terminal lug	
Grid side (AC)		
Nominal AC power at 1200 Vdc and cos φ =1.0 (at 25°C)	3800 kW	3960 kW
AC apparent power at 1200 Vdc (at 25°C / at 40°C / at 50°C)[3) 13)]	3800 kVA / 3455 kVA / 3230 kVA	3960 kVA / 3610 kVA / 3365 kVA
Max. AC current $I_{AC, max}$ (at 25°C / at 40°C / at 50°C)	3320 A / 3020 A / 2820 A	3320 A / 3020 A / 2820 A
Max. total harmonic distortion	< 3% at nominal power	
Nominal AC voltage / AC voltage range[1) 8)]	660 V / 528 V to 759 V	690 V / 552 V to 759 V
AC power frequency / range	50 Hz / 47 Hz to 53 Hz 60 Hz / 57 Hz to 63 Hz	
Min. short-circuit ratio at the AC terminals[9)]	> 2	
Cos Phi at rated power / displacement Cos Phi adjustable[8) 10)]	1 / 0.0 overexcited to 0.0 underexcited	
AC connection	with busbar system (three busbars, one per line conductor)	
Efficiency		
Max. efficiency[2)]	98.8%	
Protective Devices		
Input-side disconnection point	DC load break switch	
Output-side disconnection point	AC circuit breaker	
DC overvoltage protection	Surge arrester, type I	
AC overvoltage protection (optional)	Surge arrester, class I	
Lightning protection (according to IEC 62305-1)	Lightning Protection Level III	
Insulation monitoring	●	
Degree of protection: electronics / air duct / connection area (as per IEC 60529)	IP54 / IP34 / IP34	
General Data		
Dimensions (W / H / D)	2815 / 2318 / 1588 mm (110.8 / 91.3 / 62.5 inch)	
Weight	< 3700 kg / < 8200 lb	
Self-consumption (max.[4)] / partial load[5)] / average[6)])	< 8100 W / < 1800 W / < 2000 W	
Self-consumption (standby)	< 370 W	
Internal (8.4 kVA transformer) / external auxiliary power supply	● / ○	
Noise emission[7)]	65.0 dB(A)	
Operating temperature range (optional)[8)]	(−40°C) −25°C to 60°C / (−40°F) −13°F to 140°F	
Temperature range (standby)	−40°C to 60°C / −40°F to 140°F	
Temperature range (storage)	−40°C to 70°C / −40°F to 158°F	
Max. permissible value for relative humidity (condensing / non-condensing)	95% to 100% (2 month/year) / 0% to 95%	
Maximum operating altitude above MSL[8)] 1000 m / 2000 m[11)]	● / ○	
Fresh air consumption	6500 m³/h	
Features		
Grid forming / black start ready	○ / ○	
Communication	Ethernet, Modbus Master, Modbus Slave	
Communication with SMA string monitor (transmission medium)	Modbus TCP / Ethernet (FO MM, Cat-5)	
Enclosure / roof color	RAL 9016 / RAL 7004	
Supply transformer for external loads	○ (2.5 kVA)	
Standards and directives complied with	CE, IEC / EN 62109-1 / -2, AR-N 4110 / 4120, Arrêté du 23/04/08	
EMC standards	IEC 61000-6-2, EN 55011, CISPR11, FCC Part 15 Class A	
Quality standards and directives complied with	VDI/VDE 2862 page 2, DIN EN ISO 9001	
Type designation	SCS 3800 UP	SCS 3950 UP

● Standard features ○ Optional – Not available

1) Below nominal AC voltage, AC power decreases in the same proportion
2) Efficiency measured without internal power supply
3) AC apparent power at higher dc voltages on request
4) Self-consumption at rated operation
5) Self-consumption at < 75% Pn at 25°C
6) Self-consumption averaged out from 5% to 100% Pn at 25°C
7) Sound pressure level at a distance of 10 m
8) Values apply only to inverters. Permissible values for SMA MV solutions from SMA can be found in the corresponding data sheets
9) A short-circuit ratio of < 2 requires a special approval from SMA
10) Max. power values (S/P/Q) can be requested based on project specific design
11) Earlier temperature-dependent de-rating and reduction of DC open-circuit voltage
12) Battery short circuit disconnection has to be done on the battery side with ultra rapid battery string or group fuses, e.g. fuse type aR/aBat & DC time constant Tau (L/R) <=1ms
13) Depending on the ratio of reactive power (cos φ), an extended power derating may occur
14) Please check the manual for further information
15) Fused DC input equipped with optional 750 A, 900 A or 1250 A fuses

SYSTEM DIAGRAM



Grid-connected functions

- Setpoints for active and reactive power
- Static grid support Q(U), P(f)
- Dynamic grid support (FRT)
- Active islanding detection (AID)
- High compatibility with different battery types

Compatible with energy management system functionalities

- External static grid supporting functions
- Ramp-rate control of PV power
- Peak shaving
- Energy shifting
- Genset optimization control
- Reducing necessary spinning reserve of gensets
- Battery start-up and stop sequence
- Operates the battery within optimal operation window
- Grid Forming
- Black Start

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Appendix L

VBB Fire Report of Technical Findings

January 25, 2022

Victorian Big Battery Fire: July 30, 2021

REPORT OF TECHNICAL FINDINGS

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Background

The Victorian Big Battery (VBB) is a 300-Megawatt (MW)/450-Megawatt hour (MWh) grid-scale battery storage project in Geelong, Australia. VBB is one of the largest battery installations in the world and can power over one million Victorian homes for 30 minutes during critical peak load situations.[1] It is designed to support the renewable energy industry by charging during times of excess renewable generation. The VBB is fitted with 212 Tesla Megapacks to provide the 300-MW/450-MWh of energy storage. The Megapack is a lithium-ion battery energy storage system (BESS) consisting of battery modules, power electronics, a thermal management system, and control systems all pre-manufactured within a single cabinet that is approximately 7.2 meters (m) in length, 1.6 m deep and 2.5 m in height (23.5 feet [ft] x 5.4 ft x 8.3 ft).

On Friday, July 30th, 2021, a single Megapack at VBB caught fire and spread to a neighboring Megapack during the initial installation and commissioning of the Megapacks. The fire did not spread beyond these two Megapacks and they burned themselves out over the course of approximately six hours. There were no injuries to the general public, to site personnel or to emergency first responders as the Megapacks failed safely (i.e., slowly burned themselves out with no explosions or deflagrations), as they are designed to do in the event of a fire. Per the guidance in Tesla's Lithium-Ion Battery Emergency Response Guide[2] (ERG), emergency responders permitted the Megapack to burn and consume itself while nearby exposures were being monitored at a safe distance. The total impact to the site was two out of the 212 Megapacks were fire damaged, or less than 1% of the BESS.

Following the emergency response, a detailed, multi-entity fire investigation commenced on August 3, 2021. The investigation process included local regulatory entities, Tesla, outside third-party engineers and subject matter experts. The investigation process involved analyzing both the fire origin and cause as well as the root cause of the fire propagation to the neighbor Megapack. In addition, given this is the first fire event in a Megapack installation to date, a review of the emergency response has been performed to identify any lessons learned from this fire event.

This report summarizes those investigations and analyses and has been prepared by Fisher Engineering, Inc. (FEI) and Energy Safety Response Group (ESRG), two independent engineering and energy storage fire safety consulting firms. In addition, this report provides a list of lessons learned from the fire and also highlights the procedural, software and hardware changes that have been implemented based on those lessons learned.

Incident Timeline

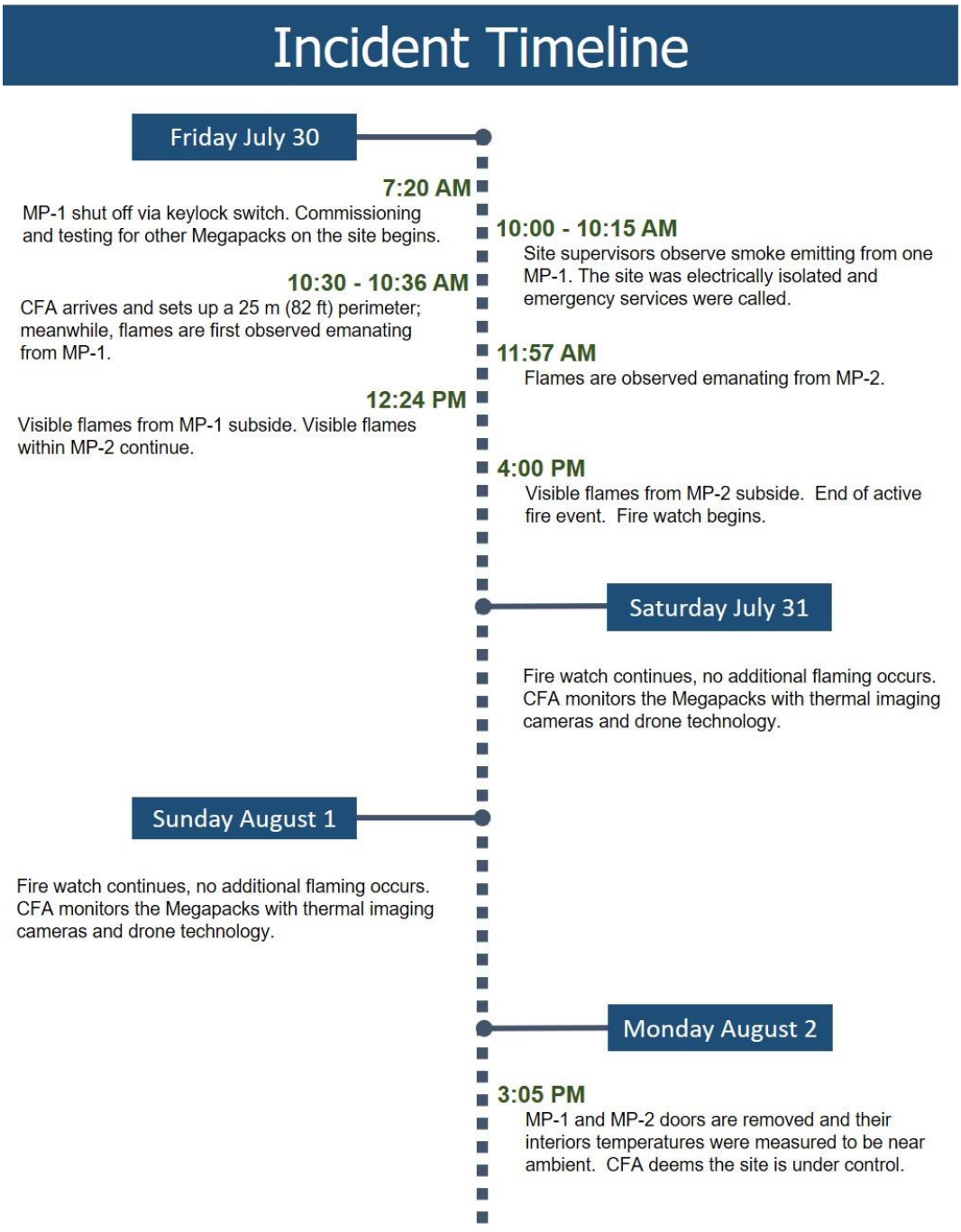
At the time of the fire, the VBB was fitted with approximately one-half of the 212 total Megapacks intended for the site. The Megapacks that were installed at VBB were undergoing routine testing and commissioning on the day of the fire. At 7:20 AM Australian Eastern Standard Time (AEST) on the morning of July 30, 2021, commissioning and testing of a number of Megapacks commenced. One such Megapack (denoted herein as MP-1), was not going to be tested that day and was therefore shut off manually by means of the keylock switch.[3] At the time MP-1 was shut down via the keylock switch, the unit displayed no abnormal conditions to site personnel. Around 10:00 AM, smoke was observed emitting from MP-1 by site personnel. Site personnel

[1] https://victorianbigbattery.com.au/

[2] https://www.tesla.com/sites/default/files/downloads/Lithium-Ion_Battery_Emergency_Response_Guide_en.pdf

[3] The keylock switch is a type of "lock out tag out" switch on the front of the Megapack that safely powers down the unit for servicing.

electrically isolated all the Megapacks on-site and called emergency services: Country Fire Authority (CFA). The CFA arrived shortly thereafter and set up a 25 m (82 ft) perimeter around MP-1. They also began applying cooling water to nearby exposures as recommended in Tesla's ERG. The fire eventually spread into a neighbor Megapack (MP-2) installed 15 centimeters (cm), or 6 inches (in), behind MP-1. The CFA permitted MP-1 and MP-2 to burn themselves out and did not directly apply water into or onto either Megapack, as recommended in Tesla's ERG. By 4:00 PM (approximately six hours after the start of the event), visible fire had subdued and a fire watch was instituted. The CFA monitored the site for the next three days before deeming it under control on August 2, 2021, at which time, the CFA handed the site over for the fire investigation to begin.



Note: The time stamp is AEST (UTC+10) which is 19 hours ahead of USA PDT (UTC-7)

Investigation

A multi-entity fire investigation commenced on August 3, 2021. The VBB fire investigation process involved analyzing both the root cause of the initial fire in MP-1 as well as the root cause of the fire propagation into MP-2. The investigations included on-site inspections of MP-1 and MP-2 by the CFA, Energy Safe Victoria[4] (ESV), Work Safety Victoria[5] (WSV), local Tesla engineering/service teams and a local third-party independent engineering firm. In addition to the on-site work immediately after the incident, the root cause investigations also included data analysis, thermal modeling and physical testing (electrical and fire) performed by Tesla at their headquarters in California, USA and their fire test facility in Nevada, USA.

Fire Cause Investigation

On-site inspections commenced on August 3, 2021 and concluded on August 12, 2021. MP-1 and MP-2 were documented, inspected and preserved for future examinations, if necessary. Concurrently, all available telemetry data (such as internal temperatures and fault alarms) from MP-1 and MP-2 were analyzed and a series of electrical fault and fire tests were performed. The on-site investigation findings, the telemetry data analysis, electrical fault tests and fire tests, when combined, identified a very specific series of fault conditions present on July 30, 2021 that could lead to a fire event.

Fire Origin and Cause Determination

The origin of the fire was MP-1 and the most likely root cause of the fire was a leak within the liquid cooling system of MP-1 causing arcing in the power electronics of the Megapack's battery modules. This resulted in heating of the battery module's lithium-ion cells that led to a propagating thermal runaway event and the fire.

Other possible fire causes were considered during the fire cause investigation; however, the above sequence of events was the only fire cause scenario that fits all the evidence collected and analyzed to date.

Contributory Factors

A number of factors contributed to this incident. Had these contributory factors not been present, the initial fault condition would likely have been identified and interrupted (either manually or automatically) before it escalated into a fire event. These contributory factors include:

1. The supervisory control and data acquisition (SCADA) system for a Megapack required 24 hours to setup a connection for new equipment (i.e., a new Megapack) to provide full telemetry data functionality and remote monitoring by Tesla operators. Since VBB was still in the installation and commissioning phase of the project (i.e., not in operation), MP-1 had only been in service for 13 hours prior to being switched off via the keylock switch on the morning of the fire. As such, MP-1 had not been on-line for the required 24 hours, which prevented this unit from transmitting telemetry data (internal temperatures, fault alarms, etc.) to Tesla's off-site control facility on the morning of the fire.
2. The keylock switch for MP-1 was operated correctly on the morning of the fire to turn MP-1 off as the unit was not required for commissioning and testing that morning; however, this action caused telemetry systems, fault monitoring, and electrical fault safety devices[6] to be disabled or operate with

[4] Victoria's energy safety regulator

[5] Victoria's health and safety regulator

[6] These elements include, among other devices, fuses at the cell and module level for localized fault current interruption and a battery module pyro disconnect that severs the electrical connection of the battery module when a fault current is passing through the battery module.

only limited functionality. This prevented some of the safety features of MP-1 from actively monitoring and interrupting the electrical fault conditions before escalating into a fire event.

3. The exposure of liquid coolant onto the battery modules likely disabled the power supply to the circuit that actuates the pyro disconnect.[7] With a power supply failure, the pyro disconnect would not receive a signal to sever and would not be able to interrupt a fault current passing through the battery module prior to it escalating into a fire event.

Fire Propagation Investigation

The VBB fire investigation process involved analyzing not only the root cause of the initial fire in MP-1 but also the root cause of the fire propagation into MP-2. The Megapack has been designed to be installed in close proximity to each other without fire propagating to adjacent units. The design objective of the Megapack in terms of limiting fire propagation was mainly reliant on the thermal insulation of the Megapack's exterior vertical steel panels and the sheer mass of the battery modules acting as a heat sink (i.e., they are difficult to heat up). With this thermal insulation, the Megapack spacing can be as close as 15 cm (6 in) to the sides and back of each unit with 2.4 m (8 ft) aisles in front of each Megapack, as shown in Figure 1. This product spacing has been validated in UL9540A unit level tests.[8] Similar to the fire origin and cause investigation, the on-site inspections were supported simultaneously with an analysis of telemetry data (such as internal temperatures) from MP-2 and fire testing. The on-site investigation findings, the telemetry data analysis and fire tests, when combined, identified a scenario where Megapack to Megapack fire propagation can occur.

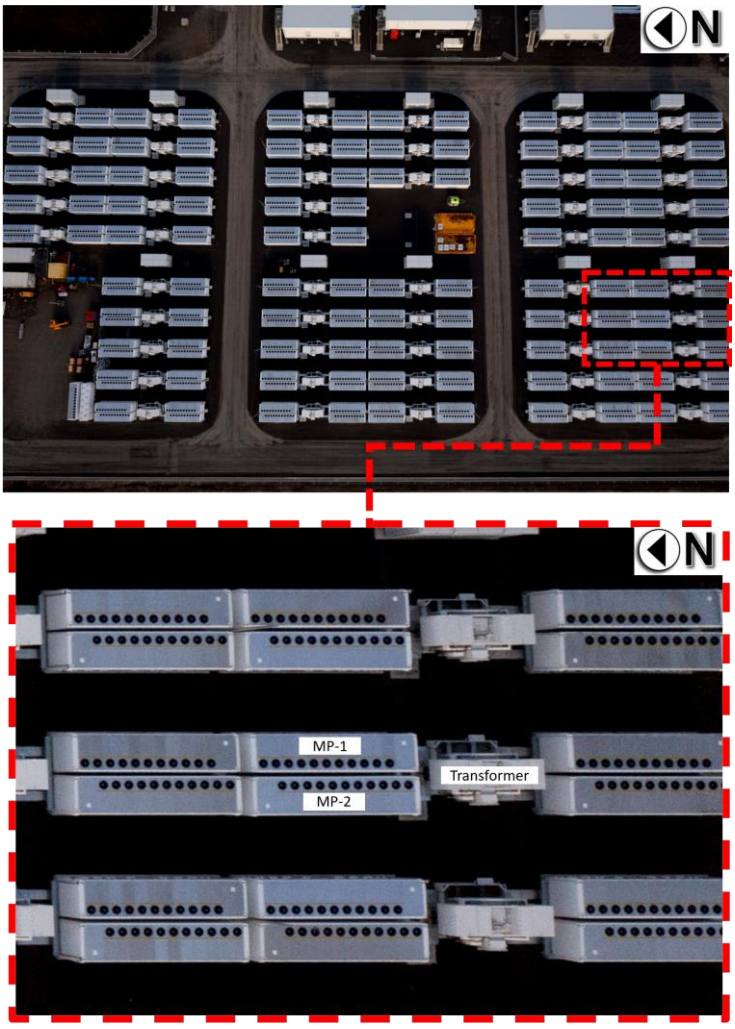


Figure 1 VBB Megapack layout (top) and area of fire origin (bottom)

[7] The pyro disconnect is a Tesla proprietary shunt-controlled pyrotechnic fuse that allows for rapid one-time actuation. There is one pyro disconnect per battery module.

[8] UL9540A, *Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems*. UL9540A is a test method developed by UL to address fire safety concerns with BESS. The test method provides a method to evaluate thermal runaway and fire propagation at the cell level, module level, and unit level. In addition to cell and module level tests, Tesla performed unit level tests to evaluate, among other fire safety characteristics, the potential for fire propagation from Megapack-to-Megapack. During unit level testing, fire propagation did not occur between Megapacks when they were installed with a spacing of 15 cm (6 in) to the sides and back of each unit.

Fire Propagation Determination

Flames exiting the roof of MP-1 were significantly impacted by the wind conditions at the time of the fire. Wind speeds were recorded between 20-30 knots[9] which pushed the flames exiting the roof of MP-1 towards the roof of MP-2. This direct flame impingement on the top of the thermal roof of MP-2 ignited the internal components of MP-2, most notably, the plastic overpressure vents that seal the battery bay[10] from the thermal roof. Once ignited, the overpressure vents provided a direct path for flames and hot gases to enter into the battery bays, thus exposing the battery modules of MP-2 to fire and/or elevated temperatures. Exposed to temperatures above their thermal runaway threshold of 139°C (282°F), the cells within the battery modules eventually failed and became involved in the fire.

Other possible fire propagation root causes were considered during the investigation; however, the above sequence of events was the only fire propagation scenario that fits all the evidence collected and analyzed to date. Of note, at the time when fire was observed within the thermal roof of MP-2, internal cell temperature readings of MP-2 had only increased by 1°C (1.8°F) from 40°C to 41°C (104°F to 105.8°F)[11] Around the same time that fire was observed within the thermal roof of MP-2, around 11:57 AM (approximately 2 hours into the fire event), communication was lost to the unit and no additional telemetry data was transmitted. However, given the internal cell temperatures of MP-2 had only recorded a 1°C (1.8°F) temperature rise 2 hours into the fire event and while the unit's roof was actively on fire, fire propagation across the 15 cm (6 in) gap via heat transfer is not the root cause of the fire propagation. Furthermore, this telemetry data from MP-2 demonstrates that the Megapack's thermal insulation can provide significant thermal protection in the event of a fire within an adjacent Megapack installed only 15 cm (6 in) away.

Contributory Factors

The wind was the dominant contributory factor in the propagation of fire from MP-1 to MP-2. At the time of the fire, a 20-30 knot (37-56 km/hr, 23-35 mph) wind was recorded out of the north. The wind conditions at the time of the fire pushed the flames exiting out of the top of MP-1 towards the top of MP-2 leading to direct flame impingement on the thermal roof of MP-2. This type of flame behavior was not observed during previous product testing or regulatory testing per UL9540A. In UL9540A unit level testing, the maximum wind speed permitted[12] during the test is 10.4 knots (19.3 km/hr, 12.0 mph); whereas, wind conditions during the VBB fire were two to three times greater in magnitude. As such, the wind conditions during the VBB fire appear to have identified a weakness in the Megapack's thermal roof design (unprotected, plastic overpressure vents in the ceiling of the battery bays) that allows Megapack-to-Megapack fire propagation. This weakness was not identified previously during product or regulatory testing and does not invalidate the Megapack's UL9540A certification, as the cause of fire propagation was primarily due to an environmental condition (wind) that is not captured in the UL9540A test method.

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9 This equates to 37-56 kilometers per hour (km/hr) or 23-35 miles per hour (mph).

10 The battery bay is an IP66 enclosure that houses the battery modules. It is distinct from the thermal roof installed above it. Plastic overpressure vents are installed in the ceiling of the battery bay, sealing the two enclosures from one another.

11 As a reference, the Megapack's normal operating cell temperature is between 20-50°C and cell thermal runaway does not occur until 139°C (98°C above cell temperatures of MP-2 before telemetry data was lost).

12 This threshold is necessary for test reliability and reproducibility. If wind conditions are not bounded in some fashion in an outdoor fire test, large variances on product performance could be introduced due to varying wind conditions.

Mitigations

The investigation of the VBB fire identified several gaps in Tesla's commissioning procedures, electrical fault protection devices and thermal roof design. Since the fire, Tesla has implemented a number of procedural, firmware, and hardware mitigations to address these gaps. These mitigations have been applied to all existing and any future Megapack installations and include:

Procedural Mitigations:

- Improved inspection of the coolant system for leaks during Megapack assembly and during end-of-line testing to reduce the likelihood of future coolant leaks.
- Reduce the telemetry setup connection time for new Megapacks from 24 hours to 1 hour to ensure new equipment is transmitting telemetry data (internal temperatures, fault alarms, etc.) to Tesla's off-site control facility for remote monitoring.
- Avoid utilizing the Megapack's keylock switch during commissioning or operation unless the unit is actively being serviced. This procedural mitigation ensures telemetry, fault monitoring, and electrical fault safety devices (such as the pyro disconnect) are active while the Megapack is idle (such as during testing and commissioning).

Firmware Mitigations:

- Added additional alarms to the coolant system's telemetry data to identify and respond (either manually or automatically) to a possible coolant leak.
- Keep all electrical safety protection devices active, regardless of keylock switch position or system state. This firmware mitigation allows electrical safety protection devices (such as the pyro disconnect) to remain in an active mode, capable of actuating when electrical faults occur at the battery modules, no matter what the system status is.
- Active monitoring and control of the pyro disconnect's power supply circuit. In the event of a power supply failure (either through an external event such as a coolant exposure or some other means), the Megapack will automatically actuate the pyro disconnect prior to the loss of its power supply.

Hardware Mitigations

- Installation of newly designed, thermally insulated steel vent shields within the thermal roof of all Megapacks. These vent shields protect the plastic overpressure vents from direct flame impingement or hot gas intrusion, thus keeping the IP66 battery bay enclosures isolated from a fire above in the thermal roof. Their performance was validated through a series of fire tests, including unit level fire testing of entire Megapack units.[13] The vent shields are placed over the top of the overpressure vents and will come standard on all new Megapack installations. For existing Megapacks, the vent shields can be installed in the field (retrofit) with minimal effort or disruption to the unit. At the time of this report, the vent shields are nearing production stage and will be retrofitted to applicable Megapack sites shortly.

[13] The tests confirmed that, even with the entire thermal roof fully involved in fire, the overpressure vents will not ignite and the battery modules below remain relatively unaffected by the fire above. For instance, the cells within the battery modules saw a less than 1°C temperature rise while the entire thermal roof was fully involved in fire.

Emergency Response

Beyond the origin and cause and propagation investigations, another key aspect of the VBB fire was the emergency response. The CFA is the responsible fire service organization for VBB, and the facility is in their initial response jurisdiction. The location of the VBB facility is in a semi-rural location. The nearest fire station is the CFA Lovely Banks, approximately 4 km (2.5 miles) distance from VBB and thus relatively close, though other resources had more extended travel distances.

Upon arrival around 10:30 AM, CFA immediately established incident command (IC) in accordance with their protocols, and the IC worked closely with the facility representatives and subject matter experts (SMEs). This close coordination continued throughout the entire event. The facility was evacuated and all-site personnel accounted-for upon notification of the emergency event and the commencement of fire service operations. A 25 m (82 ft) perimeter was established around MP-1 while water application and cooling strategies were discussed with facility representatives and subject matter experts (SMEs). The decision was made to provide exposure protection to Megapacks and transformers adjacent to MP-1 and MP-2 using water hose lines, as recommended in Tesla's ERG. The fire eventually propagated into MP-2; however, flame spread did not advance any further than MP-1 and MP-2. The two Megapacks were permitted to burn themselves out, during which time the CFA did not directly apply water into or onto either Megapack. By 4:00 PM (approximately six hours after the start of the event), visible flames had subdued and a fire watch was instituted. The CFA continued to monitor the site for the next three days before deeming it under control on August 2, 2021, at which time, the fire investigation began.

Key Takeaways

A thorough review of the VBB fire emergency response yielded the following key takeaways:

- Effective Pre-incident Planning: VBB had both an Emergency Action Plan (EAP) and an Emergency Response Plan (ERP). Both plans were available to emergency responders and were effectively used during the VBB fire. For example, all site employees and contractors followed proper evacuation protocols during the fire and as a result, no injuries occurred to those personnel.
- Coordination with SMEs: VBB had thorough pre-incident plans that clearly identified the SMEs, how to contact them, their role and other key tasks. It was reported that the facility SMEs stayed in close contact with the CFA IC throughout the VBB fire, providing valuable information and expertise for the CFA to draw upon. For example, site representatives and SMEs worked closely with the CFA in determining water application and cooling strategies of adjacent exposures.
- Water Application: A key question regarding water application is the necessary amount and duration for effective fire containment. Tesla's design philosophy is based on inherent passive protection (i.e., thermal insulation), with minimal dependence on active firefighting measures like external hose lines. As such, water was not aimed at suppressing the fire but rather protecting the exposures as directed by Tesla's ERG and the SMEs on site. All available data and visual observations of the fire indicates water had limited effectiveness in terms of reducing or stopping fire propagation from Megapack-to-Megapack. The thermal insulation appears to be the dominant factor in reducing heat transfer between adjacent Megapacks. However, water was effectively used on other exposures

(transformers, electrical equipment, etc.) to protect that equipment, which are not designed with the same level of protection as a Megapack is (i.e., thermal insulation).[14]

- The fire protection design approach of the Megapack has inherent advantages over other BESS designs in terms of safety to emergency responders. The Megapack approach minimizes the likelihood of fire spread using passive compartmentation and separation, eliminates the danger to fire fighters of an overpressure event due to design features and a lack of confinement (e.g., outdoor versus indoor), does not rely on active firefighting measures like external hose lines and minimizes the dangers from stranded electrical energy to those involved with overhaul and de-commissioning with a fire response approach permitting the Megapack to burn itself out.

Environmental Concerns

The Environment Protection Authority Victoria (EPA) deployed two mobile air quality monitors within 2 km (1.2 miles) of the VBB site. Locations were chosen where there was potential to impact the local community. The EPA monitors confirmed "good air quality in the local community" after the incident; however, the measurements were not taken during the peak of the fire event. They were sampled around 6:00 PM, or approximately 2 hours after the fire was out. Therefore, the data cannot be used to understand the airborne hazards during the actual fire event. The data does demonstrate that two hours after the fire event, the air quality in the surrounding area was "good" and no long-lasting air quality concerns arose from the fire event.[15]

During the fire event, the CFA coordinated with site personnel to control the water run-off from fire hoses into a catchment. Water samples, collected by Tesla site personnel under the supervision of CFA, were extracted from the catchment. Laboratory results from those samples indicated that the likelihood of the fire having a material impact on the water was minimal. After the incident, as a precaution, the water was removed from the catchment, via suction trucks, and was transported to a licensed waste facility for treatment and disposal. It is estimated that approximately 900,000 liters of water was disposed of from the site after the event.

Community Concerns

Neoen, the project developer and owner, pro-actively engaged with the local community during and following the VBB fire. These engagements included door-to-door visits, phone calls and emails with the residential and agricultural properties within a 2-3 km (1.2-1.9 mile) radius of the VBB site. Neoen found their prior community outreach during the project planning stages to be invaluable as this outreach provided up-to-date contact information for Neoen when reaching out to the local community during and following the fire. In addition, Neoen formed an executive stakeholder steering committee compromising of key organizations within 24 hours of the incident. With multiple parties involved in the emergency response to the fire event

[14] At the time of this report, final fire department reports were not available for review and inclusion. As that information becomes available, additional information regarding water usage and effectiveness may require inclusion in this report. Although the effectiveness of external water in a Megapack fire may be limited, water should still be made available for exposure protection and other unanticipated events in the future, as required by any applicable regulatory requirements.

[15] It should be noted that prior regulatory testing (UL 9540A module level fire testing) has shown that the products of combustion of a Megapack battery module can include flammable and nonflammable gases. Based on those regulatory tests, the flammable gases were found to be below their lower flammable limit (LFL) and would not pose a deflagration or explosion risk to first responders or the general public. The nonflammable gases were found to be comparable to the smoke you would encounter in a typical Class A structure fire and do not contain any unique, or atypical, gases beyond what you would find in the combustion of modern combustible materials.

actively participating in the steering committee, this helped ensure that from the outset communication was timely, efficient, well-coordinated across different organizations and accurate.

In addition to the community outreach, Neoen and Tesla also briefed multiple industry, State and Federal Government Departments and Agencies immediately following the VBB fire and at the conclusion of the investigation process. These briefings helped ensure the wider energy sector with interests in BESS were able to be kept directly informed as information became available.

Overhaul and Remediation

On July 29, 2021 nearly half of the Megapacks had been installed and the site was in the testing and commissioning stage of the project. Following the fire event on July 30, 2021, fire department personnel, regulatory agencies and other emergency responders remained on-site for precautionary purposes until August 2, 2021. At that time the site was turned over for regulatory fire investigations to begin. On-site fire investigations started on August 3, 2021 and continued until August 12, 2021. During this time, starting on August 6, 2021, the site was permitted to continue the installation of Megapacks while the area around MP-1 remained cordoned off for the investigation. On September 23rd, 2021, less than two months after the fire, VBB was re-energized and testing and commissioning restarted. Remediation of the damaged equipment followed shortly after, and lasted a total of three days. All testing and commissioning efforts were completed without any further incidents and on December 8, 2021, VBB officially opened.

Lessons Learned

The VBB fire exposed a number of unlikely factors that, when combined, contributed to the fire initiation as well as its propagation to a neighboring unit. This collection of factors had never before been encountered during previous Megapack installations, operation and/or regulatory product testing. This section summarizes those factors as well as the emergency response to the fire, discusses the lessons learned from this fire event, and highlights the mitigations Tesla has implemented in response.

1. Commissioning Procedures

Lessons learned related to commissioning procedures include: (1) limited supervision/monitoring of telemetry data during the first 24 hours of commissioning and (2) the use of the keylock switch during commissioning and testing. These two factors prevented MP-1 from transmitting telemetry data (internal temperatures, fault alarms, etc.) to Tesla's control facility and placed critical electrical fault safety devices (such as the pyro disconnect) in a state of limited functionality, reducing the Megapack's ability to actively monitor and interrupt electrical fault conditions prior to them escalating into a fire event.

Since the VBB fire, Tesla has modified their commissioning procedures to reduce the telemetry setup connection time for new Megapacks from 24 hours to 1 hour and to avoid utilizing the Megapack's keylock switch unless the unit is actively being serviced.

2. Electrical Fault Protection Devices

Lessons learned related to electrical fault protection devices include: (1) coolant leak alarms; (2) the pyro disconnect being unable to interrupt fault currents when the Megapack is off via the keylock switch and (3) the pyro disconnect likely being disabled due to a power supply loss to the circuit that actuates it. These three factors prevented the pyro disconnect of MP-1 from actively monitoring and interrupting the electrical fault conditions before escalating into a fire event.

Since the VBB fire, Tesla has implemented a number of firmware mitigations that keep all electrical safety protection devices active, regardless of keylock switch position or system state, and to actively monitor and control the pyro disconnect's power supply circuit. Furthermore, Tesla has added additional alarms to better identify and respond (either manually or automatically) to coolant leaks. Additionally, although this fire event was likely initiated by a coolant leak, unexpected failures of other internal components of the Megapack could create similar damage to the battery modules. These new firmware mitigations do not only address damage from a coolant leak. They also permit the Megapack to better identify, respond, contain and isolate issues within the battery modules due to failures of other internal components, should they occur in the future.

3. Fire Propagation

Lessons learned related to fire propagation include: (1) the significant role external, environmental conditions (such as wind) can have on a Megapack fire and (2) the identification of a weakness in the thermal roof design that permits Megapack-to-Megapack fire propagation. These two factors led to direct flame impingement on the plastic overpressure vents that seal the battery bay from the thermal roof. With a direct path for flames and hot gases to enter into the battery bays, the cells within the battery modules of MP-2 failed and became involved in the fire.

Since the VBB fire, Tesla has devised (and validated through extensive testing) a hardware mitigation that protects the overpressure vents from direct flame impingement or hot gas intrusion via the installation of new, thermally insulated, steel vent shields. The vent shields are placed on top of the overpressure vents and will come standard on all new Megapack installations. For existing Megapacks, the vent shields can be easily installed in the field. At the time of this report, the vent shields are nearing production stage and will be retrofitted to applicable Megapack sites shortly.

4. Megapack Spacing

Lessons learned related to Megapack spacing include: no changes are required to the installation practices of the Megapack with the vent shield mitigation (as described above) in place. Based on an analysis of telemetry data within MP-2 during the VBB fire, the Megapack's thermal insulation can provide significant thermal protection in the event of a fire within an adjacent Megapack installed 15 cm (6 in) away. The internal cell temperatures of MP-2 only increased by 1°C (1.8°F), from 40°C to 41°C (104°F to 105.8°F), before communication was lost to the unit, presumably due to fire, around 11:57 AM (approximately 2 hours into the fire event). Fire propagation was triggered by the weakness in the thermal roof, as described above in #3, and not due to heat transfer via the 15 cm (6 in) gap between Megapacks. With the vent shield mitigation in place, the weakness has been addressed and validated through unit level fire testing (i.e., tests involving the ignition of the Megapack's thermal roof). These tests confirmed that, even with the thermal roof fully involved in a fire, the overpressure vents will not ignite and the battery modules remain relatively unaffected with internal cell temperatures rising less than 1°C.

5. Emergency Response

Lessons learned from the emergency response to the VBB fire include: (1) effective pre-incident planning is invaluable and can reduce the likelihood of injuries; (2) coordination with SMEs, either on site or remotely, can provide critical expertise and system information for emergency responders to draw upon; (3) the effectiveness of applying water directly to adjacent Megapacks appears to provide limited benefits; however, water application to other electrical equipment, with inherently less fire protection built into their designs (such as transformers), can be a useful tactic to protect that equipment; (4) the fire protection design

approach of the Megapack has inherent advantages over other BESS designs in terms of safety to emergency responders; (5) the EPA indicated that there was “good” air quality 2 hours after the fire demonstrating that no long-lasting air quality concerns arose from the fire event; (6) water samples indicated that the likelihood of the fire having a material impact on firefighting water was minimal; (7) prior community engagement during the project planning stages is invaluable as it enabled Neoen to quickly update the local community and address immediate questions and concerns; (8) early, factual and where possible, face-to-face engagement with the local community is essential when a fire event is unfolding to keep the general public informed; (9) an executive stakeholder steering committee from the key organizations involved in the emergency response can help ensure that any pubic communications are timely, efficient, coordinated and accurate; and (10) effective coordination between stakeholders at the site allowed for rapid and thorough handover process after the incident, the swift and safe decommissioning of the damaged units and the site’s quick return to service.

In summary, the VBB fire event proceeded in accordance with its fire protection design and pre-incident planning. It presented no unusual, unexpected, or surprising characteristics (i.e., explosions) or resulted in any injuries to site personnel, the general public or emergency responders. It was isolated to the units directly involved, had minimal environmental impact, did not adversely impact the electrical grid, and had appreciably short mission interruption.

Appendix M

Sungrow Battery Spacing Review Documentation

Prüfbericht-Nr.: *Test Report No.:*	**CN21GYRR 001**	**Auftrags-Nr.:** *Order No.:*	244370534	**Seite 1 von 56** *Page 1 of 56*
Kunden-Referenz-Nr.: *Client Reference No.:*	2182037	**Auftragsdatum:** *Order date.:*	Oct 28, 2021	
Auftraggeber: *Client:*	Sungrow Energy Storage Technology Co.,Ltd. No.788 Mingchuan Road, Boyan Technology Park, Hi-tech Zone, Hefei City, 230088 Anhui, P.R. China			
Prüfgegenstand: *Test item:*	Battery Rack			
Bezeichnung / Typ-Nr.: *Identification / Type No.:*	R287-111, R344-111 R578-111, R688-111			
Auftrags-Inhalt: *Order content:*	Test report			
Prüfgrundlage: *Test specification:*	UL 9540A: 2019 (Fourth Edition)			
Wareneingangsdatum: *Date of receipt:*	Nov 15, 2021			
Prüfmuster-Nr.: *Test sample No.:*	Engineering sample			
Prüfzeitraum: *Testing period:*	Nov 15, 2021 ~ Nov 17, 2021			
Ort der Prüfung: *Place of testing:*	See clause 1.1 of main report			
Prüflaboratorium: *Testing laboratory:*	See clause 1.1 of main report			
Prüfergebnis*: *Test result*:*	See main report			



geprüft von / *tested by:*

December 13, 2021 Marvin Peng&David Zhou / Engineer

Datum *Date*	**Name/Stellung** *Name/Position*	**Unterschrift** *Signature*

kontrolliert von / *reviewed by:*

December 13, 2021 Bowen Dong / Reviewer

Datum *Date*	**Name/Stellung** *Name/Position*	**Unterschrift** *Signature*

Sonstiges / *Other:*

Zustand des Prüfgegenstandes bei Anlieferung: *Condition of the test item at delivery:*

Prüfmuster vollständig und unbeschädigt
Test item complete and undamaged

* Legende:	1 = sehr gut P(ass) = entspricht o.g. Prüfgrundlage(n)	2 = gut	3 = befriedigend F(ail) = entspricht nicht o.g. Prüfgrundlage(n)	4 = ausreichend N/A = nicht anwendbar	5 = mangelhalt N/T = nicht getestet
Legend:	1 = very good P(ass) = passed a.m. test specifications(s)	2 = good	3 = satisfactory F(ail) = failed a.m. test specifications(s)	4 = sufficient N/A = not applicable	5 = poor N/T = not tested

Dieser Prüfbericht bezieht sich nur auf das o.g. Prüfmuster und darf ohne Genehmigung der Prüfstelle nicht auszugsweise vervielfältigt werden. Dieser Bericht berechtigt nicht zur Verwendung eines Prüfzeichens.

This test report only relates to the a. m. test sample. Without permission of the test center this test report is not permitted to be duplicated in extracts. This test report does not entitle to carry any test mark.

V04

INTRODUCTION

Model fire codes and energy storage system standards require energy storage systems to comply with UL 9540, which in turn requires battery cells and modules to comply with UL 1973. Compliance with these standards reduces the risk of batteries and battery energy storage systems (BESS) creating fire, shock or personal injury hazards. However, they do not evaluate the ability of the BESS installed as intended and with fire suppression mechanisms in place if necessary, from contributing to a fire or explosion in the end use installations.

To address these fire and explosion hazards associated with the installation of a BESS, the fire and other codes require energy storage systems to meet certain location, separation, fire suppression and other criteria. Those codes also provide a means to provide an equivalent level of safety based on large-scale fire testing of anticipated BESS installations.

UL 9540A is intended to provide a test method that can be used as a basis for validating the safety of a BESS installation in lieu of meeting the specific criteria provided in those codes. The data generated can be used to determine the fire and explosion protection required for installation of a BESS.

The test method is initiated through the establishment of a thermal runaway condition that leads to combustion within the BESS. The test method outlined in UL 9540A consists of several steps – cell level testing, module level testing, unit level testing and installation level testing. The cell and module level testing steps are information gathering steps to inform the unit and installation level testing.

The following outlines the information that may gathered as part of the testing:

a) Cell level – An individual cell fails in a manner that leads to thermal runaway and fire through a suitable method such as external heating. Data such as off-gassing contents, temperatures at venting and temperatures at thermal runaway are recorded.

b) Module level – One or more cells within a BESS module fail in the manner determined during the cell level testing. Data such as fire propagation in the module, temperatures on the failed cells and surrounding cells, off-gassing contents and heat release data are gathered.

c) Unit level – A complete BESS is installed surrounded by target (e.g. dummy) BESS and walls separated at a distance as intended in its installation. The module level test is repeated on a module located in the BESS in the most unfavorable location. Data such as temperature within the BESS, on surrounding walls and target BESS; incident heat flux on walls and target BESS; observation of fire propagation from BESS to target units and walls as well as observance of explosions or evidence of re-ignition within the BESS; and heat release and off-gassing contents are gathered.

d) Installation level – This test is a repeat of the unit level test with the test conducted within a test room and with the intended fire suppression system installed as well as any overhead cables (that can lead to fire propagation) installed. This test is intended to validate the fire suppression system for the BESS installation. Data such as temperature within the BESS, on surrounding walls and target BESS; incident heat flux on walls and target BESS; fire propagation from the BESS to target units, walls or overhead cables and any observable explosion incidents or re-ignition within the BESS; and off-gassing contents (if needed) and heat release are gathered.

Contents

1 GENERAL INFORMATION 4

1.1 TEST SPECIFICATION 4
1.2 GENERAL REMARKS 4
1.3 LIST OF ATTACHMENTS 5
1.4 REVISION INFORMATION 5
1.5 DEFINITIONS 6

2 GENERAL PRODUCT INFORMATION 7

2.1 CELL 7
2.1.1 Product information and parameters 7
2.1.2 Cell level test information 8
2.2 MODULE 8
2.2.1 Product information and parameters 8
2.2.2 Diagram with overall dimension 10
2.2.3 Layout of the module contents 11
2.2.4 Configuration diagram of the module 11
2.3 BATTERY SYSTEM (RACK) 14
2.3.1 Manufacture information and model list 14
2.3.2 Product information 16
2.4 PHOTO 18

3 UNIT LEVEL TEST (SECTION 8 OF UL 9540A) 20

3.1 GENERAL 20
3.2 UNIT SAMPLE PREPARATION 21
3.3 SETUP OF THE TEST 22
3.3.1 Battery system installation information 22
3.3.2 Test site setup 22
3.3.3 Thermal runaway setup 25
3.4 OBSERVATIONS AND RECORDS 27
3.5 TEMPERATURE MEASUREMENTS 30
3.5.1 Temperature measurement of initiating cells 30
3.5.2 Temperature measurement of units 32
3.5.3 Temperature measurement of instrumented walls 36
3.6 HEAT FLUX MEASUREMENT 39
3.7 CHEMICAL HEAT RELEASE RATE MEASUREMENT 40
3.8 CONVECTIVE HEAT RELEASE RATE MEASUREMENT 43
3.9 GAS GENERATION MEASUREMENT 44
3.10.1 Total gas release 45
3.10.2 Gas components 46
3.10 PHOTOS 51

4 LIST OF TEST AND MEASUREMENT INSTRUMENTS 56

1 General information

1.1 Test specification

Standard: ANSI/CAN/UL 9540A: 2019 (Fourth Edition)

Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

This report presents the result of unit level tests of UL 9540A: 2019.

All tests were conducted at TUV Rheinland (Shanghai) Co., Ltd. and TUV Rheinland's partner labs that were under supervision of TÜV Rheinland's engineer.

Testing period: Nov 15, 2021 ~ Nov 17, 2021

Refer to Clause 4 for test and measurement instruments.

1.2 General remarks

This report is descriptive and provide the test data only.

The test results presented in this report relate only to the object tested.

This report shall not be reproduced, except in full, without the written approval of the testing laboratory.

Throughout this report a ☐ comma / ☒ point is used as the decimal separator.

1.3 List of attachments

Video records of the test from 4 different directions were provided in .mp4 format. Complete records were provided in 4 separate documents, file number listed as below:

NY202111224-1.mp4

NY202111224-2.mp4

NY202111224-3.mp4

NY202111224-4.mp4

1.4 Revision information

New report, not applicable

1.5 Definitions

CELL – The basic functional electrochemical unit containing an assembly of electrodes, electrolyte, separators, container, and terminals. It is a source of electrical energy by direct conversion of chemical energy.

MODULE – A subassembly that is a component of a BESS that consists of a group of cells or electrochemical capacitors connected together either in a series and/or parallel configuration (sometimes referred to as a block) with or without protective devices and monitoring circuitry.

UNIT – A frame, rack or enclosure that consists of a functional BESS which includes components and subassemblies such as cells, modules, battery management systems, ventilation devices and other ancillary equipment.

BATTERY SYSTEM (BS) – Is a component of a BESS and consists of one or more modules typically in a rack configuration, controls such as the BMS and components that make up the system such as cooling systems, disconnects and protection devices.

BATTERY ENERGY STORAGE SYSTEM (BESS) – Stationary equipment that receives electrical energy and then utilizes batteries to store that energy to supply electrical energy at future time. The BESS, at a minimum consists of one or more modules, a power conditioning system (PCS), battery management system (BMS) and balance of plant components.

a) INITIATING BATTERY ENERGY STORAGE SYSTEM UNIT (INITIATING BESS) – A BESS unit which has been equipped with resistance heaters in order to create the internal fire condition necessary for the installation level test (Section 9).

b) TARGET BATTERY ENERGY STORAGE SYSTEM UNIT (TARGET BESS) – The enclosure and/or rack hardware that physically supports and/or contains the components that comprise a BESS. The target BESS unit does not contain energy storage components, but serves to enable instrumentation to measure the thermal exposure from the initiating BESS.

Note: Depending upon the configuration and design of the BESS (e.g. the BESS is composed of multiple separate parts within separate enclosures), the unit level test can be done at battery system level. In such case, the BESS is be read as BS throughout this report.

NON-RESIDENTIAL USE – Intended for use in commercial, industrial or utility owned locations.

RESIDENTIAL USE – In accordance with this standard, intended for use in one or two family homes and town homes and individual dwelling units of multi-family dwellings.

THERMAL RUNAWAY- The incident when an electrochemical cell increases its temperature through self-heating in an uncontrollable fashion. The thermal runaway progresses when the cell's generation of heat is at a higher rate than the heat it can dissipate. This may lead to fire, explosion and gas evolution.

STATE OF CHARGE (SOC) – The available capacity in a BESS, pack, module or cell expressed as a percentage of rated capacity.

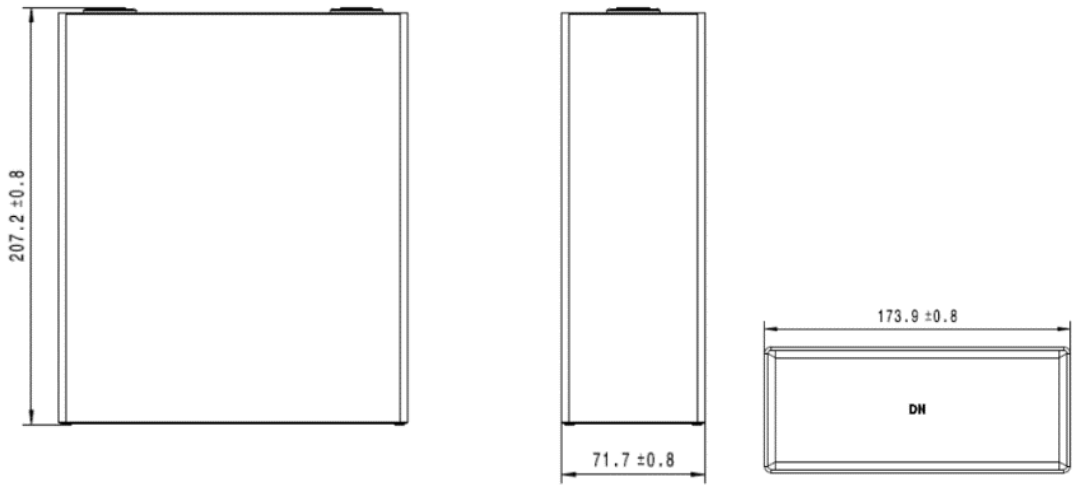
2 General Product Information

The product information and parameters were provided by the client as below.

2.1 Cell

2.1.1 Product information and parameters

Manufacturer .....:	CATL	
Model .....:	CB2W0 CB310	
Chemistry .....:	LiFePO4	
Physical configuration .....:	Prismatic	
	Weight:	5410 ± 300 g
Electrical rating .....:	Rated capacity:	280 Ah
	Nominal voltage:	3.2 V
Standard charge method .....:	Charge current:	280 A
	End of charge voltage:	3.65 V
	Cut off current:	14 A
Standard discharge method .....:	Discharge current:	280 A
	End of discharge voltage:	2.5 V
Diagram with overall dimension		



Model Difference: Cell model CB2W0 is identical to model 001CB310 except for the rated charging/discharging current declared, documented in UL with project No. 4789439215. Models CB2W0 and CB310 are identical to model 001CB310 except for model names, and the declared ratings of pulse charging and discharging current.

2.1.2 Cell level test information

Cell level thermal runaway test information is from CSA cell level test report 80008629 provided by the client.

Thermal Runaway Methodology ..... :	External heating method with ceramic heater 1 PCS, rated 220/230V, 500W
Average Cell Surface Temperature at Gas Venting ..... :	143.3°C
Average Cell Surface Temperature at Thermal Runaway..... :	209.8°C

2.2 Module

2.2.1 Product information and parameters

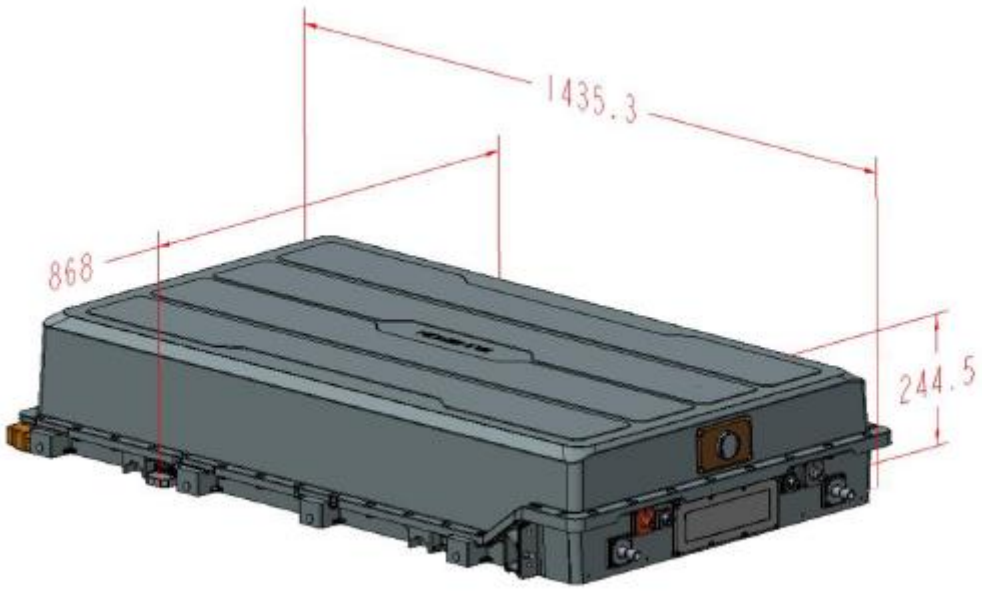
The product information and parameters are provided by the client as below.

Manufacturer name.....:	SUNGROW ENERGY STORAGE TECHNOLOGY CO., LTD.		
Model number .....:	P573AL-112 P573BL-112	P286BL-112	P573-111 P573B-111
Physical configuration.....:	Metal enclosure with plastic cover		
	Weight: ≤400kg	≤230kg	≤400kg
	Cells in series/parallel: 64 in series	32 in series	64 in series
Cooling method.....:	Liquid Cooling		
Separation between cells ....:	0.45 mm separation between cells by air		
Electrical rating .....:	Rated capacity: 280 Ah	280 Ah	280 Ah
	Nominal voltage: 204.8V	102.4V	204.8V
Standard charge method .....:	Charge current: 280 A	280 A	140A
	End of charge voltage: 233.6 V	116.8 V	233.6 V
	Cut of current: 14 A	14 A	14 A
Standard discharge method :	Discharge current: 280 A	280 A	140A
	End of discharge voltage: 172.8 V	86.4 V	172.8 V

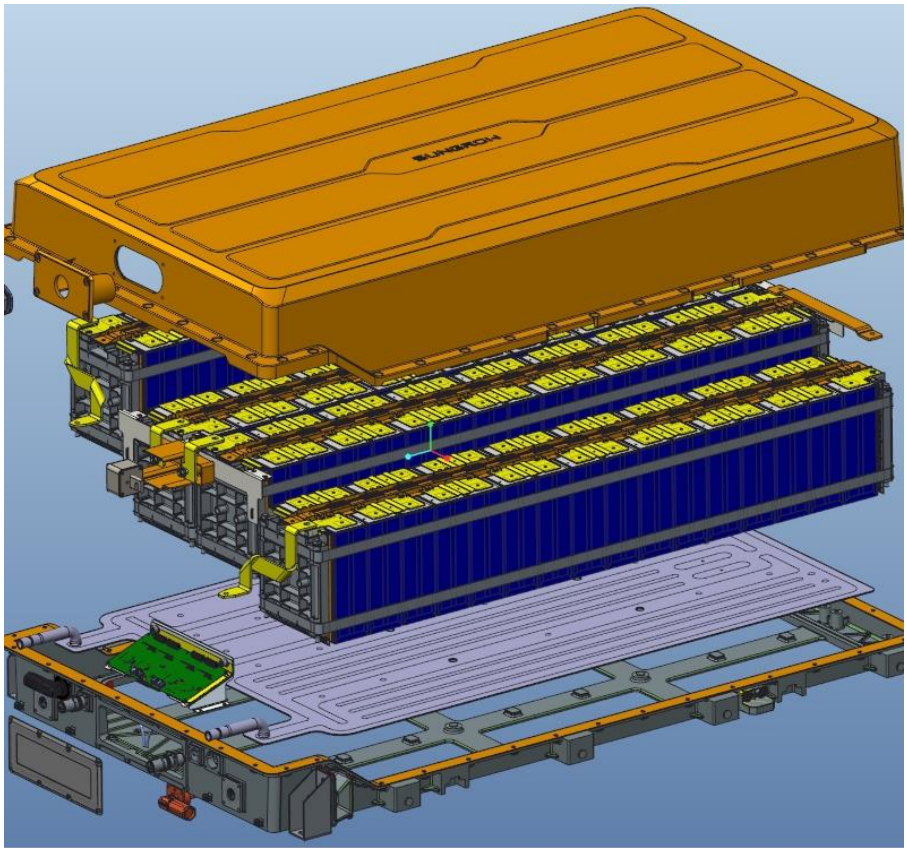
Compliance with UL 1973 ...:	Under certification, not finished

Manufacturer name.....:	SUNGROW ENERGY STORAGE TECHNOLOGY CO., LTD.	
Model number .....:	P537AL-112 P537BL-112	P537AL-111 P537BL-111
Physical configuration.....:	Metal enclosure with plastic cover	
	Weight: ≤384kg	≤384kg
	Cells in series/parallel: 60 in series	60 in series
Cooling method.....:	Liquid Cooling	
Separation between cells ....:	0.45 mm separation between cells by air	
Electrical rating .....:	Rated capacity: 280 Ah	280 Ah
	Nominal voltage: 192V	192V
Standard charge method.....:	Charge current: 280 A	140 A
	End of charge voltage: 219 V	219 V
	Cut of current: 14 A	14 A
Standard discharge method :	Discharge current: 280 A	140 A
	End of discharge voltage: 150 V	150V
Compliance with UL 1973 ...:	Under certification, not finished	

2.2.2 Diagram with overall dimension

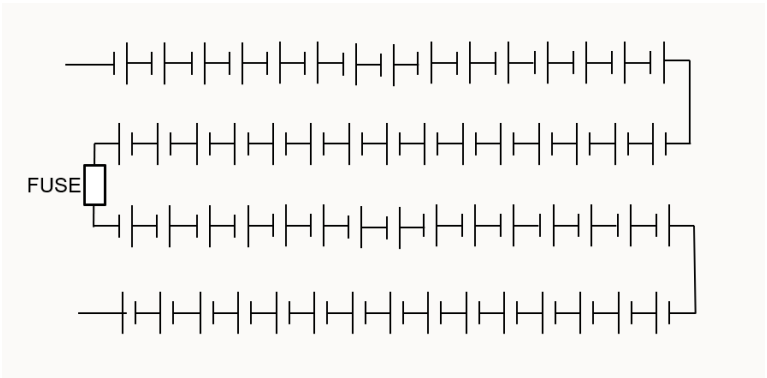


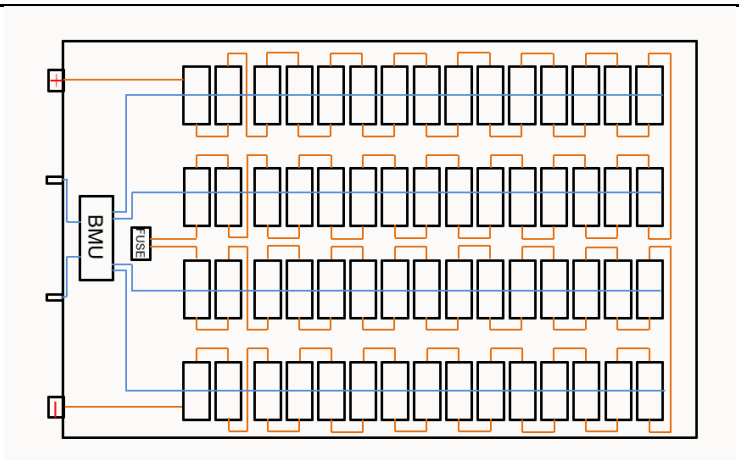
2.2.3 Layout of the module contents



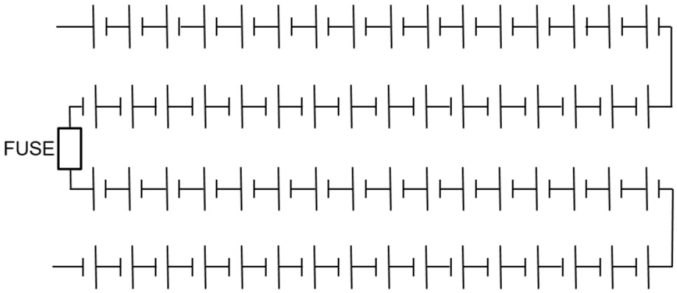
2.2.4 Configuration diagram of the module

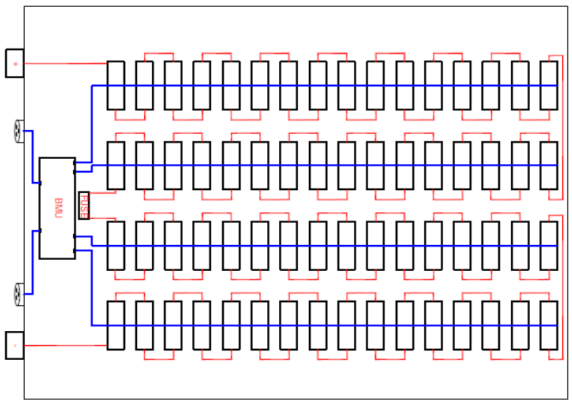
1P60S



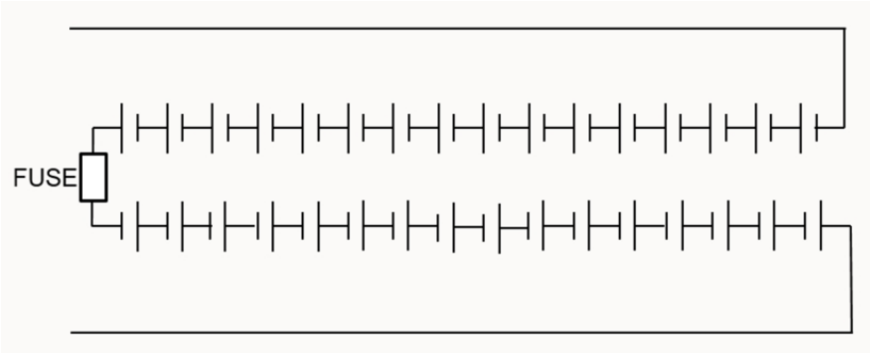


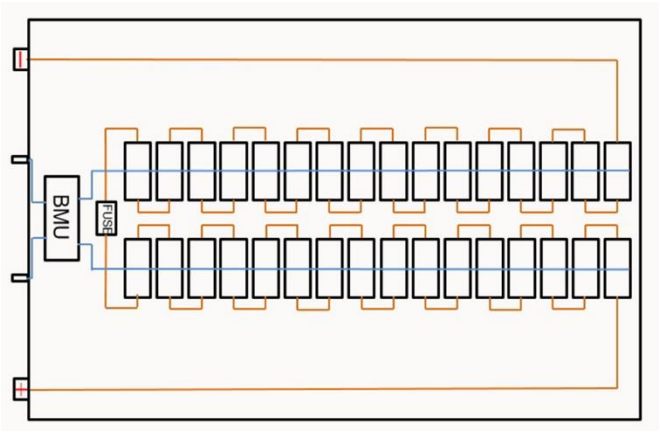
1P64S





1P32S





2.3 Battery system (rack)

2.3.1 Manufacture information and model list

	Battery system	Battery system	Battery system
Product	LFP Lithium Ion Energy Storage System	LFP Lithium Ion Energy Storage System	LFP Lithium Ion Energy Storage System
Type/model	R344-111	R287-111	R688-111
Cell Capacity [Ah]	280	280	280
Cell Quantity	384	320	768
Battery structure	(64S)6S	(64S)5S	((64S)6S)2P
Nominal voltage [V]	1228.8	1024	1228.8
Rated capacity [Wh]	344064	286720	688128
Upper limit charging voltage [V]	1401.6	1168	1401.6
Recommend charging current [A]	140	140	140
Maximum charging current [A]	140	140	140
Recommend discharging current [A]	140	140	140
Maximum discharging current [A]	140	140	140
Discharge cut-off voltage [V]	1036.8	864	1036.8
Temperature range for charging [°C]	0 to 50*	0 to 50*	0 to 50*
Temperature range for discharging [°C]	-30 to 50*	-30 to 50*	-30 to 50*
Temperature threshold for protection	50	-	50
Overcharge protected voltage supply by battery system	≥3.65V /Cell	-	≥3.65V /Cell
Recommend charging method by manufacturer	Charge at constant current 140A until the voltage reaches 1401.6V, then switch to constant voltage 1401.6V till charge current drops to 14A	Charge at constant current 140A until the voltage reaches 1168V, then switch to constant voltage 1168V till charge current drops to 14A	Charge at constant current 140A until the voltage reaches 1401.6V, then switch to constant voltage 1401.6V till charge current drops to 14A
Dimension [mm]	Rack: 3117±10mm(W)×1474±10 mm(D) ×520±10mm(H) DC/DC: 720±5mm(W)×788±5mm(D) ×294±5mm(H)	Rack: 3117±10mm(W)×1474±10 mm(D) ×520±10mm(H) DC/DC: 720±5mm(W)×788±5mm(D) ×294±5mm(H)	Rack: 3117±10mm(W)×1474±10 mm(D) ×1040±10mm(H) DC/DC: 720±5mm(W)×788±5mm(D) ×294±5mm(H)
Weight [kg]	Rack: ≤2400kg DC/DC: 75kg	Rack: ≤2000kg DC/DC: 75kg	Rack: ≤4800kg DC/DC: 75kg
Ingress Protection (IP)	IP65	IP65	IP65
Protective Class	I	I	I
Cooling type	Liquid cooling	Liquid cooling	Liquid cooling
Altitude	4000m	4000m	4000m

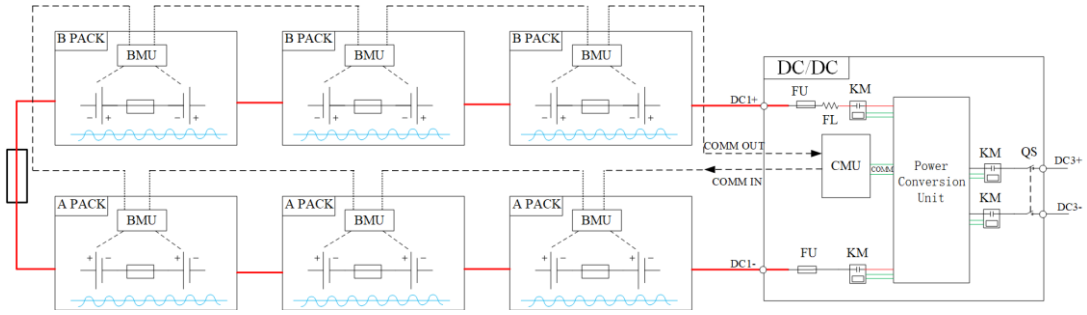
*: Constant Power 172kW and max charging and discharging current is 140A when ambient temperature is no more than 45°C, it will start derating when ambient temperature more than 45°C. The battery cell shall be heated first through the liquid cycle when discharging below -20°C.

	Battery system
Product	LFP Lithium Ion Energy Storage System
Type/model	R573-111
Cell Capacity [Ah]	280
Cell Quantity	640
Battery structure	((64S)5S)2P
Nominal voltage [V]	1024
Rated capacity [Wh]	573440
Upper limit charging voltage [V]	1168
Recommend charging current [A]	140
Maximum charging current [A]	140
Recommend discharging current [A]	140
Maximum discharging current [A]	140
Discharge cut-off voltage [V]	864
Temperature range for charging [°C]	0 to 50*
Temperature range for discharging [°C]	-30 to 50*
Temperature threshold for protection	50
Overcharge protected voltage supply by battery system	≥3.65V/Cell
Recommend charging method by manufacturer	Charge at constant current 140A until the voltage reaches 1168V, then switch to constant voltage 1168V till charge current drops to 14A
Dimension [mm]	Rack: 3117±10mm(W)×1474±10mm(D) ×1040±10mm(H) DC/DC: 720±5mm(W)×788±5mm(D) ×294±5mm(H)
Weight [kg]	Rack: ≤4000kg DC/DC: 75kg
Ingress Protection (IP)	IP65
Protective Class	I
Cooling type	Liquid cooling
Altitude	4000m

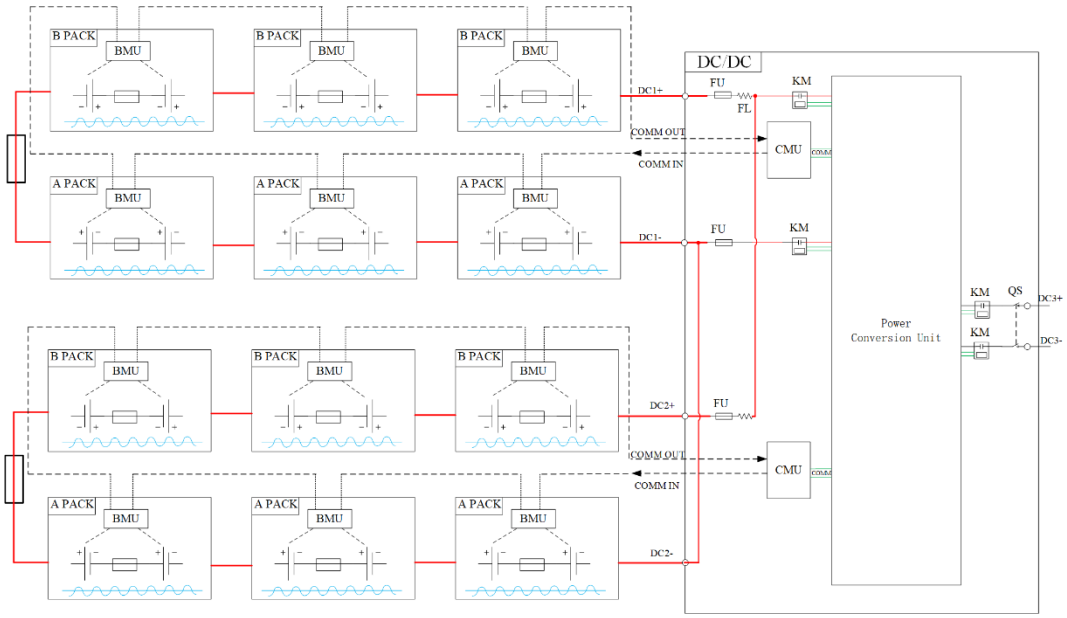
2.3.2 Product information

This product is used for Energy Storage System.
The EUTs covered by this report are 4 models of LFP lithium ion battery energy storage systems which include one DC-DC converter box and several battery packs in series(parallel) connection. The number of battery packs are 5, 6, 10,12 for model R287-111, R344-111, R573-111 and R688-111.

Block diagram for R344-111 is as below (R287-111 is the same except for one less pack) :



Block diagram for R688-111 is as below (R573-111 is the same except for two fewer packs) :

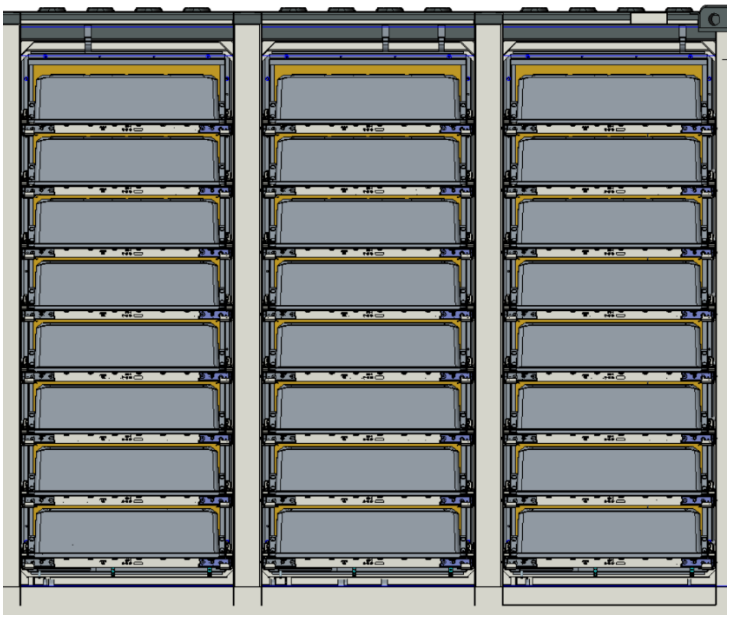


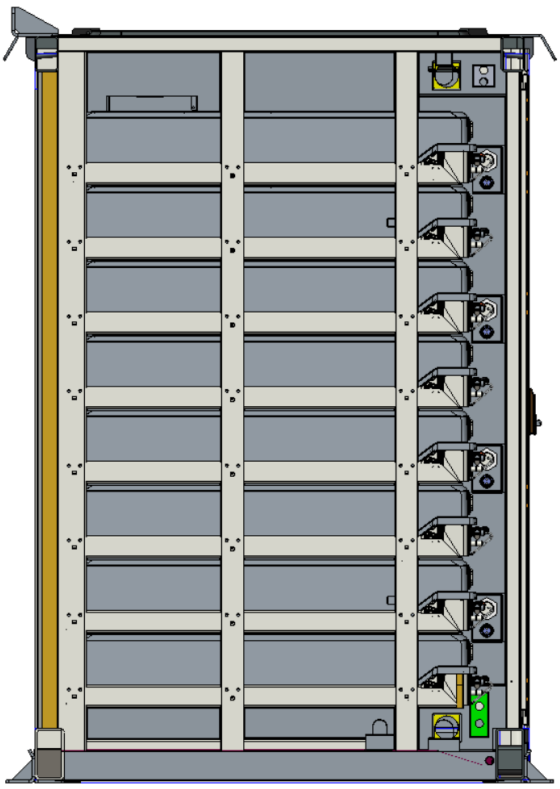
Each battery pack contains 64 cells in structure 64S. And it contains one BMU board for measuring and collecting the cell parameters and uploading the information of cell voltage and temperature to CMU in DC-DC converter box.
DC-DC box: Including CMU function and DC-DC converter which is certified with UL 1741.

The EUTs are indoor type. The insulation between the DC circuit and the metal enclosure is basic insulation. And the insulation between the DC circuit and communication ports is reinforced insulation or double insulation.
BMS functional safety was evaluated according to IEC 60730-1 Annex H by TÜV Rheinland.

Compliance with UL9540 ..... :	without
Compliance with UL1973 ..... :	Yes, (repot number: CN21XPKR 001)
Integrated fire protection system in the unit ..... :	No integrated fire protection system

Diagram with dimension of R688-111





2.4 Photo

Module



Battery Rack



3 Unit level test (section 8 of UL 9540A)

3.1 General

Unit level testing corresponds with the testing anticipated by fire codes and other codes impacting energy storage system installations to evaluate the large scale fire performance of BESS units installed in, on or adjacent to buildings or in other areas and their resultant performance to qualify for exceptions to limits in the codes imposed on these installations. The limitations where exceptions may be sought are limitations on the size of the individual BESS units, the total number of BESS units installed within a room, and the separation distances between BESS units and between BESS units and walls of the building.

In this test the initiating BESS unit is placed a set distance from target BESS units simulating BESS units identical to the initiating BESS unit, and from simulated walls representative on the installation. A thermal runaway is induced in cells, using the same approach as used in the module level testing within one of the modules in the initiating BESS, and a variety of measurements are taken. The results are intended to be used to verify that a fire within a single BESS unit will not spread to other units, nor breach the walls or the BESS enclosure (if provided), and there shall be no flying debris or explosive discharge of gases.

The test arrangement include the largest (energy) BESS unit for the installation to be represented by the test, and minimum spacing to adjacent walls and BESS units. The BESS may be tested with an internal fire suppression system provided by the manufacturer if that fire suppression system is required to be installed in the BESS. Optional internal fire suppression systems are not included in the unit level testing.

The test monitors the fire behavior of the BESS unit and measures heat release rates (convective and chemical); gas generation and composition; smoke release rate; maximum heat flux on the target BESS units, wall surfaces and within the accessible means of egress; maximum surface temperatures of the walls and modules within the target BESS units; and documents any explosions, deflagrations and flying debris from the BESS under test.

3.2 Unit sample preparation

The battery system is constructed with open rack without enclosure. One series of the rack with 6 complete modules was considered as a unit for purposes of the test.

All 6 module samples were conditioned together as a unit, through 3 charge/ discharge cycles per the manufacturer's instructions to verify that the module was functional.

The Charge/discharge was performed at 140A. Each cycle was defined as a charge to 100% SOC and allowed to rest 60 minutes and then discharged to an end of discharge voltage (EODV) determined by the module specification. Refer to section 2.2 for the end of the condition of charge and discharge.

Cycling was conducted on Sep 16, 2021 under ambient temperature 25°C ± 3°C and R.H. 70% ± 5%.

3.3 Setup of the test

3.3.1 Battery system installation information

The installation information was provided by the client as below.

Intended use location ..... :	☐ Residential	☒ Non-residential
	☐ Non-residential rooftop	
	☐ Non-residential open garage use	
Type of installation ..... :	☒ Indoor	☐ Outdoor
	☒ Floor/ground mounted	☐ Wall mounted
Row(s) of installation	☐ Single	☒ Multiple

3.3.2 Test site setup

Two instrumented walls with 3.8 m height and 3.55 m width form a right angle. Walls were constructed of 5/8 in gypsum painted flat black.

Three racks were used for the purpose of the test. As specified by the manufacture, the two target racks will be installed up and down of the initial unit. All racks were positioned facing instrumented wall A. See Figure 1 and 2 and photos on page 47.

The initiating unit (unit A) was positioned at the middle, adjacent to the two instrumented wall sections.

The minimum separation distance from the rack to wall and between racks were defined by the client. Subject to the actual conditions of the testing environment, there was 1cm tolerance in the actual setup.

Figure 1 was the test site setup diagram with separation distance.

The test side setup was located under the smoke collection hood of the calorimeter measurement system.

Figure 1. Test site setup diagram with separation distance. (Top view)

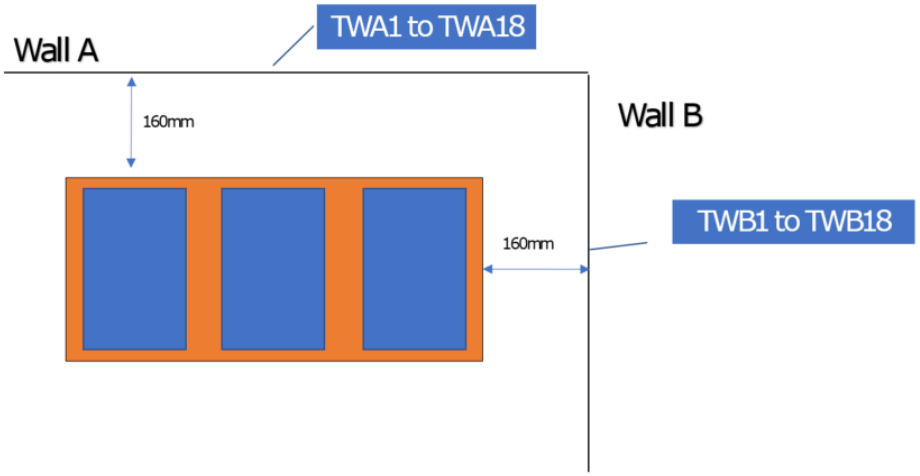
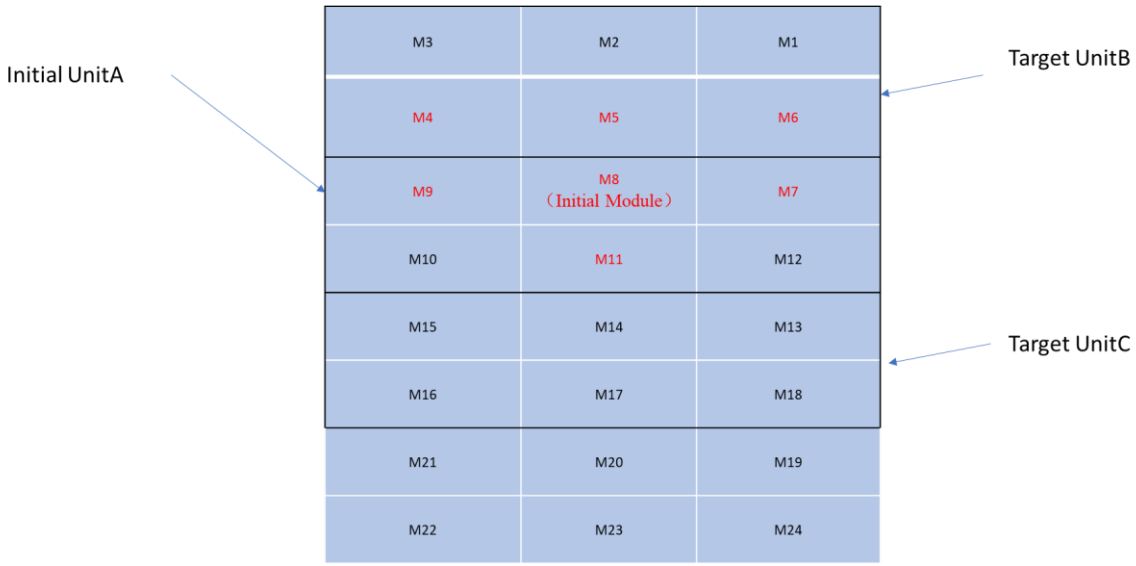


Figure 2. Test site setup diagram with separation distance. (Front view)



For the purpose of this test, the modules were numbered according to the electrical continuity.

In Initial Unit A, modules numbers from M7 to M12.

In Target Unit B, modules numbers from M1 to M6 which was the target unit situated above the Initial Unit A.

In Target Unit C, modules numbers from M13 to M18 which was the target unit situated below the Initial Unit A.

See Figure 3.

4 complete modules were used for unit A (M7 to M9 and M11).

3 complete modules were used for unit B (M4 to M6) to check the possible propagation form unit to unit.

Empty modules without cells were used for the other modules.

Figure 3. Module numbering in units showing fully populated modules in red.

M3	M2	M1
M4	M5	M6
M9	M8 （Initial Module）	M7
M10	M11	M12
M15	M14	M13
M16	M17	M18
M21	M20	M19
M22	M23	M24

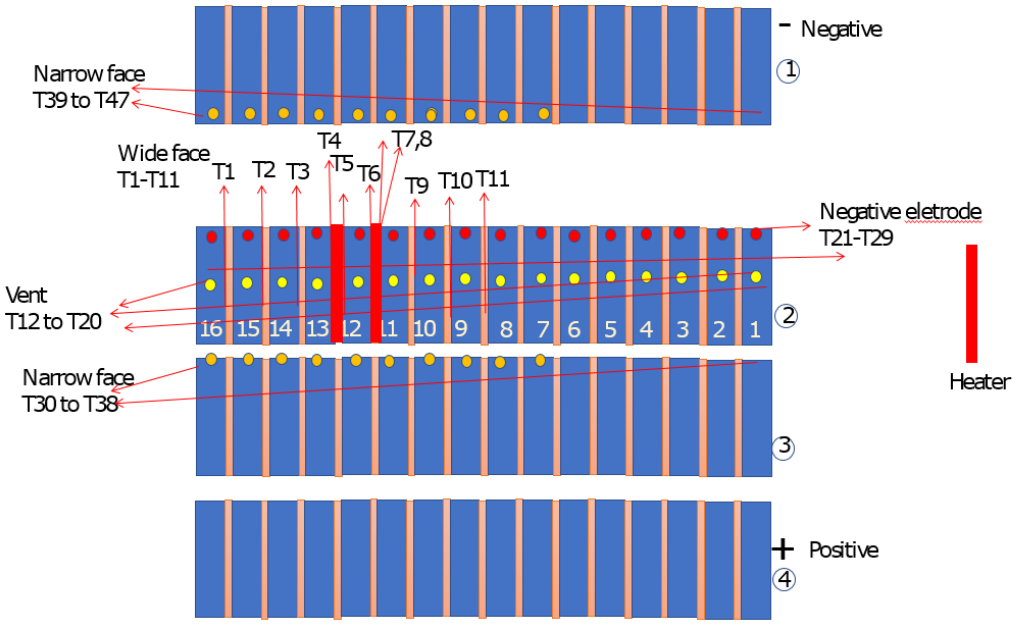
3.3.3 Thermal runaway setup

External heating method, agreed with the client, was used to initiate the thermal runaway within the module.

Module M8 was prepared with two heaters inside. Same as the method in module level test.

Cells inside the module were numbered from 1 to 16 as Figure 3.

Figure 3. Cell numbering inside the initiating module



Consider the unit level installation and airflow of the liquid cooling in the module. #11, #12 and #13 cell located in the back of the module were chosen as target cell to be forced into thermal runaway.

The cell #12 was heated by two external heater on each wide side, the cell #11 and cell#13 was heated by one external heater on wide near cell #12. The heater is rated 220VAC/500 W (size 207*174*4mm).

11 glass fiber thermocouples Type K, 24 AWG were attached to the center of the wide surface of #1 to #16 cells. 20 glass fiber thermocouples Type K, 24 AWG were attached on the center of narrow surface of opposite cells near #7 to #16 cells.

The initiating module M8, internal voltage sample wire and signal wire covered by glass fiber tube. The BMS control board was disabled during the test.

A PID controller was used to control the voltage supply to the heater and maintain a 5.5°C/min heating rate. When heater temperature reached to 180°C (T-set), hold about 60min (10:10 to 11:10), then continue to heat and maintain a 4°C/min to 7°C/min heating rate.

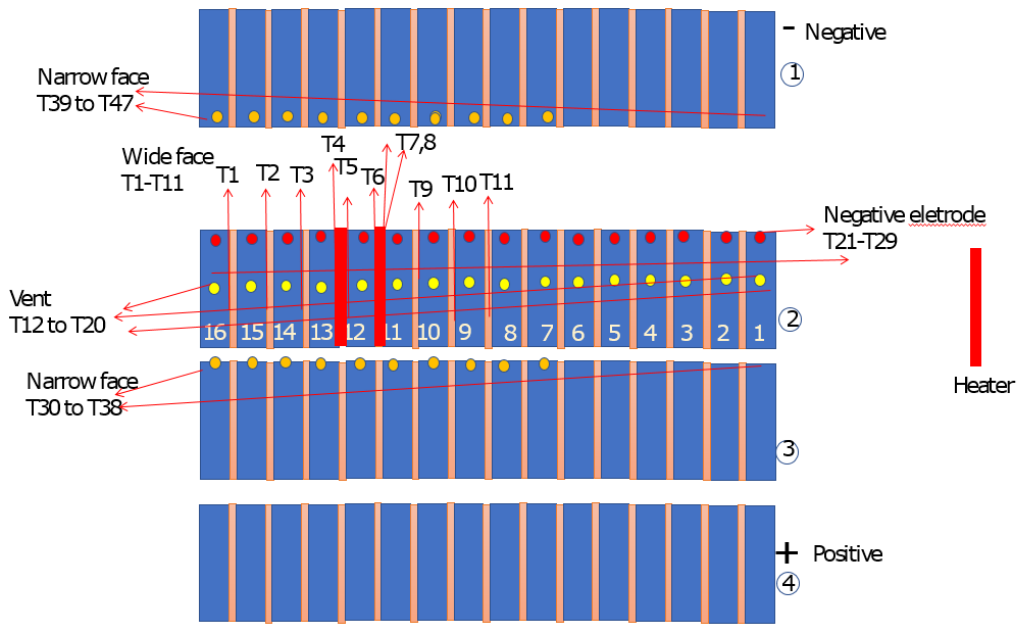
Once thermal runaway was observed, the heaters were immediately de-energized.

Four thermocouples(located below the heater at the wide surface center of #11,#12,#13 cell and two thermocouples located below the heater at the wide surface center of #4 cell were used to feedback the temperature to the controller.

6 glass fibers insulated thermocouples on the center of the wide surface of #14 to #16, #8-#10 cell s to check the possible propagation from cell to cell.

Voltage of the module are monitored during the test.

Figure 5: Thermocouples on module M8



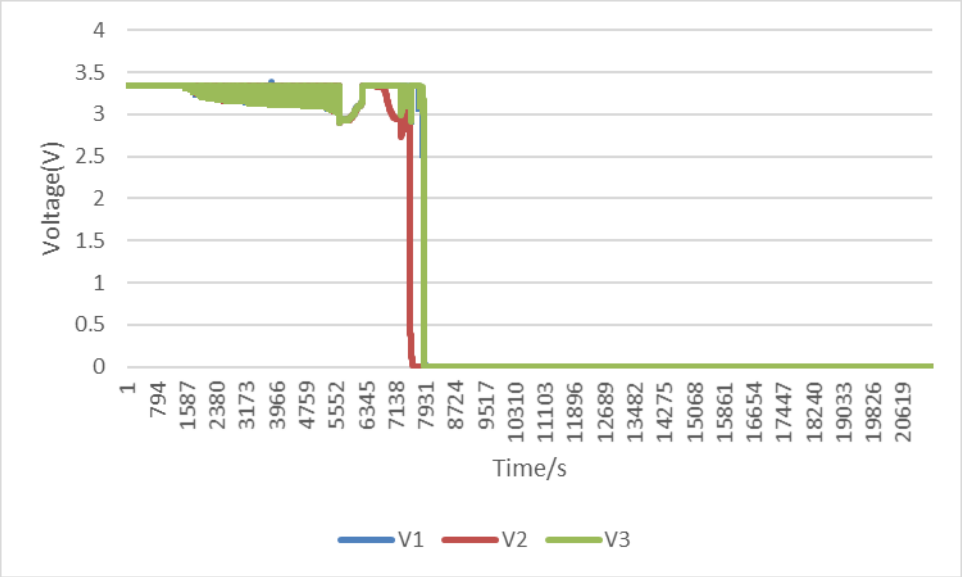
3.4 Observations and records

Before the test, the initiating module was charged to 100% SOC and allowed to stabilize for a minimum of 1 h and a maximum of 8 h before the start of the test.

The ambient condition at the initiation of the test was 25°C, 66% RH.

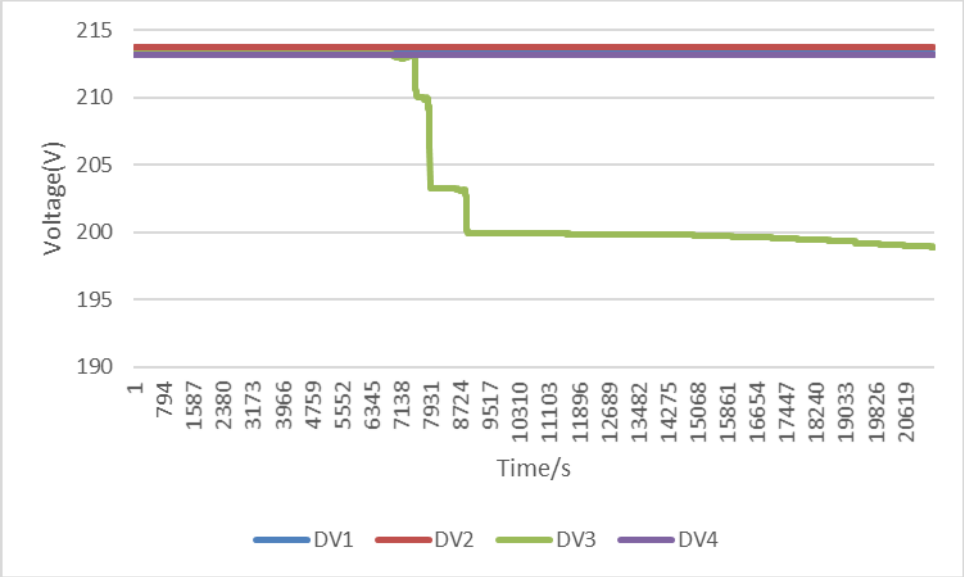
The voltage of the modules was recorded as below:

Figure 6: Voltage record of cells during the test



V1: Cell voltage of #13
V2: Cell voltage of #12
V2: Cell voltage of #11

Figure 7: Voltage record of Modules during the test



DV1: Module voltage of #4
DV2: Module voltage of #5
DV3: Module voltage of #6
DV4: Module voltage of #8

Tests were performed on Sep 16, 2021, started at 09:40 AM.

Observations during the test:

Audible pop was heard on 11:14 AM (the pressure relief valve burst), followed by smoke release after several seconds.

A large amount of white smoke was observed after thermal runaway.

Cell to cell propagation was observed in the initial model.

Module to module propagation was not observed.

No flying debris or explosive discharge of gases observed during test.

No sparks, electrical arcs, or other electrical events observed during test.

No external flaming was observed during the test.

Observations after the test:

Leakage outside the initiating module enclosure was observed. See photos in page 46~54.

No damage and contamination on the instrument walls.

No damage and contamination on the modules of target units.

The plastic top enclosure near the initial cell of module M8 was melted and significantly damaged. Module voltage of M8 was 198.6 Vdc.

Four cells inside the initial module M5 was damaged. Cell to cell propagation was observed on cell #14 after receiving thermal energy from cell #13. Voltage measured on each remaining undamaged in other sub-modules were 3.33Vdc.

Weight loss of the initiating module was 1.7 kg (before test 401.5kg, after test 399.8kg)

See photos in page 53.

3.5 Temperature measurements

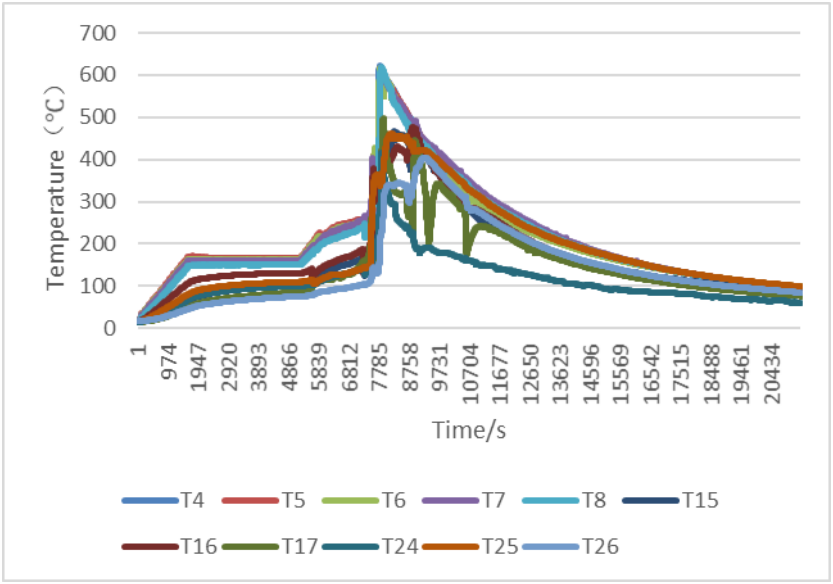
3.5.1 Temperature measurement of initiating cells

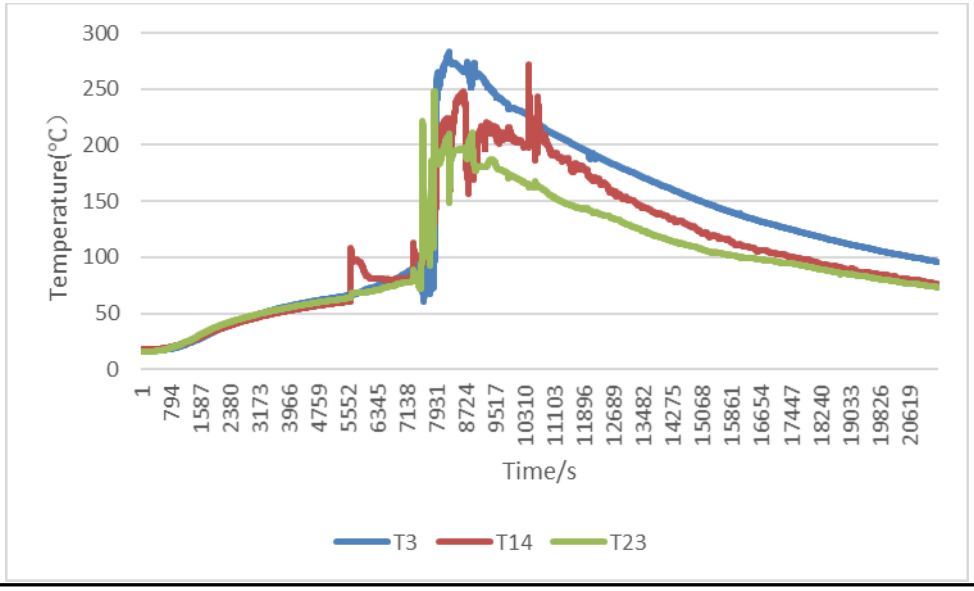
Surface temperature of cells #8 - #16 was recorded during the test. Cell to cell propagation occured during the test. See Figure 6 for the temperature vs time curve.

Cell thermal runaway occurred on cell #12, #13, #11 in turn at around 11:46, 11:50, 11:52 Maximum temperature 617.4°C, 623.7°C,619.5°C were measured on the cell #12, #13, #11 surface.

Cell to cell thermal runaway propagation occurred on cell #14. Maximum temperature 283.8°C was measured on the cell #14 surface.

Figure 8. Surface temperatures of thermal runaway cells on module M8





Cell in other sub-module did not go to thermal runaway, maximum temperature 108.2°C, 131.7°C, 553.8°C, 353.5°C, 646.6°C, 566.6°C, 133.7°C, 142.7°C, 163.7°C were measured on narrow surface center of cell near cells #8 - #16 in sub-modules 1 and 3.

Figure 9. Surface temperatures of no thermal runaway cells on sub-module 3 of module M8

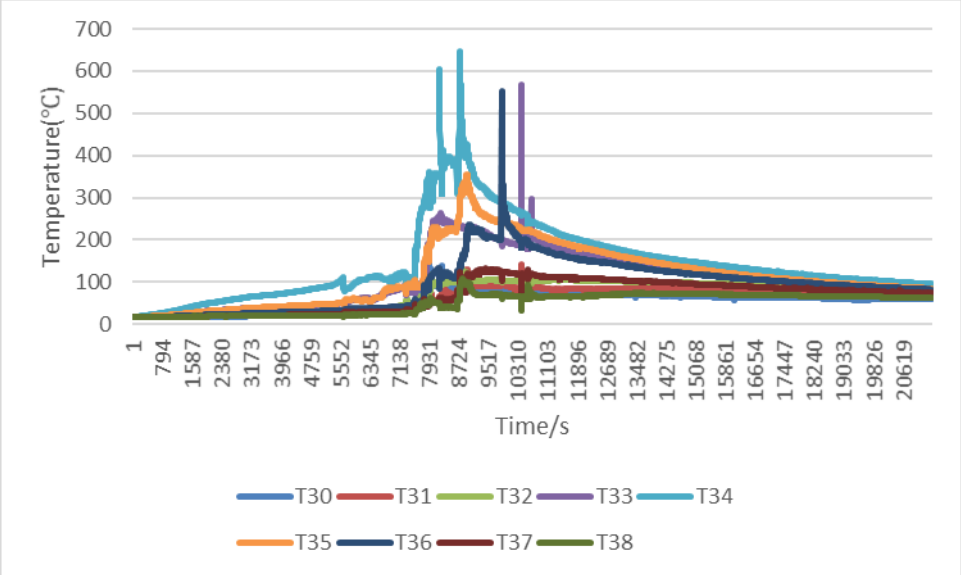
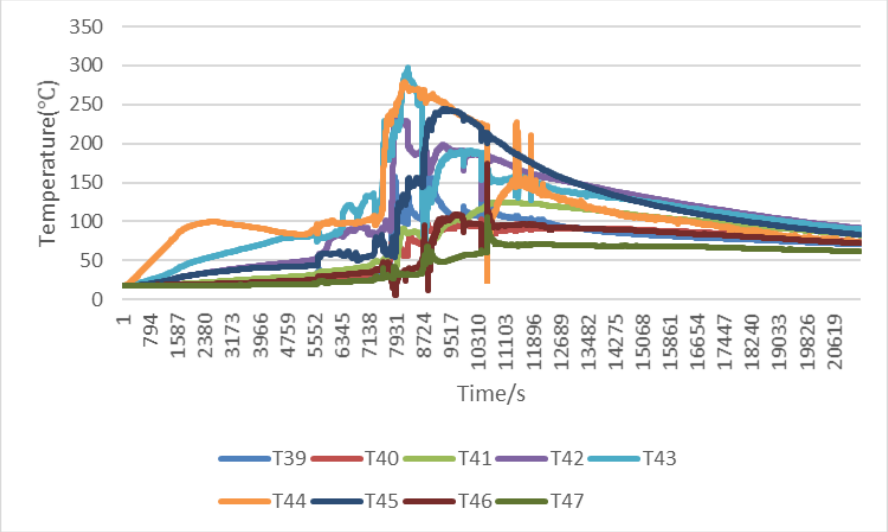


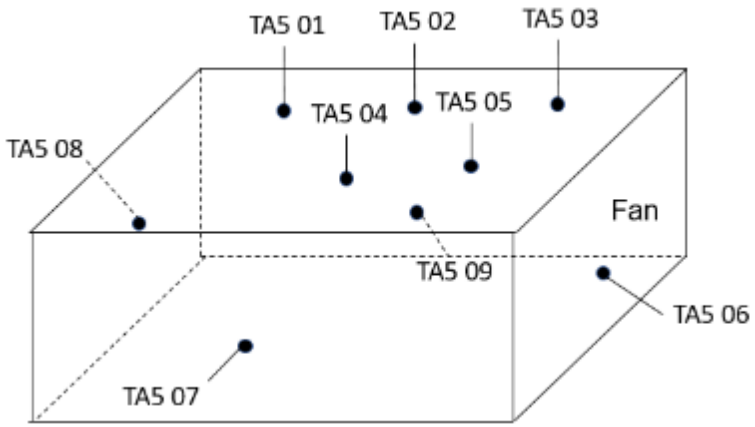
Figure 10. Surface temperatures of no thermal runaway cells on sub-module 1 of module M8



3.5.2 Temperature measurement of units

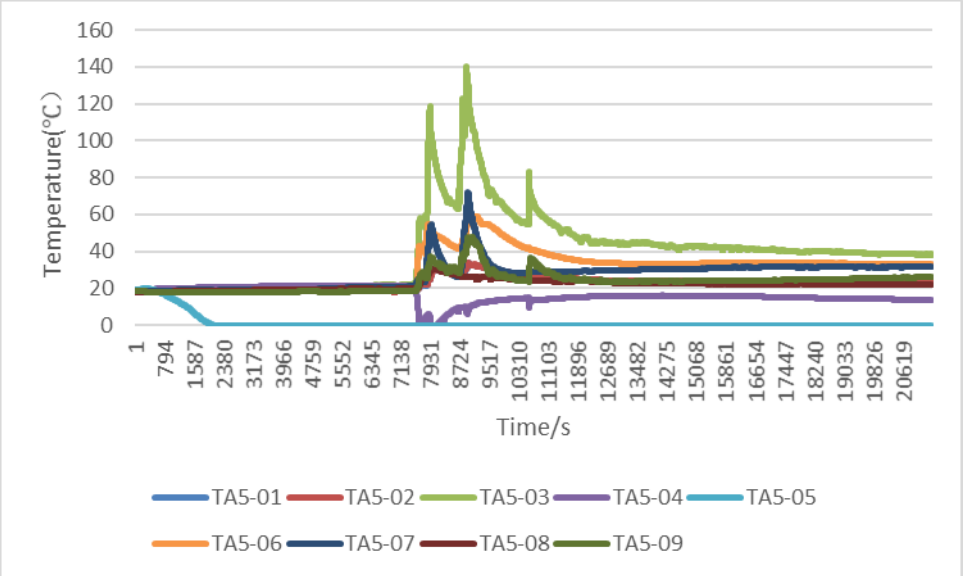
9 glass fiber insulated thermocouples (TA5 01~TA5 09), Type K, 24 AWG were attached to the external surface of module M8, as below Figure 11.

Figure 11. thermocouple of module M5 surface



TA5 01~TA5 03 were located on the top surface above cell in sub-module2. TA5 04, TA5 05 were located on the top surface above cell in sub-module3. TA5 06 was located in front of module, TA5 07 was located on the left side surface, TA5 08 located on the rear side, TA5 02 was located on the right side surface. Maximum temperature 407.3°C was measured on top of the module near #4 cell.

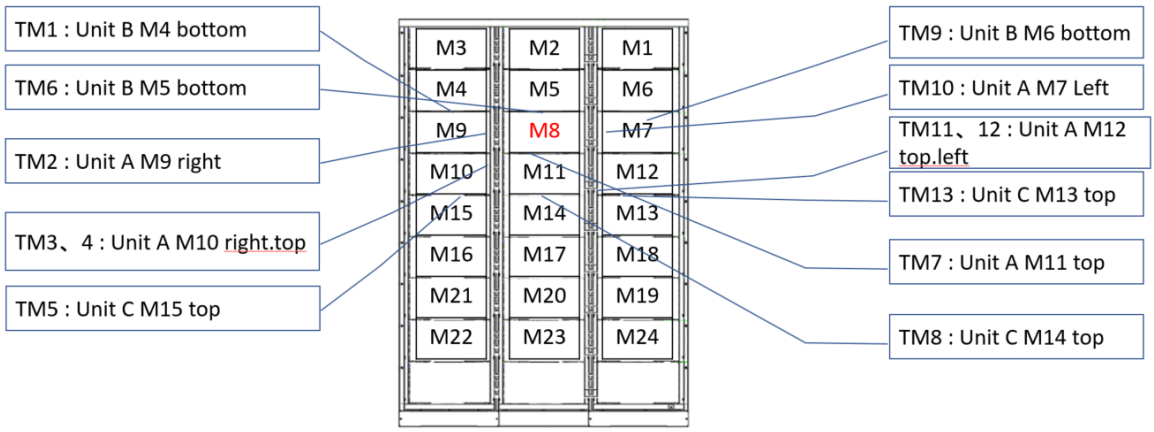
Figure 12. Surface temperatures of initiating module M8



13 glass fiber insulated thermocouples (TM1 to TM13), Type K, 24 AWG were attached to the center of the top surface of modules M4 to M15.

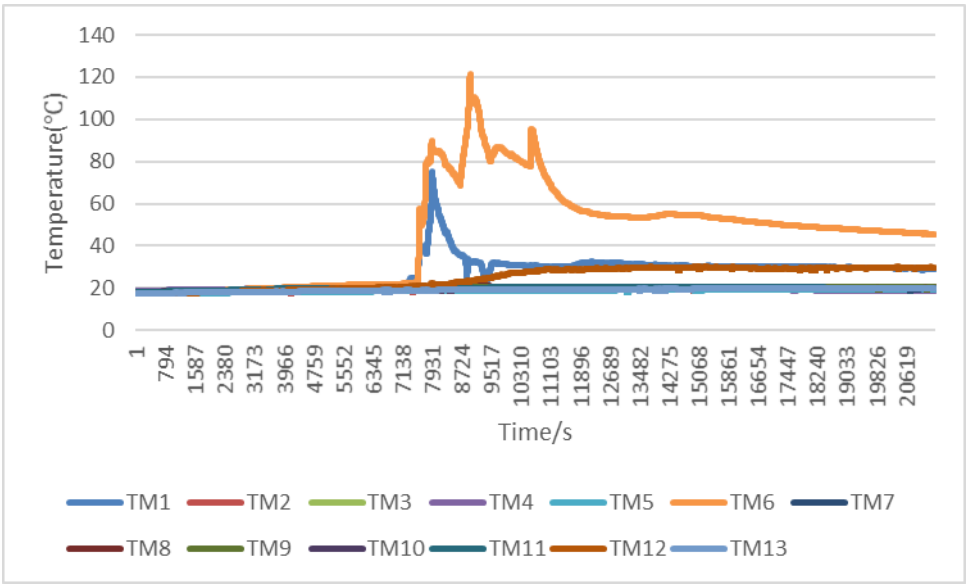
Maximum temperature 121.5°C was measured on bottom of the module M5.

Figure 13. Thermocouple location on modules in units A,B,C (Rack 1)



View direction: towards instrument wall A with reference to Figure 2

Figure 14. Surface temperatures of modules from M4 to M15

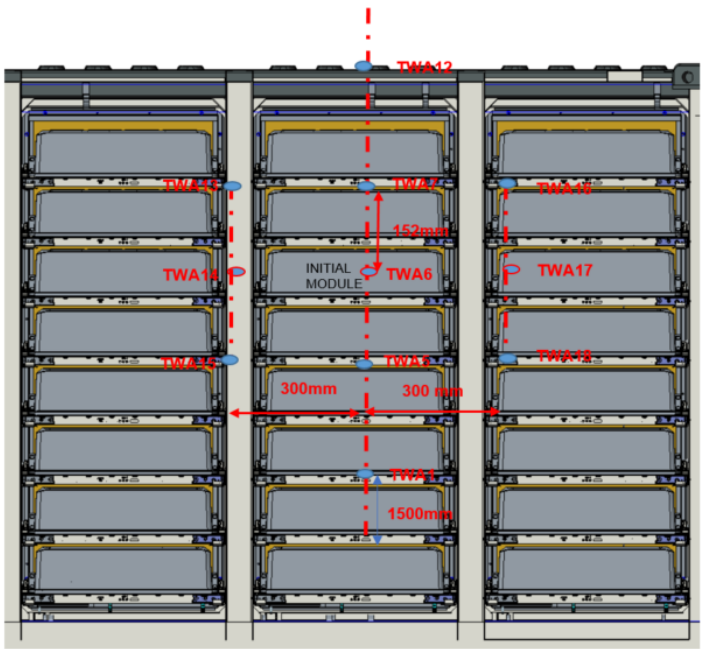


Maximum temperature 121.4°C was measured on side surface of the module M5 of Unit B.

Maximum temperature 21.2°C was measured on rear surface of the module M14 of Unit C.

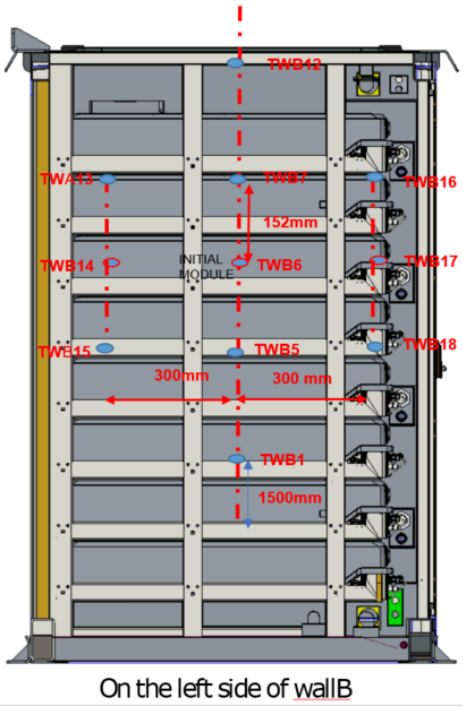
Figure 15. Thermocouple location on the back side of Wall A

View direction: from instrument wall A with reference to Figure 2



On the back side of wallA

Figure 16. Thermocouple location on the left side of wall B



On the left side of wallB

View direction: towards instrument wall B with reference to Figure 2

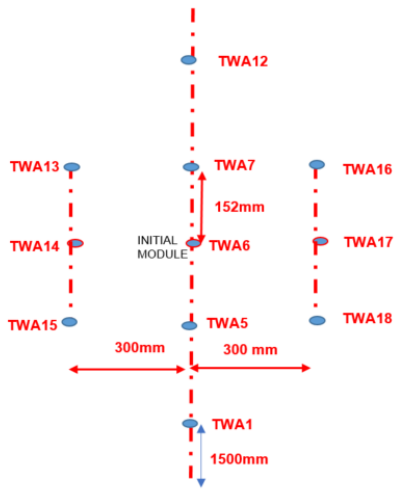
3.5.3 Temperature measurement of instrumented walls

Wall surface temperatures were measured in vertical arrays at 152 mm intervals for the full height of the instrumented wall sections using Type K, 30 AWG thermocouple. The thermocouple arrays were collinear with the centre line of Initial Unit A. The red line in Figure 12 shows the thermocouple arrays on the wall.

The first thermocouple starts from 1500 mm from ground. Total 36 thermocouples were used for each array. The thermocouples were numbered from low to high as TWA1 to TWA18 for wall A and TWB1 to TWB18 for wall B.

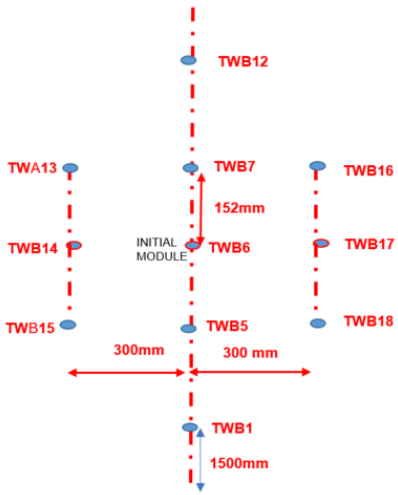
Figure 17. Vertical position of the thermocouples on the wall

Instrumented wall A



View direction: towards instrument wall A with reference to Figure 2

Instrumented wall B



View direction: towards instrument wall B with reference to Figure 2

Additional 6 thermocouples were positioned horizontally near the initial module M8 300 mm away from the vertical array each side, on instrumented wall A and wall B. See Figure 18.

Maximum temperature measured on instrument wall A was 21.4°C at TWA13, temperature curve see figure 18 for detail.

Maximum temperature measured on instrument wall B was 24.6°C at TWB10, temperature curve see figure 19 for detail.

Figure 18. Horizontal position of the thermocouples on the wall A and wall B

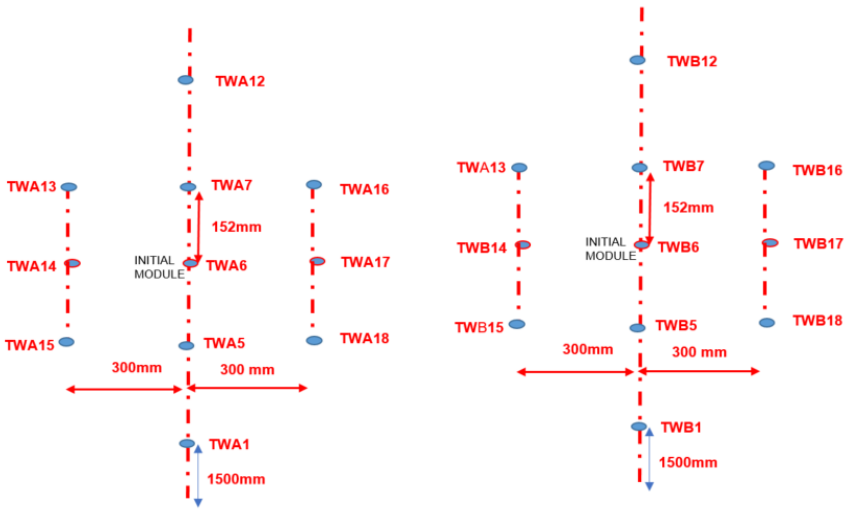


Figure 19. Temperatures on instrument wall A.

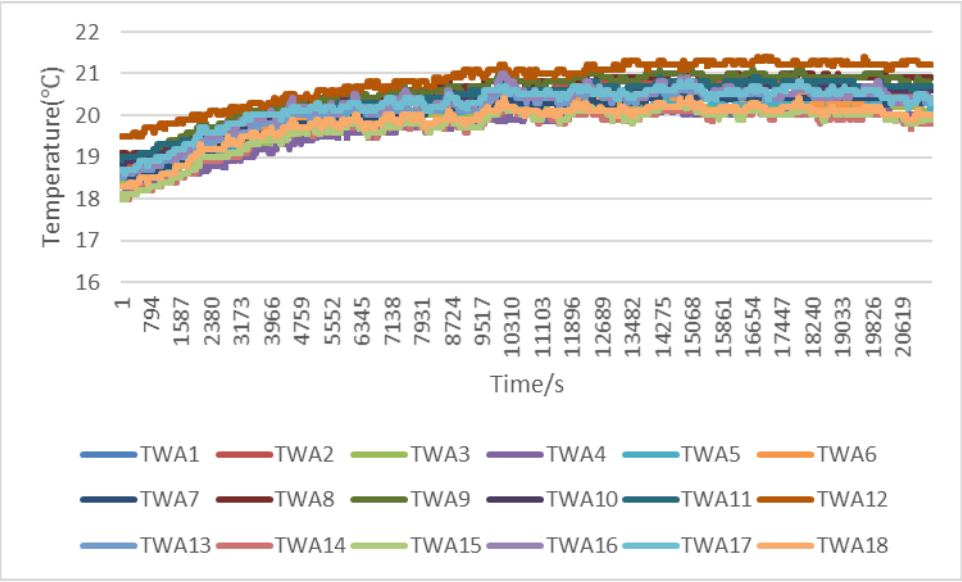
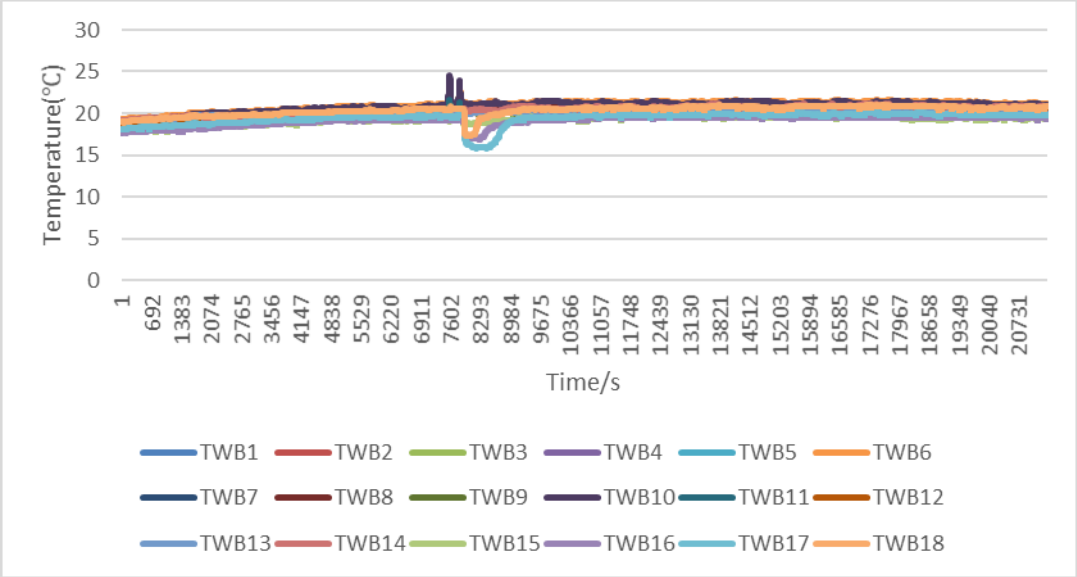


Figure 20. Temperatures on instrument wall B.



3.6 Heat flux measurement

Two sensors were placed on the surface of instrumented wall A, wall B and adjacent unit A that faces the initiating unit.

The sensors were collinear with the vertical thermocouple array. One was positioned at the height equivalent to module M8 top edge, which was estimated to receive the greatest heat flux due to the thermal runaway of the initiating module within the initiating unit. Another was positioned at the height equivalent to module M11 top edge, which was estimated to receive the greatest surface heat flux due to the thermal runaway of the initiating unit.

Figure 21 shows the positions of the sensors. Sensor H1 & H2 were positioned at unit A; All sensors were numbered from low to high.

Figure 21. Heat flux sensor locations on unit

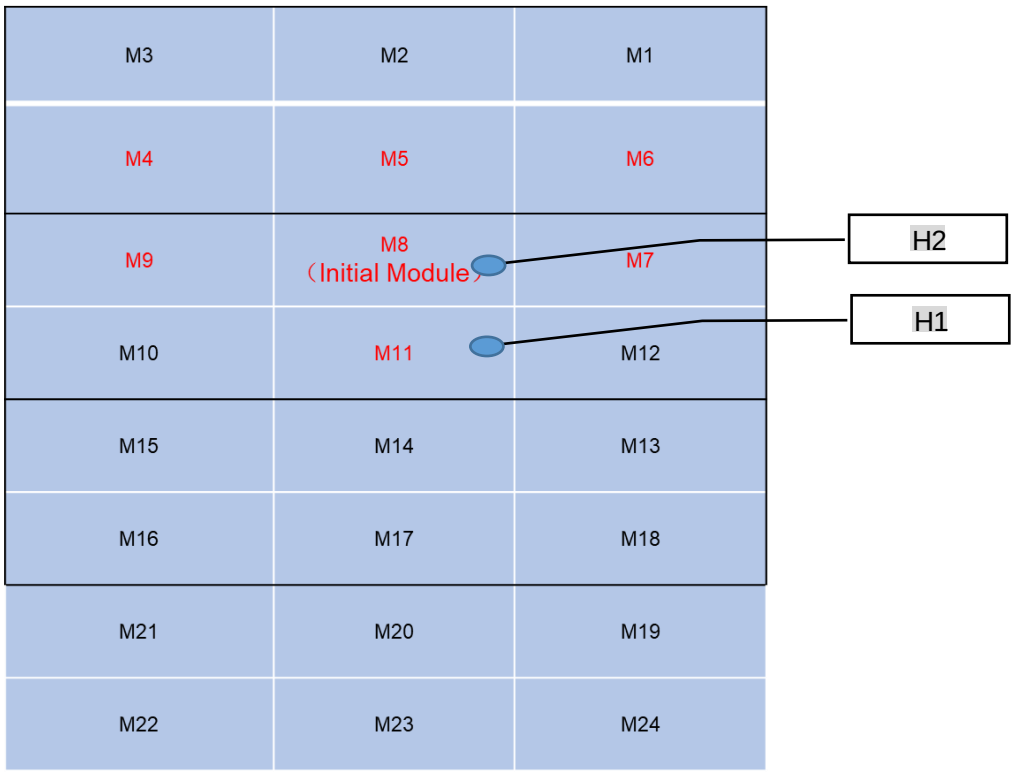
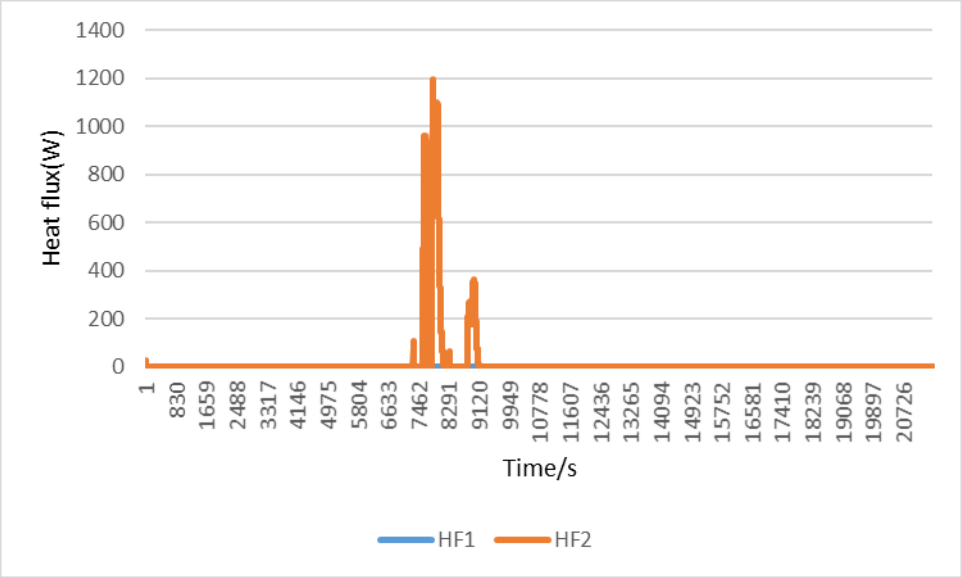


Figure 22. Measured heat flux of target wall and target units



3.7 Chemical heat release rate measurement

The chemical heat release rates were measured by an oxygen consumption calorimeter measurement system consisting of a paramagnetic oxygen analyzer, non-dispersive infrared carbon dioxide and carbon monoxide analyzer, velocity probe, and a Type K thermocouple.

The instrumentations are located in the exhaust duct of the heat release rate calorimeter.

The chemical heat release rate was calculated at each of the flows as follows:

$$HRR_1 = \left[E \times \varphi - (E_{co} - E) \times \frac{1-\varphi}{2} \times \frac{X_{co}}{X_{O_2}}\right] \times \frac{\dot{m}_e}{1+\varphi \times (\alpha - 1)} \times \frac{M_{O_2}}{M_a} \times (1 - X^o_{H_2O}) \times X^o_{O_2}$$

In which:

HRR_t = total heat release rate, as a function of time (kW)

E = Net heat released for complete combustion per unit of oxygen consumed (adjusted for oxygen contained within cell chemistry, 13,100 kJ/kg)

E_{CO} = Net heat released for complete combustion per unit of oxygen consumed, for CO (adjusted for oxygen contained within cell chemistry, 17,600 kJ/kg)

φ = Oxygen depletion factor (non-dimensional), where:

$$\varphi = \frac{X^o_{O_2} \times [1 - X_{CO_2} - X_{CO}] - X_{O_2} \times [1 - X^o_{CO_2}]}{X^o_{O_2} \times [1 - X_{O_2} - X_{CO_2} - X_{CO}]}$$

X_{CO} = Measured mole fraction of CO in exhaust flow (non-dimensional)

X_{CO_2} Measured mole fraction of CO_2 in exhaust flow (non-dimensional)

$X°_{CO_2}$ = Measured mole fraction of CO_2 in incoming air (non-dimensional)

$X°_{H_2O}$ = Measured mole fraction of H_2O in incoming air (non-dimensional)

X_{O_2} = Measured mole fraction of O_2 in exhaust flow (non-dimensional)

$X°_{O_2}$ = Measured mole fraction of O_2 in incoming air (non-dimensional)

α = Combustion expansion factor (non-dimensional; normally a value of 1.105)

M_a = Molecular weight of incoming and exhaust air (29 kg/kmol)

M_{O_2} = Molecular weight of oxygen (32 kg/kmol)

$\dot{m}_e$ = Mass flow rate in exhaust duct (kg/s), in which:

$$\dot{m}_e = C \times \sqrt{\frac{\Delta p}{T_e}}$$

or

$$\dot{m}_e = 26.54 \times \frac{A \times k_c}{f(\mathrm{Re})} \times \sqrt{\frac{\Delta p}{T_e}}$$

C = Orifice plate coefficient (in $kg^{1/2}m^{1/2}K^{1/2}$)

Δp = Pressure drop across orifice plate or bidirectional probe (Pa)

T_e = Combustion gas temperature at orifice plate or bidirectional probe (K)

A = Cross sectional area of the duct (m^2)

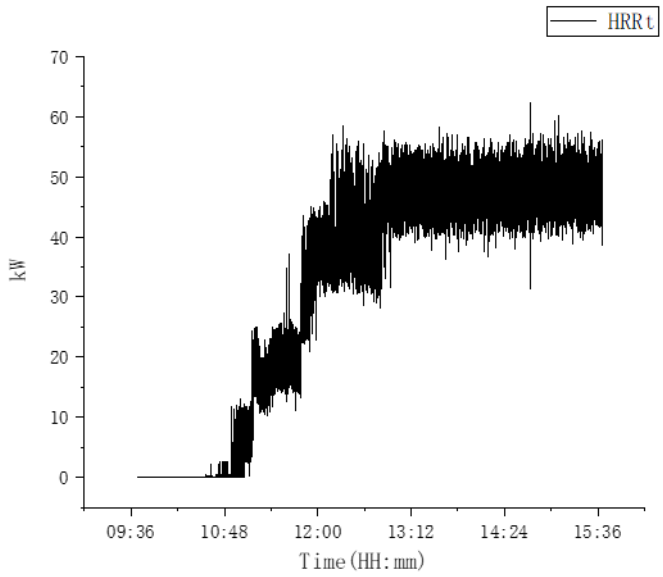
k_c = Velocity profile shape factor (non-dimensional)

$f(Re)$ = Reynolds number correction (non-dimensional)

The heat release rate measurement system was calibrated at 50kW and 70kW heat release rate using a standard propane burner before the test. The calibrations were performed using flows of 1078mg/s and 1510mg/s of propane.

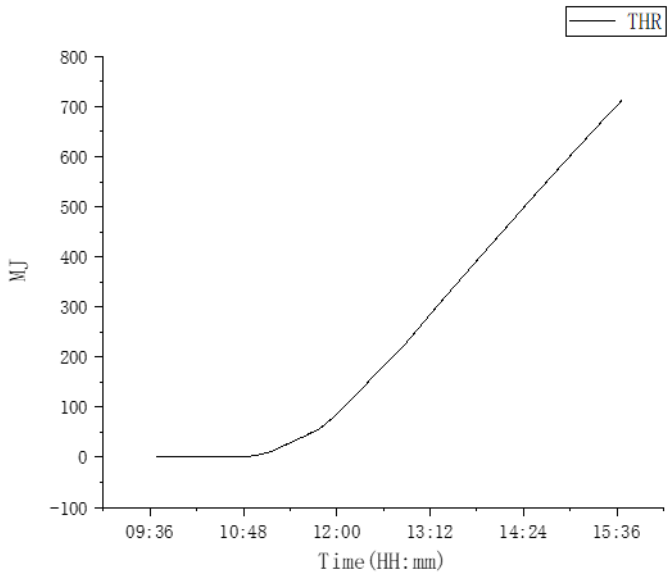
Measured peak chemical heat release rate HRR_t was 62.37kW

Figure 23. HRRt curve



Measured total heat release THR through the test was 712.474 MJ

Figure 24. THR curve



3.8 Convective heat release rate measurement

The convective heat release rate was measured using thermopile, a velocity probe, and a Type K thermocouple, located in the exhaust system of the exhaust duct.

The convective heat release rate was calculated at each of the flows as follows:

$$HRR_c = V_e A \frac{353.22}{T_e} \int_{T_o}^{T} C_p dT$$

Where:

HRR_c = *The convective heat release rate (kW)*

V_e = *The exhaust velocity (m/s)*

A = *The exhaust duct cross sectional area (m^2)*

T_e = *The temperature at the location where exhaust velocity is measured (K)*

$353.22/T_e$ = *The density of air at the velocity measurement location (kg/m^3)*

T_o = *The ambient temperature (K) in the test room*

T = *The thermopile temperature (K)*

$$\int_{T_o}^{T} C_p dT = A_0(T - T_o) + A_1 / 2(T^2 - T_o^2) + A_2 / 3(T^3 - T_o^3) + A_3 / 4(T^4 - T_o^4)$$

Cp = Specific heat of air (kJ/kg-K), given as $\boldsymbol{C_p = A_0 + A_1 T + A_2 T^2 + A_3 T^3}$, where:

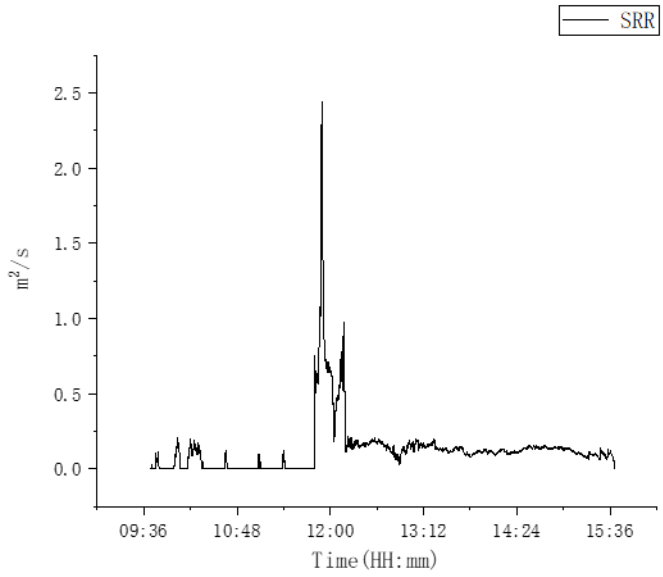
A_0 = *0.9950*

A_1 = *-5.29933E-05*

A_2 = *3.21022E-07*

A_3 = *-1.22004E-10*

Figure 25. Peak smoke release rate SRR: 22.5863 m2/s



3.9 Gas generation measurement

The composition, velocity and temperature of the vent gases were measured within the calorimeter's exhaust duct.

Gas compositions were measured using a Fourier-Transform Infrared Spectrometer with a resolution of 1 cm^{-1} and a path length of 4.2 m within the calorimeter's exhaust duct.

The total hydrocarbon content of the vent gas was measured using flame ionization detection.

Hydrogen gas was measured with electrochemical method.

Composition, velocity and temperature measurement instrumentation were collocated with heat release rate calorimetry instrumentation.

3.10.1 Total gas release

The flow rates of various gases were integrated over the test duration and the total cumulative volume of gas calculated for the total test duration (09:05 ~ 16:20) was presented in the below table.

The total cumulative volume of gases before cell venting (09:05 ~ 10:06) was also presented in the table for reference. Which may be considered as ambient gases background before the test.

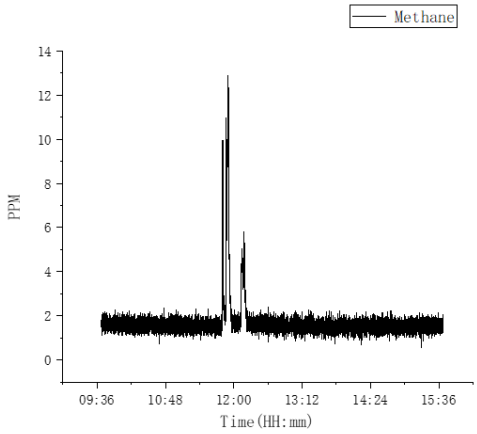
Gas type	Gas components		Total volume of gas (L)	
			Before cell venting	Throughout the test
Hydrocarbon species	Methane	CH_4	0.5	26.1
	Ethylene	C_2H_4	0.7	15.2
	Ethane	C_2H_6	0.2	6.5
	Propane	C_3H_8	0.1	36.3
	Propylene	C_3H_6	0	69.1
Hydrogen halide species	Hydrogen Fluoride	HF	0	12.2
Nitrogen containing species	Nitrous Oxide	NO	0.2	6.8
Others	Carbon Monoxide	CO	0	60.1
	Carbon Dioxide	CO_2	20670.4	54337.6
	Hydrogen	H_2	0	164.8
	Dimethyl carbonate(DMC)	$C_3H_6O_3$	0.3	177.2
	Ethylmethyl carbonate	$C_4H_8O_3$	0.1	30.7
	Oil as octane		0	5.9
Total Hydrocarbons				262.3

Note:
1) The collection time is from 09:40 to 16:20;
2) The carbon dioxide in the air during this period1) was also counted;
3) Total hydrocarbon gas volume was measured by flame ionization detection (FID);
4) Total volume of carbon monoxide (CO) and carbon dioxide (CO2) was measured using nondispersive infrared spectroscopy (NDIR);
5) The volume of hydrogen (H2) was measured using electrochemical with MODEL5000 sensor.

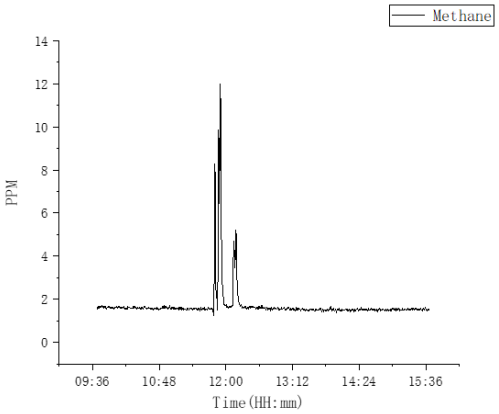
3.10.2 Gas components

Concentrations of the gases were scaled based on the measured flow rate of the exhaust system and were presented in the standard volume flow rate of gas ventilated in below figures.

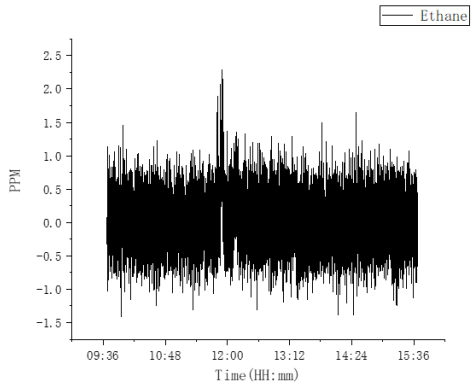
Figure 26. Hydrocarbon species



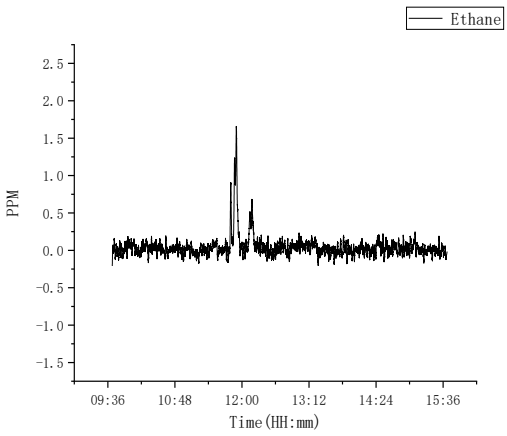
Raw original data



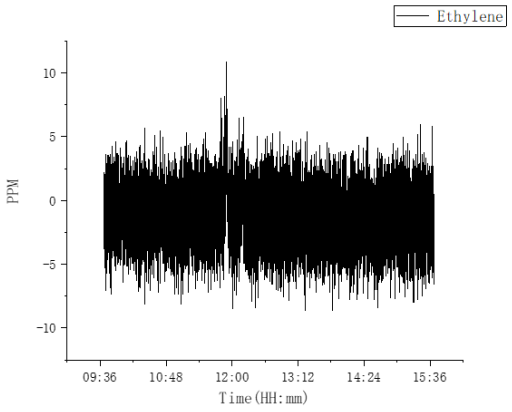
Savitzky-Golay filtered data



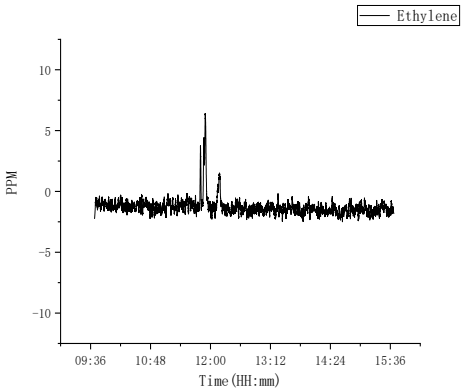
Raw original data



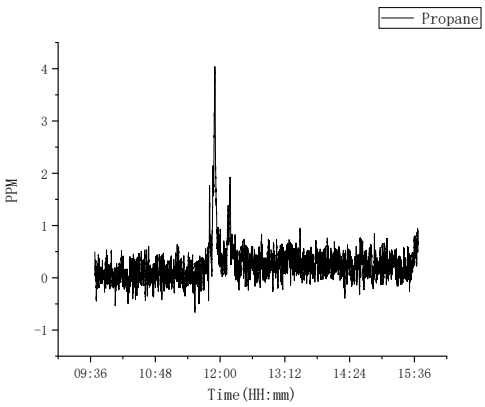
Savitzky-Golay filtered data



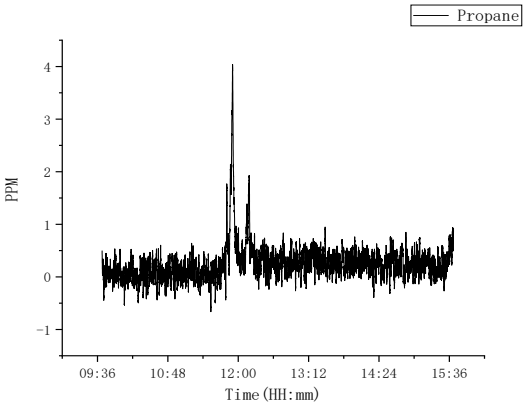
Raw original data



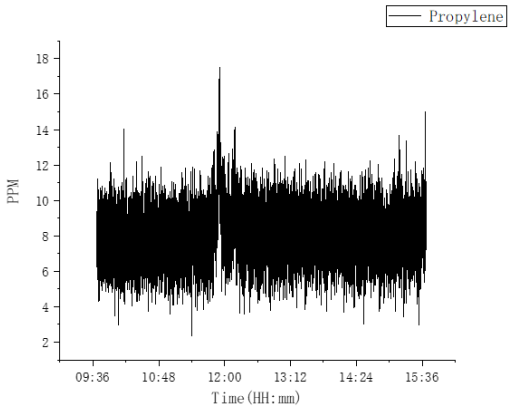
Savitzky-Golay filtered data



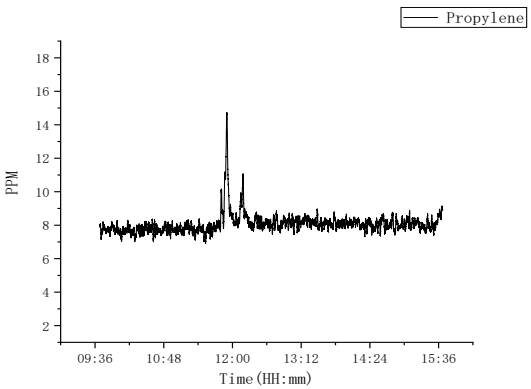
Raw original data



Savitzky-Golay filtered data

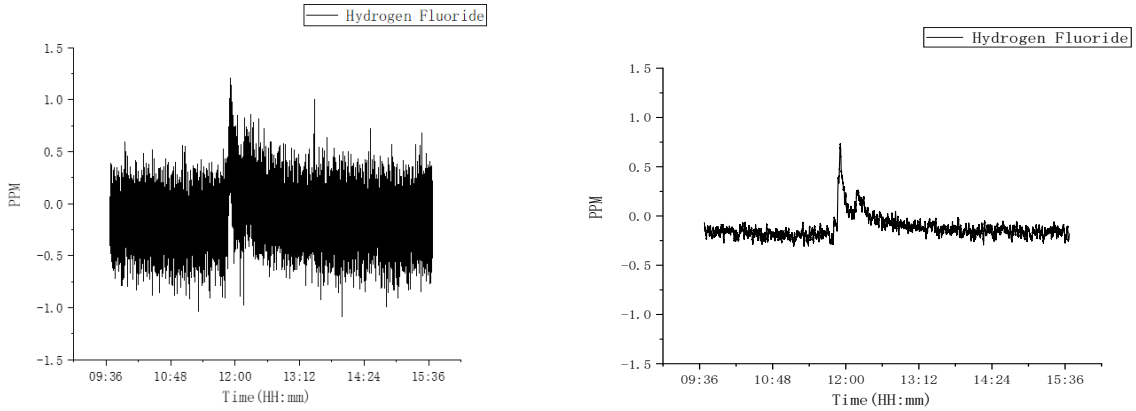


Raw original data



Savitzky-Golay filtered data

Figure 27. Hydrogen halide species



Raw original data

Savitzky-Golay filtered data

Figure 28. Nitrogen containing species

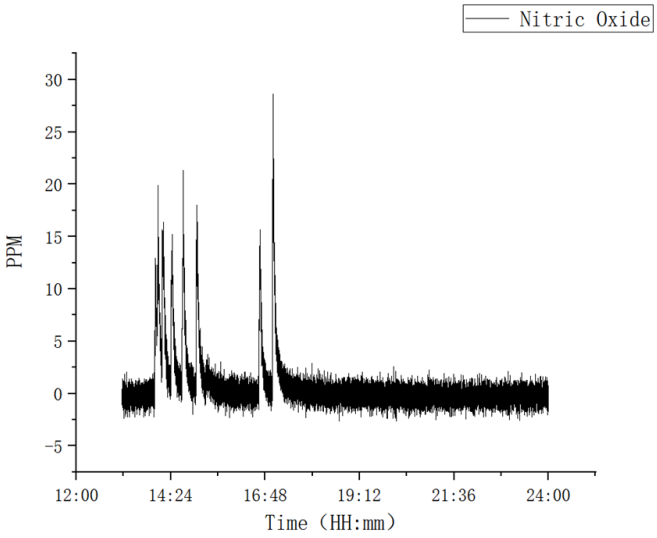


Figure 29. H_2 containing species

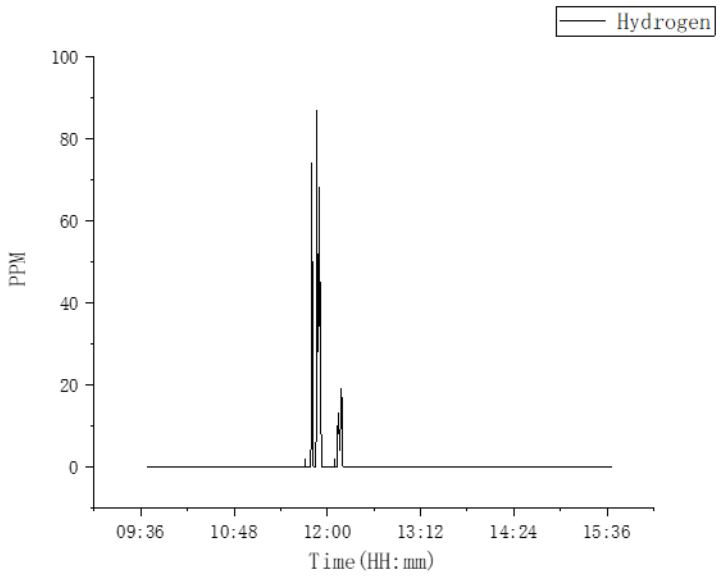
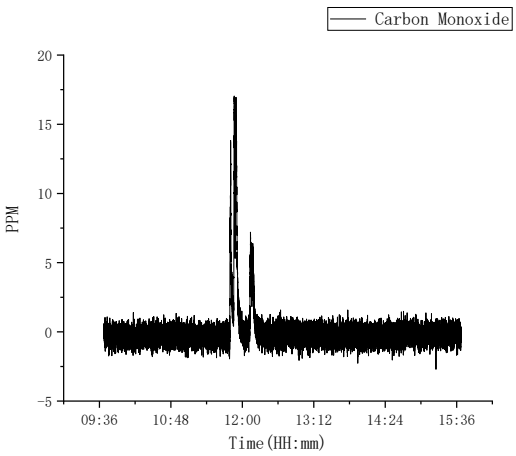
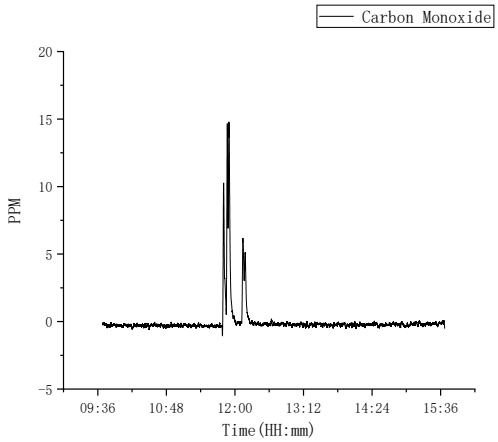


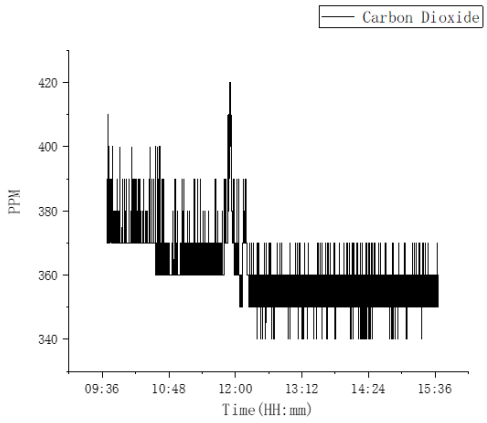
Figure 30. CO, CO_2 containing species



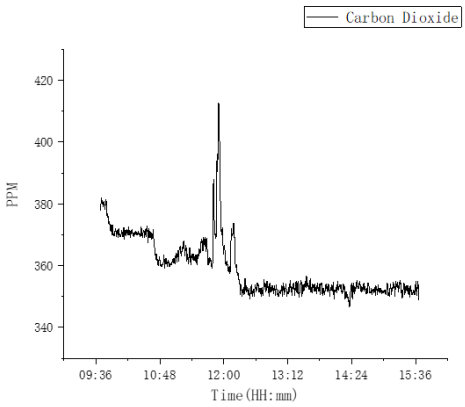
Raw original data



Savitzky-Golay filtered data



Raw original data



Savitzky-Golay filtered data

Note: Since raw original data is hard to interpret. Savitzky-Golay filtered data is also provided as this smooths the data and increases the precision of the data without distorting the signal tendency.

3.10 Photos

Initial module



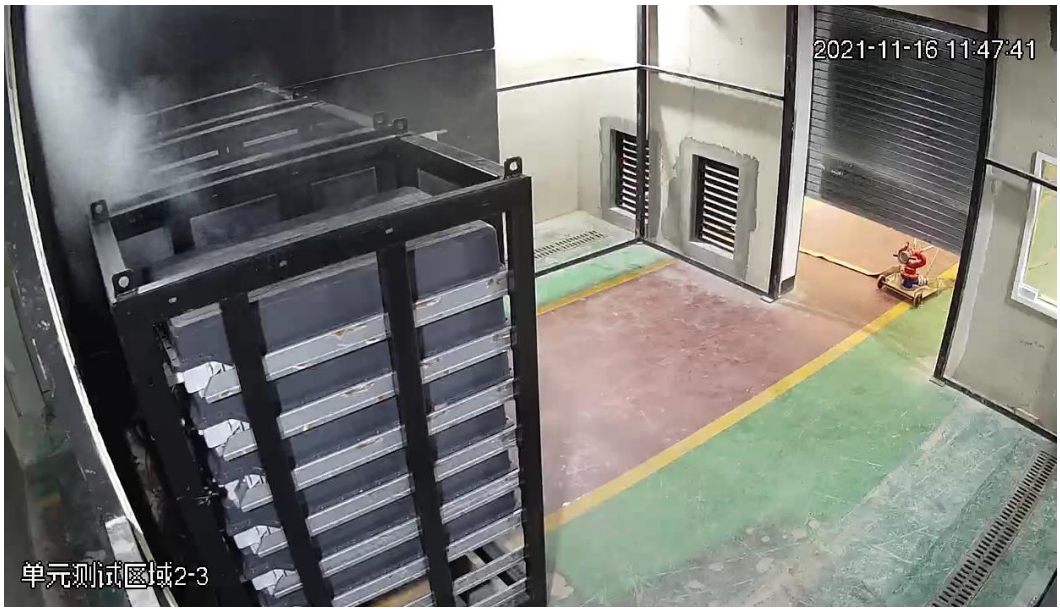


Test setup





Smoke release during the test





Photos after the test

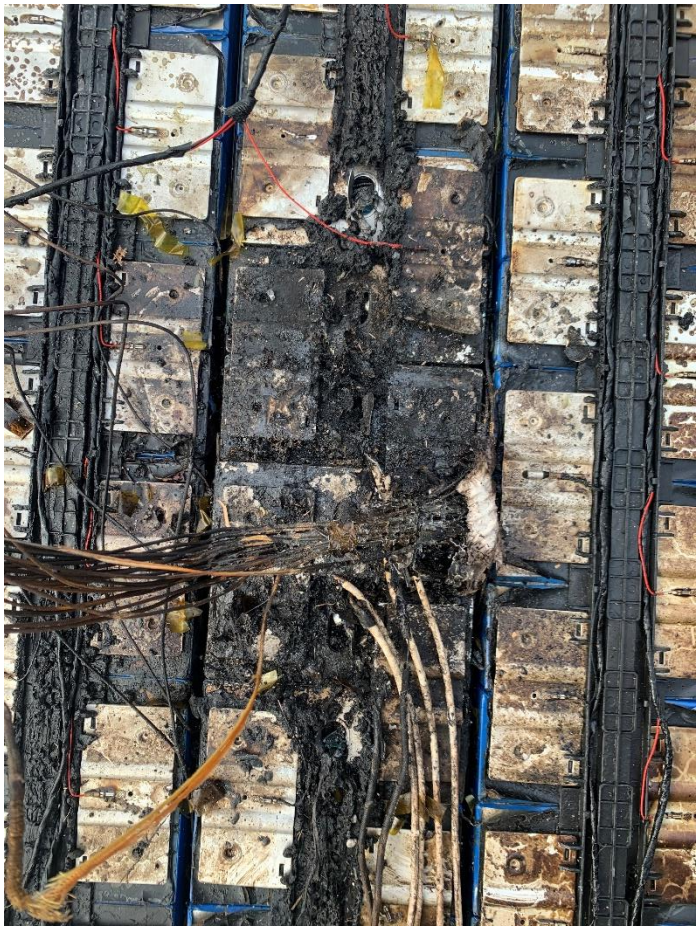




Initial module after test



Initial cell after test



4 List of Test and Measurement Instruments

No.	Equipment		Model	Rating	Inventory no.	Last Cal. date
1	Ambient monitor		WSB-2-H1	0-40°C，10-90%RH	T-125	2021.07.24
2	Ambient monitor		WSB-2-H1	0-40°C，10-90%RH	S-050	2021.05.31
3	Data acquisition equipment		DTM	0-1000°C	S-029	2021.04.19
4	Data acquisition equipment		ADAM-4117 ADAM-4118 MT4W DTB4824	0-10V 0-1000°C 0-100V 0-1000°C	S-028-3 S-028-4 S-030-(5~8) S-046-2	2021.04.19 2021.05.06 2021.07.19 2021.07.20
5	Digital multi-meter		FLUKE101	0-600V	S-038	2021.04.22
6	Tape		1000mm 5000mm	0-1000mm 0-5000mm	S-040 S-042	2021.04.22 2021.04.22
7	Electronic scale		TCS-500	0-500kg	S-039	2021.04.19
8	Oxygen consumption calorimeter measurement system	Paramagnetic oxygen analyzer	SERVOMEX MultiExact 4100	O_2: 0-21% CO_2: 0-10% CO: 0-1%	S-024	2021.03.20
		CO and CO2 sensor				
		Velocity probe	WIKA	0~0.4MPa	S-024-5	2021.03.08
		Photo detector	DP101MD	-100~100Pa	S-024-4	2021.03.08
		Light filter	——	25%、50、75%	S-024-6 S-024-7 S-024-8	2021.03.12
9	Palladium-nickel thin-film solid state sensor		H2scan 740B MODEL5000 OMD-650	500ppm-100% 0-4% <20%	S-023-1 S-023-2 S-023-3	2021.03.20
10	Fourier-Transform Infrared Spectrometer		MG6000	0.01ppm-100%	S-019	2021.03.20
11	Flame Ionization Detector		ABB AO2000	0-3000ppm	S-025	2021.03.20
12	Thermopile		OMEGA TT-K-24	0-260℃	S-026	2021.04.01

13	Heat flux measurement equipment	Schmidt-Boelter, 64-5-20	0-50kW	S-031 S-032 S-033 S-034 S-035 S-036 S-037 S-065	2021.06.21

End of Test Report

Appendix N

CATL Battery Spacing Review Documentation

Letter of Attestation

Document: 80028282 **Master Contract:** N/A

Project: 80051872 **Date Issued:** Sep 30, 2020

Issued to: Contemporary Amperex Technology Co., Limited
No. 2 Xingang Road, Zhangwan Town, Jiaocheng District
Ningde City, Fujian Province 352100, P. R. China
Attention: Ms. Sandy Lv

CSA Group hereby confirms that it has completed an evaluation of: Li-ion Battery Rack, models R852280-P-T-I-1, R852280-E-T-I-1, Rx52280-P-T-U-1, Rx52280-E-T-U-1, FRx52280-P-T-U-0, FRx52280-E-T-U-0, Ox52280-P, Ox52280-E (x means module number 4-8)

CSA Group hereby attests that the products identified above and described in test report 80028282 dated Jan 17, 2020 complies with the following standards/tests, to the extent applicable:

UL 9540A Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems, 3rd edition, Revision Date Jun 15, 2018, Section 8 Unit Level Testing.

Issued by: *Joseph Zhou*

CSA Group

THIS LETTER OF ATTESTATION DOES NOT AUTHORIZE THE USE OF THE CSA MARK ON THE SUBJECT PRODUCTS.
QUOTATIONS FROM THE TEST REPORT OR THE USE OF THE NAME OF THE CANADIAN STANDARDS ASSOCIATION AND CSA GROUP OR ITS REGISTERED TRADEMARK, IN ANY WAY, IS NOT PERMITTED WITHOUT PRIOR WRITTEN CONSENT OF CSA GROUP.

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Descriptive Report and Test Results

MASTER CONTRACT: N/A
REPORT: 80028282
PROJECT: 80051872

Edition 1: Feb 25, 2020; Project 80028282 - Cleveland
Issued by Joseph Zhou, Reviewed by Anuj Amin

Edition 2: Sep 30, 2020; Project 80051872 - Cleveland
Prepared by Joseph Zhou, Authorized by Anuj Amin

Contents: Letter of Attestation - Page 1 to 1
Description and Tests - Pages 1 to 28

PRODUCTS

Li-ion Battery Rack, models R852280-P-T-I-1, R852280-E-T-I-1, Rx52280-P-T-U-1, Rx52280-E-T-U, FRx52280-P-T-U-0, FRx52280-E-T-U-0, Ox52280-P, Ox52280-E (x means module number 4-8)

APPLICABLE REQUIREMENTS

UL 9540A - Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems, 3rd edition

MARKINGS

N/A

ALTERATIONS

N/A

FACTORY TESTS

N/A

Test related only to the items tested.This report shall not be reproduced, except in full, without the approval of CSA Group.

8501 East Pleasant Valley Road, Cleveland, OH, U.S.A. 44131-5575
Telephone: 216-524-4990 1.800.463.6727 Fax: 216-642-3463 www.csagroup.org

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DESCRIPTION

Testing Laboratory Name:	CCIC-CSA International Certification Co., Ltd. Kunshan Branch
Address:	Building 8, Tsinghua Science Park, No. 1666 Zu chongzhi Rd (S), Kunshan, Jiangsu (215347)
Testing Program:	**Custom Test:** Latter of Attestation [X] Testing Only [ ] Note: Mark "X" in applicable test program block

If tests were performed at another facility, then described below:

Testing Laboratory Name:	Contemporary Amperex Technology Co., Limited
Address:	No.2 Xingang Road, Zhangwan Town, Jiaocheng District Ningde, Fujian, 150 35200, China
Facility Number: **Qualification**	N/A

	As above / or describe otherwise
Customer:	Contemporary Amperex Technology Co., Limited
Address:	No.2 Xingang Road, Zhangwan Town, Jiaocheng District Ningde, Fujian, 150 35200, China

Tested By: Jianfang Zhu, Test Engineer
Name, Title

Jianfang Zhu, Test Engineer 2019-11-30 to 2019-12-4
Signature *Date (YYYY-MM-DD)*

☐ **Reviewed by:** Joseph Zhou/Giggle Pei, Certifier
☒ **Witnessed by:**
Name, Title

Joseph Zhou 2019-12-04
Signature *Date (YYYY-MM-DD)*

Version: 2019-05-09

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Product Details	
Test Request:	☐ Cell Level Testing ☐ Module Level Testing ☒ Unit Level Testing ☐ Installation Level Testing
Manufacturer	☐ Cell: ☐ Module: ☒ Unit: Contemporary Amperex Technology Co., Limited
Brand name / Trademark	☐ Cell: ☐ Module: ☒ Unit: NA
Model Number	☐ Cell: ☐ Module: ☒ Unit: refer to the models indicated on the cover page
Date of receipt of test sample(s)	2019-11-30 (YYYY-MM-DD)
Cell/Battery Type	Li-ion, LFP
Approximate Dimension (mm)	☐ Cell: ☐ Module: ☒ Unit: 924*1185*2329 (W*D*H) [mm]
Mass (g)	☐ Cell: ☐ Module: ☒ Unit: 3100kg
DUT Sample/Serial Number	☐ Cell: ☐ Module: ☒ Unit: TD19-0237
DUT Nominal Voltage Rating (V)	☐ Cell: ☐ Module: ☒ Unit: 1331.2
DUT Nominal Charge Capacity Rating (Ah)	☐ Cell: ☐ Module: ☒ Unit: 280
Fire Mitigation Strategies: (For installation level testing)	☒ Water: ☐ Other (Specify): ☐ N/A
Additional Information	N/A

Model Difference: refer to table below for the model differences:

Model No.	Suffix 1	Rated Current, A	Suffix 2	
R852280-P-T-U-1	P	280	U	UL approved
R852280-P-T-I-1	P	280	I	IEC approved
R852280-E-T-U-1	E	140	U	UL approved
R852280-E-T-I-1	E	140	I	IEC approved

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Per client confirmed, models subjected for US certification are the same as models approved IEC standard certification, herein, test performed on models R852280-P-T-U-1 was considered representative of models R852280-P-T-I-1, R852280-E-T-U-1, R852280-E-T-I-1.

Description of changes from models R852280-P-T-I-1, R852280-E-T-I-1, R852280-P-T-U-1, R852280-E-T-U-1 to Rx52280-P-T-U-1, Rx52280-E-T-U-1 (x means module number 4-8).

Compared to models R852280-P-T-I-1, R852280-E-T-I-1, R852280-P-T-U-1, R852280-E-T-U-1, the following changes were included to add models Rx52280-P-T-U-1 and Rx52280-E-T-U-1 (x means module number 4-8)

1. Change the rating label for weight, voltage ranges and capacities;
2. Change the name of component cell from 001CB310 to CB310 and CB2W0.
3. Add new critical components, like Service Plug-Alternate (MSD) and HV connector (B+, B-, HV+, HV-).
4. Update the liquid cooling tube adapter on the top.

Description of changes from Rx52280-P-T-U-1, Rx52280-E-T-U-1 to FRx52280-P-T-U-0, FRx52280-E-T-U-0 (x means module number 4-8):

Compared to models Rx52280-P-T-U-1, Rx52280-E-T-U-1, the following changes were included to add models FRx52280-P-T-U-0, FRx52280-E-T-U-0 (x means module number 4-8):

1. Cancel the rack door, rack feet and baseboard.
2. Change the grounding position to left bottom of rack frame; cancel grounding position on the top.
3. Cancel the water protection cover on the top of rack.
4. Change the shape of cabling outlet on the top of rack.
5. Change the nameplate position: two pieces on the left and right side of rack frame.
6. Size change: 914mm*1185mm*2327mm changed to 919mm*1250mm*2248mm

Model series Ox52280-P, Ox52280-E are same as model series Rx52280-P-T-U-1, Rx52280-E-T-U-1 except for the location of control box and addition of liquid chiller.

Based on the model difference indicated, no additional test deemed necessary for the above alternation.

THE TESTING SPECIFIED IN THIS PROCEDURE IS INHERENTLY DANGEROUS

DO NOT ATTEMPT TO PERFORM THIS TEST UNLESS YOU HAVE BEEN PROPERLY TRAINED REGARDING SAFELY WORKING WITH THE HAZARDS INVOLVED

Important Test Consideration:

- As some batteries expose in test described above, it is important that personal be protected from the flying fragments, explosive force, and sudden release of heat, chemical burns, and noise result from such explosions. The test area is to be well ventilated to protect personal from possible harmful fumes or gases.
- Temperature of the surface of the battery casing shall be monitored during the tests described above. All personal involve in the testing of batteries are to be instructed never to approach a battery until the surface temperature return to ambient temperature.

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- Test shall be conducted in separate room or equipped with an adequate safety barrier separating the test area from observer.

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UL 9540 A – Definition

- "BATTERY ENERGY STORAGE SYSTEM (BESS)" - Stationary equipment that receives electrical energy and then utilizes batteries to store that energy for later use in order to supply electrical energy when needed. The BESS consists of one or more modules, a power conditioning system (PCS) and balance of plant components.

a) INITIATING BATTERY ENERGY STORAGE SYSTEM UNIT (INITIATING BESS) – A BESS unit which has been equipped with resistance heaters in order to create the internal fire condition necessary for the installation level test (Section 8).
b) TARGET BATTERY ENERGY STORAGE SYSTEM UNIT (TARGET BESS) – The enclosure and/or rack hardware that physically supports and/or contains the components that comprise a BESS. The target BESS unit does not contain energy storage components, but serves to enable instrumentation to measure the thermal exposure from the initiating BESS.

- "CELL" -The basic functional electrochemical unit containing an assembly of electrodes, electrolyte, separators, container, and terminals. It is a source of electrical energy by direct conversion of chemical energy.

- "DUT" – Device under test.

- "ELECTRICAL RESISTANCE HEATERS" – Devices that convert electrical energy supplied from a laboratory source into thermal energy.

- "FLEXIBLE FILM HEATERS" – Electrical resistance heaters of a film, tape or otherwise thin sheet like construction that easily conform to the surface of cells.

- "MODULE" – A subassembly that is a component of a BESS that consists of a group of cells or electrochemical capacitors connected together either in a series and/or parallel configuration (sometimes referred to as a block) with or without protective devices and monitoring circuitry.

- "STATE OF CHARGE (SOC)" – The available capacity in a BESS, pack, module or cell expressed as a percentage of rated capacity.

- "THERMAL RUNAWAY" – The incident when an electrochemical cell increases its temperature through self-heating in an uncontrollable fashion. The thermal runaway progresses when the cell's generation of heat is at a higher rate than the heat it can dissipate. This may lead to fire, explosion and gas evolution.

- "UNIT" – A frame, rack or enclosure that consists of a functional BESS which includes components and subassemblies such a cells, modules, battery management systems, ventilation devices and other ancillary equipment.

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UL 9540A Third Edition, Dated June 15, 2018 - Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

Section	Requirement	Test (T) / Waive (W) / Not App. (N/A)	Comments
1	**Scope:** The test methodology in this document evaluates the fire characteristics of a battery energy storage system that undergoes thermal runaway. Fire protection requirements not related to battery energy storage system equipment are covered by appropriate installation codes.		
	Section 6: Cell Level Test	W	1. Cell testing not requested by manufacturer Cell Thermal runaway methodology: External heating method with ceramic heater 1 PCS, rated 220/230V, 500W Cell Surface temperature at gas venting (ºC): 143.3 Cell Surface temperature at thermal runaway(ºC): 209.8 Gas Composition and LFL: C2H4, C2H6, C3H6, C3H8, H2, CH4, CO, CO2 Lower Flammability Limit(LFL) = 6.14%@12~18 ºC,101.3~101.5kPa Pmax:109.36PSI(0.754MPa) Pmax Rise Rate: 23153.83(159.64MPa/Sec) PSI/Sec Lower Flammability Limit(LFL）at venting temperature = 5.4%@143±1°C, 101±2kPa Gas Burning Velocity: 0.584m/s @ ambient temperature (22~30°C), atmospheric pressure See project 80040846 for Cell Level testing data provided by manufacturer
	Section 7: Module Level Test	W	Module testing not requested by manufacturer Cell Thermal Runaway Methodology: External heating method with ceramic heater 1 PCS, rated 220/230V, 500W Cell Surface Temperature at Gas Venting (ºC): 92.3 Cell Surface temperature at thermal runaway(ºC): 123.9 Module Heat Release Rate (kW/m^2): 0 Cell/Module Gas Generation and Composition: C2H2, C2H4, C2H6, C3H6, C3H8, H2, CH4, CO, CO2

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Section	Requirement	Test (T) / Waive (W) / Not App. (N/A)	Comments
			Module External Flaming and Flying Debris Hazard: N/A, no fire or explosion, no flying debris during test Module Location of Flame Venting: Not applied no fire occurred during the whole testing See project 80025390 for Module Level testing data provided by manufacturer
	Section 8: Unit Level Test	T	Manufacturer Name: Contemporary Amperex Technology Co., Limited Model: R852280-P-T-U-1 Electrical Rating: nominal voltage 1331.2V BESS Energy (Whr): 332736 BESS Capacity (Ahr): 280 Number of Module: 8 Module Configuration: 52S-1P Approximate Dimension (mm): 924*1185*2329 (W*D*H) Weight (kg): 3100 BMS Model no: N/A Fire Detection System: N/A Fire Suppression System: N/A Fire Detection/Suppression System (Optional/Part of system): N/A Manufacturer request to perform test with Fire Detection/suppression System (Yes/No): No, no fire detection/suppression test designed on the battery system. BESS Enclosure Material: Metallic BESS Comply with UL 1973 Requirement (Yes/No): Yes, refer to Certification No. CU 50272100 001 from TUV Rheinland, and report No. 64.280.20.60131.01 from TUV SUD
	Section 9: Installation Level Test (With fire mitigation strategies)	N/A	1. BESS Meet Unit level performance requirement and No Installation Level test required.

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UL 9540A Third Edition, Dated June 15, 2018 - Section 8 Unit Level Testing

Section	Requirement	Comments	Verdict
Possible test case verdicts: Test case does not apply to the test object: Test object does meet the requirement: Test object does not meet the requirement:		N/A (Not Applicable) P (Pass) F (Fail)	
8	Unit Level Testing		P
8.1	BESS Sample tested within 8 after charging BESS as per manufacturer specification to obtain maximum operating state of charge.	Manufacture recommended charge/discharge method: Charging Procedure: CP-CV Charging Voltage (V): 1497.6 Charging Current (A): see below： 1. charge the unit with 0.25P(93184W) to cell voltage 3.65V 2. charge the unit with 0.1P(37273.6W) to cell voltage 3.65V 3. charge the unit with 0.05P(18636.8W) to cell voltage 3.65V Charging End Condition (A): 14A Discharging Procedure: CP Discharging Current (A): 140 0.25P(93184W) End of Discharge Voltage (V): 2.5V/Cell Rest Duration after charging (HH:MM): 8h	P
	Following test configuration used for testing.	See below	P
	- Installation of BESS unit with two or more rows	confirmed	P
	- Installation of BESS units with a single row	See above	N/A

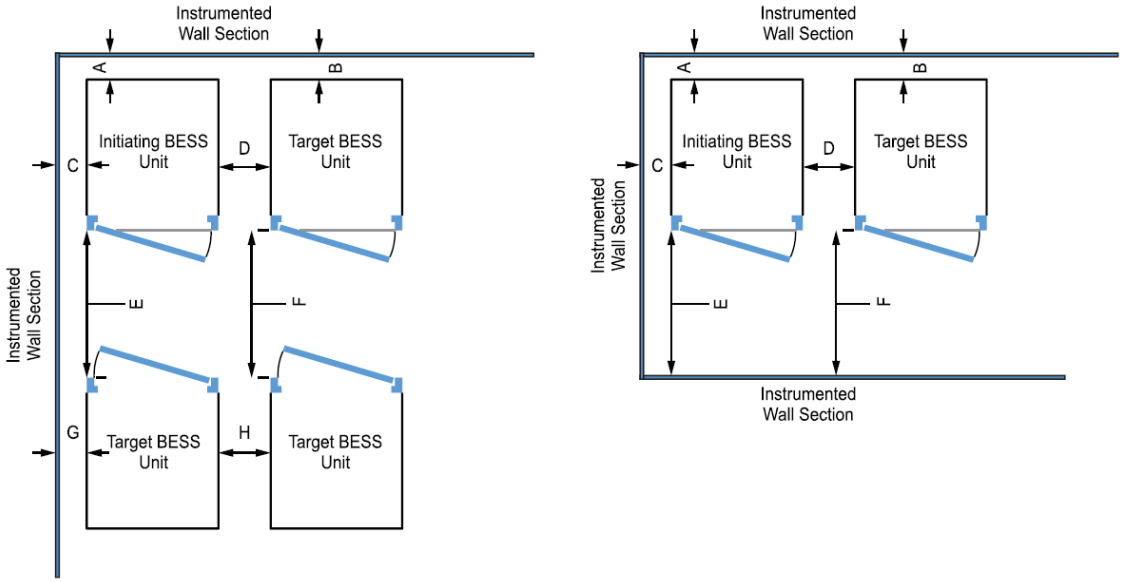
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Section	Requirement	Comments	Verdict

Possible test case verdicts:

Test case does not apply to the test object: N/A (Not Applicable)
Test object does meet the requirement: P (Pass)
Test object does not meet the requirement: F (Fail)

Figure 8.1
Examples of potential SBA test arrangements



ID.	Location	Required Value (mm)	Measured Value (mm)
A	Separation distance between the initiating BESS unit and instrumented wall section behind initiating BESS unit.	160	150
B	Separation distance between the target BESS unit and instrumented wall section to the side of target BESS unit.	160	150
C	Separation distance between the initiating BESS unit and instrumented wall section to the side of the initiating BESS unit.	260	250
D	Separation distance between initiating BESS unit and target BESS unit.	10	10
E	Separation distance between initiating BESS unit and target BESS unit or instrumented wall section.	10	10
F	Separation distance between target BESS unit and target BESS unit or instrumented wall section.	10	10
G	Separation distance between target BESS unit and instrumented wall section.	260	250
H	Separation distance between target BESS units.	10	10

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Section	Requirement	Comments	Verdict
Possible test case verdicts: Test case does not apply to the test object: N/A (Not Applicable) Test object does meet the requirement: P (Pass) Test object does not meet the requirement: F (Fail)			
	Note: The physical spacing between BESS units (both initiating and target) and adjacent walls shall be representative of the intended installation. For example, the left side of Figure 8.1 shows a layout of BESS units of two or more rows. The right side of Figure 8.1 shows a layout of BESS units of a single row, with an instrumented wall taking place of the target BESS units as the nearest potential item exposed to thermal energy from the initiating BESS unit in thermal runaway		
	The initiating BESS unit contained components representative of a BESS unit in a complete installation.	☒ Conformed	P
	Combustible components that interconnect the initiating and target BESS units included during testing.	☒ Conformed	P
	Target BESS units have the outer cabinet (if part of the design), racking, module enclosures, and components that retain cells components.	☒ Conformed Shelf included in the target BESS, also the module enclosure included to retain the cells.	P
	BESS unit included an integral fire suppression system	No integral fire suppression system designed in the BESS unit	N/A
	BESS unit provided with optional fire suppression system	No optional fire suppression system provided for the BESS unit.	N/A
	Ambient temperature during BESS charging and at beginning of test……..……..……: Note: Ambient indoor laboratory conditions shall be 25 ±5°C (77 ±9°F) and 50 ±25% RH at the initiation of the test.	Temperature(ºC): 22. 1 to 24. 4 Humidity (% RH): 50% to 75%	P
8.2	Any access door(s) or panels on the initiating BESS unit and adjacent target BESS units were closed, latched and locked at the beginning and duration of the test.	☐ Conformed No access door or panel designed on both the initiating and target BESS units	N/A
	The initiating BESS unit was positioned adjacent to two instrumented wall sections	☒ Conformed	P

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Section	Requirement	Comments	Verdict
Possible test case verdicts: Test case does not apply to the test object: Test object does meet the requirement: Test object does not meet the requirement:		N/A (Not Applicable) P (Pass) F (Fail)	
	Instrumented wall sections extend not less than 1.6 ft. (0.49 m) horizontally beyond the exterior of the target BESS units.	☒ Conformed	P
	Instrumented wall sections were minimum of 12-ft (3.66-m) tall at least 2-ft (0.61-m) taller than the BESS unit height.	☒ Conformed Height of the instrumented wall: 3.66m, Height of the BESS: 2329 mm.	P
	The surface of the instrumented wall sections were covered with 5/8-in (16-mm) gypsum wall board and painted flat black.	☒ Conformed	P
	The initiating BESS unit was centred underneath an appropriately sized smoke collection hood of an oxygen consumption calorimeter.	☐ Conformed The Initiating BESS unit was centered underneath a smoke collection hood without oxygen consumption calorimeter.	N/A
	The heat release rate measurement system was calibrated using an atomized heptane diffusion burner.	☐ Conformed Un-calibrated for the heat release rate measurement system.	N/A
	The convective heat release rate was measured using thermopile, a velocity probe, and a Type K thermocouple, located in the exhaust system of the exhaust duct.	☐ Conformed See above	N/A
	Separation distance shown above in Section 8.1 were specified by manufacturer	☒ Conformed	P
	Wall surface temperature measurements were collected for BESS intended for installation in locations with combustible construction as defined by NFPA 220.	☒ Conformed	P
	Wall surface temperatures were measured in vertical array(s) at 6-in (152-mm) intervals for the full height of the instrumented wall sections	☒ Conformed	P

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Section	Requirement	Comments	Verdict
Possible test case verdicts: Test case does not apply to the test object: Test object does meet the requirement: Test object does not meet the requirement:		N/A (Not Applicable) P (Pass) F (Fail)	
	24-gauge Type-K exposed junction thermocouples were be used to measure wall surface temperatures.	☒ Conformed	P
	Thermocouples were secured to gypsum surfaces by the use of staples placed over the insulated portion of the wires. The thermocouple tip is to be depressed into the gypsum so as to be flush with the gypsum surface at the point of measurement and held in thermal contact with the surface at that point by the use of pressure-sensitive paper tape.	☒ Conformed	P
	Wall surface temperature measuring thermocouple arrays were horizontally positioned in the wall locations anticipated to receive the greatest thermal exposure from the initiating BESS unit.	☒ Conformed	P
	Heat flux were measured with the sensing element of a water-cooled Schmidt-Boelter gauge at the surface of each instrumented wall	See below	N/A
	- Collinear with the vertical thermocouple array	☐ Conformed Water-cooled Schmidt-Boelter gauge was installed on the surface of the instrumented wall collinear with the vertical thermocouple array.	N/A
	- Positioned at the elevation estimated to receive the greatest heat flux due to the thermal runaway of the initiating module; and	☐ Conformed No fire ignited during the testing. The gauge was installed at the height estimated to receive the greatest heat flux due to thermal runaway of the initiating module.	N/A
	- Positioned at the elevation estimated to receive the greatest heat flux during potential propagation of	☐ Conformed No fire ignited during the testing. One gauge was installed at the height of the initial BESS unit	N/A

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Section	Requirement	Comments	Verdict
Possible test case verdicts: Test case does not apply to the test object: Test object does meet the requirement: Test object does not meet the requirement:		N/A (Not Applicable) P (Pass) F (Fail)	
	thermal runaway within the initiating BESS unit.	enclosure which was estimated to receive the greatest heat flux within the initiating BESS unit.	
	Heat flux were measured with a water-cooled Schmidt-Boelter gauge at the surface of each adjacent target BESS unit that faces the initiating BESS unit	☐ Conformed No fire ignited during the testing. Gauge was installed at the surface of the No.2 target BESS unit which is close to the initial BESS unit.	N/A
	Heat flux gauges were positioned at the elevation estimated to receive the greatest surface heat flux due to the thermal runaway of the initiating module	☐ Conformed Gauge was set up at the elevation estimated to receive the greatest surface heat flux. No fire ignited no heat fluxed during the testing.	N/A
	Twenty-four (24) gauge Type-K exposed junction thermocouples were installed to measure the temperature of the surface proximate to the cells and between the cells and exposed face of the module. Each module enclosure were instrumented with at least one thermocouple	☒ Conformed	P
	An internal fire condition was created within a single module in the initiating BESS unit	See below	P
	- The position of the module was selected to present the greatest thermal exposure to adjacent modules (e.g. above, below, laterally), based on the results from the module level test	☒ Conformed	P
	- The setup (i.e. type, quantity and positioning) of equipment for initiating thermal runaway in the module was same as that used to initiate and propagate thermal runaway within the module level test (Section 7); and	☒ Conformed	P

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Section	Requirement	Comments	Verdict
Possible test case verdicts: Test case does not apply to the test object: Test object does meet the requirement: Test object does not meet the requirement:		N/A (Not Applicable) P (Pass) F (Fail)	
	- A minimum of two 24-gauge Type-K thermocouples were placed within each module to provide data to monitor the thermal conditions within non-initiating modules.	☒ Conformed 2 thermocouples were placed in each module of the initiating BESS unit	P
	- Additional thermocouples were be placed to account for convoluted enclosure interior geometries in non-initiating modules.	☒ Conformed 1 thermocouples were placed in each module of the target BESS unit	P
	The composition, velocity and temperature of BESS unit vent gases were be measured within the calorimeter's exhaust duct.	☒ Conformed	P
	Gas composition was measured using a Fourier-Transform Infrared Spectrometer with a minimum resolution of 1 cm^{-1} and a path length of at least 6.6 ft. (2.0 m), or equivalent gas analyser.	☒ Conformed GC-MS was used for gas composition measurement	P
	Composition, velocity and temperature instrumentation shall be collocated with heat release rate calorimetry instrumentation.	☐ Conformed No fire ignited, no propagation occurred with the DUT	N/A
	The hydrocarbon content of the vent gas was measured using flame ionization detection	☐ Conformed GC-MS used, the gas composition was measured off line.	N/A
	Test Terminated at following test condition	See below	P
	- Temperatures measured inside each module within the initiating BESS unit return to ambient temperature;	☒ Conformed	P

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Section	Requirement	Comments	Verdict
Possible test case verdicts: Test case does not apply to the test object: Test object does meet the requirement: Test object does not meet the requirement:		N/A (Not Applicable) P (Pass) F (Fail)	
	- The fire propagates to adjacent units or to adjacent walls; or	☐ Conformed No fire ignited, no propagation occurred between adjacent cells in the initiating module.	N/A
	- Condition hazardous to test staff or the test facility requires mitigation.	☐ Conformed No condition hazards to the test staff or the facilities	N/A

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Section 8.3	**TD19-0237**
Sample No	TD-0196
Open Circuit Voltage of Initiating BESS Before Test(Vdc):	1404.4
Thermal runaway initiation Method:	External Heating
Location of Initiating module within BESS:	Module No.5. In 1# BESS from the BMS controller box ） Refer to page 22 for target module location and cell location in the initial BESS.

Heat Release Rate

The convective heat release rate shall be calculated using the following equation:

$$HRR_c = V_e A \frac{353.22}{T_e} \int_{T_o}^{T} C_p dT$$

In which:
HRRc = The convective heat release rate (kW)
Ve = The exhaust velocity (m/s)
A = The exhaust duct cross sectional area (m2)
Te = The temperature at the location where exhaust velocity is measured (K)
353.22/Te = The density of air at the velocity measurement location (kg/m3)
To = The ambient temperature (K) in the test room

T = The thermopile temperature (K)

$$\int_{T_o}^{T} C_p dT = A_0(T - T_o) + A_1/2(T^2 - T_o^2) + A_2/3(T^3 - T_o^3) + A_3/4(T^4 - T_o^4)$$

Cp = Specific heat of air (kJ/kg-K), given as Cp = A0 + A1T + A2T2 + A3T3, in which:
A0 = 0.9950
A1 = -5.29933E-05
A2 = 3.21022E-07
A3 = -1.22004E-10

Heat Release Rate Calculation: The heat release rate equals to almost 0 KW in the stage when the unit was forced into thermal runaway as no fire ignited and no propagation occurred between adjacent cells after thermal runaway forced during the whole testing.

Observation of Flying Debris or Explosive Discharge of Gases

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No flying debris or explosion triggered during unit level thermal runaway testing. See video records for further information.

Flammable Gas Generation and Composition Data

See Note

Activation of Integral Fire Protection System.

N/A, no fire protection system designed on the battery rack.

Temperature Measurement

Thermocouple Location	Temperature Limit (ºC)	Measured Maximum Temperature (ºC)
Ambient Temperature Before Test	-	23.8
Wall Surface Temperature	119.8	19.5（T25）
Maximum Target BESS Temperature	143.3	21.6（2# BESS, T5）
Maximum Surface temperature of Module within Target BESS	143.3	21.6（2# BESS, T5）

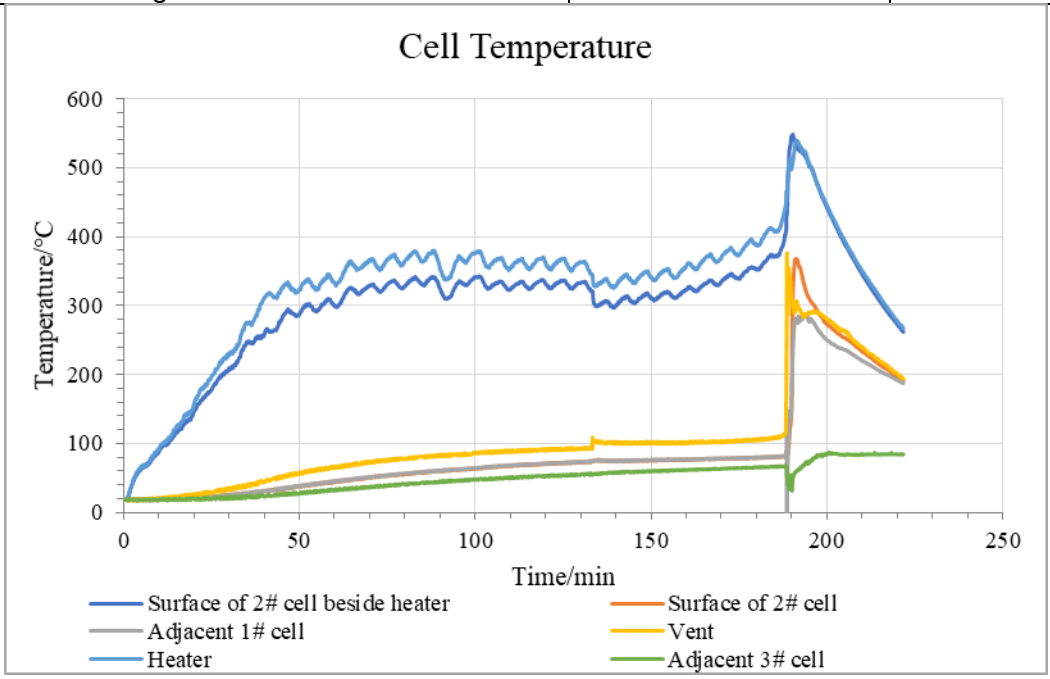


Fig.1 Cell Temperature during Unit Level Testing

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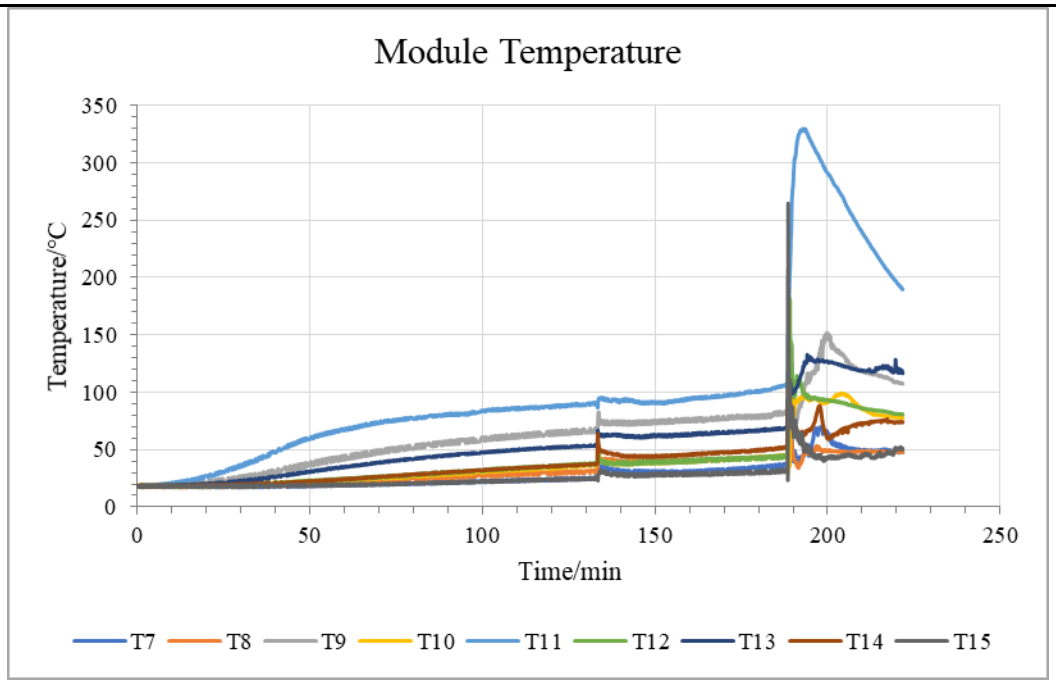


Fig.2 Cell Temperature in target module during Unit Level Testing

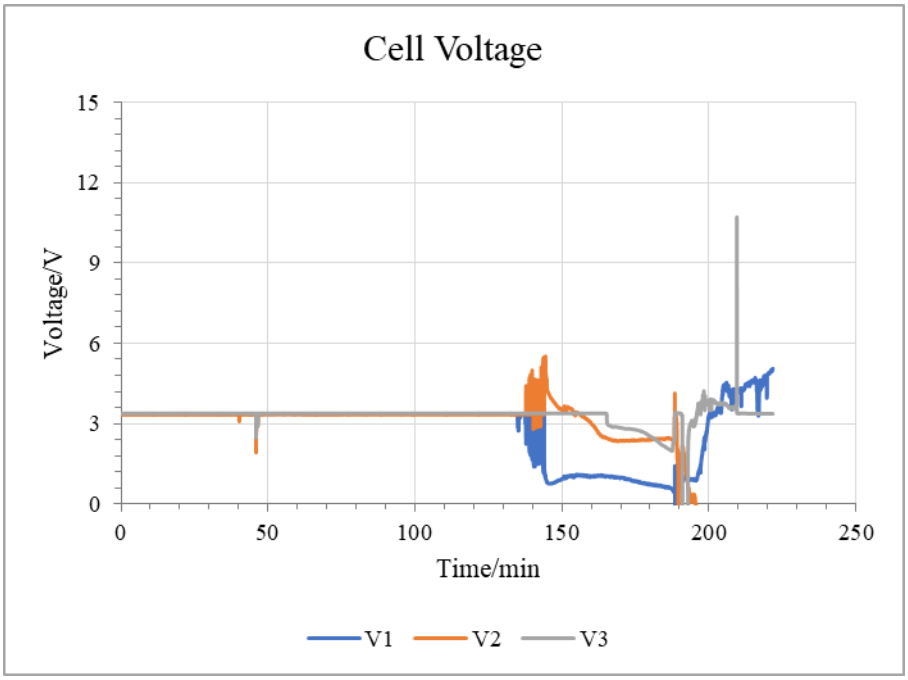


Fig.3 Cell Voltage in target module during Unit Level Testing

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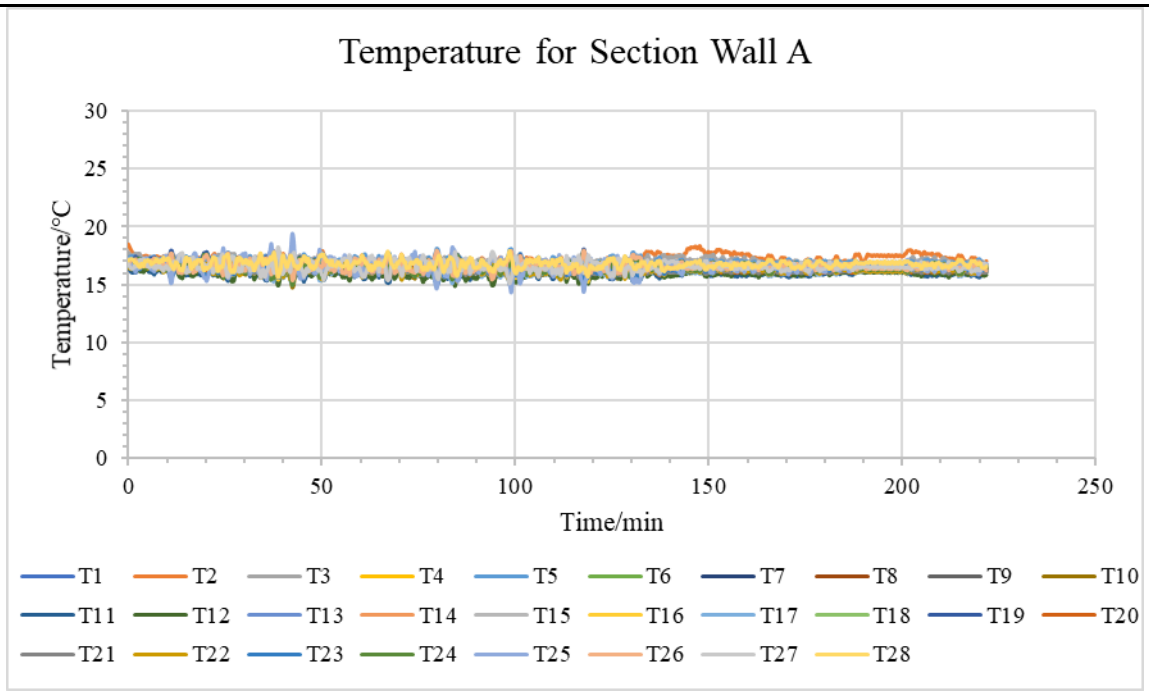


Fig. 4 Temperature of Section Wall A

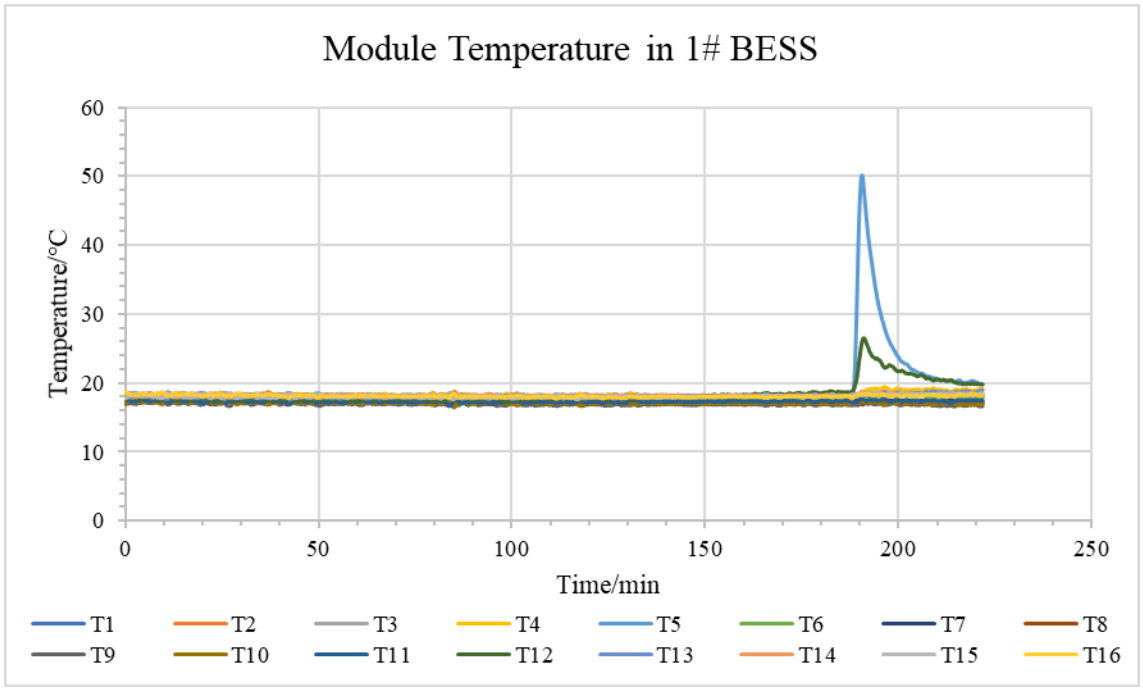


Fig. 5 Module Temperature in 1# BESS

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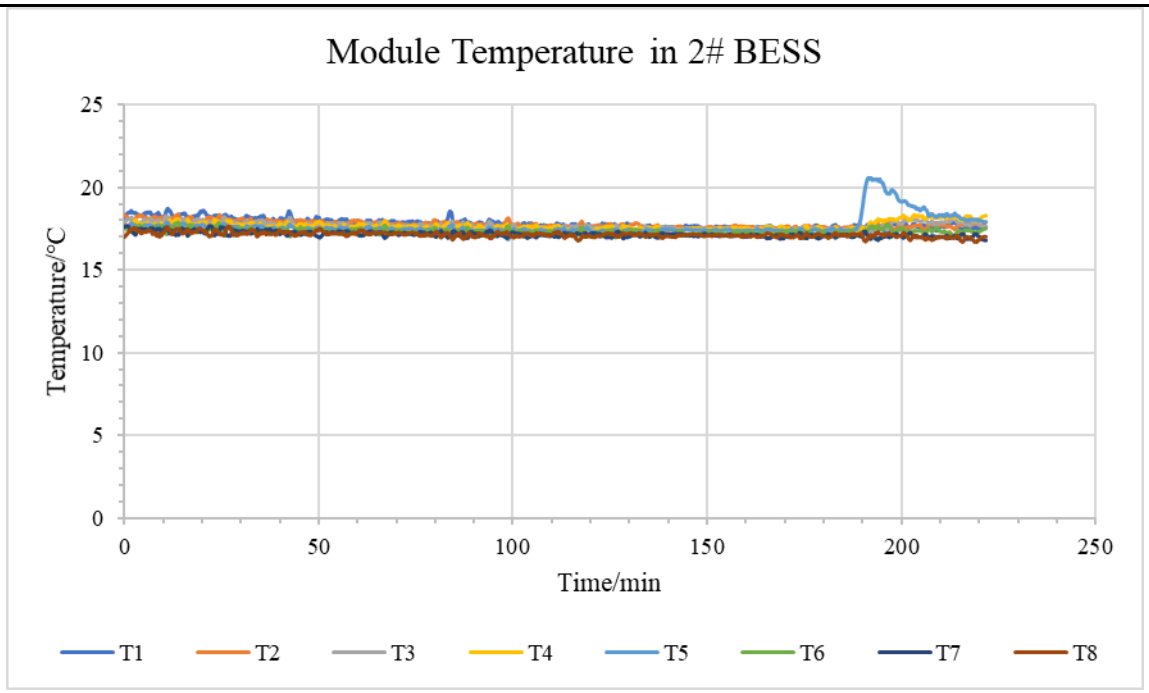


Fig. 6 Module Temperature in 2# Target BESS

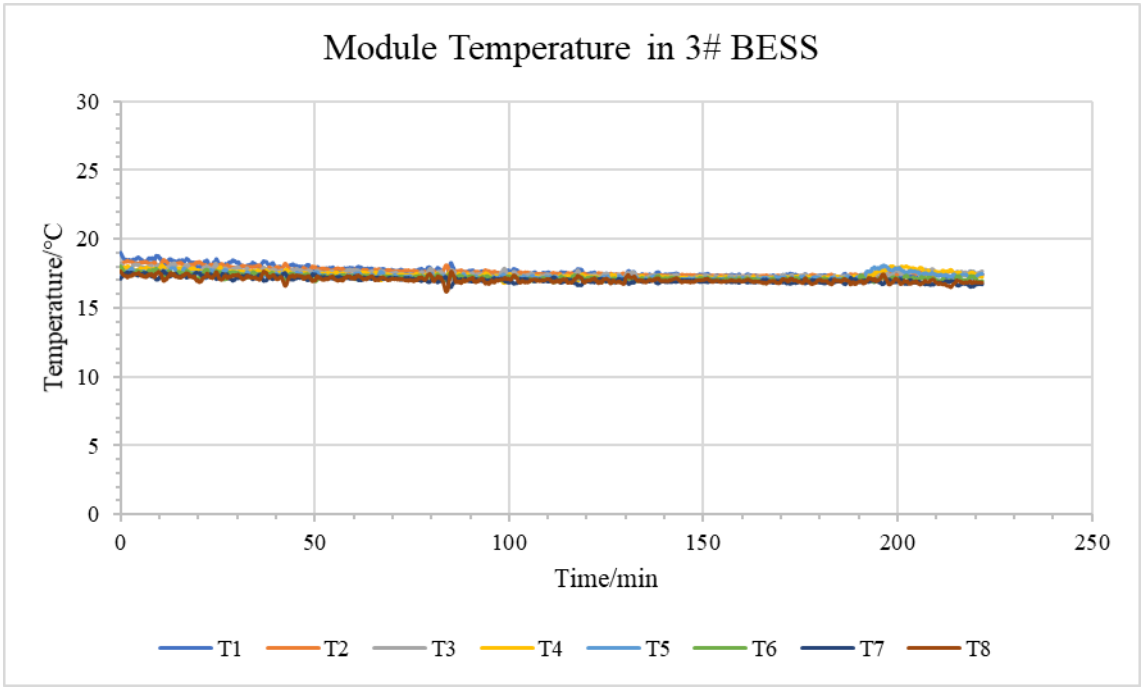


Fig. 7 Module Temperature（3# BESS）

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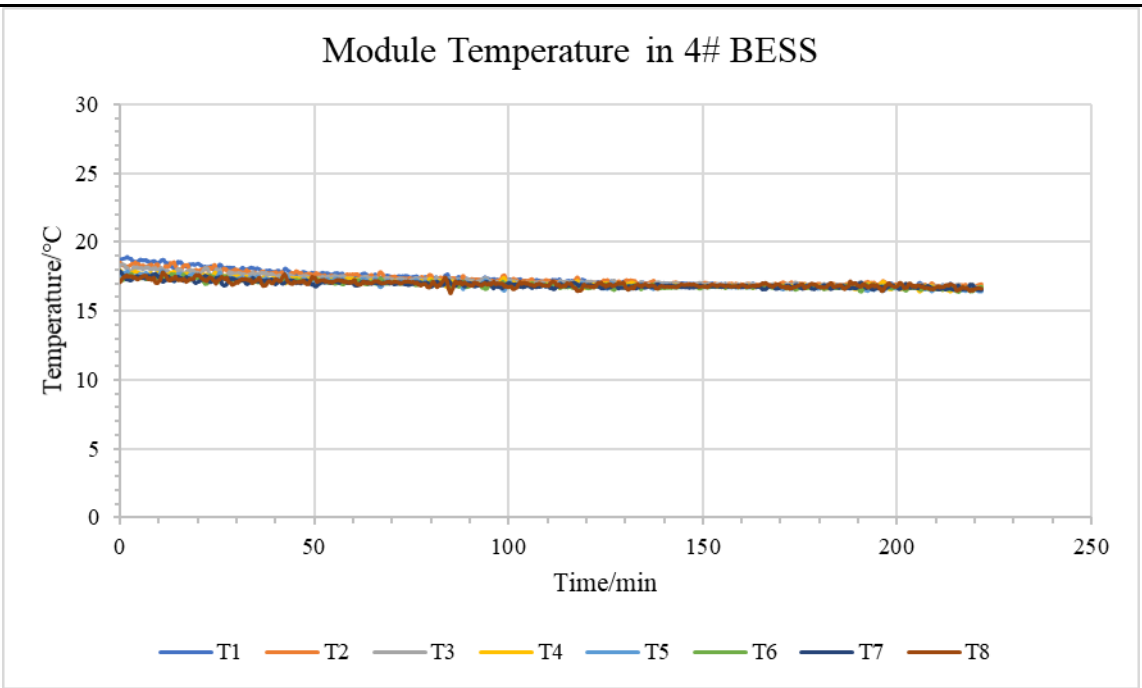


Fig. 8 Module Temperature（4# BESS）

Heat Flux Measurement

Heat flux Location	Measured Maximum Heat Flux (kW/m^2)
Target Wall 1	N/A, see note
Target Wall 2	N/A, see note
Target BESS Unit 1	N/A, see note
Target BESS Unit 2	N/A, see note

Supplementary information:

Note: Heat was not measured on above heat flux location, as no fire ignited during the whole testing.

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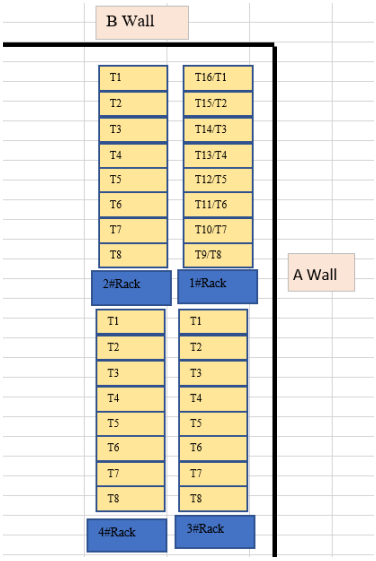


Fig 9 Module Temp in BESS

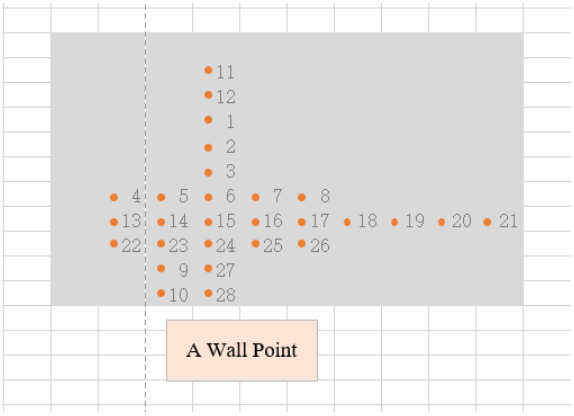


Fig. 10 Section Wall Temp

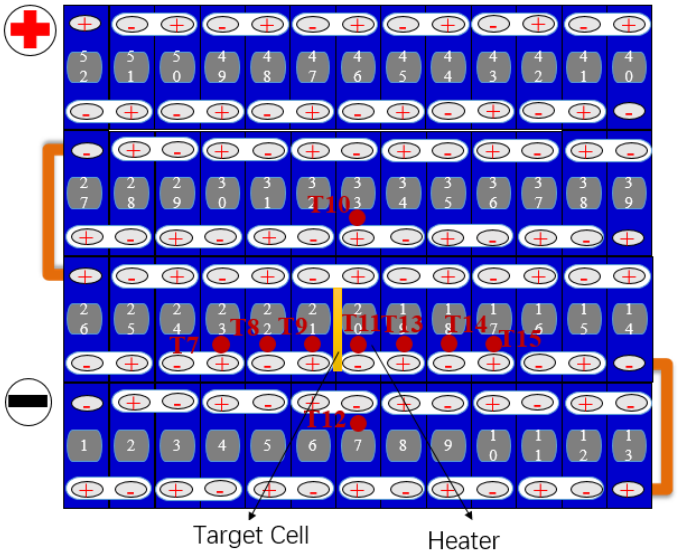


Fig. 11 Heater Location in Module

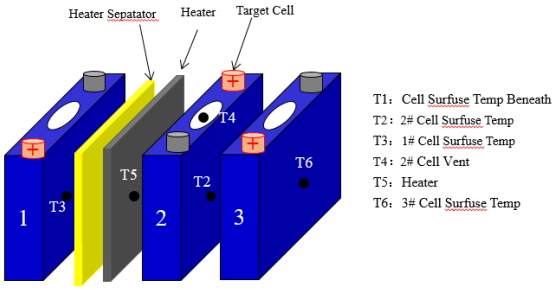


Fig. 12 Thermal Couple Location on Cell

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Fig 13 BESS under Test

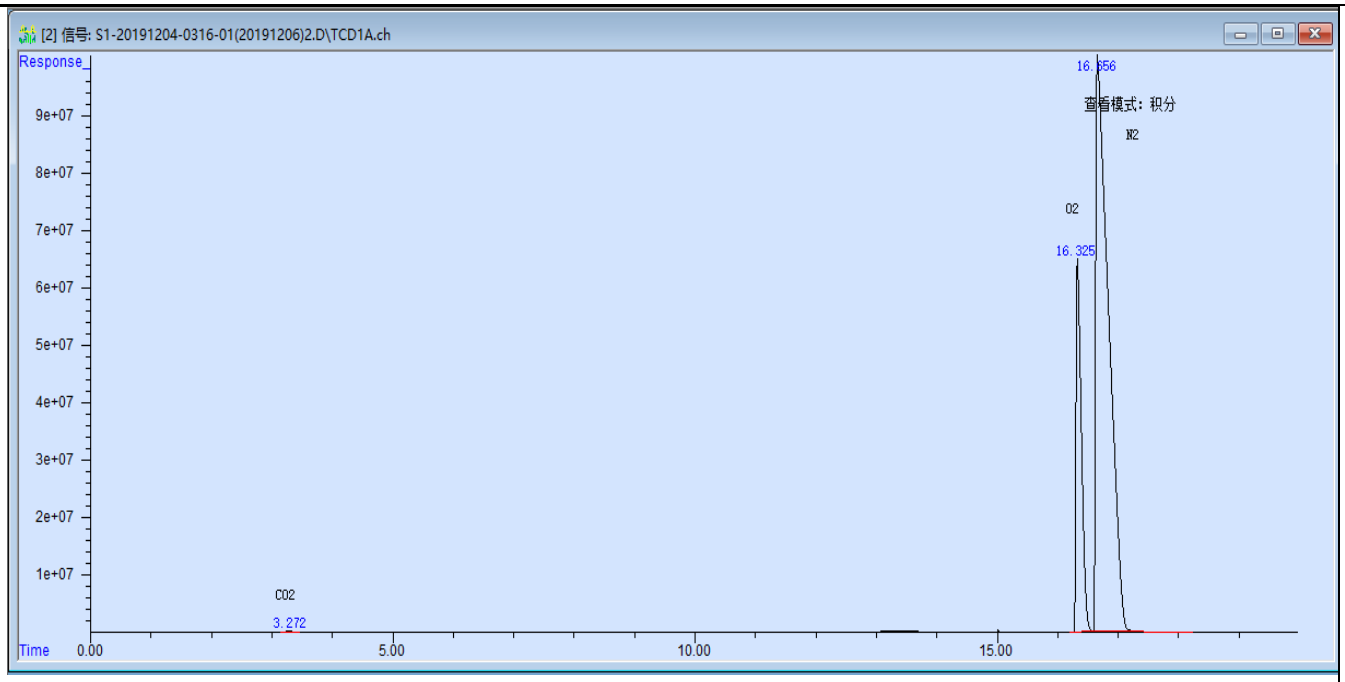


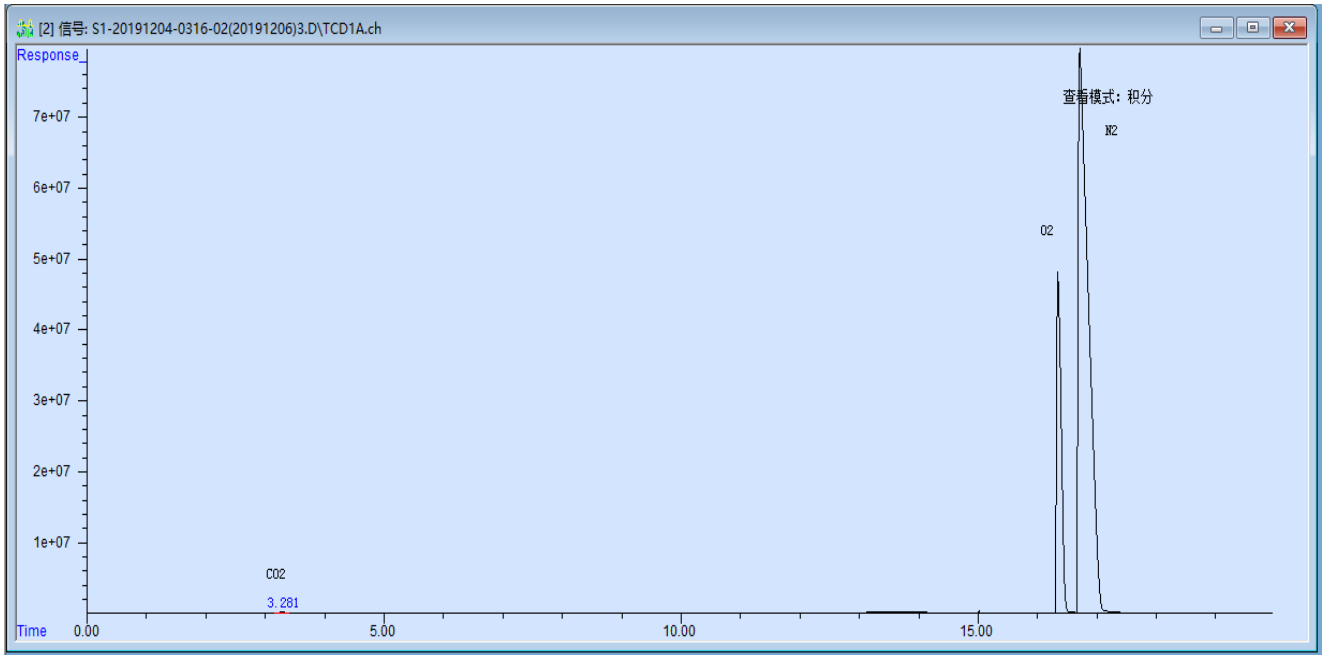
Fig.14 Initial BESS after Test

Gas composition analysis

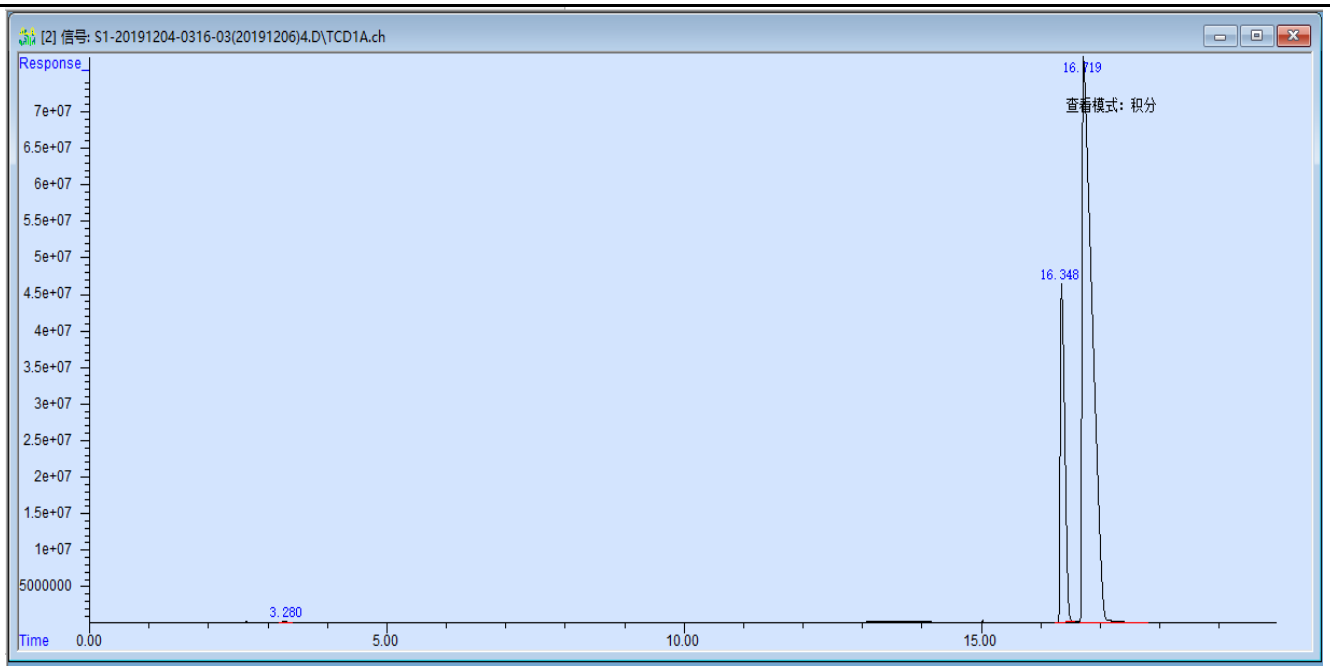
Sample No.	Gas Components									
	CO2	C2H2	C2H4	C2H6	C3H6	H2	O2	N2	CH4	CO
S1-20191204-0316-01	0.06	/	/	/	/	/	21.45	78.49	/	/
S1-20191204-0316-02	0.06	/	/	/	/	/	21.25	78.69	/	/
S1-20191204-0316-03	0.06	/	/	/	/	/	21.23	78.71	/	/
S1-20191204-0316-04	0.18	0.01	0.02	0.01	0.02	0.44	21.09	78.18	0.01	0.05
S1-20191204-0316-05	0.19	0.01	0.02	0.01	0.02	0.52	21.08	78.10	0.01	0.05
S1-20191204-0316-06	0.06	/	/	/	/	/	21.55	78.38	/	/
S1-20191204-0316-07	0.11	/	0.01	/	0.01	0.12	21.26	78.47	/	0.02
S1-20191204-0316-08	0.11	/	0.01	/	0.01	0.11	21.23	78.50	/	0.02

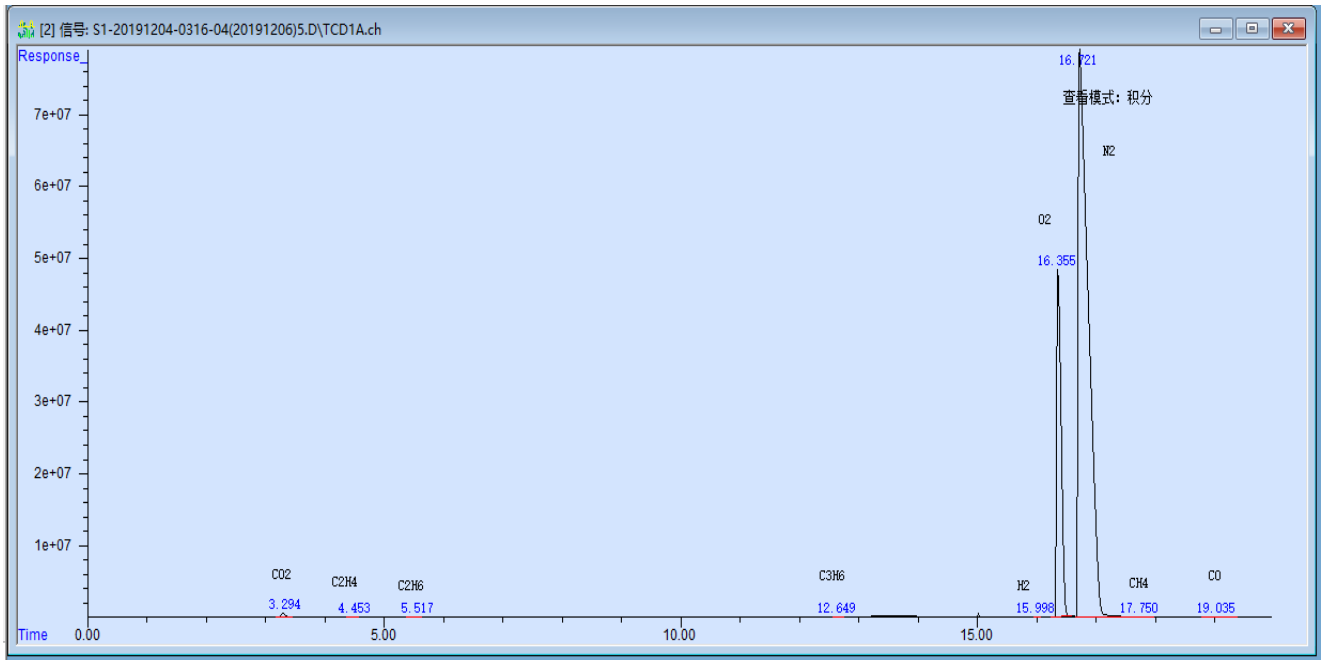
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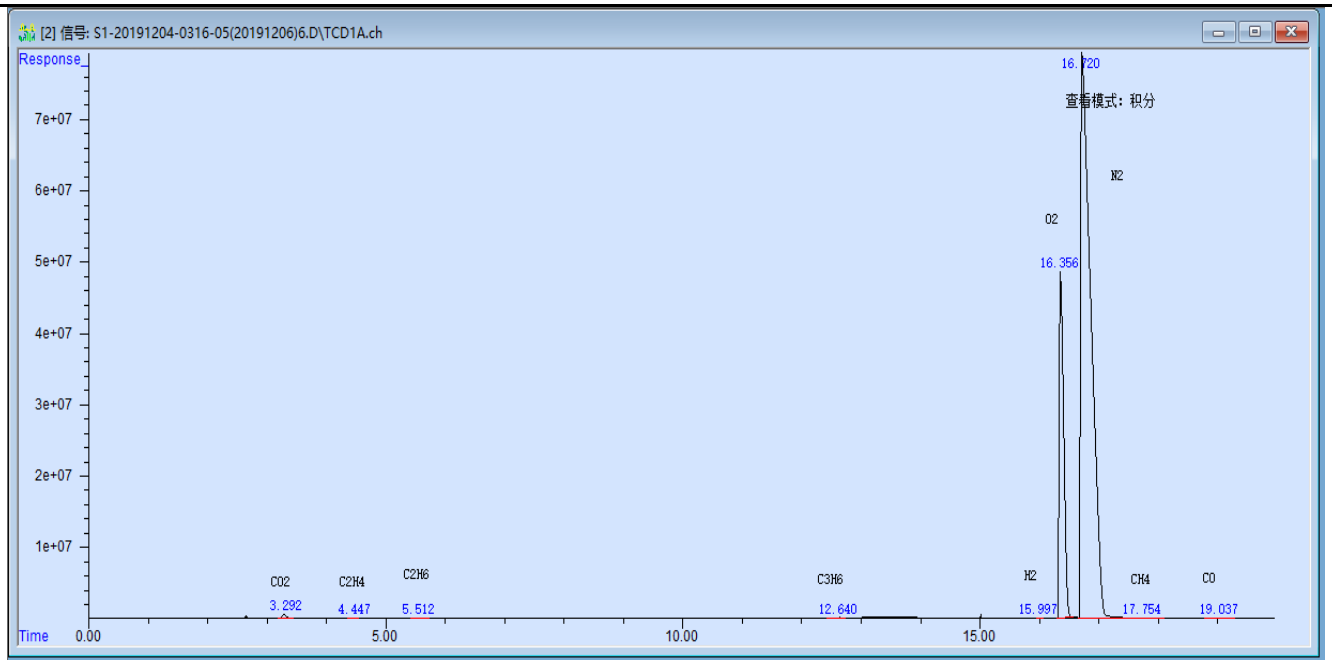


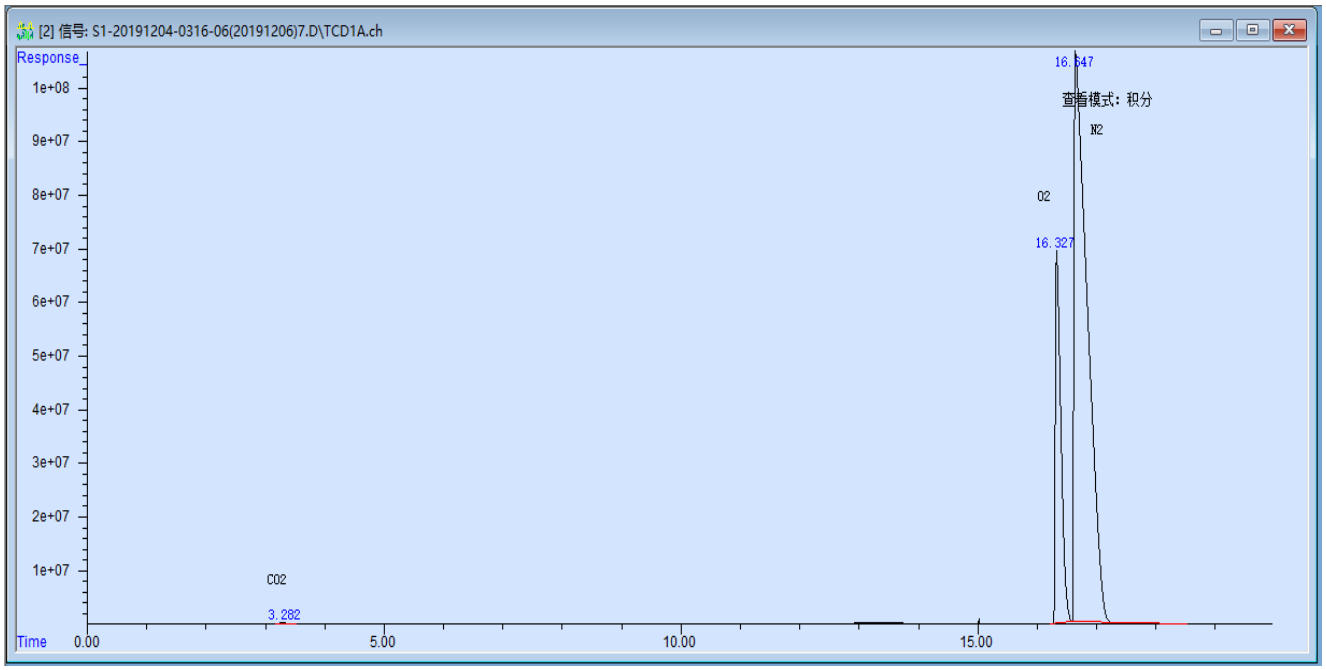
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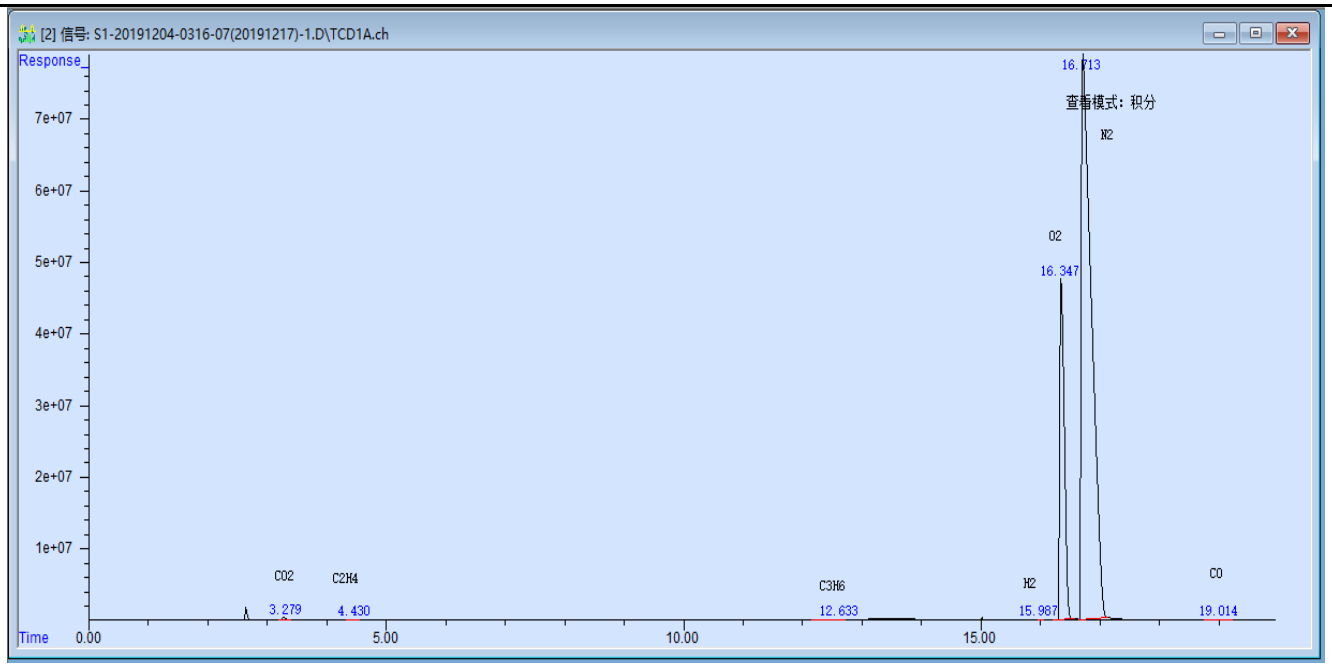


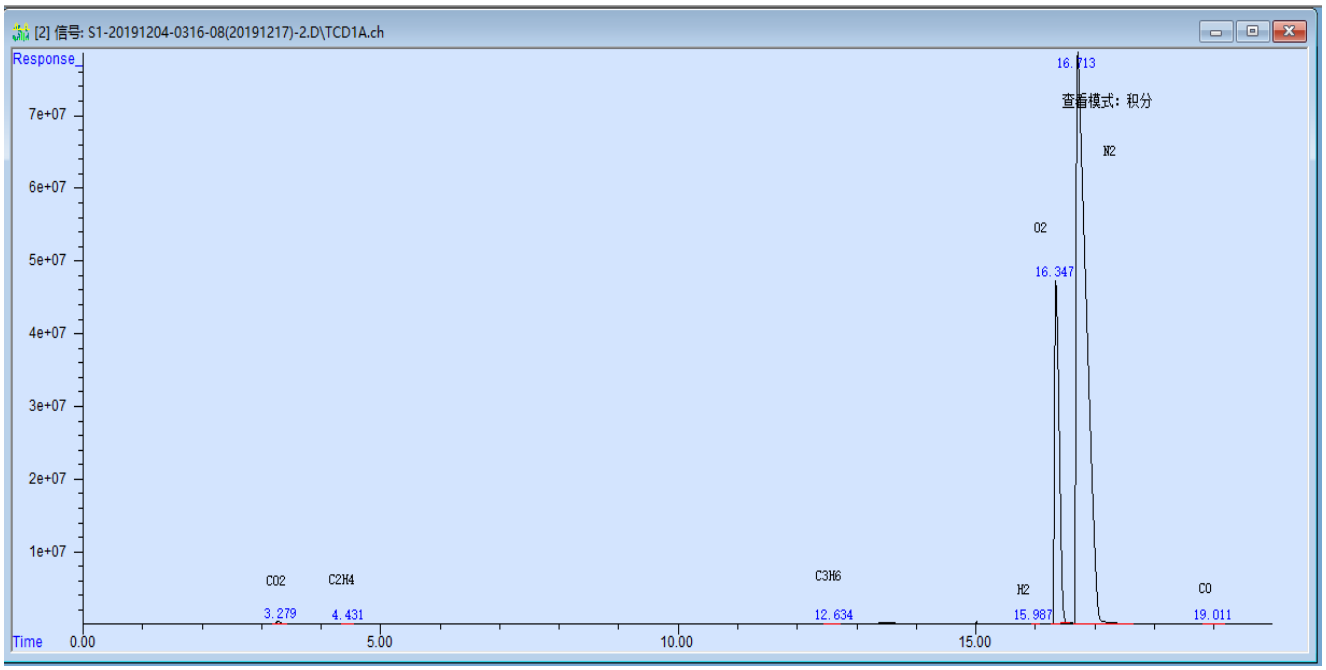
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Equipment Used: Item no. 1,2,3,4,5,6
Date Start: 19/11/30 (YY/MM/DD)
Date End: 19/12/04 (YY/MM/DD)

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Test Equipment

Item No.	Inventory Code / ID	Description	Mfr	Model	Range Used	Calibration Date (YYYY-MM-DD)	Next Calibration Due Date (YYYY-MM-DD)
1	73B0E01460	Chamber	/	HTP-900-40-AW-D	-40~80℃	2019-02-20	2020-02-19
2	740TE01325	Battery Charge/Discharge System	Suoying	GBBT-110/300-2	10~110V, 5~300A	2019-02-19	2020-02-18
3	73TME00069	Data Logger	HIOKI	LR8401-21	-50~300℃	2019-07-12	2020-07-11
4	L108248/GACH0006	GC-MS	Agilent	5977-7890B	-	2018-10-19	2020-10-18
5	74MUE00013	Multi-Meter	Fluke	1587C	0～600Vdc	2019-08-15	2020-08-14
6	72BAQ00359	Scale	Shanghai Mingpai	XK3190-A12+E	0～400kg	2019-05-23	2020-05-22

---End of Report---

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Appendix O

EVE Power Battery Spacing Review Documentation

Prüfbericht-Nr.: *Test Report No.:*	**CN22GHM1 001**	**Auftrags-Nr.:** *Order No.:*	244427912	**Seite 1 von 51** *Page 1 of 51*
Kunden-Referenz-Nr.: *Client Reference No.:*	2182037	**Auftragsdatum:** *Order date.:*	Aug 06, 2022	
Auftraggeber: *Client:*	**Sungrow Energy Storage Technology Co.,Ltd.** No.788 Mingchuan Road, Boyan Technology Park, Hi-tech Zone, Hefei City, 230088 Anhui, P.R. China			
Prüfgegenstand: *Test item:*	Battery Rack			
Bezeichnung / Typ-Nr.: *Identification / Type No.:*	R286AL-141, R344AL-141, R573AL-143, R688AL-143			
Auftrags-Inhalt: *Order content:*	Test report			
Prüfgrundlage: *Test specification:*	UL 9540A: 2019 (Fourth Edition)			
Wareneingangsdatum: *Date of receipt:*	Aug 30, 2021			
Prüfmuster-Nr.: *Test sample No.:*	Engineering sample			
Prüfzeitraum: *Testing period:*	Sept 02, 2021 ~ Sept 17, 2022			
Ort der Prüfung: *Place of testing:*	See clause 1.1 of main report			
Prüflaboratorium: *Testing laboratory:*	See clause 1.1 of main report			
Prüfergebnis*: *Test result*:*	See main report			



geprüft von / *tested by:*			**kontrolliert von** / *reviewed by:*		
October 08, 2022	Simon Wang / Engineer		October 08, 2022	Bowen Dong / Reviewer	
Datum *Date*	**Name/Stellung** *Name/Position*	**Unterschrift** *Signature*	**Datum** *Date*	**Name/Stellung** *Name/Position*	**Unterschrift** *Signature*

Sonstiges / *Other:*

Zustand des Prüfgegenstandes bei Anlieferung: *Condition of the test item at delivery:*

Prüfmuster vollständig und unbeschädigt
Test item complete and undamaged

* Legende:	1 = sehr gut	2 = gut	3 = befriedigend	4 = ausreichend	5 = mangelhalt
	P(ass) = entspricht o.g. Prüfgrundlage(n)		F(ail) = entspricht nicht o.g. Prüfgrundlage(n)	N/A = nicht anwendbar	N/T = nicht getestet
Legend:	1 = very good	2 = good	3 = satisfactory	4 = sufficient	5 = poor
	P(ass) = passed a.m. test specifications(s)		F(ail) = failed a.m. test specifications(s)	N/A = not applicable	N/T = not tested

Dieser Prüfbericht bezieht sich nur auf das o.g. Prüfmuster und darf ohne Genehmigung der Prüfstelle nicht auszugsweise vervielfältigt werden. Dieser Bericht berechtigt nicht zur Verwendung eines Prüfzeichens.

This test report only relates to the a. m. test sample. Without permission of the test center this test report is not permitted to be duplicated in extracts. This test report does not entitle to carry any test mark.

INTRODUCTION

Model fire codes and energy storage system standards require energy storage systems to comply with UL 9540, which in turn requires battery cells and modules to comply with UL 1973. Compliance with these standards reduces the risk of batteries and battery energy storage systems (BESS) creating fire, shock or personal injury hazards. However, they do not evaluate the ability of the BESS installed as intended and with fire suppression mechanisms in place if necessary, from contributing to a fire or explosion in the end use installations.

To address these fire and explosion hazards associated with the installation of a BESS, the fire and other codes require energy storage systems to meet certain location, separation, fire suppression and other criteria. Those codes also provide a means to provide an equivalent level of safety based on large-scale fire testing of anticipated BESS installations.

UL 9540A is intended to provide a test method that can be used as a basis for validating the safety of a BESS installation in lieu of meeting the specific criteria provided in those codes. The data generated can be used to determine the fire and explosion protection required for installation of a BESS.

The test method is initiated through the establishment of a thermal runaway condition that leads to combustion within the BESS. The test method outlined in UL 9540A consists of several steps – cell level testing, module level testing, unit level testing and installation level testing. The cell and module level testing steps are information gathering steps to inform the unit and installation level testing.

The following outlines the information that may gathered as part of the testing:

a) Cell level – An individual cell fails in a manner that leads to thermal runaway and fire through a suitable method such as external heating. Data such as off-gassing contents, temperatures at venting and temperatures at thermal runaway are recorded.

b) Module level – One or more cells within a BESS module fail in the manner determined during the cell level testing. Data such as fire propagation in the module, temperatures on the failed cells and surrounding cells, off-gassing contents and heat release data are gathered.

c) Unit level – A complete BESS is installed surrounded by target (e.g. dummy) BESS and walls separated at a distance as intended in its installation. The module level test is repeated on a module located in the BESS in the most unfavorable location. Data such as temperature within the BESS, on surrounding walls and target BESS; incident heat flux on walls and target BESS; observation of fire propagation from BESS to target units and walls as well as observance of explosions or evidence of re-ignition within the BESS; and heat release and off-gassing contents are gathered.

d) Installation level – This test is a repeat of the unit level test with the test conducted within a test room and with the intended fire suppression system installed as well as any overhead cables (that can lead to fire propagation) installed. This test is intended to validate the fire suppression system for the BESS installation. Data such as temperature within the BESS, on surrounding walls and target BESS; incident heat flux on walls and target BESS; fire propagation from the BESS to target units, walls or overhead cables and any observable explosion incidents or re-ignition within the BESS; and off-gassing contents (if needed) and heat release are gathered.

Contents

1 GENERAL INFORMATION 4

1.1 TEST SPECIFICATION 4
1.2 GENERAL REMARKS 4
1.3 LIST OF ATTACHMENTS 5
1.4 REVISION INFORMATION 5
1.5 DEFINITIONS 6

2 GENERAL PRODUCT INFORMATION 7

2.1 CELL 7
2.1.1 Product information and parameters 7
2.1.2 Cell level test information 8
2.2 MODULE 8
2.2.1 Product information and parameters 8
2.2.2 Diagram with overall dimension 9
2.2.3 Layout of the module contents 9
2.2.4 Configuration diagram of the module 10
2.3 BATTERY SYSTEM (RACK) 11
2.3.1 Manufacture information and model list 11
2.3.2 Product information 12
2.4 PHOTO 14

3 UNIT LEVEL TEST (SECTION 8 OF UL 9540A) 16

3.1 GENERAL 16
3.2 UNIT SAMPLE PREPARATION 17
3.3 SETUP OF THE TEST 18
3.3.1 Battery system installation information 18
3.3.2 Test site setup 18
3.3.3 Thermal runaway setup 21
3.4 OBSERVATIONS AND RECORDS 24
3.5 TEMPERATURE MEASUREMENTS 26
3.5.1 Temperature measurement of initiating cells 26
3.5.2 Temperature measurement of units 29
3.5.3 Temperature measurement of instrumented walls 32
3.6 HEAT FLUX MEASUREMENT 35
3.7 CHEMICAL HEAT RELEASE RATE MEASUREMENT 37
3.8 CONVECTIVE HEAT RELEASE RATE MEASUREMENT 39
3.9 GAS GENERATION MEASUREMENT 40
3.9.1 Total gas release 40
3.9.2 Gas components 41
3.10 PHOTOS 44

4 LIST OF TEST AND MEASUREMENT INSTRUMENTS 50

1 General information

1.1 Test specification

Standard: ANSI/CAN/UL 9540A: 2019 (Fourth Edition)

Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

This report presents the result of unit level tests of UL 9540A: 2019.

All tests were conducted at TUV Rheinland (Shanghai) Co., Ltd. and TUV Rheinland's partner labs that were under supervision of TÜV Rheinland's engineer.

Testing period: Sept 02, 2022 ~ Sept 17, 2022

Refer to Clause 4 for test and measurement instruments.

1.2 General remarks

This report is descriptive and provide the test data only.

The test results presented in this report relate only to the object tested.

This report shall not be reproduced, except in full, without the written approval of the testing laboratory.

Throughout this report a ☐ comma / ☒ point is used as the decimal separator.

1.3 List of attachments

Video records of the test from 2 different directions were provided in .mp4 format.
Complete records were provided in 6 separate documents, file number listed as below:

20220902 Sungrow unit UL9540A video ch02 (01-02).mp4;

20220902 Sungrow unit UL9540A video ch03 (01-04).mp4;

1.4 Revision information

New report, not applicable

1.5 Definitions

CELL – The basic functional electrochemical unit containing an assembly of electrodes, electrolyte, separators, container, and terminals. It is a source of electrical energy by direct conversion of chemical energy.

MODULE – A subassembly that is a component of a BESS that consists of a group of cells or electrochemical capacitors connected together either in a series and/or parallel configuration (sometimes referred to as a block) with or without protective devices and monitoring circuitry.

UNIT – A frame, rack or enclosure that consists of a functional BESS which includes components and subassemblies such as cells, modules, battery management systems, ventilation devices and other ancillary equipment.

BATTERY SYSTEM (BS) – Is a component of a BESS and consists of one or more modules typically in a rack configuration, controls such as the BMS and components that make up the system such as cooling systems, disconnects and protection devices.

BATTERY ENERGY STORAGE SYSTEM (BESS) – Stationary equipment that receives electrical energy and then utilizes batteries to store that energy to supply electrical energy at future time. The BESS, at a minimum consists of one or more modules, a power conditioning system (PCS), battery management system (BMS) and balance of plant components.

a) INITIATING BATTERY ENERGY STORAGE SYSTEM UNIT (INITIATING BESS) – A BESS unit which has been equipped with resistance heaters in order to create the internal fire condition necessary for the installation level test (Section 9).

b) TARGET BATTERY ENERGY STORAGE SYSTEM UNIT (TARGET BESS) – The enclosure and/or rack hardware that physically supports and/or contains the components that comprise a BESS. The target BESS unit does not contain energy storage components, but serves to enable instrumentation to measure the thermal exposure from the initiating BESS.

Note: Depending upon the configuration and design of the BESS (e.g. the BESS is composed of multiple separate parts within separate enclosures), the unit level test can be done at battery system level. In such case, the BESS is be read as BS throughout this report.

NON-RESIDENTIAL USE – Intended for use in commercial, industrial or utility owned locations.

RESIDENTIAL USE – In accordance with this standard, intended for use in one or two family homes and town homes and individual dwelling units of multi-family dwellings.

THERMAL RUNAWAY- The incident when an electrochemical cell increases its temperature through self-heating in an uncontrollable fashion. The thermal runaway progresses when the cell's generation of heat is at a higher rate than the heat it can dissipate. This may lead to fire, explosion and gas evolution.

STATE OF CHARGE (SOC) – The available capacity in a BESS, pack, module or cell expressed as a percentage of rated capacity.

2 General Product Information

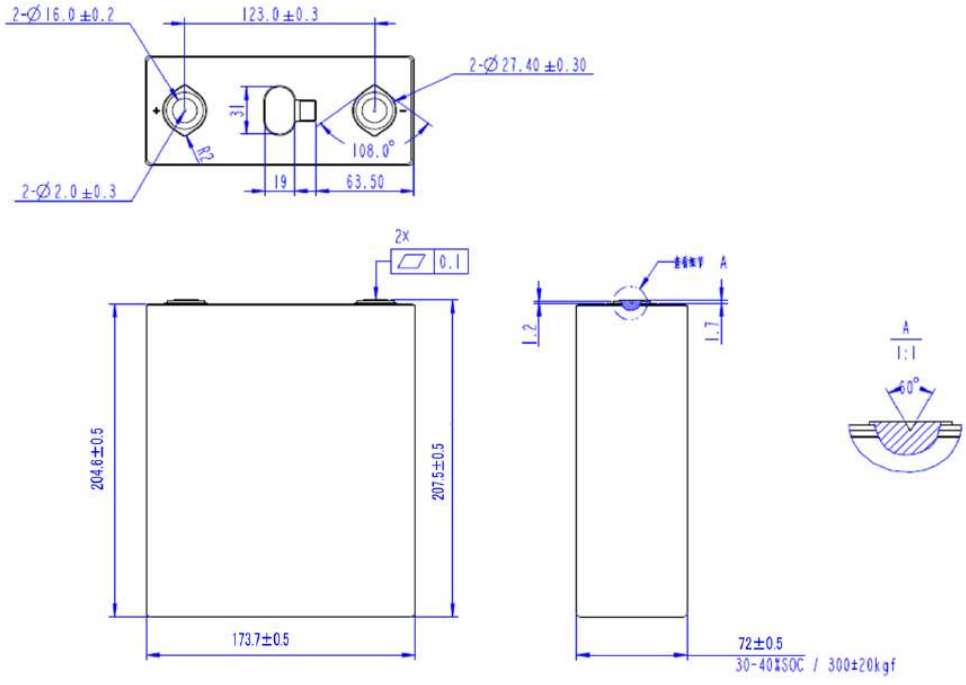
The product information and parameters were provided by the client as below.

2.1 Cell

2.1.1 Product information and parameters

Manufacturer ..... :	EVE POWER Co., Ltd.	
Model number ..... :	LF280K	
Chemistry ..... :	LiFePO4	
Physical configuration..... :	Prismatic	
	Weight:	5420±300 g
Electrical rating ..... :	Rated capacity:	280 Ah
	Nominal voltage:	3.2 V
Standard charge method ..... :	Charge current:	140 A
	End of charge voltage:	3.65 V
	Cut off current:	14 A
Standard discharge method ..... :	Discharge current:	140 A
	End of discharge voltage:	2.5 V

Diagram with overall dimension



2.1.2 Cell level test information

Cell level thermal runaway test information is from UL cell level test report 4789795626 provided by the client.

Thermal Runaway Methodology.....:	Two pieces 203.0 mm by 152.4 mm film heater for each sample
Cell Surface Temperature at Gas Venting...:	146.9°C
Cell Surface Temperature at Thermal Runaway .....:	147.7°C

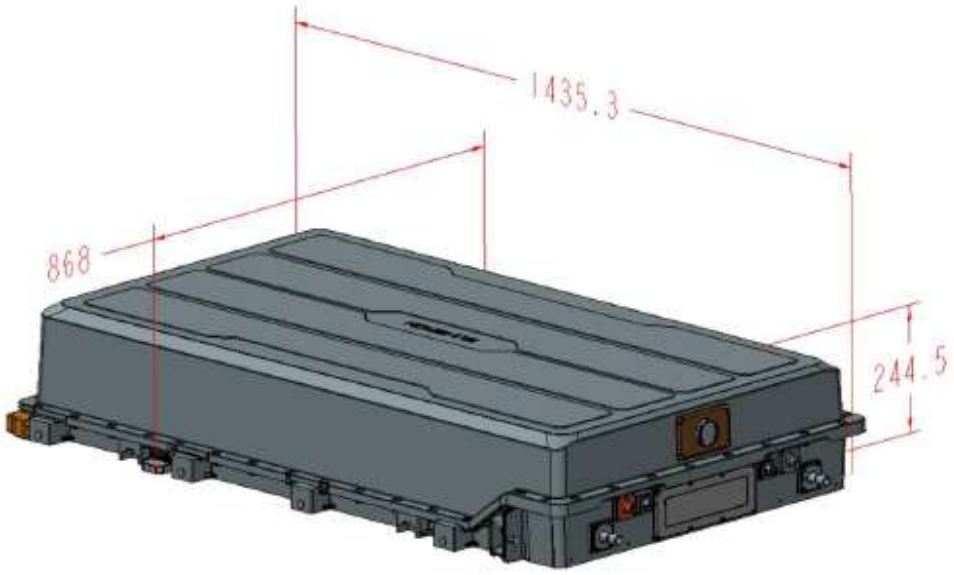
2.2 Module

2.2.1 Product information and parameters

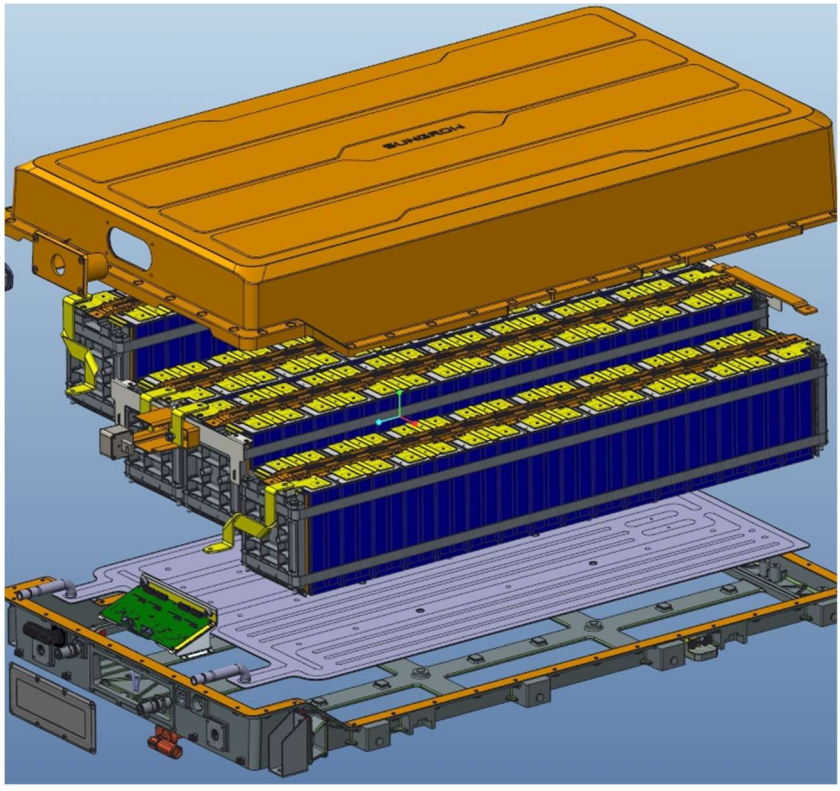
The product information and parameters are provided by the client as below.

Manufacturer name ..... :	SUNGROW ENERGY STORAGE TECHNOLOGY CO., LTD.
Type/Model..... :	P573AL-141, P573BL-141
Physical configuration..... :	Metal enclosure with plastic cover
	Weight: 400±12 kg
	Cells in series/parallel: 64 in series
Cooling method ..... :	Liquid Cooling
Separation between cells ..... :	0.45 mm separation between cells by air
Electrical rating..... :	Rated capacity: 280 Ah
	Nominal voltage: 204.8V
Standard charge method..... :	Charge current: 140 A
	End of charge voltage: 233.6 V
	Cut of current: 14 A
Standard discharge method ..... :	Discharge current: 140 A
	End of discharge voltage: 172.8 V
Compliance with UL 1973..... :	Under certification, not finished

2.2.2 Diagram with overall dimension

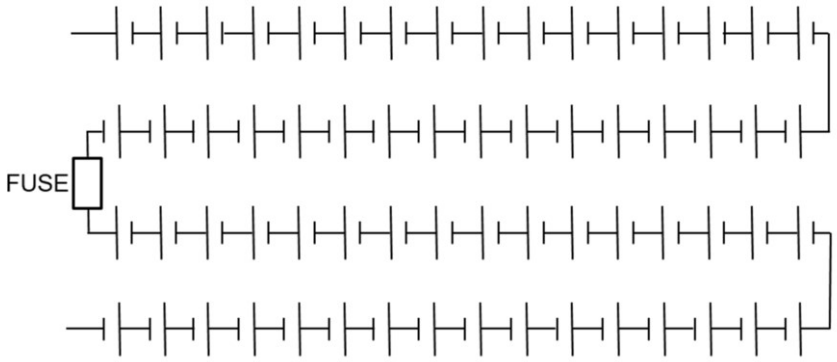


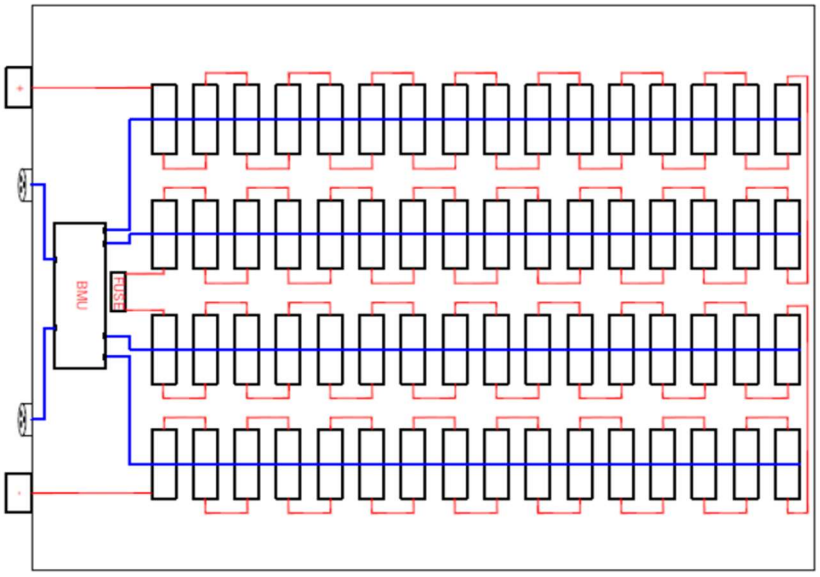
2.2.3 Layout of the module contents



2.2.4 Configuration diagram of the module

1P64S





2.3 Battery system (rack)

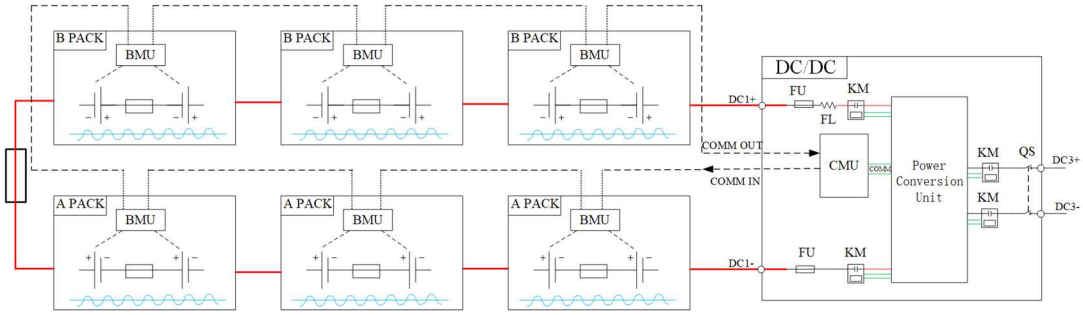
2.3.1 Manufacture information and model list

	Battery system	Battery system	Battery system	Battery system
Product	LFP Lithium Ion Energy Storage System	LFP Lithium Ion Energy Storage System	LFP Lithium Ion Energy Storage System	LFP Lithium Ion Energy Storage System
Type/model	R286AL-141	R344AL-141	R573AL-143	R688AL-143
Cell Capacity [Ah]	280	280	280	280
Cell Quantity	320	384	640	768
Battery structure	(64S)5S	(64S)6S	((64S)5S)2P	((64S)6S)2P
Nominal voltage [V]	1024	1228.8	1024	1228.8
Rated capacity [Wh]	286720	344064	573440	688128
Upper limit charging voltage [V]	1168	1401.6	1168	1401.6
Recommend charging current [A]	140	140	140	140
Maximum charging current [A]	140	160	140	140
Recommend discharging current [A]	140	140	140	140
Maximum discharging current [A]	140	160	140	140
Discharge cut-off voltage [V]	864	1036.8	864	1036.8
Temperature range for charging [°C]	0 to 50*	0 to 50*	0 to 50*	0 to 50*
Temperature range for discharging [°C]	-30 to 50*	-30 to 50*	-30 to 50*	-30 to 50*
Temperature threshold for protection	53	53	53	53
Overcharge protected voltage supply by battery system	≥3.65V /Cell	≥3.65V /Cell	≥3.65V /Cell	≥3.65V /Cell
Recommend charging method by manufacturer	Charge at constant current 140A until the voltage reaches 1168V, then switch to constant voltage 1168V till charge current drops to 14A	Charge at constant current 140A until the voltage reaches 1401.6V, then switch to constant voltage 1401.6V till charge current drops to 14A	Charge at constant current 140A until the voltage reaches 1168V, then switch to constant voltage 1168V till charge current drops to 14A	Charge at constant current 140A until the voltage reaches 1401.6V, then switch to constant voltage 1401.6V till charge current drops to 14A
Dimension [mm]	Rack:3117±10mm(W)×1474±10mm(D)×520±10mm(H) DC/DC:720±5mm(W)×788±5mm(D)×294±5mm(H)	Rack:3117±10mm(W)×1474±10mm(D)×520±10mm(H) DC/DC:720±5mm(W)×788±5mm(D)×294±5mm(H)	Rack:3117±10mm(W)×1474±10mm(D)×1040±10mm(H) DC/DC:720±5mm(W)×788±5mm(D)×294±5mm(H)	Rack:3117±10mm(W)×1474±10mm(D)×1040±10mm(H) DC/DC:720±5mm(W)×788±5mm(D)×294±5mm(H)
Weight [kg]	Rack: ≤2025kg DC/DC: 75kg	Rack: ≤2430kg DC/DC: 75kg	Rack: ≤4050kg DC/DC: 75kg	Rack: ≤4860kg DC/DC: 75kg
Ingress Protection (IP)	IP65	IP65	IP65	IP65
Protective Class	I	I	I	I
Cooling type	Liquid cooling	Liquid cooling	Liquid cooling	Liquid cooling
Altitude	4000m	4000m	4000m	4000m

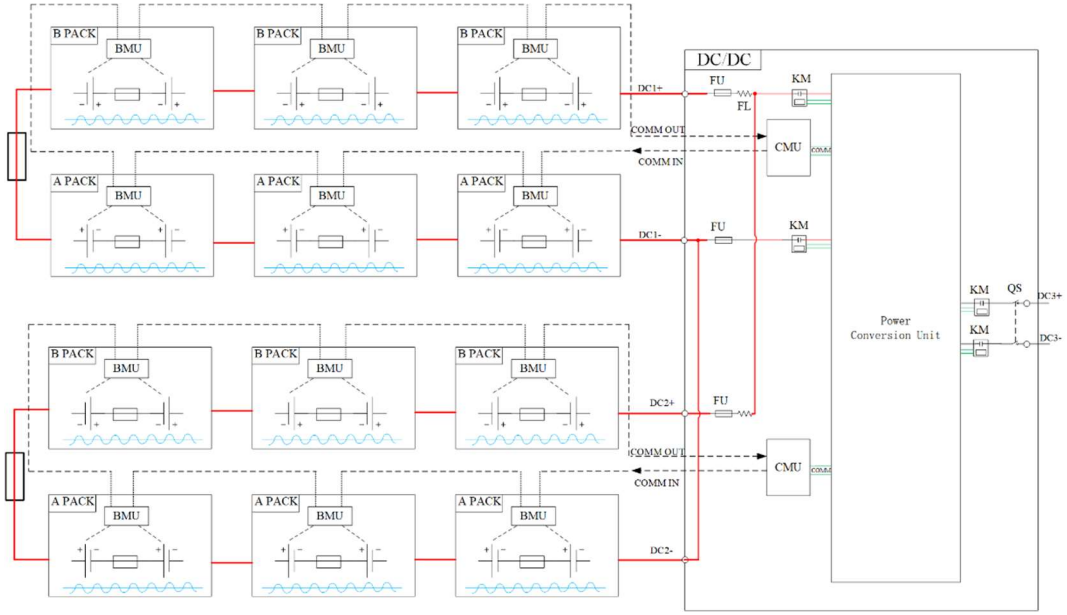
2.3.2 Product information

This product is used for Energy Storage System.
The EUTs covered by this report are 4 models of LFP lithium ion battery energy storage systems which include one DC-DC converter box and several battery packs in series(parallel) connection. The number of battery pack is 5, 6, 10,12 for model R286AL-141, R344AL-141, R573AL-143 and R688AL-143.

Block diagram for R344AL-141 is as below (R286AL-141 is the same except for one less pack) :



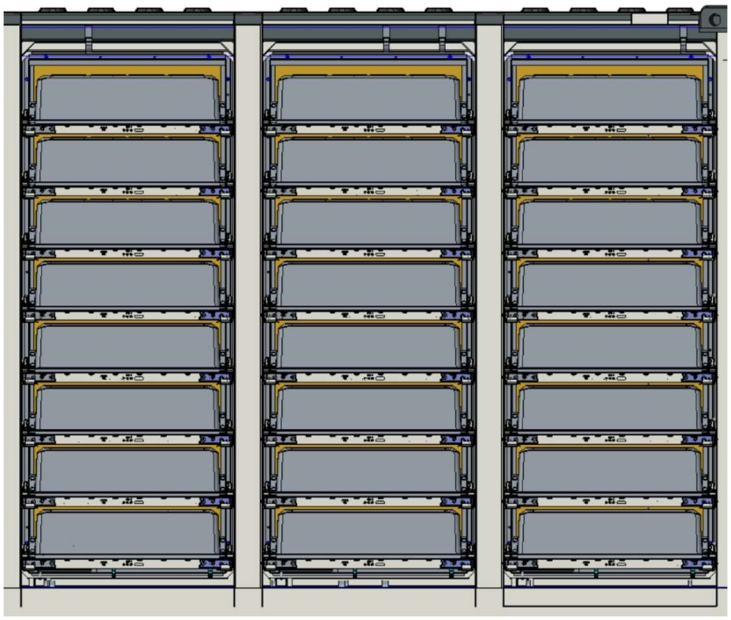
Block diagram for R688AL-143 is as below (R573AL-143 is the same except for two less packs) :

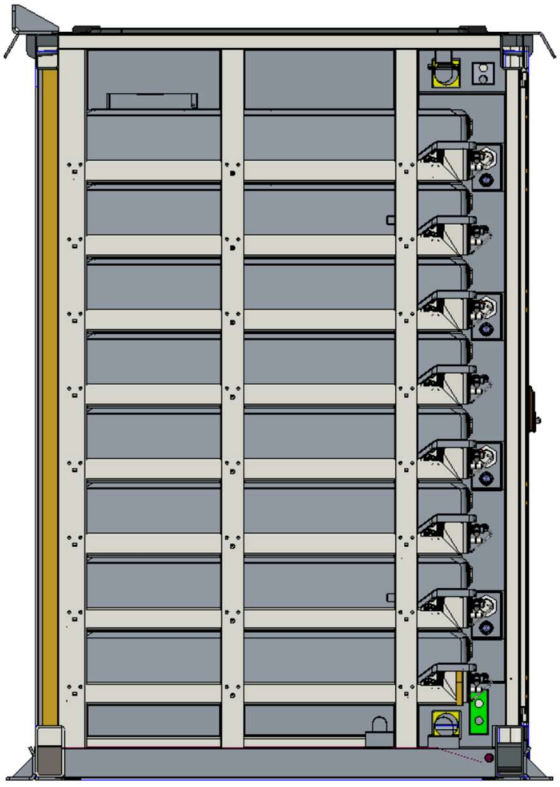


Each battery pack contains 64 cells in structure 64S. And it contain one BMU board for measuring and collecting the cell parameters and uploading the information of cell voltage and temperature to CMU in DC-DC converter box.
DC-DC box: Including CMU function and DC-DC converter which certified with UL 1741.
The EUTs are indoor type. The insulation between the DC circuit and the metal enclosure is basic insulation. And the insulation between the DC circuit and communication ports is reinforced insulation or double insulation.
BMS functional safety was evaluated according to IEC 60730-1 Annex H by TÜV Rheinland.

Compliance with UL9540..... :	without
Compliance with UL1973..... :	On-going
Integrated fire protection system in the unit..... :	No integrated fire protection system

Diagram with dimension of R688AL-143





2.4 Photo

Module



Battery Rack



3 Unit level test (section 8 of UL 9540A)

3.1 General

Unit level testing corresponds with the testing anticipated by fire codes and other codes impacting energy storage system installations to evaluate the large scale fire performance of BESS units installed in, on or adjacent to buildings or in other areas and their resultant performance to qualify for exceptions to limits in the codes imposed on these installations. The limitations where exceptions may be sought are limitations on the size of the individual BESS units, the total number of BESS units installed within a room, and the separation distances between BESS units and between BESS units and walls of the building.

In this test the initiating BESS unit is placed a set distance from target BESS units simulating BESS units identical to the initiating BESS unit, and from simulated walls representative on the installation. A thermal runaway is induced in cells, using the same approach as used in the module level testing within one of the modules in the initiating BESS, and a variety of measurements are taken. The results are intended to be used to verify that a fire within a single BESS unit will not spread to other units, nor breach the walls or the BESS enclosure (if provided), and there shall be no flying debris or explosive discharge of gases.

The test arrangement include the largest (energy) BESS unit for the installation to be represented by the test, and minimum spacing to adjacent walls and BESS units. The BESS may be tested with an internal fire suppression system provided by the manufacturer if that fire suppression system is required to be installed in the BESS. Optional internal fire suppression systems are not included in the unit level testing.

The test monitors the fire behavior of the BESS unit and measures heat release rates (convective and chemical); gas generation and composition; smoke release rate; maximum heat flux on the target BESS units, wall surfaces and within the accessible means of egress; maximum surface temperatures of the walls and modules within the target BESS units; and documents any explosions, deflagrations and flying debris from the BESS under test.

3.2 Unit sample preparation

The battery system is constructed with open rack without enclosure. Three columns and two rows of the racks with 6 complete modules was considered as a unit for purposes of the test.

All 6 module samples were conditioned together as a unit, through 3 charge/ discharge cycles per the manufacturer's instructions to verify that the module was functional.

The Charge/discharge was performed at 140A. Each cycle was defined as a charge to 100% SOC and allowed to rest 60 minutes and then discharged to an end of discharge voltage (EODV) determined by the module specification. Refer to section 2.2 for the end of the condition of charge and discharge.

Cycling was conducted on Sept 01, 2022 under ambient temperature 25°C ± 3°C and R.H. 70% ± 5%.

3.3 Setup of the test

3.3.1 Battery system installation information

The installation information was provided by the client as below.

Intended use location ..... :	☐ Residential	☒ Non-residential
	☐ Non-residential rooftop	
	☐ Non-residential open garage use	
Type of installation ..... :	☒ Indoor	☐ Outdoor
	☒ Floor/ground mounted	☐ Wall mounted
Row(s) of installation	☐ Single	☒ Multiple

3.3.2 Test site setup

Two instrumented walls with 3.8 m height and 3.55 m width form a right angle. Walls were constructed of 5/8 in gypsum painted flat black.

Three racks were used for the purpose of the test. As specified by the manufacture, the two target racks will be installed up and down of the initial unit. All racks were positioned facing instrumented wall A. See Figure 1 and 2 and photos on page 45.

The initiating unit (unit A) was positioned at the middle, adjacent to the two instrumented wall sections.

The minimum separation distance from the rack to wall and between racks were defined by the client. Subject to the actual conditions of the testing environment, there was 1cm tolerance in the actual setup.

Figure 1 was the test site setup diagram with separation distance.

The test side setup was located under the smoke collection hood of the calorimeter measurement system.

Figure 1. Test site setup diagram with separation distance. (Top view)

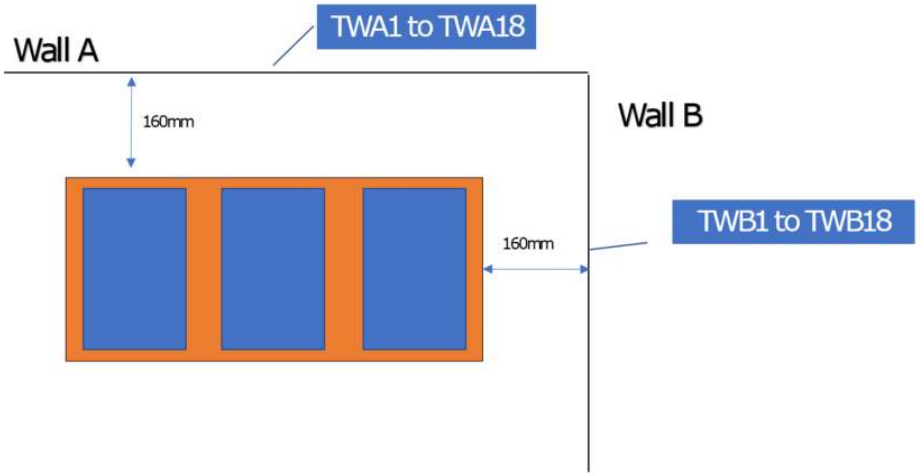
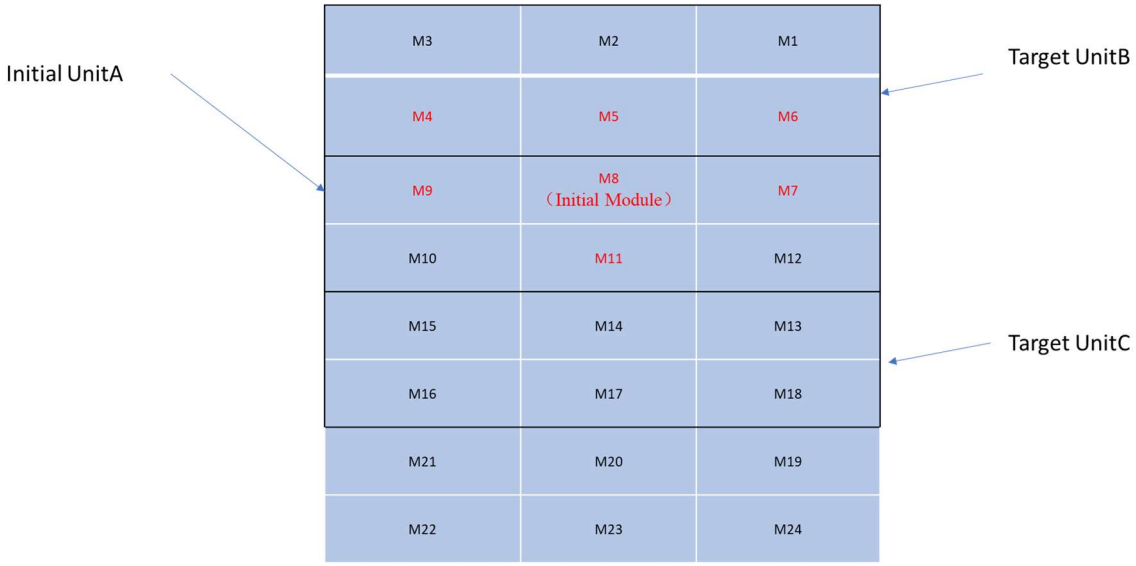


Figure 2. Test site setup diagram with separation distance. (Front view)



For the purpose of this test, the modules were numbered according to the electrical continuity.

In Initial Unit A, modules numbers from M7 to M12.

In Target Unit B, modules numbers from M1 to M6 which was the target unit situated above the Initial Unit A.

In Target Unit C, modules numbers from M13 to M18 which was the target unit situated below the Initial Unit A.

See Figure 3.

4 complete modules were used for unit A (M7 to M9 and M11).

3 complete modules were used for unit B (M4 to M6) to check the possible propagation form unit to unit.

Empty modules without cells were used for the other modules.

Figure 3. Module numbering in units showing fully populated modules in red.

M3	M2	M1
M4	M5	M6
M9	M8 （Initial Module）	M7
M10	M11	M12
M15	M14	M13
M16	M17	M18
M21	M20	M19
M22	M23	M24

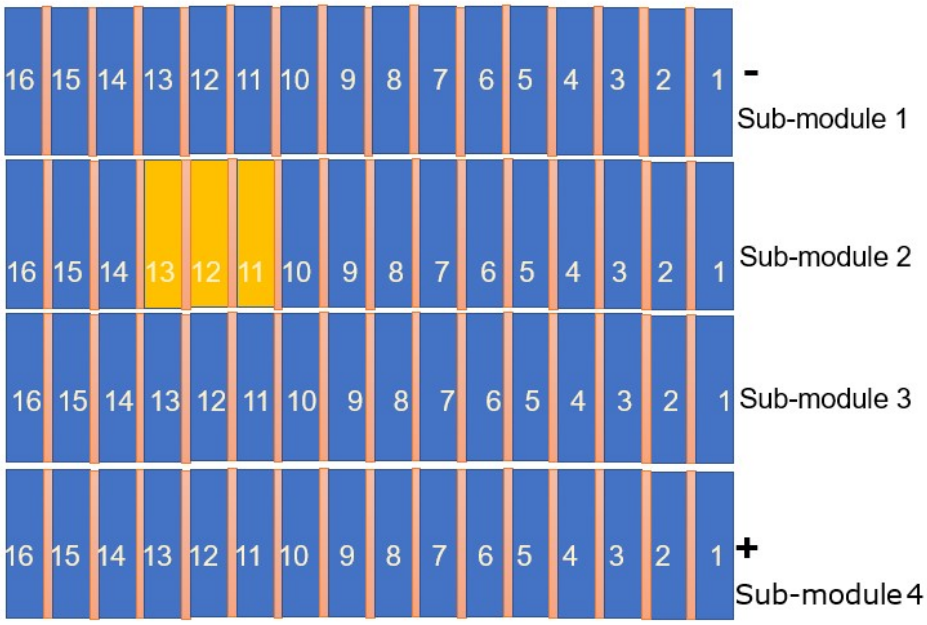
3.3.3 Thermal runaway setup

External heating method, agreed with the client, was used to initiate the thermal runaway within the module.

Module M8 was prepared with two heaters inside. Same as the method in module level test.

For convenient show the temperature condition of internal cells, numbering four lines cells from negative electrode to positive electrode for sub-module 1 to sub-module 4. Numbering cells in every sub-modules from electrodes side to another side for cell 1 to cell 16, see figure 4 for detail.

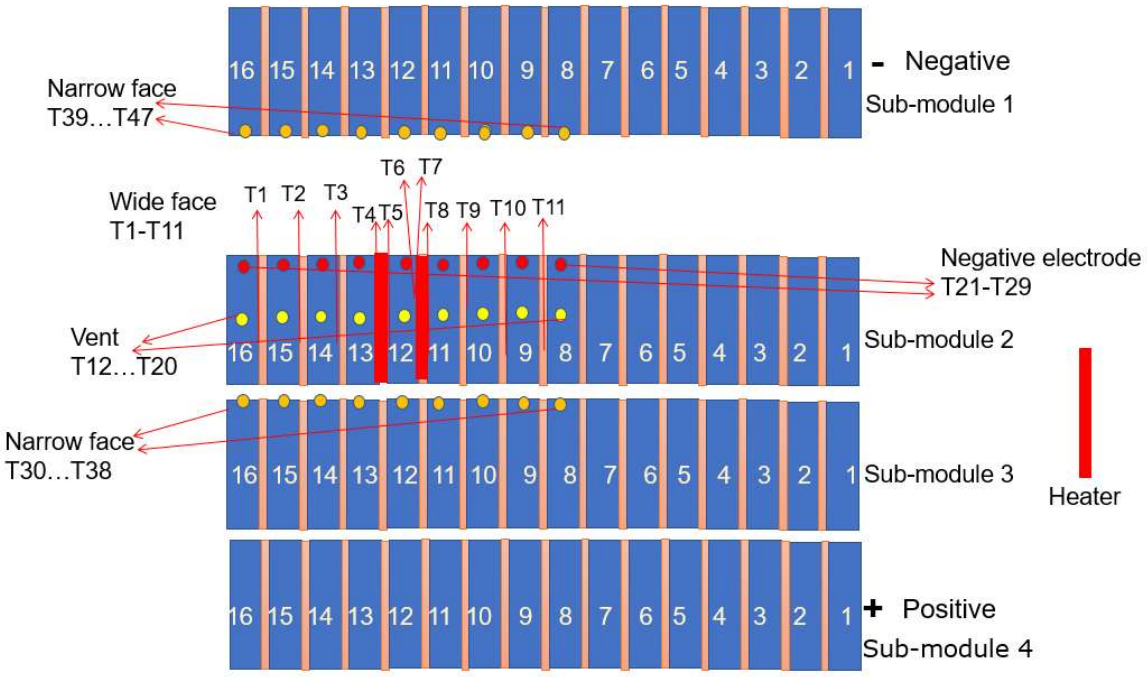
Figure 4. Cell numbering inside the initiating module



Consider the unit level installation and airflow of the liquid cooling in the module. #11, #12 and #13 cells of sub-module 2 were chosen as target cell to be forced into thermal runaway.

The cell #12 was heated by two external heater on each wide side, the cell #11 and cell#13 was heated by one external heater on wide near cell #12. The heater is rated 220VAC/500 W (size 207*174*4mm).

Figure 5. Thermocouples on initiating module M8



In sub-module 1,

9 glass fiber thermocouples (#39-#47) Type K, 24AWG were attached on the #16-#8 cells center of narrow surface near sub-module 2, used to check the possible propagation form cell to cell.

In sub-module 2,

1 glass fiber thermocouples (#T7) Type K, 14AWG was attached on the center of wide surface of #12 cell under heater used to feedback the temperature to the heater controller.

4 glass fiber thermocouples (#T4, #T5, #T6, #T8) were attached on the center of wide surface of #13, #12 and #10 cells under heater used to determine the thermal runaway of initiating cells.

6 glass fiber thermocouples (#1-#3, #9-#11) were attached on the center of wide surface of #16-#14, #10-#8 cells under heater used to check the possible propagation from cell to cell.

8 glass fiber thermocouples (#12-#20) were attached above the vent of #16-#8 cells used to record the venting time.

8 glass fiber thermocouples (#21-#29) were attached on the negative electrode of #16-#8 cells used to observe the temperature change.

In sub-module 3,

9 glass fiber thermocouples (#30-#38) Type K, 24AWG were attached on the #16-#8 cells center of narrow surface near sub-module 2, used to check the possible propagation form cell to cell.

The initiating module M8, Internal voltage sample wire and signal wire covered by glass fiber tube. The BMS control board disabled during test.

Manual control the voltage supply to the heater and maintain a 4°C/min to 7°C/min heating rate. When heater temperature reached to 150°C (T-set), hold about 30min (10:13 to 10:43), then continue to heat and maintain a 4°C/min to 7°C/min heating rate.

Once thermal runaway was observed, the heaters were immediately de-energized.
One thermocouple located below the heater at the center of #12 cell surface was used to feedback the temperature to the controller.

Voltage of the module are monitored during test.

The units was located under the smoke collection hood of the calorimeter measurement system.

3.4 Observations and records

Before the test, the initiating module was charged to 100% SOC and allowed to stabilize for a minimum of 1 h and a maximum of 8 h before the start of the test.

The ambient condition at the initiation of the test was 25°C, 66% RH.

The voltage of the modules was recorded as below:

Figure 6: Voltage record of cells during the test

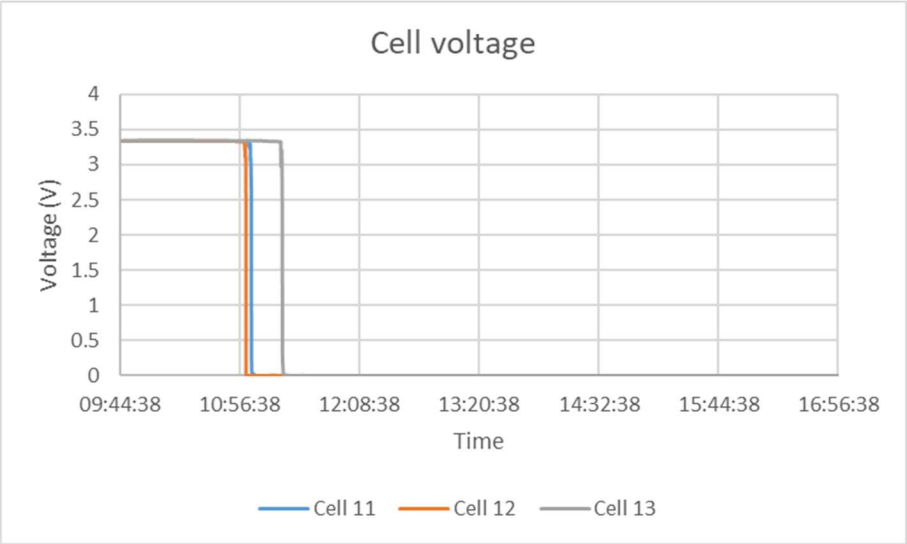
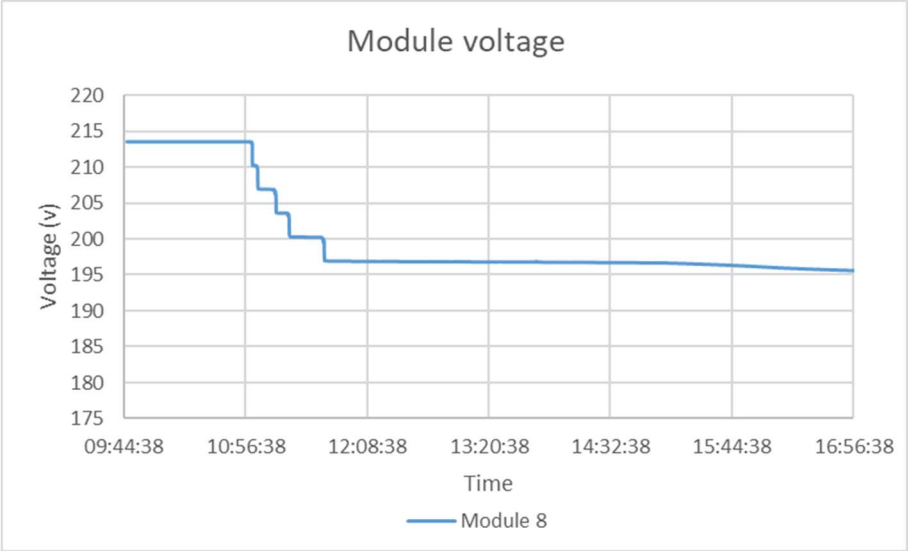


Figure 7: Voltage record of modules during the test



Tests were performed on Sep 02, 2022, started at 09:50 AM.

Observations during the test:

Audible pop was heard on 10:55 AM (the pressure relief valve burst), followed by smoke release after several seconds.

A large amount of white smoke was observed after thermal runaway.

Cell to cell propagation was observed in the initial model.

Module to module propagation was not observed.

No flying debris or explosive discharge of gases observed during test.

No sparks, electrical arcs, or other electrical events observed during test.

No external flaming was observed during the test.

Observations after the test:

No damage and contamination on the instrument walls.

No damage and contamination on the modules of target units.

The plastic top enclosure near the initial cell of module M8 was melted and significantly damaged. Module voltage of M8 was 194.8 Vdc.

Five cells inside the initial module M8 were damaged. Cell to cell propagation were observed on cells #14, #15 of sub-module 2 after receiving thermal energy from cell #13. Voltage measured on each remaining undamaged in other sub-modules were 3.33Vdc.

Weight loss of the initiating module was 1.5 kg (before test 401.5kg, after test 400.0kg)

See photos in page 44~49.

3.5 Temperature measurements

3.5.1 Temperature measurement of initiating cells

Surface temperature of cells #8 - #16 of sub-module 1 to sub-module 3 was recorded during the test. Cell to cell propagation occurred during the test. See Figure 8 for the temperature vs time curve.

Cell thermal runaway occurred on cell #12, #13, #11 in turn at around 11:00, 11:03, 11:12 Maximum temperature 566.7°C, 555.1°C, 449.0°C were measured on the cell #12, #13, #11 surface.

Cell to cell thermal runaway propagation occurred on cell #14, #15. Maximum temperature 587.5°C, 512.3°C were measured on the cell #14, #15 surface.

Figure 8. Surface temperatures of thermal runaway cells on module M8 (sub-module 2)

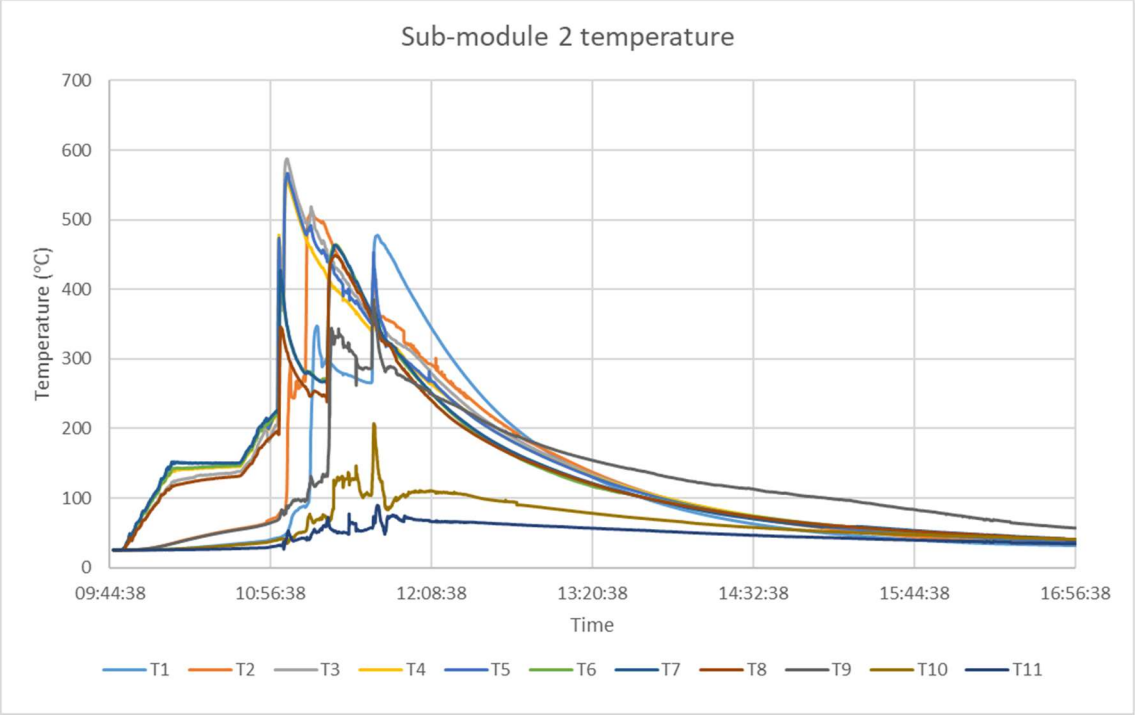


Table 1 Maximum temperature of sub-module 2 cells

Thermocouple no.	Location	Maximum temp.(℃)
T1	Wide surface of Cell #16	477. 9
T2	Wide surface of Cell #15	512. 3
T3	Wide surface of Cell #14	587. 5
T4	Wide surface of Cell #13	555.1
T5	Wide surface of Cell #12	566. 7
T6	Wide surface of Cell #12	464. 7
T7	Wide surface of Cell #12 for feedback	463. 2

T8	Wide surface of Cell #11	449. 0
T9	Wide surface of Cell #10	385. 0
T10	Wide surface of Cell #9	207. 2
T11	Wide surface of Cell #8	89. 9

Cells thermal runaway in sub-module 1 did not occur, maximum temperature see table 2 for detail.

Figure 9. Surface temperatures of no thermal runaway cells on sub-module 1 of module M8

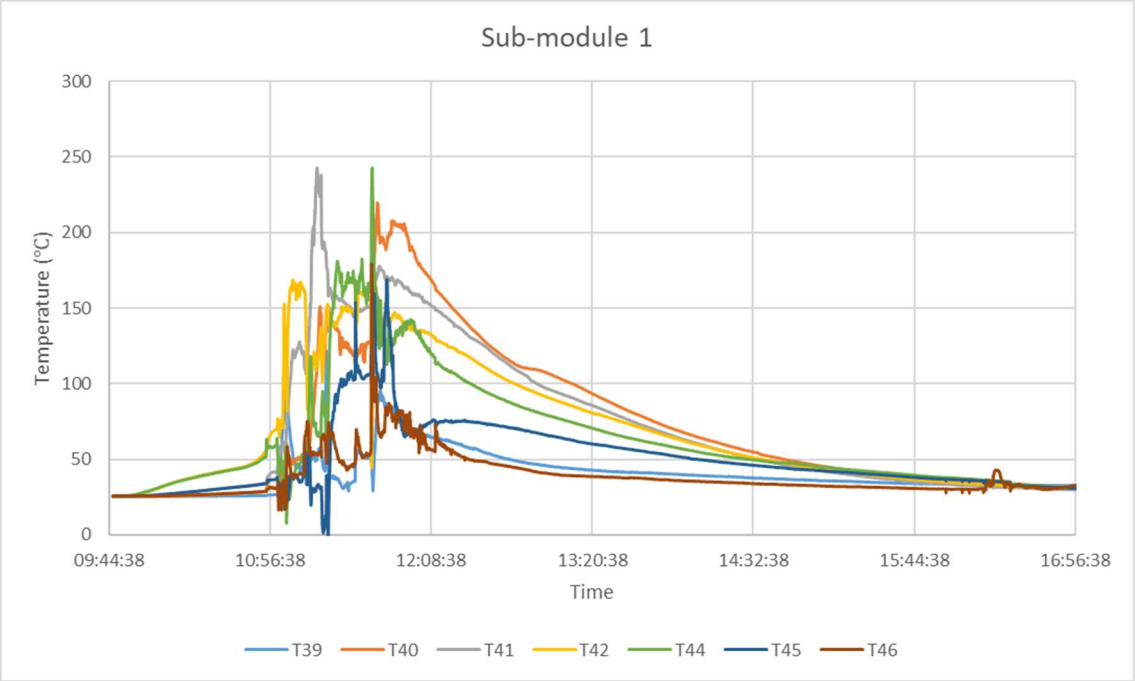


Table 2 Maximum temperature of sub-module 1 cells

Thermocouple no.	Location	Maximum temp.(℃)
T39	Narrow surface of cell #16	120.7
T40	Narrow surface of cell #15	219.6
T41	Narrow surface of cell #14	242.8
T42	Narrow surface of cell #13	168.8
T43	Narrow surface of cell #12	--
T44	Narrow surface of cell #11	242.7
T45	Narrow surface of cell #10	169.0
T46	Narrow surface of cell #9	179.2
T47	Narrow surface of cell #8	-

Note: #T43, 47 thermocouples may be damaged during test.

Cells thermal runaway in sub-module 3 did not occur, maximum temperature see table 3 for detail.

Figure 10. Surface temperatures of no thermal runaway cells on sub-module 3 of module M8

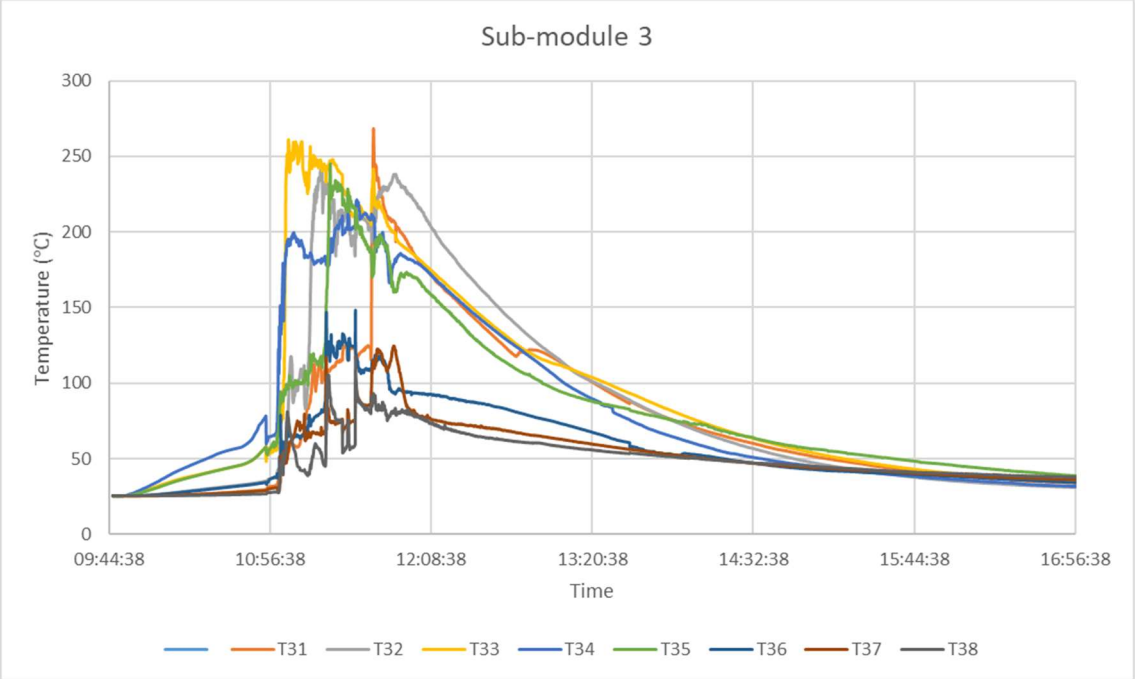


Table 3 Maximum temperature of sub-module 3 cells

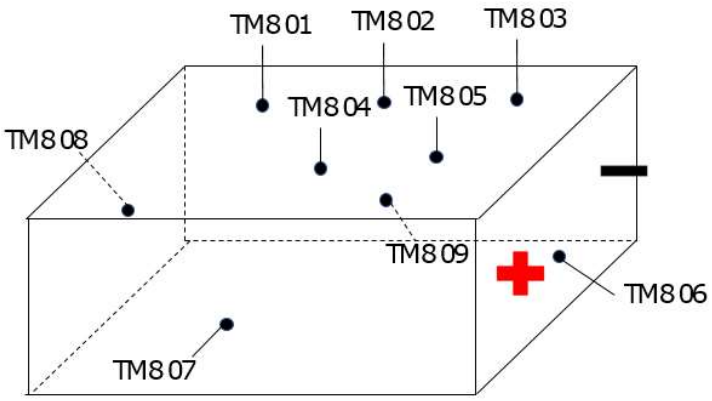
Thermocouple no.	Location	Maximum temp.(℃)
T30	Narrow surface of cell #16	--
T31	Narrow surface of cell #15	268.4
T32	Narrow surface of cell #14	241.5
T33	Narrow surface of cell #13	261.0
T34	Narrow surface of cell #12	221.3
T35	Narrow surface of cell #11	244.7
T36	Narrow surface of cell #10	148.3
T37	Narrow surface of cell #9	124.5
T38	Narrow surface of cell #8	116.7

Note: #T30 thermocouples may be damaged during test.

3.5.2 Temperature measurement of units

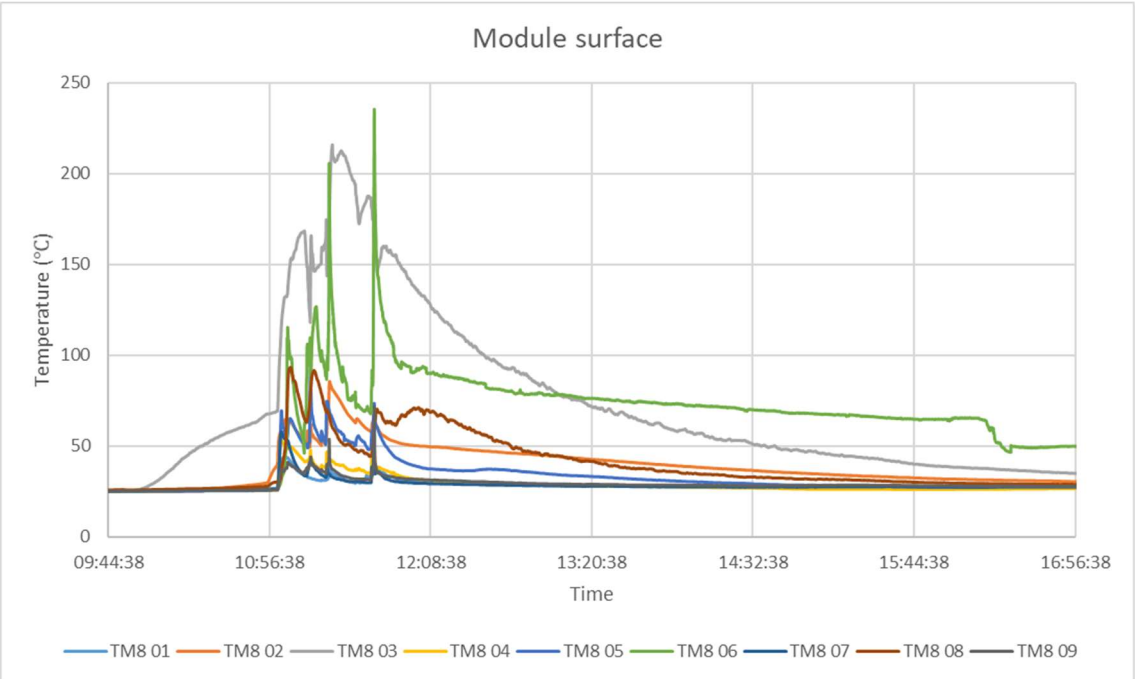
9 glass fiber insulated thermocouples (TM8 01~TM8 09), Type K, 24 AWG was attached on the external surface of module M8, as below Figure 8.

Figure 11. Thermocouple of module M8 surface



TM8 01~TM8 03 located on top surface above cell in sub-module2. TM8 04, TM8 05 located on top surface above cell in sub-module 3. TM8 06 located on front of module (electrode side), TM8 07 located on the left side surface, TM8 08 located on the rear side, TM8 09 located on the right side surface. Maximum temperature 235.5°C was measured on top of the module near #12 cell.

Figure 12. Surface temperatures of initiating module M8

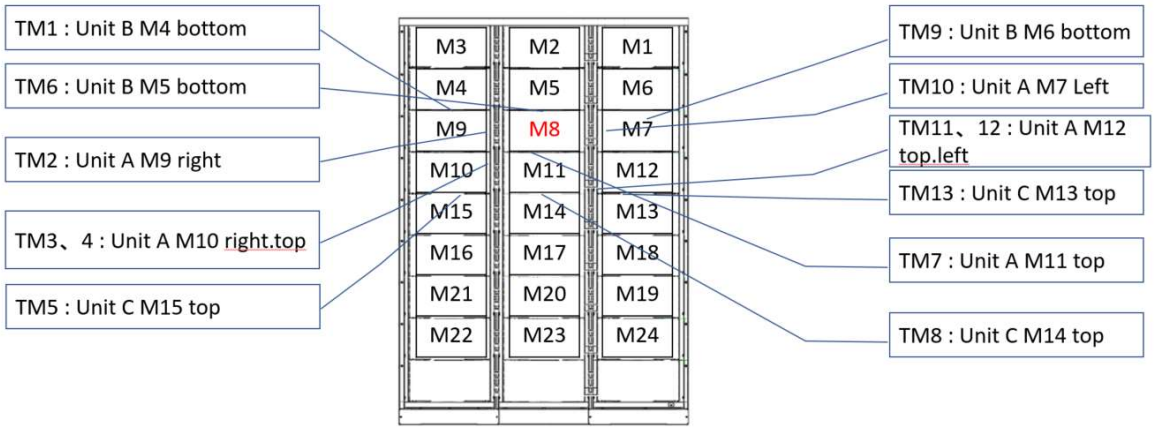


13 glass fiber insulated thermocouples (TM1 to TM13), Type K, 24 AWG were attached to the center of the top surface of modules M4 to M15.

Maximum temperature 30.5°C was measured on bottom surface of the module M5 of Unit B.

Maximum temperature 30.8°C was measured on top surface of the module M14 of Unit C.

Figure 13. Thermocouple location on modules in units A,B,C (Rack 1)



View direction: towards instrument wall A with reference to Figure 2

Figure 14. Surface temperatures of modules from M4 to M15

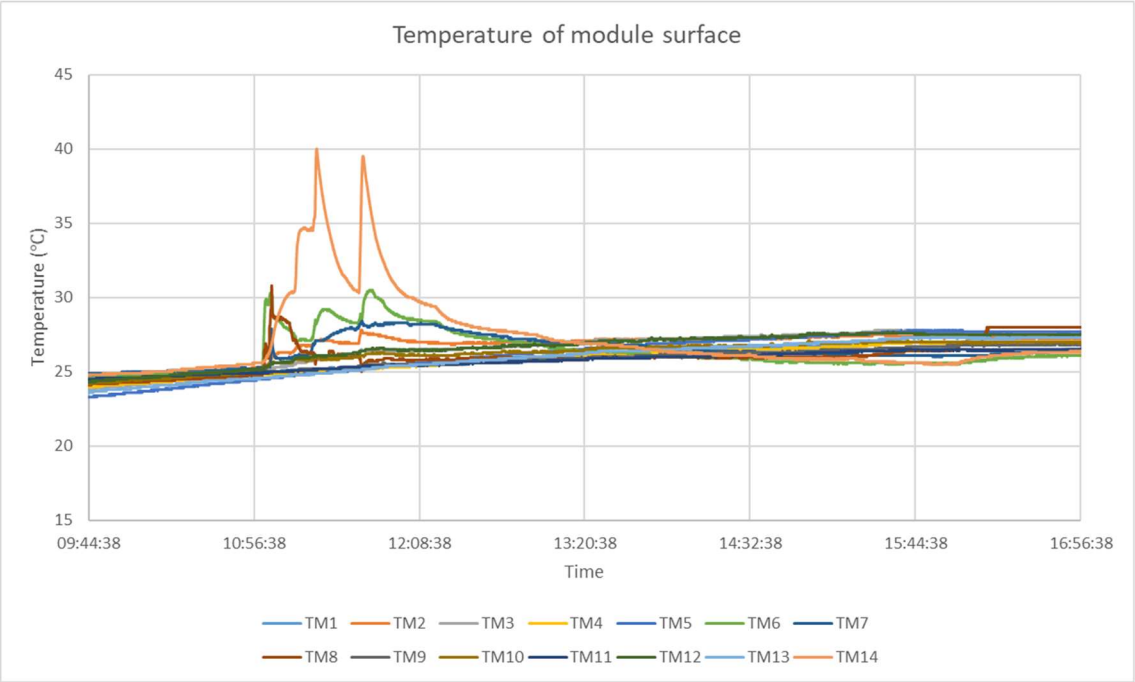


Figure 15. Thermocouple location on the back side of Wall A

View direction: from instrument wall A with reference to Figure 2

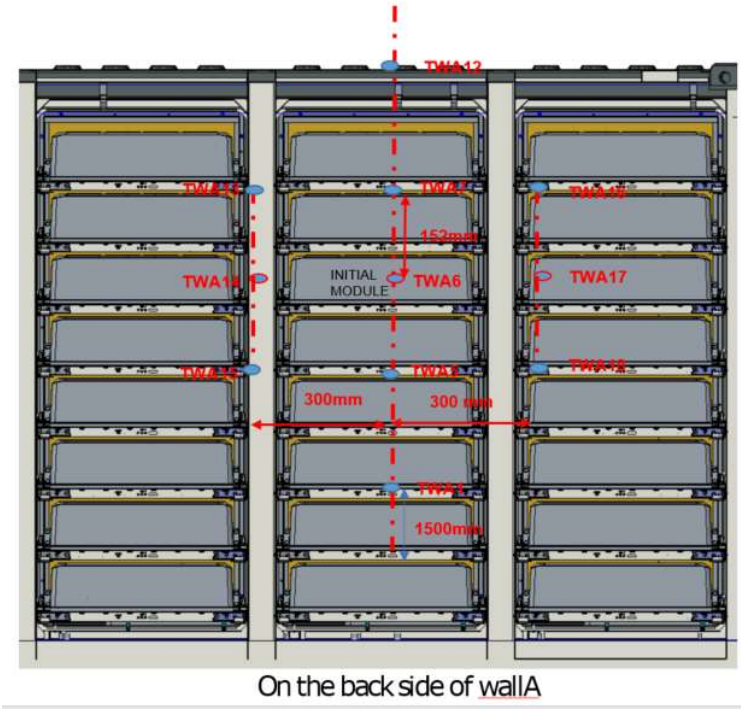
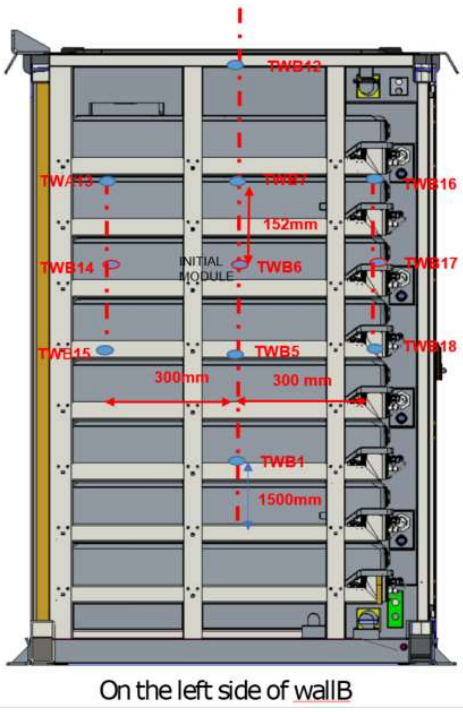


Figure 16. Thermocouple location on the left side of wall B

View direction: towards instrument wall B with reference to Figure 2



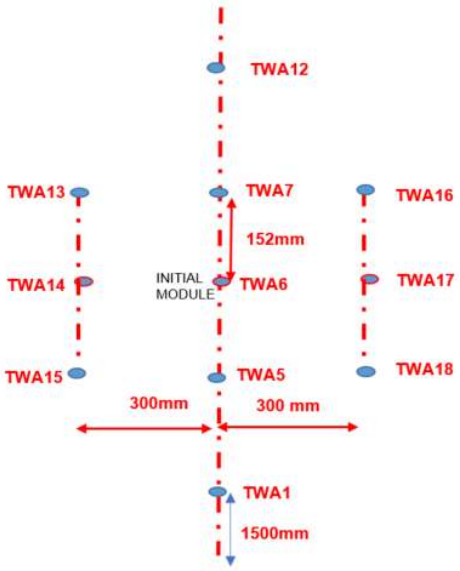
3.5.3 Temperature measurement of instrumented walls

Wall surface temperatures were measured in vertical arrays at 152 mm intervals for the full height of the instrumented wall sections using Type K, 30 AWG thermocouple. The thermocouple arrays were collinear with the centre line of Initial Unit A. The red line in Figure 12 shows the thermocouple arrays on the wall.

The first thermocouple starts from 1500 mm from ground. Total 36 thermocouples were used for each array. The thermocouples were numbered from low to high as TWA1 to TWA18 for wall A and TWB1 to TWB18 for wall B.

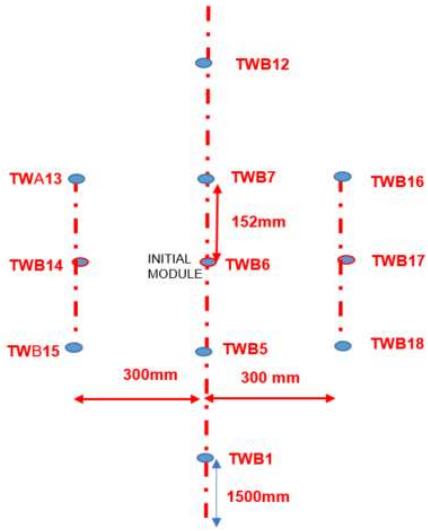
Figure 17. Vertical position of the thermocouples on the wall

Instrumented wall A



View direction: towards instrument wall A with reference to Figure 2

Instrumented wall B



View direction: towards instrument wall B with reference to Figure 2

Additional 6 thermocouples were positioned horizontally near the initial module M8 300 mm away from the vertical array each side, on instrumented wall A and wall B. See Figure 18.

Maximum temperature measured on instrument wall A was 24.3°C at TWA13, temperature curve see figure 19 for detail.

Maximum temperature measured on instrument wall B was 23.9°C at TWB3, temperature curve see figure 20 for detail.

Figure 18. Horizontal position of the thermocouples on the wall A and wall B

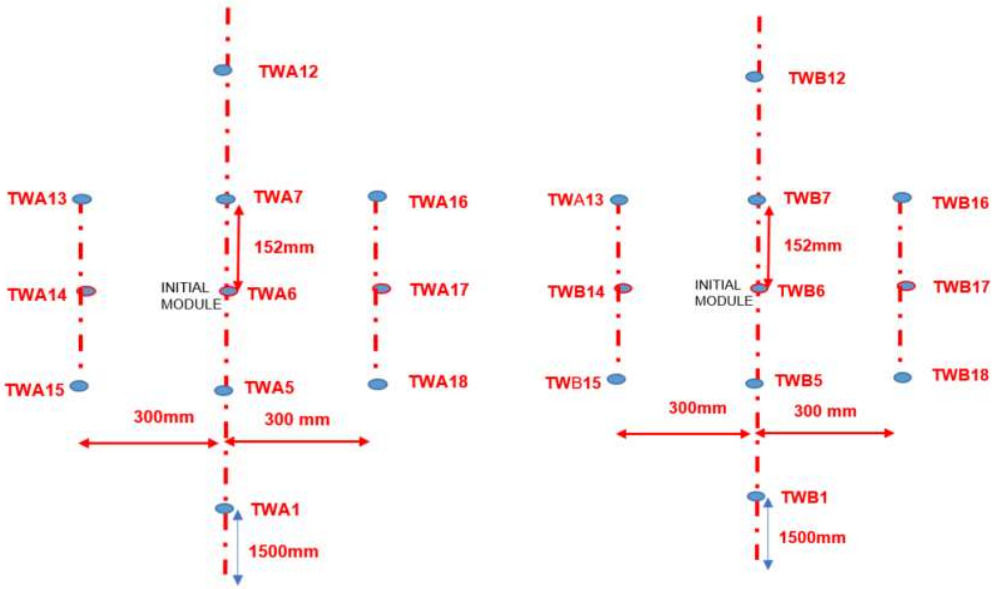


Figure 19. Temperatures on instrument wall A.

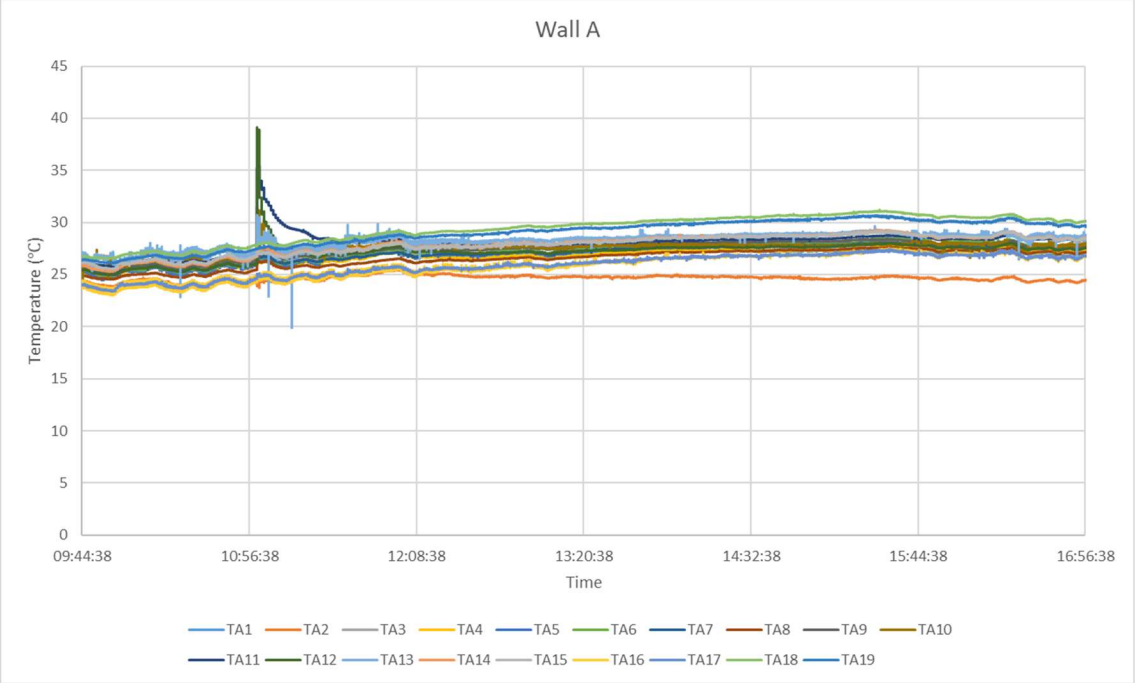
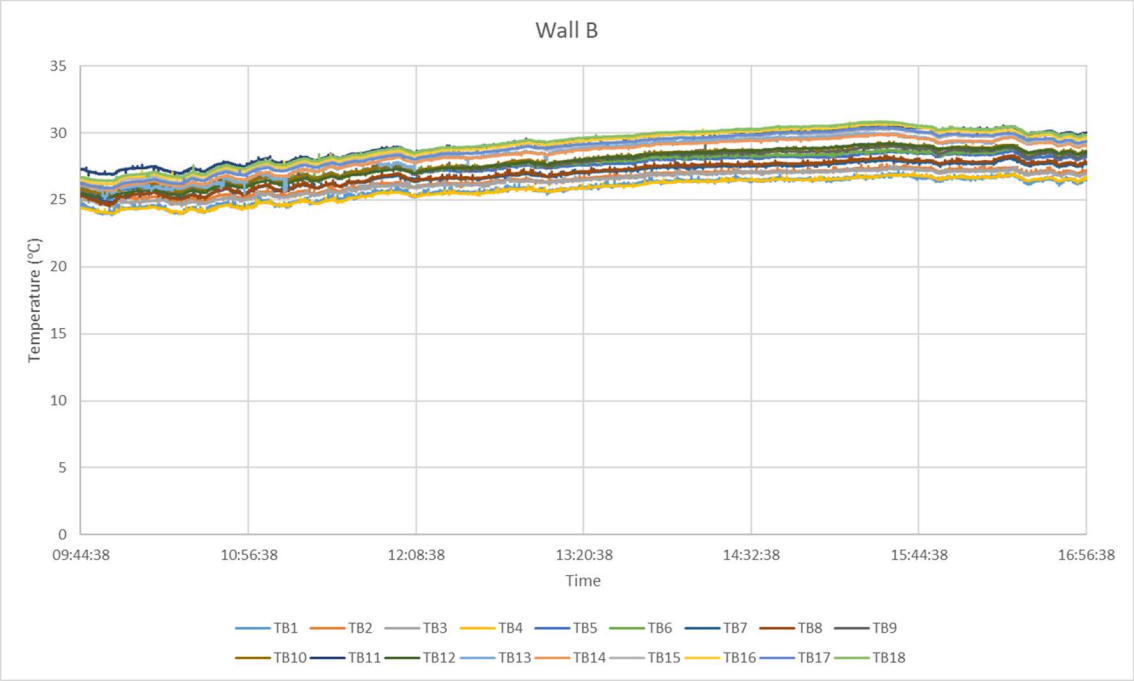


Figure 20. Temperatures on instrument wall B.



3.6 Heat flux measurement

Two sensors were placed on the surface of instrumented wall A, wall B and adjacent unit A that faces the initiating unit.

The sensors were collinear with the vertical thermocouple array. One was positioned at the height equivalent to module M8 top edge, which was estimated to receive the greatest heat flux due to the thermal runaway of the initiating module within the initiating unit. Another was positioned at the height equivalent to module M11 top edge, which was estimated to receive the greatest surface heat flux due to the thermal runaway of the initiating unit.

Figure 21 shows the positions of the sensors. Sensor H1 & H2 were positioned at unit A; H3&H4 were positioned at wall A, H5&H6 were positioned at wall B, All sensors were numbered from low to high.

Measured heat flux of target wall and target units are zero.

Figure 21. Heat flux sensor locations on unit

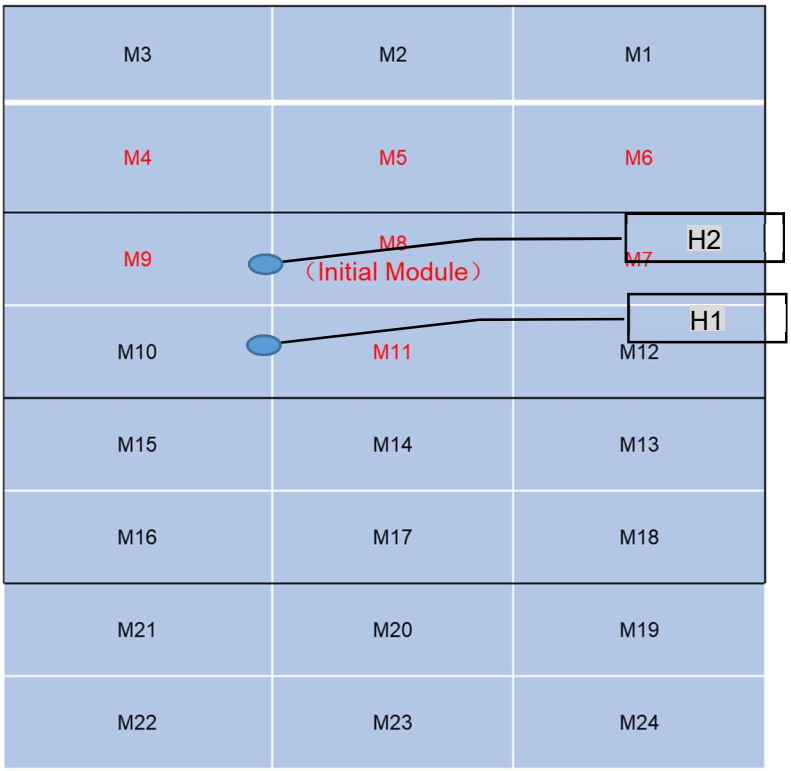
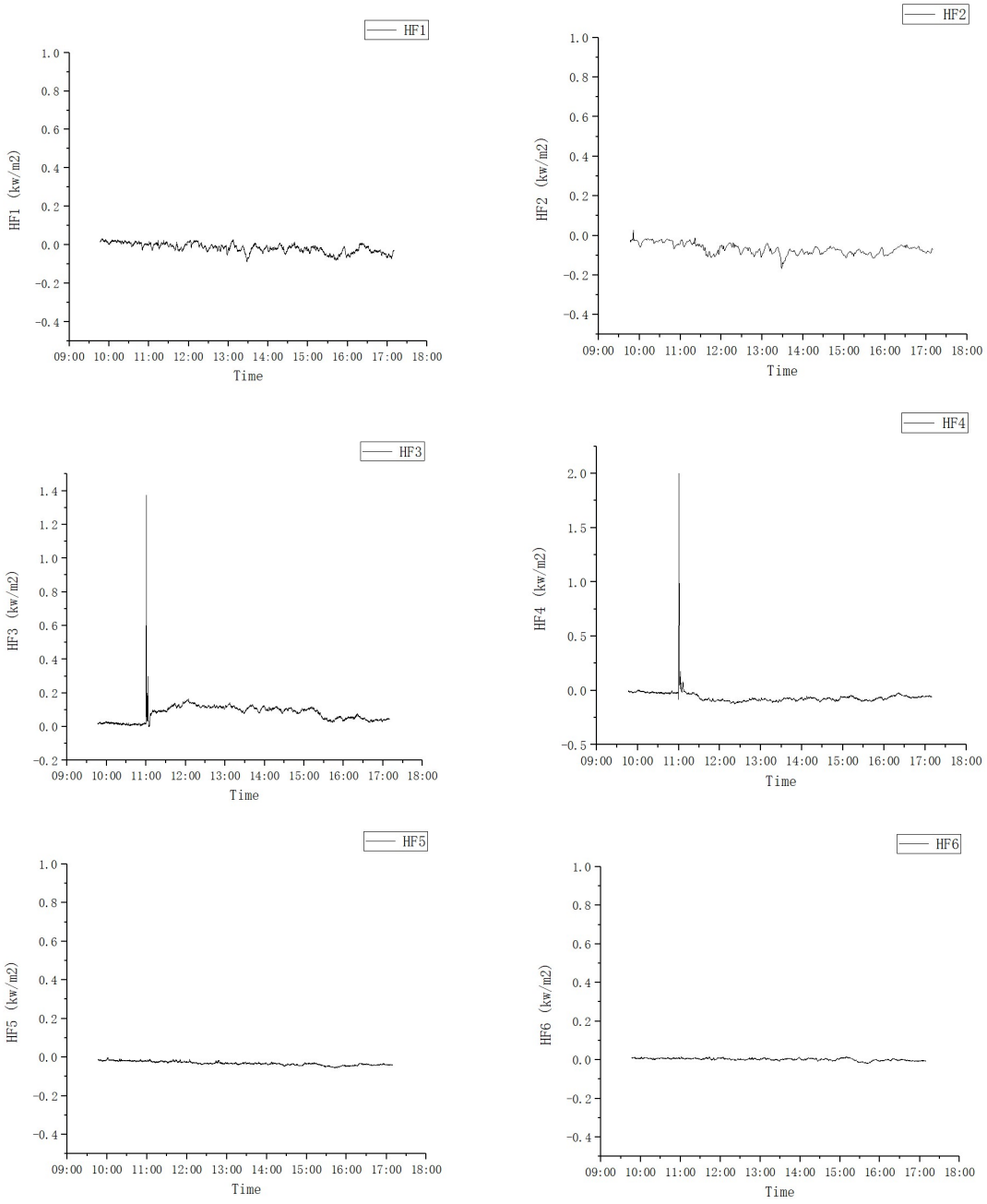


Figure 22. Measured heat flux of target wall and target units



3.7 Chemical heat release rate measurement

The chemical heat release rates were measured by an oxygen consumption calorimeter measurement system consisting of a paramagnetic oxygen analyzer, non-dispersive infrared carbon dioxide and carbon monoxide analyzer, velocity probe, and a Type K thermocouple.

The instrumentations are located in the exhaust duct of the heat release rate calorimeter.

The chemical heat release rate was calculated at each of the flows as follows:

$$HRR_1 = \left[E \times \varphi - (E_{co} - E) \times \frac{1-\varphi}{2} \times \frac{X_{co}}{X_{O_2}}\right] \times \frac{\dot{m}_e}{1+\varphi \times (\alpha - 1)} \times \frac{M_{O_2}}{M_a} \times (1 - X^o_{H_2O}) \times X^o_{O_2}$$

In which:

HRR_t = *total heat release rate, as a function of time (kW)*

E = *Net heat released for complete combustion per unit of oxygen consumed (adjusted for oxygen contained within cell chemistry, 13,100 kJ/kg)*

E_{CO} = *Net heat released for complete combustion per unit of oxygen consumed, for CO (adjusted for oxygen contained within cell chemistry, 17,600 kJ/kg)*

φ = *Oxygen depletion factor (non-dimensional), where:*

$$\varphi = \frac{X^o_{O_2} \times [1 - X_{CO_2} - X_{CO}] - X_{O_2} \times [1 - X^o_{CO_2}]}{X^o_{O_2} \times [1 - X_{O_2} - X_{CO_2} - X_{CO}]}$$

X_{CO} = *Measured mole fraction of CO in exhaust flow (non-dimensional)*

X_{CO_2} *Measured mole fraction of* CO_2 *in exhaust flow (non-dimensional)*

$X°_{CO_2}$ = *Measured mole fraction of* CO_2 *in incoming air (non-dimensional)*

$X°_{H_2O}$ = *Measured mole fraction of* H_2O *in incoming air (non-dimensional)*

X_{O_2} = *Measured mole fraction of* O_2 *in exhaust flow (non-dimensional)*

$X°_{O_2}$ = *Measured mole fraction of* O_2 *in incoming air (non-dimensional)*

α = *Combustion expansion factor (non-dimensional; normally a value of 1.105)*

M_a = *Molecular weight of incoming and exhaust air (29 kg/kmol)*

M_{O_2} = *Molecular weight of oxygen (32 kg/kmol)*

$\dot{m}_e$ = *Mass flow rate in exhaust duct (kg/s), in which:*

$$\dot{m}_e = C \times \sqrt{\frac{\Delta p}{T_e}}$$

or

$$\dot{m}_e = 26.54 \times \frac{A \times k_c}{f(\mathrm{Re})} \times \sqrt{\frac{\Delta p}{T_e}}$$

C = Orifice plate coefficient (in $kg^{1/2}m^{1/2}K^{1/2}$)

Δp = Pressure drop across orifice plate or bidirectional probe (Pa)

T_e = Combustion gas temperature at orifice plate or bidirectional probe (K)

A = Cross sectional area of the duct (m^2)

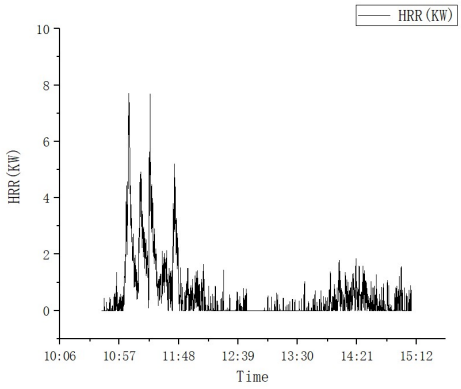
k_c = Velocity profile shape factor (non-dimensional)

$f(Re)$ = Reynolds number correction (non-dimensional)

The heat release rate measurement system was calibrated at 50kW and 70kW heat release rate using a standard propane burner before the test. The calibrations were performed using flows of 1078mg/s and 1510mg/s of propane.

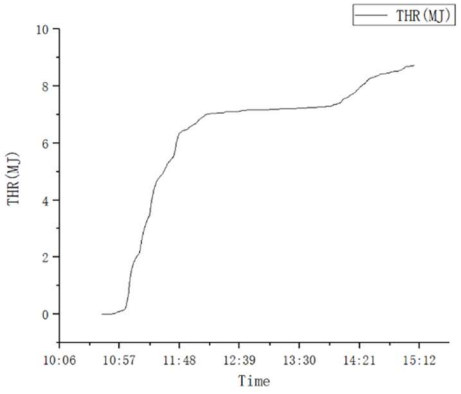
Measured peak chemical heat release rate HRR_t was 7.713kW

Figure 23. HRRt curve



Measured total heat release THR through the test was 8.736 MJ

Figure 24. THR curve



3.8 Convective heat release rate measurement

The convective heat release rate was measured using thermopile, a velocity probe, and a Type K thermocouple, located in the exhaust system of the exhaust duct.
The convective heat release rate was calculated at each of the flows as follows:

$$HRR_c = V_e A \frac{353.22}{T_e} \int_{T_o}^{T} C_p dT$$

Where:

HRR_c = The convective heat release rate (kW)

V_e = The exhaust velocity (m/s)

A = The exhaust duct cross sectional area (m^2)

T_e = The temperature at the location where exhaust velocity is measured (K)

$353.22/T_e$ = The density of air at the velocity measurement location (kg/m^3)

T_o = The ambient temperature (K) in the test room

T = The thermopile temperature (K)

$$\int_{T_o}^{T} C_p dT = A_0(T - T_o) + A_1/2(T^2 - T_o^2) + A_2/3(T^3 - T_o^3) + A_3/4(T^4 - T_o^4)$$

Cp = Specific heat of air (kJ/kg-K), given as $C_p = A_0 + A_1T + A_2T^2 + A_3T^3$, where:

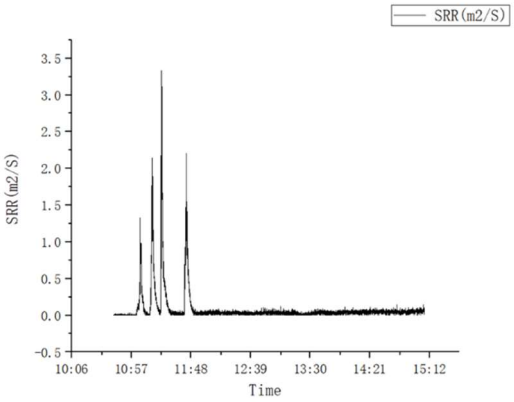
A_0 = 0.9950

A_1 = -5.29933E-05

A_2 = 3.21022E-07

A_3 = -1.22004E-10

Figure 25. Peak smoke release rate SRR: 3.339 m2/s



3.9 Gas generation measurement

The composition, velocity and temperature of the vent gases were measured within the calorimeter's exhaust duct.

Gas compositions were measured using a Fourier-Transform Infrared Spectrometer with a resolution of 1 cm^{-1} and a path length of 4.2 m within the calorimeter's exhaust duct.

The total hydrocarbon content of the vent gas was measured using flame ionization detection.

Hydrogen gas was measured with electrochemical method.

Composition, velocity and temperature measurement instrumentation were collocated with heat release rate calorimetry instrumentation.

3.9.1 Total gas release

The flow rates of various gases were integrated over the test duration and the total cumulative volume of gas calculated for the total test duration (09:50 ~ 16:53) was presented in the below table.

The total cumulative volume of gases before cell venting (09:50 ~ 10:55) was also presented in the table for reference. Which may be considered as ambient gases background before the test.

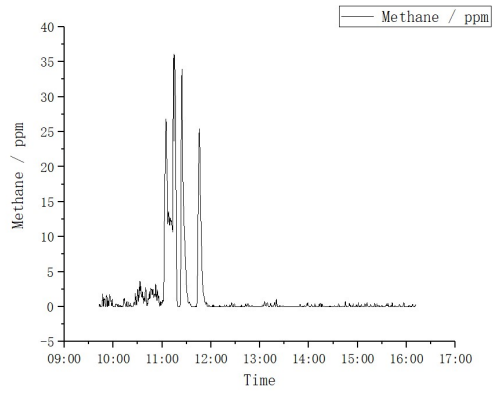
Gas type	Gas components		Total volume of gas (L)	
			Before cell venting	Throughout the test
Hydrocarbon species	Methane	CH_4	1.40	54.56
	Acetylene	C_2H_2	0.90	4.10
	Ethylene	C_2H_4	0.87	35.04
	Ethane	C_2H_6	0.33	20.06
	Propane	C_3H_8	0.18	32.23
Hydrogen halide species	Hydrogen Cyanide	HCN	0.04	3.80
	Hydrogen Fluoride	HF	0.00	4.43
Nitrogen containing species	Nitrogen Monoxide	NO	0.1	29.1
	Nitrous Oxide	N_2O	1.34	21.62
Others	Carbon Monoxide	CO	0.00	115.10
	Carbon Dioxide [2)]	CO_2	896.00	6112.00
	Hydrogen	H_2	0.00	71.39
	Oil as octane	--	0	25.3
	Formaldehyde	CH_2O	0.01	0.37
	Methanol	CH_4O	0.46	10.27
Total Hydrocarbons (equivalent to C_3H_8, measured by FID)				1547.57

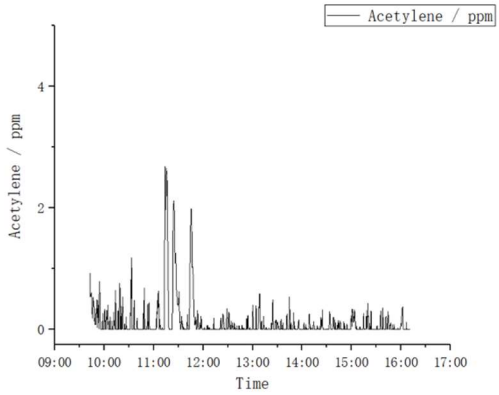
Note:
1) The collection time is from 09:50 to 16:53;
2) The carbon dioxide in the air during this period1) was also counted;
3) 3) The Hydrogen was measured by palladium nickel thin film solid state sensor.

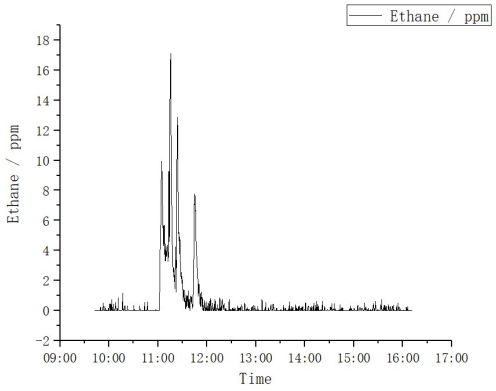
3.9.2 Gas components

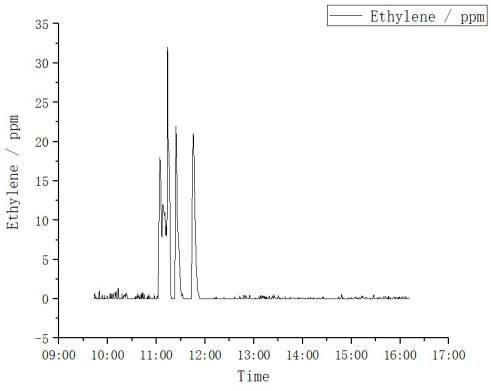
Concentrations of the gases were scaled based on the measured flow rate of the exhaust system and were presented in the standard volume flow rate of gas ventilated in below figures.

Figure 26. Hydrocarbon species









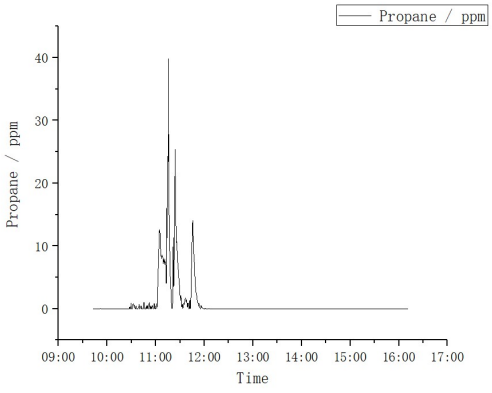


Figure 27. Hydrogen halide species

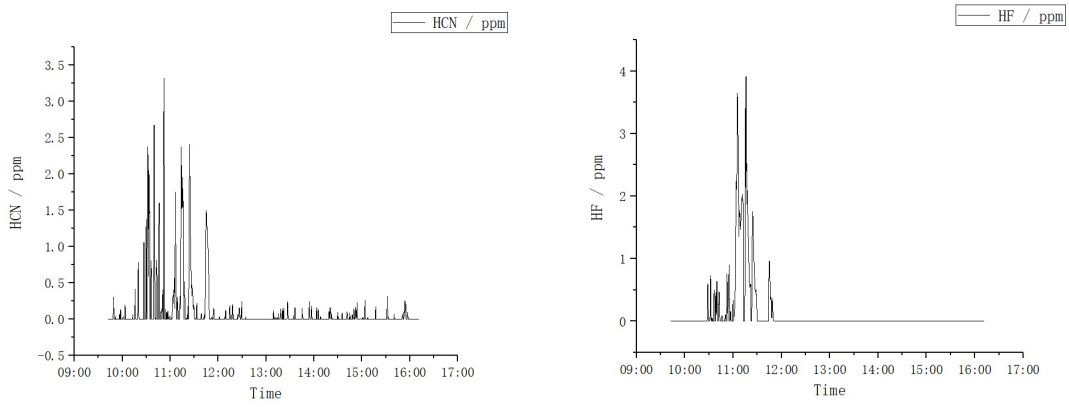


Figure 28. Nitrogen containing species

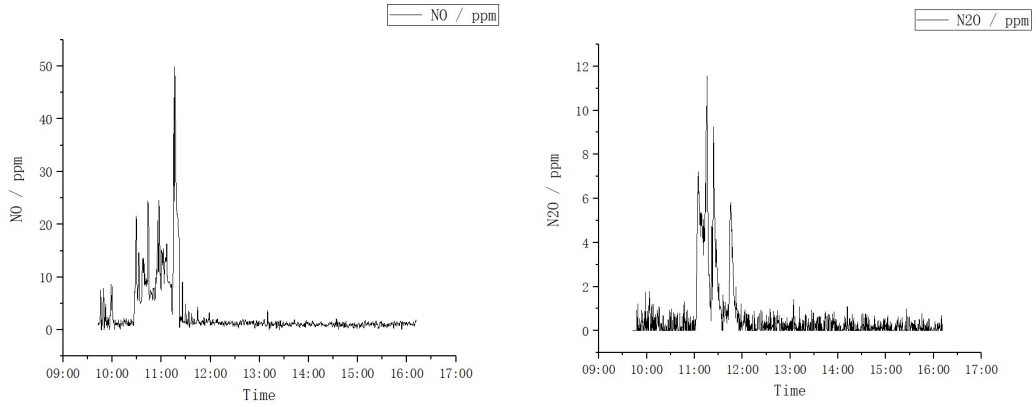


Figure 29. H_2 containing species

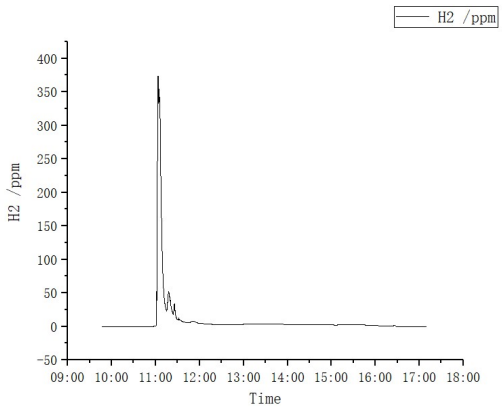
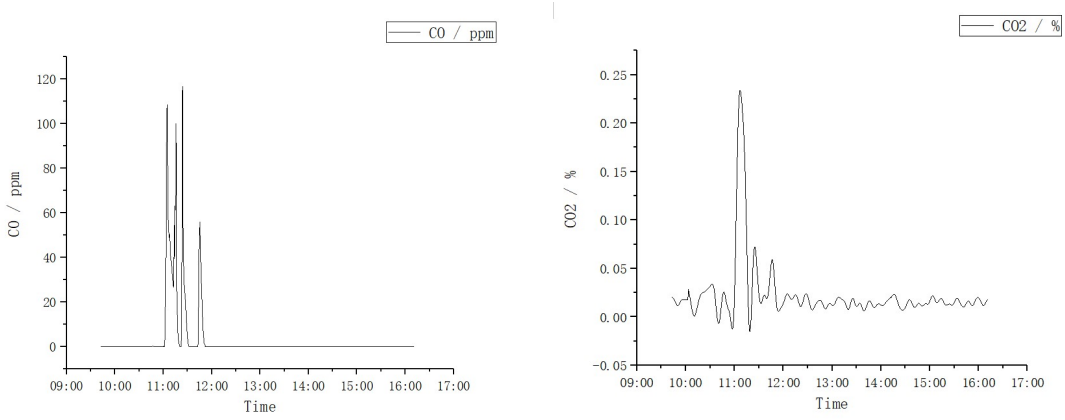


Figure 30. CO, CO_2 containing species



3.10 Photos

Initial module





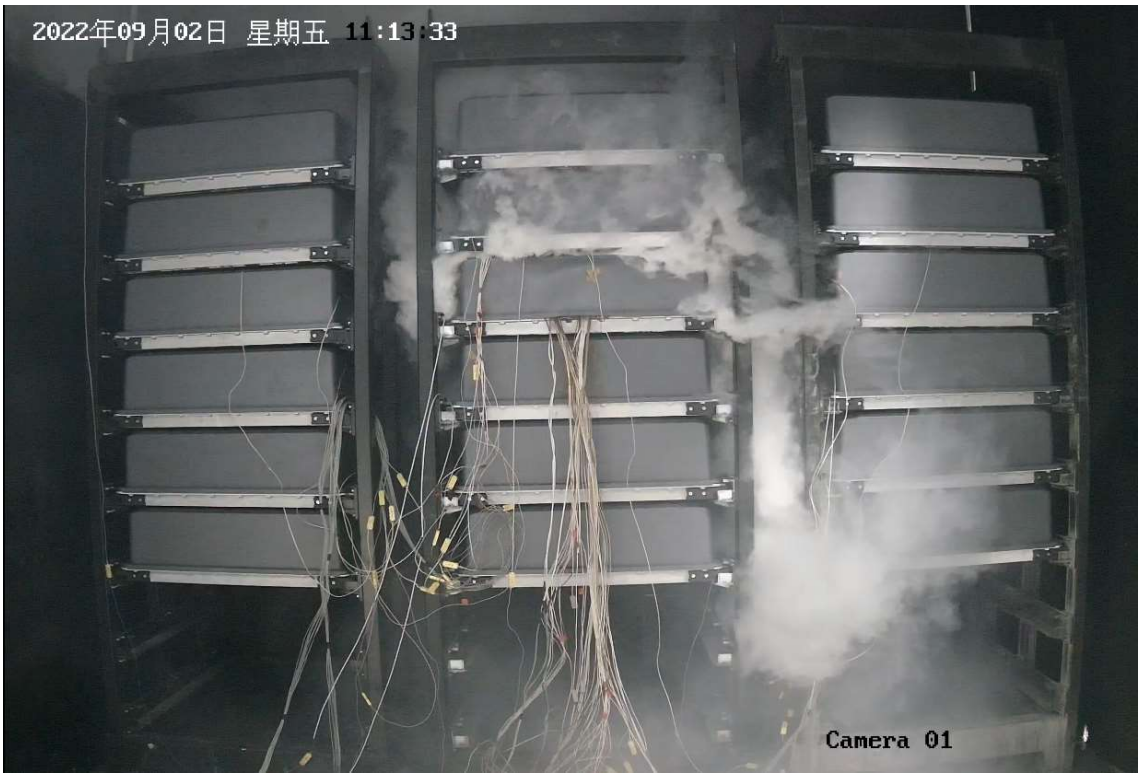
Test setup





Smoke release during the test





Photos after the test





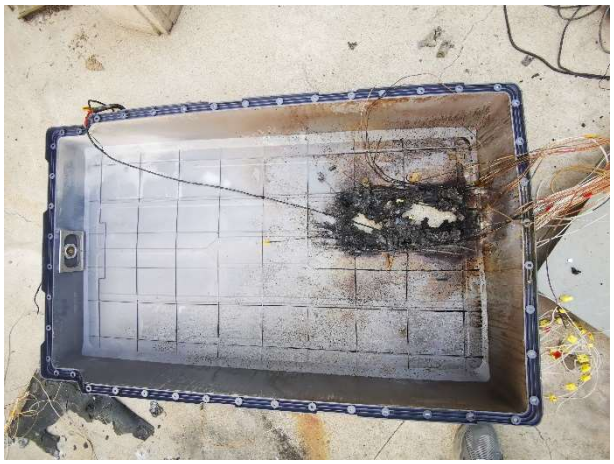




Initial module after test









4 List of Test and Measurement Instruments

No.	Equipment	Model	Rating	Inventory no.	Last Cal. date
1	Ambient temperature and humidity	HWP01-10S	-30℃~50℃, 20%RH~100%RH	12005577	2022.5.16
2	Data acquisition equipment	DAQ970A	3-slot cardcage with 6½ digit (22 bit) internal DMM 0.004%, accuracy 0.06% Vac	TY2020000138	2022.3.5
3	Electronic scale	CHAOOUC1	0-500KG	65960494169	2022.3.9
4	Paramagnetic oxygen analyser	SERVOMEX4100	O2: paramagnetic sensor, range 0-25%, accuracy 0.02%, response time T90 < 7S	ZY2020000018-1	2022.3.9
5	Velocity probe	2671-25L-D-11-G2-E-N	4-20mA output, range 0-250pa, accuracy ± 1% F.S	ZY2020000018-2	2022.4.12
6	Photo detector	PDA36A2	Thorlabs optical receiver, wavelength range (350-1000) mm, gain adjustable, voltage output (0-10) V, instability < 0.1%	ZY2020000018-3	2022.4.12
7	Fourier-Transform Infrared Spectrometer	atmosFIR	Spectral scanning range: 485 - 7500cm-1; Spectral repeatability: < 0.1cm-1	ZY2020000018-5	2022.4.12
8	Non-dispersive infrared carbon dioxide and carbon monoxide sensor	SERVOMEX4100	CO2: infrared sensor, measuring range 0-10%, accuracy 1% F.S, response time T90 < 7S Co: infrared sensor, measuring range 0-1%, accuracy 1% F.S, response time T90 < 8s	ZY2020000018-4	2022.3.9
9	Palladium-nickel thin-film solid state sensor	MODEL 2000	Range: 0-2000ppm, temperature less than 100 C, -90~110kPa	ZY2021000210	2022.4.30
10	Flame ionization detector	3010	Accuracy: 2.0%	19937	2022.3.10

11	Heat flux measurement equipment	MW88-JTC08C	0 ~ ± 99999 w / m2, - 250 ~ 980 ℃, accuracy 5%, response time less than 0.1s,	ZY2020000010	2022.4.13
12	Thermopile	RS-WD-HW-1	0-200 ℃, 4-20mA, response speed < 0.15s	28348141942	2022.4.12
13	Ambient temperature and humidity	HWP01-10S	-30℃~50℃, 20%RH~100%RH	12005577	2022.5.16

End of Test Report

Appendix P

Ruipu Energy Battery Spacing Review Documentation

Prüfbericht-Nr.: *Test Report No.:*	**CN22216G 001**	**Auftrags-Nr.:** *Order No.:*	244371117	**Seite 1 von 54** *Page 1 of 54*
Kunden-Referenz-Nr.: *Client Reference No.:*	2182037	**Auftragsdatum:** *Order date.:*	Nov 01, 2021	
Auftraggeber: *Client:*	Sungrow Energy Storage Technology Co.,Ltd. No.788 Mingchuan Road, Boyan Technology Park, Hi-tech Zone, Hefei City, 230088 Anhui, P.R. China			
Prüfgegenstand: *Test item:*	Battery Rack			
Bezeichnung / Typ-Nr.: *Identification / Type No.:*	R286AL-121, R344AL-121, R573AL-123, R688AL-123			
Auftrags-Inhalt: *Order content:*	Test report			
Prüfgrundlage: *Test specification:*	UL 9540A: 2019 (Fourth Edition)			
Wareneingangsdatum: *Date of receipt:*	Dec 06, 2021			
Prüfmuster-Nr.: *Test sample No.:*	Engineering sample			
Prüfzeitraum: *Testing period:*	Dec 09, 2021 ~ Dec 11, 2021			
Ort der Prüfung: *Place of testing:*	See clause 1.1 of main report			
Prüflaboratorium: *Testing laboratory:*	See clause 1.1 of main report			
Prüfergebnis*: *Test result*:*	See main report			



geprüft von / *tested by:*

March 19, 2022	David Zhou / Engineer	
Datum *Date*	**Name/Stellung** *Name/Position*	**Unterschrift** *Signature*

kontrolliert von / *reviewed by:*

March 19, 2022	Bowen Dong / Reviewer	
Datum *Date*	**Name/Stellung** *Name/Position*	**Unterschrift** *Signature*

Sonstiges / *Other:*

Zustand des Prüfgegenstandes bei Anlieferung: *Condition of the test item at delivery:* **Prüfmuster vollständig und unbeschädigt** Test item complete and undamaged

* Legende:	1 = sehr gut	2 = gut	3 = befriedigend	4 = ausreichend	5 = mangelhalt
	P(ass) = entspricht o.g. Prüfgrundlage(n)		F(ail) = entspricht nicht o.g. Prüfgrundlage(n)	N/A = nicht anwendbar	N/T = nicht getestet
Legend:	1 = very good	2 = good	3 = satisfactory	4 = sufficient	5 = poor
	P(ass) = passed a.m. test specifications(s)		F(ail) = failed a.m. test specifications(s)	N/A = not applicable	N/T = not tested

Dieser Prüfbericht bezieht sich nur auf das o.g. Prüfmuster und darf ohne Genehmigung der Prüfstelle nicht auszugsweise vervielfältigt werden. Dieser Bericht berechtigt nicht zur Verwendung eines Prüfzeichens.

This test report only relates to the a. m. test sample. Without permission of the test center this test report is not permitted to be duplicated in extracts. This test report does not entitle to carry any test mark.

INTRODUCTION

Model fire codes and energy storage system standards require energy storage systems to comply with UL 9540, which in turn requires battery cells and modules to comply with UL 1973. Compliance with these standards reduces the risk of batteries and battery energy storage systems (BESS) creating fire, shock or personal injury hazards. However, they do not evaluate the ability of the BESS installed as intended and with fire suppression mechanisms in place if necessary, from contributing to a fire or explosion in the end use installations.

To address these fire and explosion hazards associated with the installation of a BESS, the fire and other codes require energy storage systems to meet certain location, separation, fire suppression and other criteria. Those codes also provide a means to provide an equivalent level of safety based on large-scale fire testing of anticipated BESS installations.

UL 9540A is intended to provide a test method that can be used as a basis for validating the safety of a BESS installation in lieu of meeting the specific criteria provided in those codes. The data generated can be used to determine the fire and explosion protection required for installation of a BESS.

The test method is initiated through the establishment of a thermal runaway condition that leads to combustion within the BESS. The test method outlined in UL 9540A consists of several steps – cell level testing, module level testing, unit level testing and installation level testing. The cell and module level testing steps are information gathering steps to inform the unit and installation level testing.

The following outlines the information that may gathered as part of the testing:

a) Cell level – An individual cell fails in a manner that leads to thermal runaway and fire through a suitable method such as external heating. Data such as off-gassing contents, temperatures at venting and temperatures at thermal runaway are recorded.

b) Module level – One or more cells within a BESS module fail in the manner determined during the cell level testing. Data such as fire propagation in the module, temperatures on the failed cells and surrounding cells, off-gassing contents and heat release data are gathered.

c) Unit level – A complete BESS is installed surrounded by target (e.g. dummy) BESS and walls separated at a distance as intended in its installation. The module level test is repeated on a module located in the BESS in the most unfavorable location. Data such as temperature within the BESS, on surrounding walls and target BESS; incident heat flux on walls and target BESS; observation of fire propagation from BESS to target units and walls as well as observance of explosions or evidence of re-ignition within the BESS; and heat release and off-gassing contents are gathered.

d) Installation level – This test is a repeat of the unit level test with the test conducted within a test room and with the intended fire suppression system installed as well as any overhead cables (that can lead to fire propagation) installed. This test is intended to validate the fire suppression system for the BESS installation. Data such as temperature within the BESS, on surrounding walls and target BESS; incident heat flux on walls and target BESS; fire propagation from the BESS to target units, walls or overhead cables and any observable explosion incidents or re-ignition within the BESS; and off-gassing contents (if needed) and heat release are gathered.

Contents

1 GENERAL INFORMATION 4

1.1 TEST SPECIFICATION 4
1.2 GENERAL REMARKS 4
1.3 LIST OF ATTACHMENTS 5
1.4 REVISION INFORMATION 5
1.5 DEFINITIONS 6

2 GENERAL PRODUCT INFORMATION 7

2.1 CELL 7
2.1.1 Product information and parameters 7
2.1.2 Cell level test information 8
2.2 MODULE 8
2.2.1 Product information and parameters 8
2.2.2 Diagram with overall dimension 9
2.2.3 Layout of the module contents 9
2.2.4 Configuration diagram of the module 10
2.3 BATTERY SYSTEM (RACK) 11
2.3.1 Manufacture information and model list 11
2.3.2 Product information 12
2.4 PHOTO 14

3 UNIT LEVEL TEST (SECTION 8 OF UL 9540A) 16

3.1 GENERAL 16
3.2 UNIT SAMPLE PREPARATION 17
3.3 SETUP OF THE TEST 18
3.3.1 Battery system installation information 18
3.3.2 Test site setup 18
3.3.3 Thermal runaway setup 21
3.4 OBSERVATIONS AND RECORDS 24
3.5 TEMPERATURE MEASUREMENTS 26
3.5.1 Temperature measurement of initiating cells 26
3.5.2 Temperature measurement of units 29
3.5.3 Temperature measurement of instrumented walls 32
3.6 HEAT FLUX MEASUREMENT 36
3.7 CHEMICAL HEAT RELEASE RATE MEASUREMENT 37
3.8 CONVECTIVE HEAT RELEASE RATE MEASUREMENT 40
3.9 GAS GENERATION MEASUREMENT 41
3.9.1 Total gas release 42
3.9.2 Gas components 43
3.10 PHOTOS 47

4 LIST OF TEST AND MEASUREMENT INSTRUMENTS 53

1 General information

1.1 Test specification

Standard: ANSI/CAN/UL 9540A: 2019 (Fourth Edition)

Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

This report presents the result of unit level tests of UL 9540A: 2019.

All tests were conducted at TUV Rheinland (Shanghai) Co., Ltd. and TUV Rheinland's partner labs that were under supervision of TÜV Rheinland's engineer.

Testing period: Dec 09, 2021 ~ Dec 11, 2021

Refer to Clause 4 for test and measurement instruments.

1.2 General remarks

This report is descriptive and provide the test data only.

The test results presented in this report relate only to the object tested.

This report shall not be reproduced, except in full, without the written approval of the testing laboratory.

Throughout this report a ☐ comma / ☒ point is used as the decimal separator.

1.3 List of attachments

Video records of the test from 2 different directions were provided in .mp4 format.
Complete records were provided in 2 separate documents, file number listed as below:

20211210 Sungrow unit UL9540A video 001.mp4;

20211210 Sungrow unit UL9540A video 002.mp4;

1.4 Revision information

New report, not applicable

1.5 Definitions

CELL – The basic functional electrochemical unit containing an assembly of electrodes, electrolyte, separators, container, and terminals. It is a source of electrical energy by direct conversion of chemical energy.

MODULE – A subassembly that is a component of a BESS that consists of a group of cells or electrochemical capacitors connected together either in a series and/or parallel configuration (sometimes referred to as a block) with or without protective devices and monitoring circuitry.

UNIT – A frame, rack or enclosure that consists of a functional BESS which includes components and subassemblies such as cells, modules, battery management systems, ventilation devices and other ancillary equipment.

BATTERY SYSTEM (BS) – Is a component of a BESS and consists of one or more modules typically in a rack configuration, controls such as the BMS and components that make up the system such as cooling systems, disconnects and protection devices.

BATTERY ENERGY STORAGE SYSTEM (BESS) – Stationary equipment that receives electrical energy and then utilizes batteries to store that energy to supply electrical energy at future time. The BESS, at a minimum consists of one or more modules, a power conditioning system (PCS), battery management system (BMS) and balance of plant components.

a) INITIATING BATTERY ENERGY STORAGE SYSTEM UNIT (INITIATING BESS) – A BESS unit which has been equipped with resistance heaters in order to create the internal fire condition necessary for the installation level test (Section 9).

b) TARGET BATTERY ENERGY STORAGE SYSTEM UNIT (TARGET BESS) – The enclosure and/or rack hardware that physically supports and/or contains the components that comprise a BESS. The target BESS unit does not contain energy storage components, but serves to enable instrumentation to measure the thermal exposure from the initiating BESS.

Note: Depending upon the configuration and design of the BESS (e.g. the BESS is composed of multiple separate parts within separate enclosures), the unit level test can be done at battery system level. In such case, the BESS is be read as BS throughout this report.

NON-RESIDENTIAL USE – Intended for use in commercial, industrial or utility owned locations.

RESIDENTIAL USE – In accordance with this standard, intended for use in one or two family homes and town homes and individual dwelling units of multi-family dwellings.

THERMAL RUNAWAY- The incident when an electrochemical cell increases its temperature through self-heating in an uncontrollable fashion. The thermal runaway progresses when the cell's generation of heat is at a higher rate than the heat it can dissipate. This may lead to fire, explosion and gas evolution.

STATE OF CHARGE (SOC) – The available capacity in a BESS, pack, module or cell expressed as a percentage of rated capacity.

2 General Product Information

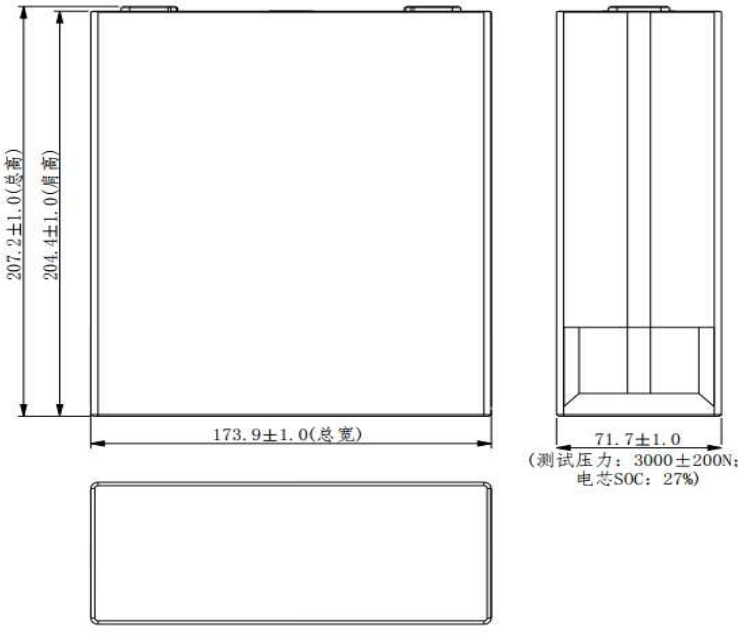
The product information and parameters were provided by the client as below.

2.1 Cell

2.1.1 Product information and parameters

Manufacturer ..... :	Ruipu Energy Co., Ltd.	
Model number ..... :	CB71173204EB	
Chemistry ..... :	LiFePO4	
Physical configuration..... :	Prismatic	
	Weight:	5340±150 g
Electrical rating ..... :	Rated capacity:	280 Ah
	Nominal voltage:	3.2 V
Standard charge method ..... :	Charge current:	280 A
	End of charge voltage:	3.65 V
	Cut off current:	14 A
Standard discharge method ..... :	Discharge current:	280 A
	End of discharge voltage:	2.5 V

Diagram with overall dimension



2.1.2 Cell level test information

Cell level thermal runaway test information is from TUV Rheinland cell level test report CN215HG7 002 provided by the client.

Thermal Runaway Methodology ..... :	External heating method with aluminum heater 1 PCS, rated 220VAC/800W, size 200mm*200mm*20 mm
Average Cell Surface Temperature at Gas Venting..... :	166.08°C
Average Cell Surface Temperature at Thermal Runaway ..... :	299.83°C

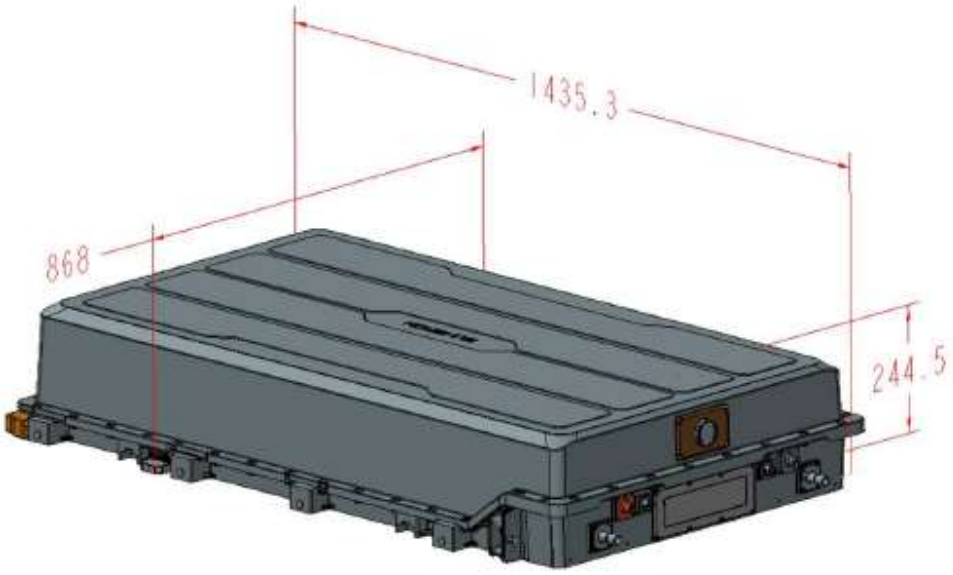
2.2 Module

2.2.1 Product information and parameters

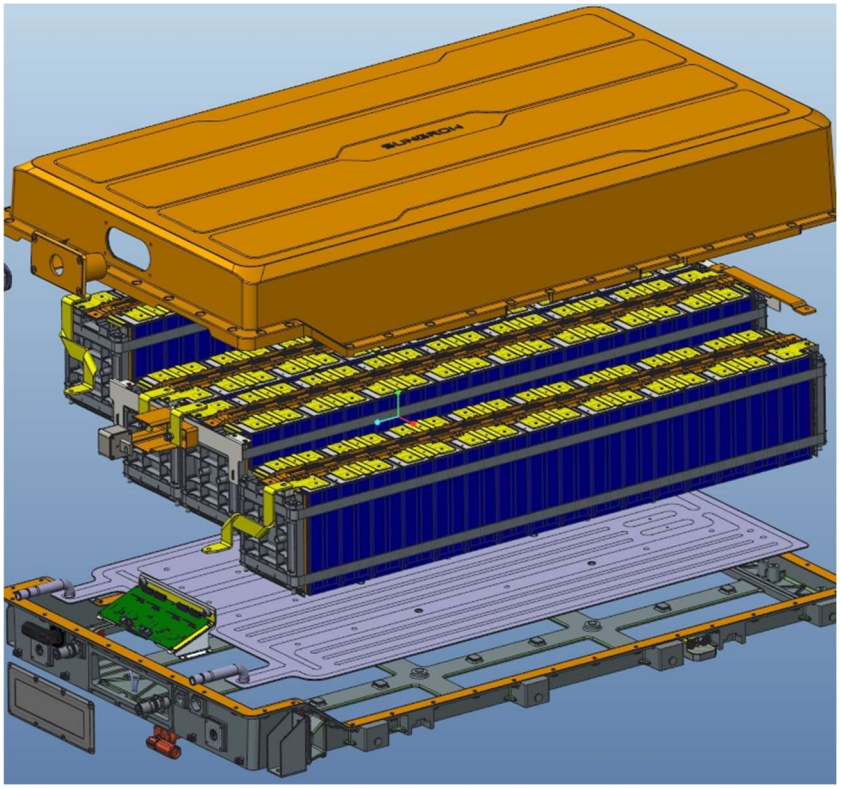
The product information and parameters are provided by the client as below.

Manufacturer name ..... :	SUNGROW ENERGY STORAGE TECHNOLOGY CO., LTD.
Type/Model..... :	P573AL-121, P573BL-121
Physical configuration..... :	Metal enclosure with plastic cover
	Weight: ≤400kg
	Cells in series/parallel: 64 in series
Cooling method ..... :	Liquid Cooling
Separation between cells ..... :	0.45 mm separation between cells by air
Electrical rating..... :	Rated capacity: 280 Ah
	Nominal voltage: 204.8V
Standard charge method ..... :	Charge current: 280 A
	End of charge voltage: 233.6 V
	Cut of current: 14 A
Standard discharge method ..... :	Discharge current: 280 A
	End of discharge voltage: 172.8 V
Compliance with UL 1973..... :	Under certification, not finished

2.2.2 Diagram with overall dimension

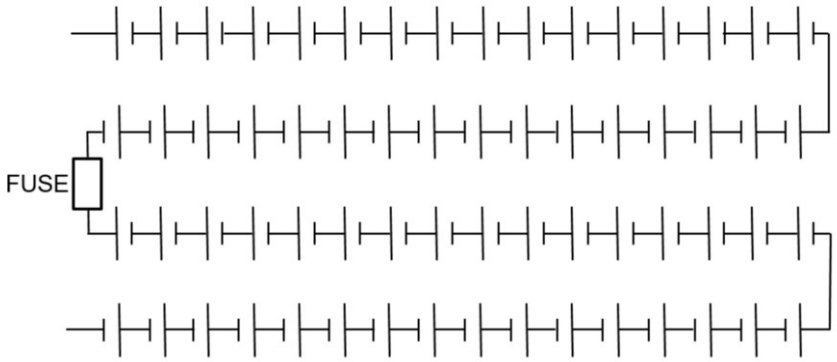


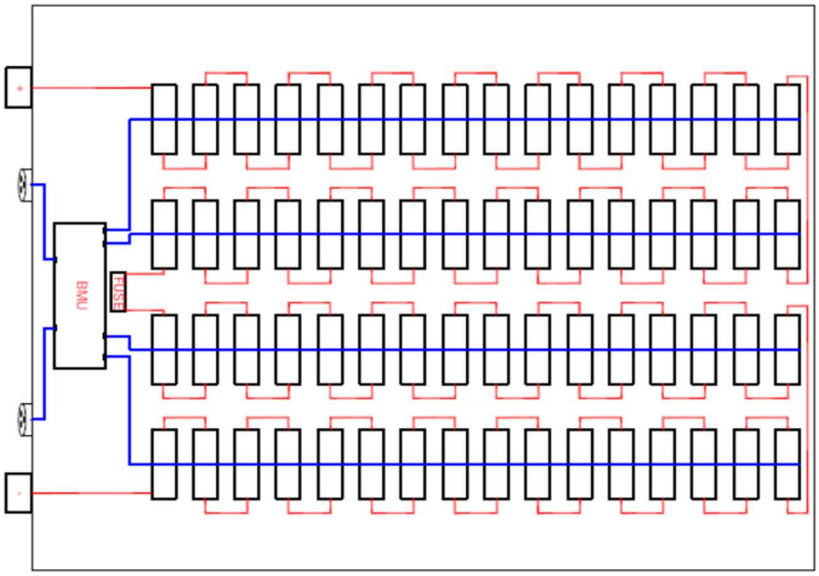
2.2.3 Layout of the module contents



2.2.4 Configuration diagram of the module

1P64S





2.3 Battery system (rack)

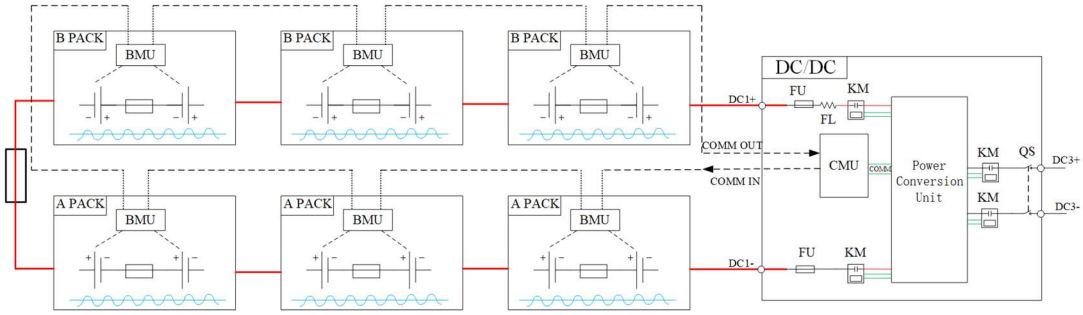
2.3.1 Manufacture information and model list

	Battery system	Battery system	Battery system	Battery system
Product	LFP Lithium Ion Energy Storage System	LFP Lithium Ion Energy Storage System	LFP Lithium Ion Energy Storage System	LFP Lithium Ion Energy Storage System
Type/model	R286AL-121	R344AL-121	R573AL-123	R688AL-123
Cell Capacity [Ah]	280	280	280	280
Cell Quantity	320	384	640	768
Battery structure	(64S)5S	(64S)6S	((64S)5S)2P	((64S)6S)2P
Nominal voltage [V]	1024	1228.8	1024	1228.8
Rated capacity [Wh]	286720	344064	573440	688128
Upper limit charging voltage [V]	1168	1401.6	1168	1401.6
Recommend charging current [A]	140	140	140	140
Maximum charging current [A]	140	160	140	140
Recommend discharging current [A]	140	140	140	140
Maximum discharging current [A]	140	160	140	140
Discharge cut-off voltage [V]	864	1036.8	864	1036.8
Temperature range for charging [°C]	0 to 50*	0 to 50*	0 to 50*	0 to 50*
Temperature range for discharging [°C]	-30 to 50*	-30 to 50*	-30 to 50*	-30 to 50*
Temperature threshold for protection	58	58	58	58
Overcharge protected voltage supply by battery system	≥3.65V /Cell	≥3.65V /Cell	≥3.65V /Cell	≥3.65V /Cell
Recommend charging method by manufacturer	Charge at constant current 140A until the voltage reaches 1168V, then switch to constant voltage 1168V till charge current drops to 14A	Charge at constant current 140A until the voltage reaches 1401.6V, then switch to constant voltage 1401.6V till charge current drops to 14A	Charge at constant current 140A until the voltage reaches 1168V, then switch to constant voltage 1168V till charge current drops to 14A	Charge at constant current 140A until the voltage reaches 1401.6V, then switch to constant voltage 1401.6V till charge current drops to 14A
Dimension [mm]	Rack:3117±10mm(W)×1474±10mm(D)×520±10mm(H) DC/DC:720±5mm(W)×788±5mm(D)×294±5mm(H)	Rack:3117±10mm(W)×1474±10mm(D)×520±10mm(H) DC/DC:720±5mm(W)×788±5mm(D)×294±5mm(H)	Rack:3117±10mm(W)×1474±10mm(D)×1040±10mm(H) DC/DC:720±5mm(W)×788±5mm(D)×294±5mm(H)	Rack:3117±10mm(W)×1474±10mm(D)×1040±10mm(H) DC/DC:720±5mm(W)×788±5mm(D)×294±5mm(H)
Weight [kg]	Rack: ≤2000kg DC/DC: 75kg	Rack: ≤2400kg DC/DC: 75kg	Rack: ≤4000kg DC/DC: 75kg	Rack: ≤4800kg DC/DC: 75kg
Ingress Protection (IP)	IP65	IP65	IP65	IP65
Protective Class	I	I	I	I
Cooling type	Liquid cooling	Liquid cooling	Liquid cooling	Liquid cooling
Altitude	4000m	4000m	4000m	4000m

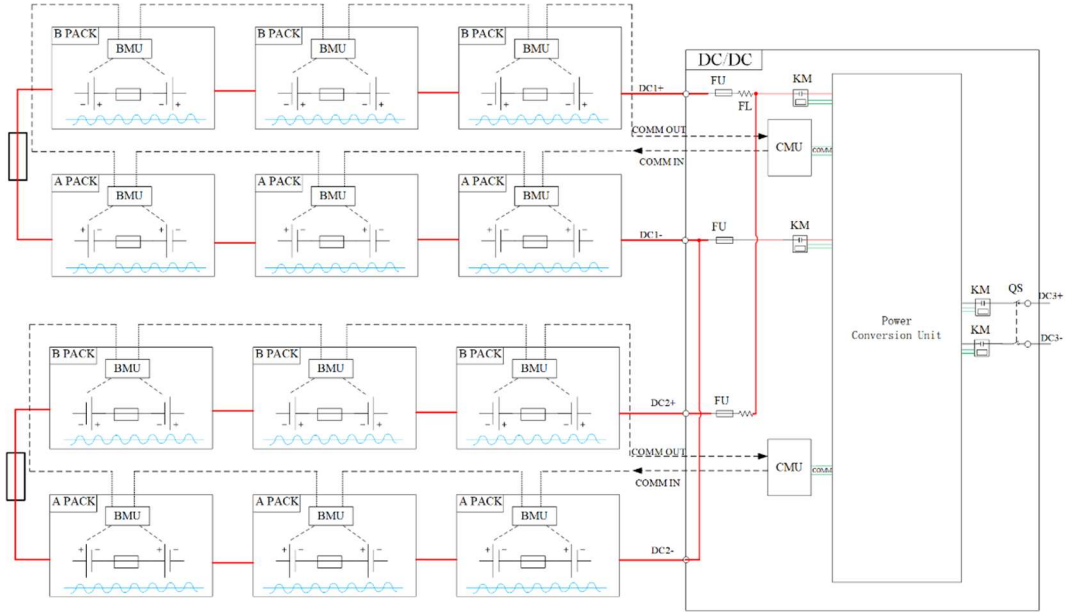
2.3.2 Product information

This product is used for Energy Storage System.
The EUTs covered by this report are 4 models of LFP lithium ion battery energy storage systems which include one DC-DC converter box and several battery packs in series(parallel) connection. The number of battery pack is 5, 6, 10,12 for model R286AL-121, R344AL-121, R573AL-123 and R688AL-123.

Block diagram for R344AL-121 is as below (R286AL-121 is the same except for one less pack) :



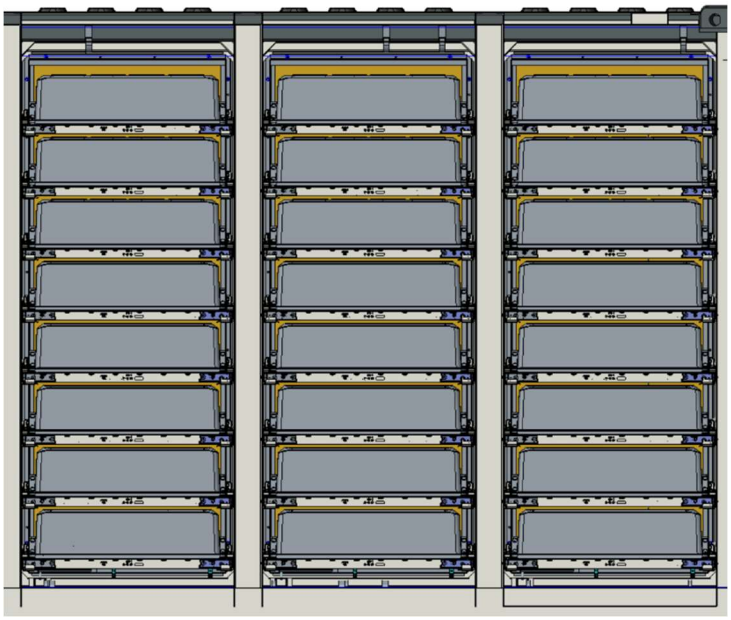
Block diagram for R688AL-123 is as below (R573AL-123 is the same except for two less packs) :

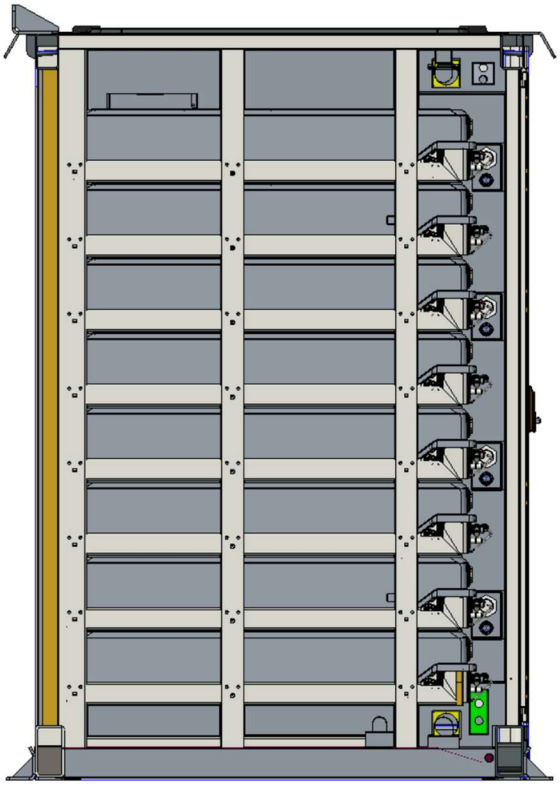


Each battery pack contains 64 cells in structure 64S. And it contain one BMU board for measuring and collecting the cell parameters and uploading the information of cell voltage and temperature to CMU in DC-DC converter box.
DC-DC box: Including CMU function and DC-DC converter which certified with UL 1741.
The EUTs are indoor type. The insulation between the DC circuit and the metal enclosure is basic insulation. And the insulation between the DC circuit and communication ports is reinforced insulation or double insulation.
BMS functional safety was evaluated according to IEC 60730-1 Annex H by TÜV Rheinland.

Compliance with UL9540..... :	without
Compliance with UL1973..... :	Yes, (repot number: CN22626J 001)
Integrated fire protection system in the unit..... :	No integrated fire protection system

Diagram with dimension of R688AL-123





2.4 Photo

Module



Battery Rack



3 Unit level test (section 8 of UL 9540A)

3.1 General

Unit level testing corresponds with the testing anticipated by fire codes and other codes impacting energy storage system installations to evaluate the large scale fire performance of BESS units installed in, on or adjacent to buildings or in other areas and their resultant performance to qualify for exceptions to limits in the codes imposed on these installations. The limitations where exceptions may be sought are limitations on the size of the individual BESS units, the total number of BESS units installed within a room, and the separation distances between BESS units and between BESS units and walls of the building.

In this test the initiating BESS unit is placed a set distance from target BESS units simulating BESS units identical to the initiating BESS unit, and from simulated walls representative on the installation. A thermal runaway is induced in cells, using the same approach as used in the module level testing within one of the modules in the initiating BESS, and a variety of measurements are taken. The results are intended to be used to verify that a fire within a single BESS unit will not spread to other units, nor breach the walls or the BESS enclosure (if provided), and there shall be no flying debris or explosive discharge of gases.

The test arrangement include the largest (energy) BESS unit for the installation to be represented by the test, and minimum spacing to adjacent walls and BESS units. The BESS may be tested with an internal fire suppression system provided by the manufacturer if that fire suppression system is required to be installed in the BESS. Optional internal fire suppression systems are not included in the unit level testing.

The test monitors the fire behavior of the BESS unit and measures heat release rates (convective and chemical); gas generation and composition; smoke release rate; maximum heat flux on the target BESS units, wall surfaces and within the accessible means of egress; maximum surface temperatures of the walls and modules within the target BESS units; and documents any explosions, deflagrations and flying debris from the BESS under test.

3.2 Unit sample preparation

The battery system is constructed with open rack without enclosure. One column of the rack with 9 complete modules was considered as a unit for purposes of the test.

All 9 module samples were conditioned together as a unit, through 3 charge/ discharge cycles per the manufacturer's instructions to verify that the module was functional.

The Charge/discharge was performed at 140A. Each cycle was defined as a charge to 100% SOC and allowed to rest 60 minutes and then discharged to an end of discharge voltage (EODV) determined by the module specification. Refer to section 2.2 for the end of the condition of charge and discharge.

Cycling was conducted on Dec 3, 2021 under ambient temperature 25°C ± 3°C and R.H. 70% ± 5%.

3.3 Setup of the test

3.3.1 Battery system installation information

The installation information was provided by the client as below.

Intended use location ..... :	☐ Residential	☒ Non-residential
	☐ Non-residential rooftop	
	☐ Non-residential open garage use	
Type of installation ..... :	☒ Indoor	☐ Outdoor
	☒ Floor/ground mounted	☐ Wall mounted
Row(s) of installation	☐ Single	☒ Multiple

3.3.2 Test site setup

Two instrumented walls with 3.8 m height and 3.55 m width form a right angle. Walls were constructed of 5/8 in gypsum painted flat black.

Three racks were used for the purpose of the test. As specified by the manufacture, the two target racks will be installed up and down of the initial unit. All racks were positioned facing instrumented wall A. See Figure 1 and 2 and photos on page 47.

The initiating unit (unit A) was positioned at the middle, adjacent to the two instrumented wall sections.

The minimum separation distance from the rack to wall and between racks were defined by the client. Subject to the actual conditions of the testing environment, there was 1cm tolerance in the actual setup.

Figure 1 was the test site setup diagram with separation distance.

The test side setup was located under the smoke collection hood of the calorimeter measurement system.

Figure 1. Test site setup diagram with separation distance. (Top view)

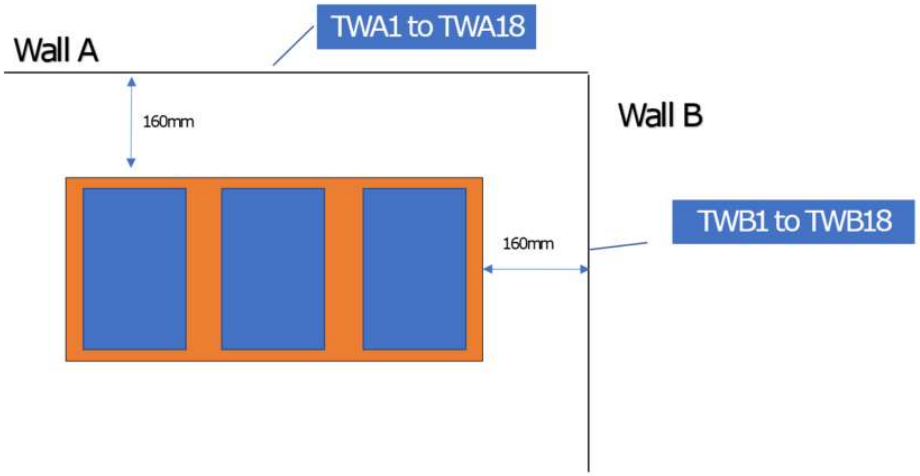
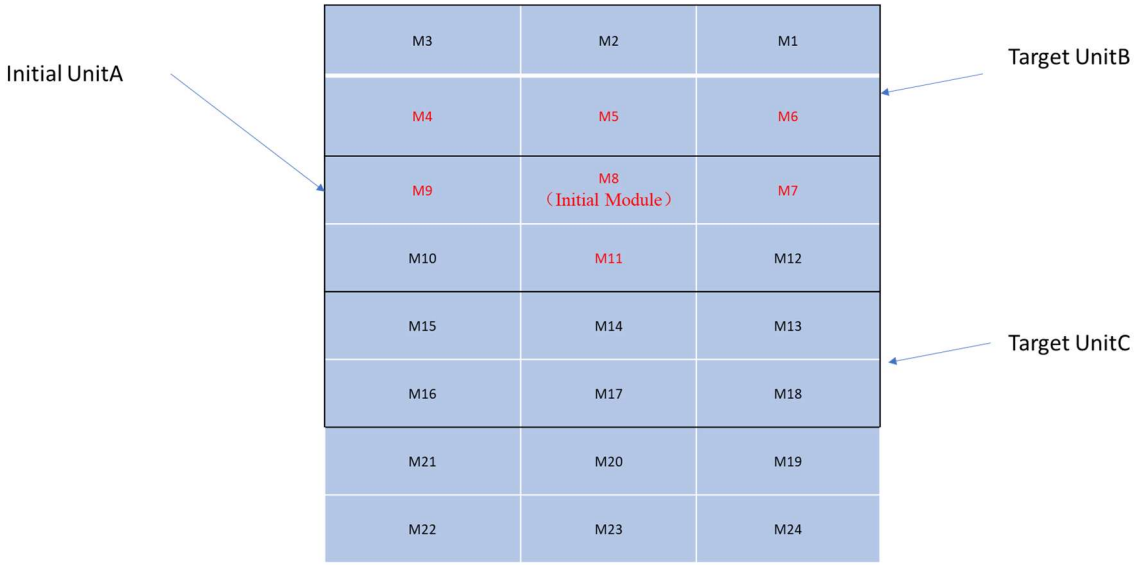


Figure 2. Test site setup diagram with separation distance. (Front view)



For the purpose of this test, the modules were numbered according to the electrical continuity.

In Initial Unit A, modules numbers from M7 to M12.

In Target Unit B, modules numbers from M1 to M6 which was the target unit situated above the Initial Unit A.

In Target Unit C, modules numbers from M13 to M18 which was the target unit situated below the Initial Unit A.

See Figure 3.

4 complete modules were used for unit A (M7 to M9 and M11).

3 complete modules were used for unit B (M4 to M6) to check the possible propagation form unit to unit.

Empty modules without cells were used for the other modules.

Figure 3. Module numbering in units showing fully populated modules in red.

M3	M2	M1
M4	M5	M6
M9	M8 （Initial Module）	M7
M10	M11	M12
M15	M14	M13
M16	M17	M18
M21	M20	M19
M22	M23	M24

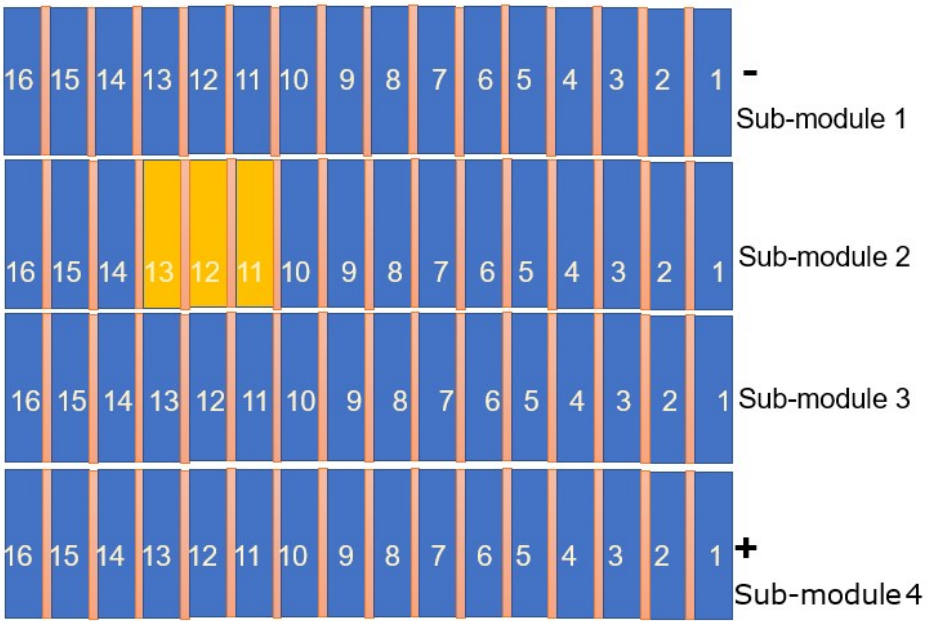
3.3.3 Thermal runaway setup

External heating method, agreed with the client, was used to initiate the thermal runaway within the module.

Module M8 was prepared with two heaters inside. Same as the method in module level test.

For convenient show the temperature condition of internal cells, numbering four lines cells from negative electrode to positive electrode for sub-module 1 to sub-module 4. Numbering cells in every sub-modules from electrodes side to another side for cell 1 to cell 16, see figure 4 for detail.

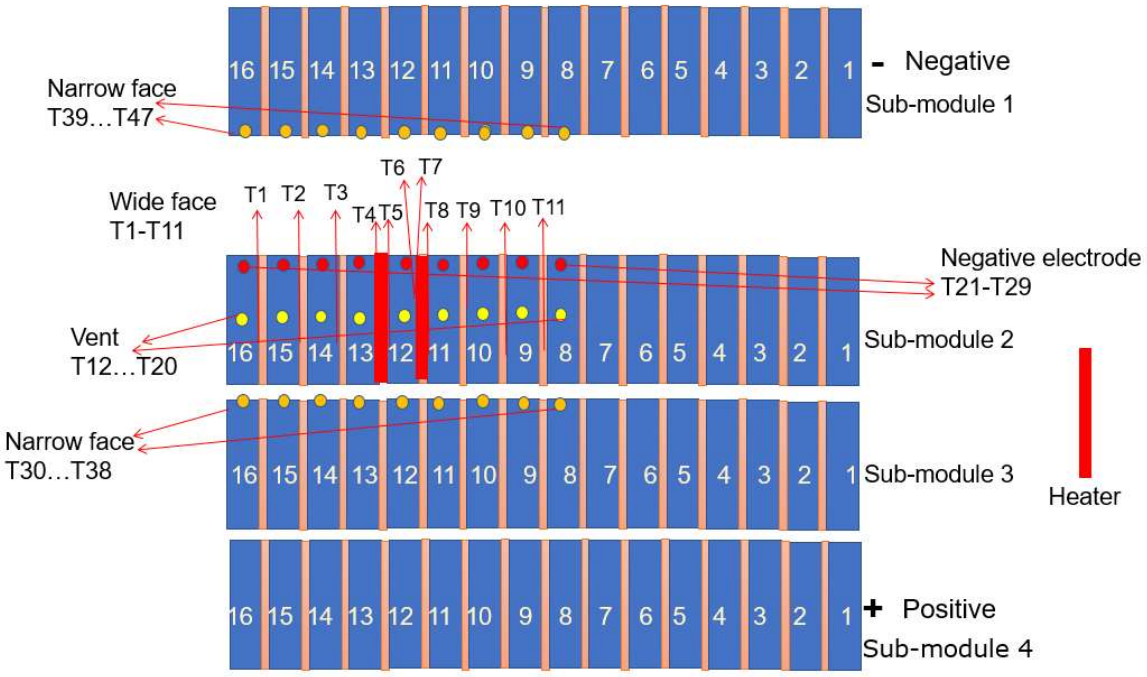
Figure 4. Cell numbering inside the initiating module



Consider the unit level installation and airflow of the liquid cooling in the module. #11, #12 and #13 cells of sub-module 2 were chosen as target cell to be forced into thermal runaway.

The cell #12 was heated by two external heater on each wide side, the cell #11 and cell#13 was heated by one external heater on wide near cell #12. The heater is rated 220VAC/500 W (size 207*174*4mm).

Figure 5. Thermocouples on initiating module M8



In sub-module 1,

9 glass fiber thermocouples (#39-#47) Type K, 24AWG were attached on the #16-#8 cells center of narrow surface near sub-module 2, used to check the possible propagation form cell to cell.

In sub-module 2,

1 glass fiber thermocouples (#T7) Type K, 14AWG was attached on the center of wide surface of #12 cell under heater used to feedback the temperature to the heater controller.

4 glass fiber thermocouples (#T4, #T5, #T6, #T8) were attached on the center of wide surface of #13, #12 and #10 cells under heater used to determine the thermal runaway of initiating cells.

6 glass fiber thermocouples (#1-#3, #9-#11) were attached on the center of wide surface of #16-#14, #10-#8 cells under heater used to check the possible propagation from cell to cell.

8 glass fiber thermocouples (#12-#20) were attached above the vent of #16-#8 cells used to record the venting time.

8 glass fiber thermocouples (#21-#29) were attached on the negative electrode of #16-#8 cells used to observe the temperature change.

In sub-module 3,

9 glass fiber thermocouples (#30-#38) Type K, 24AWG were attached on the #16-#8 cells center of narrow surface near sub-module 2, used to check the possible propagation form cell to cell.

The initiating module M8, Internal voltage sample wire and signal wire covered by glass fiber tube. The BMS control board disabled during test.

A PID controller was used to control the voltage supply to the heater and maintain a 4°C/min to 7°C/min heating rate. When heater temperature reached to 150°C (T-set), hold about 93min (11:04 to 12:37), then continue to heat and maintain a 4°C/min to 7°C/min heating rate.

Once thermal runaway was observed, the heaters were immediately de-energized.
One thermocouple located below the heater at the center of #12 cell surface was used to feedback the temperature to the controller.

Voltage of the module are monitored during test.

The units was located under the smoke collection hood of the calorimeter measurement system.

3.4 Observations and records

Before the test, the initiating module was charged to 100% SOC and allowed to stabilize for a minimum of 1 h and a maximum of 8 h before the start of the test.

The ambient condition at the initiation of the test was 25°C, 66% RH.

The voltage of the modules was recorded as below:

Figure 6: Voltage record of cells during the test

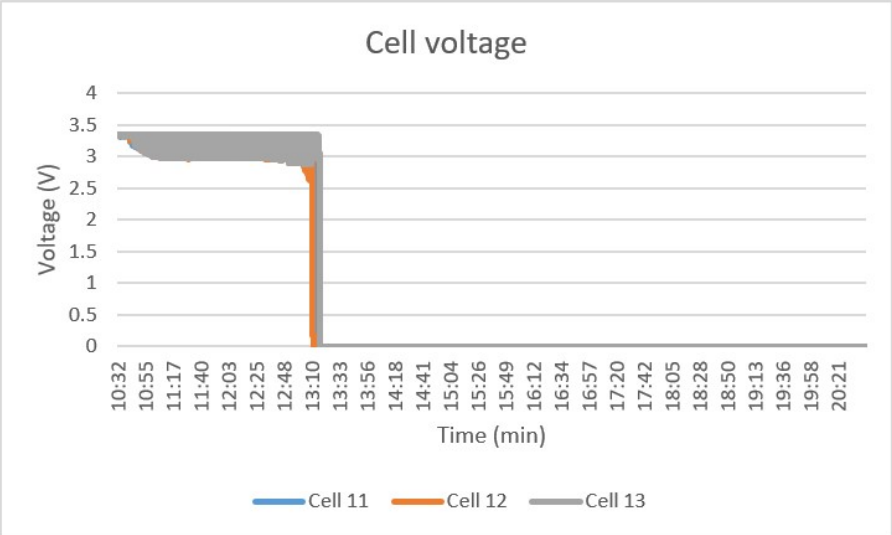
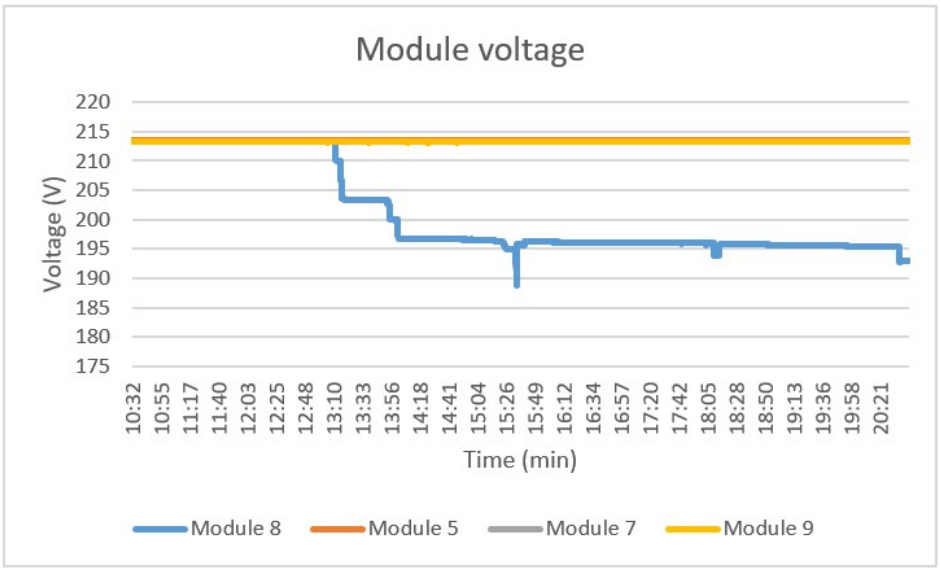


Figure 7: Voltage record of Modules during the test



Tests were performed on Sep 16, 2021, started at 09:40 AM.

Observations during the test:

Audible pop was heard on 12:46 AM (the pressure relief valve burst), followed by smoke release after several seconds.

A large amount of white smoke was observed after thermal runaway.

Cell to cell propagation was observed in the initial model.

Module to module propagation was not observed.

No flying debris or explosive discharge of gases observed during test.

No sparks, electrical arcs, or other electrical events observed during test.

No external flaming was observed during the test.

Observations after the test:

Leakage outside the initiating module enclosure was observed. See photos in page 47~52.

No damage and contamination on the instrument walls.

No damage and contamination on the modules of target units.

The plastic top enclosure near the initial cell of module M8 was melted and significantly damaged. Module voltage of M8 was 193.3 Vdc.

Six cells inside the initial module M8 were damaged. Cell to cell propagation were observed on cells #14, #15, #10 of sub-module 1 after receiving thermal energy from cell #13. Voltage measured on each remaining undamaged in other sub-modules were 3.33Vdc.

Weight loss of the initiating module was 2.0 kg (before test 406.5kg, after test 404.5kg)

See photos in page 47~52.

3.5 Temperature measurements

3.5.1 Temperature measurement of initiating cells

Surface temperature of cells #8 - #16 of sub-module 1 to sub-module 3 was recorded during the test. Cell to cell propagation occured during the test. See Figure 8 for the temperature vs time curve.

Cell thermal runaway occurred on cell #12, #13, #11 in turn at around 13:11, 13:14, 13:15 Maximum temperature 604.2°C, 643.2°C, 730.1°C were measured on the cell #12, #13, #11 surface.

Cell to cell thermal runaway propagation occurred on cell #14, #15, #10. Maximum temperature 471.0°C, 547.1°C, 468.5°C were measured on the cell #14, #15, #10 surface.

Figure 8. Surface temperatures of thermal runaway cells on module M8 (sub-module 2)

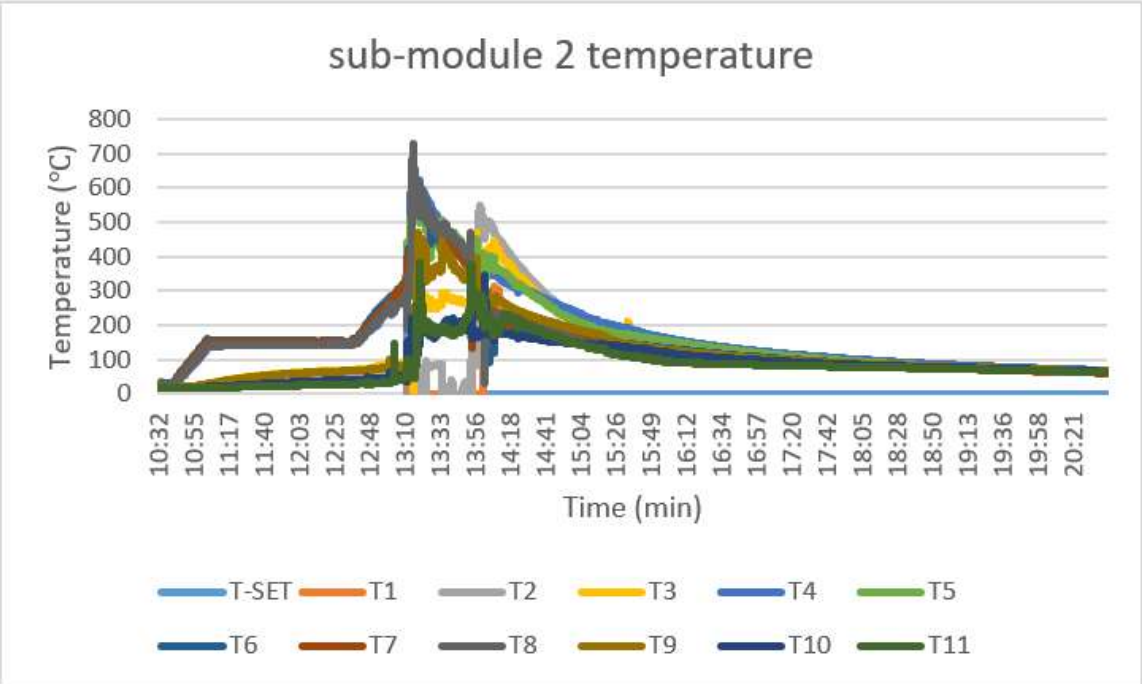


Table 1 Maximum temperature of sub-module 2 cells

Thermocouple no.	Location	Maximum temp.(℃)
T1	Wide surface of Cell #16	314.9
T2	Wide surface of Cell #15	547.1
T3	Wide surface of Cell #14	471.0
T4	Wide surface of Cell #13	643.2
T5	Wide surface of Cell #12	581.8
T6	Wide surface of Cell #12	595.4
T7	Wide surface of Cell #12 for feedback	604.2
T8	Wide surface of Cell #11	730.1
T9	Wide surface of Cell #10	468.5
T10	Wide surface of Cell #9	368.5
T11	Wide surface of Cell #8	382.1

Cells in sub-module 1 not happened thermal runaway, maximum temperature see table 2 for detail.

Figure 9. Surface temperatures of no thermal runaway cells on sub-module 1 of module M8

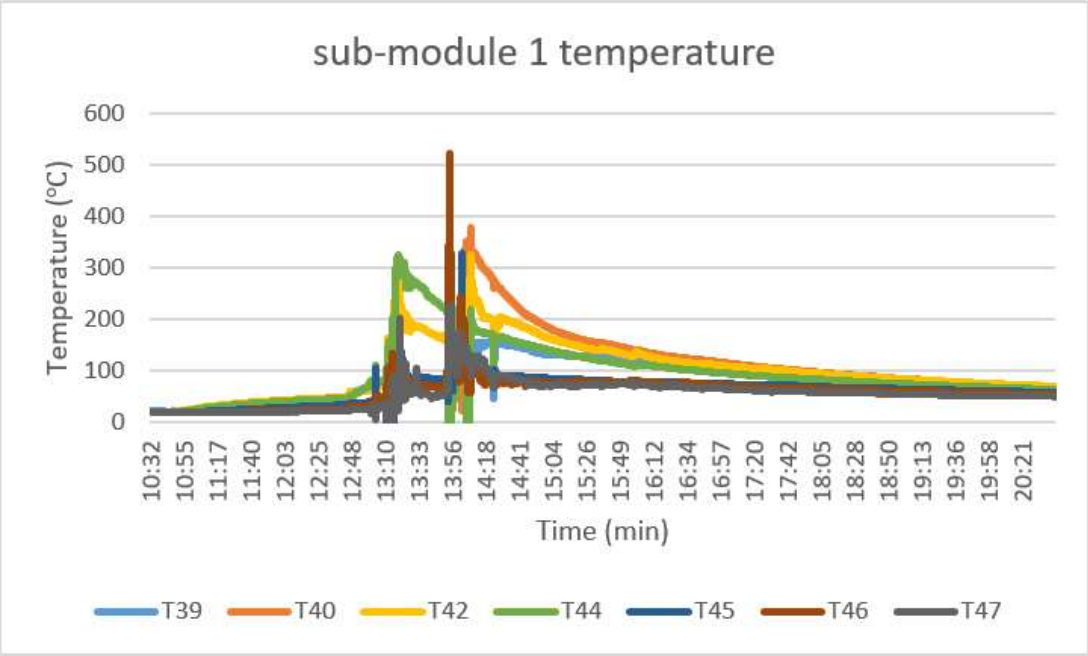


Table 2 Maximum temperature of sub-module 2 cells

Thermocouple no.	Location	Maximum temp.(℃)
T39	Narrow surface of cell #16	176.6
T40	Narrow surface of cell #15	378.5
T41	Narrow surface of cell #14	--
T42	Narrow surface of cell #13	326.9
T43	Narrow surface of cell #12	--
T44	Narrow surface of cell #11	324.4
T45	Narrow surface of cell #10	327.0
T46	Narrow surface of cell #9	523.2
T47	Narrow surface of cell #8	226.1

Cell in sub-module 3 not happened thermal runaway, maximum temperature see table 3 for detail.

Figure 10. Surface temperatures of no thermal runaway cells on sub-module 3 of module M8

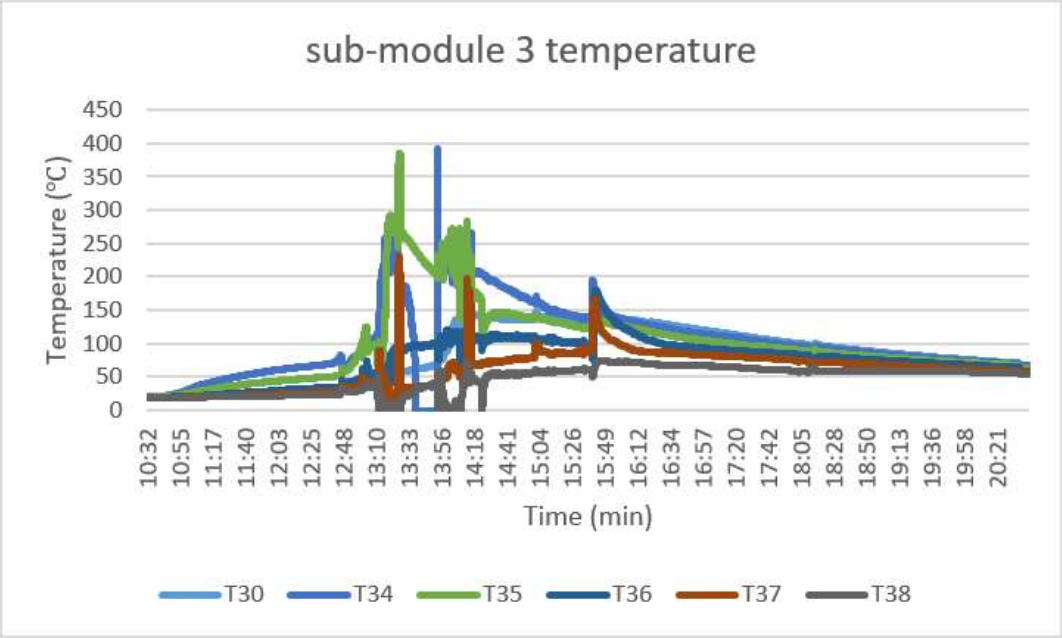


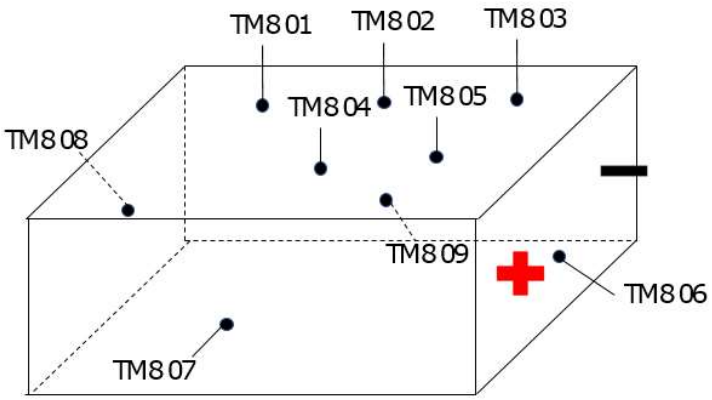
Table 3 Maximum temperature of sub-module 3 cells

Thermocouple no.	Location	Maximum temp.(℃)
T30	Narrow surface of cell #16	245.1
T31	Narrow surface of cell #15	--
T32	Narrow surface of cell #14	--
T33	Narrow surface of cell #13	--
T34	Narrow surface of cell #12	391.6
T35	Narrow surface of cell #11	384.9
T36	Narrow surface of cell #10	187.4
T37	Narrow surface of cell #9	231.2
T38	Narrow surface of cell #8	75.2

3.5.2 Temperature measurement of units

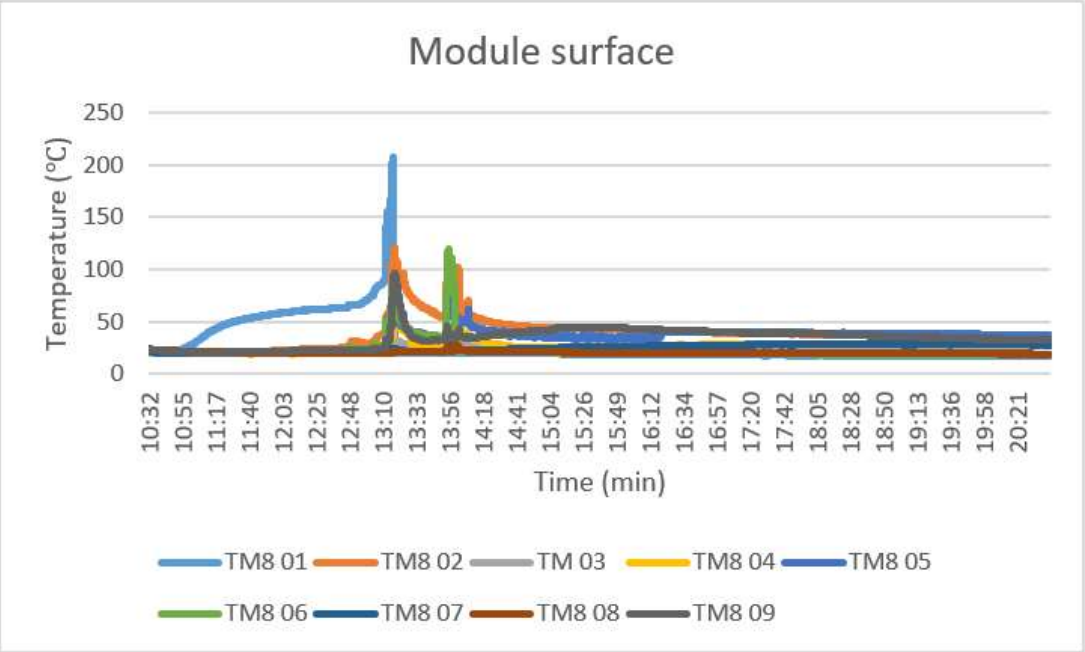
9 glass fiber insulated thermocouples (TM8 01~TM8 09), Type K, 24 AWG was attached on the external surface of module M8, as below Figure 8.

Figure 11. Thermocouple of module M8 surface



TM8 01~TM8 03 located on top surface above cell in sub-module2. TM8 04, TM8 05 located on top surface above cell in sub-module 3. TM8 06 located on front of module (electrode side), TM8 07 located on the left side surface, TM8 08 located on the rear side, TM8 09 located on the right side surface. Maximum temperature 208°C was measured on top of the module near #12 cell.

Figure 12. Surface temperatures of initiating module M8

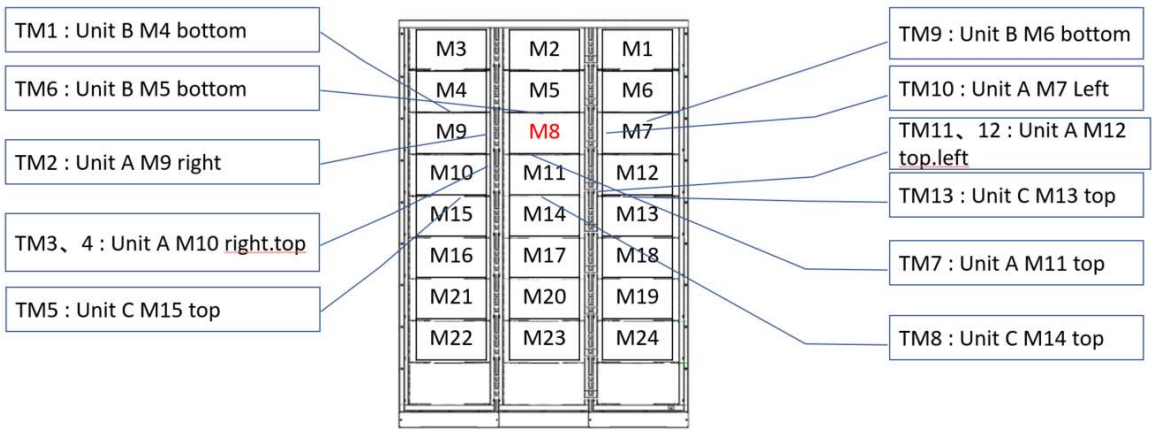


13 glass fiber insulated thermocouples (TM1 to TM13), Type K, 24 AWG were attached to the center of the top surface of modules M4 to M15.

Maximum temperature 31.4°C was measured on bottom surface of the module M5 of Unit B.

Maximum temperature 26.5°C was measured on top surface of the module M13 of Unit C.

Figure 13. Thermocouple location on modules in units A,B,C (Rack 1)



View direction: towards instrument wall A with reference to Figure 2

Figure 14. Surface temperatures of modules from M4 to M15

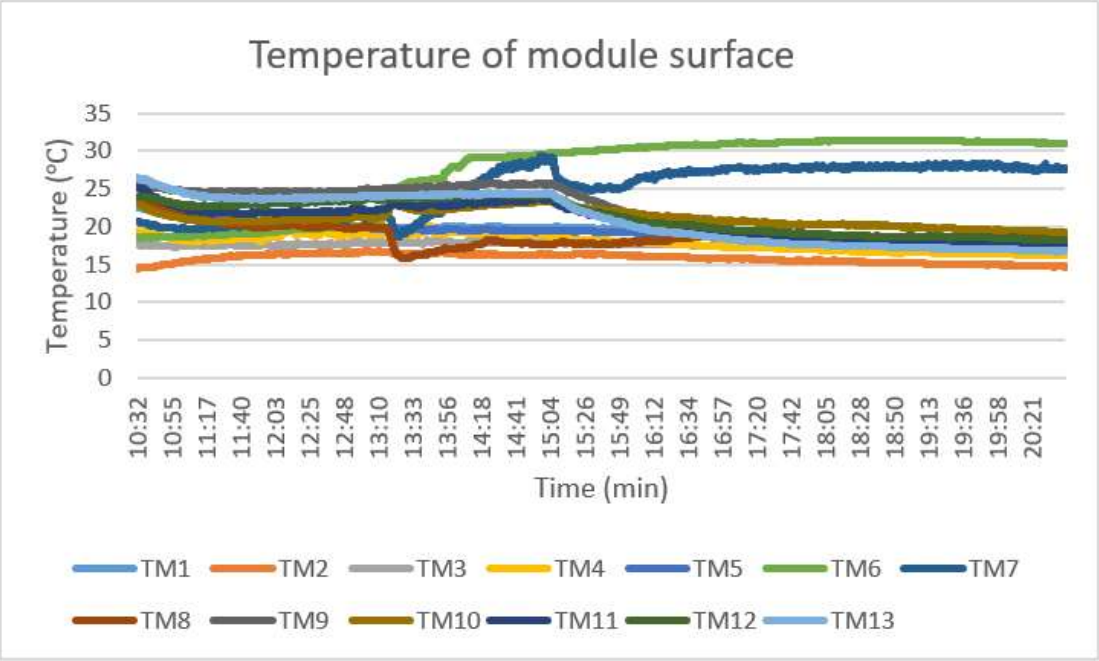


Figure 15. Thermocouple location on the back side of Wall A

View direction: from instrument wall A with reference to Figure 2

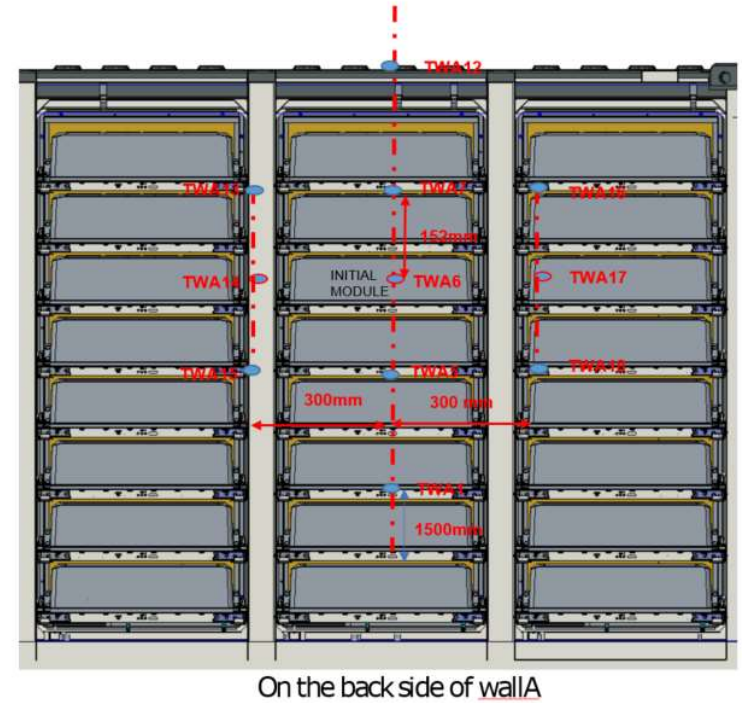
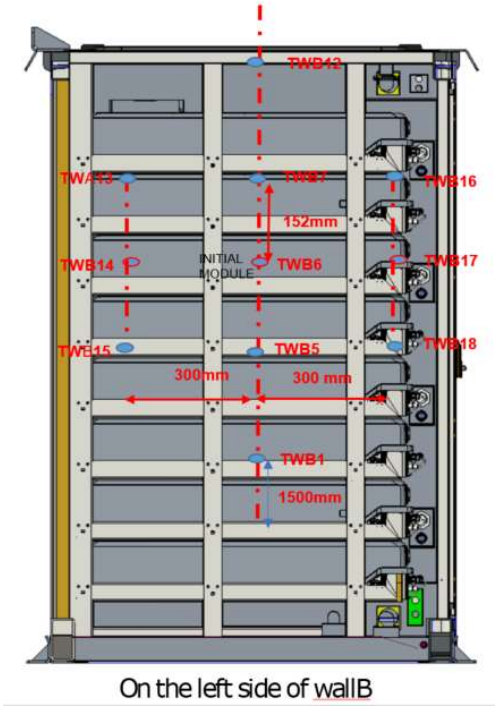


Figure 16. Thermocouple location on the left side of wall B



View direction: towards instrument wall B with reference to Figure 2

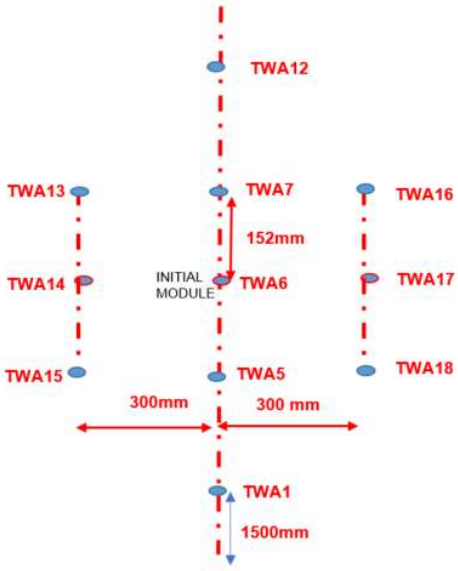
3.5.3 Temperature measurement of instrumented walls

Wall surface temperatures were measured in vertical arrays at 152 mm intervals for the full height of the instrumented wall sections using Type K, 30 AWG thermocouple. The thermocouple arrays were collinear with the centre line of Initial Unit A. The red line in Figure 12 shows the thermocouple arrays on the wall.

The first thermocouple starts from 1500 mm from ground. Total 36 thermocouples were used for each array. The thermocouples were numbered from low to high as TWA1 to TWA18 for wall A and TWB1 to TWB18 for wall B.

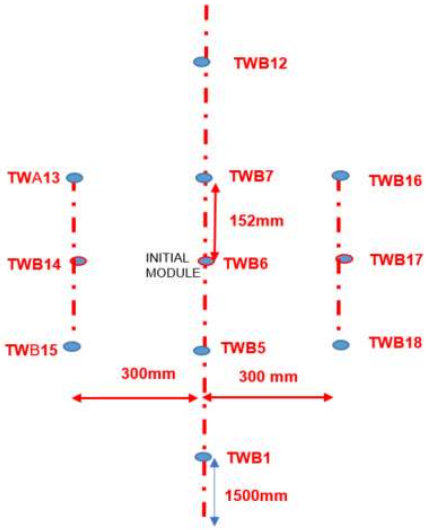
Figure 17. Vertical position of the thermocouples on the wall

Instrumented wall A



View direction: towards instrument wall A with reference to Figure 2

Instrumented wall B



View direction: towards instrument wall B with reference to Figure 2

Additional 6 thermocouples were positioned horizontally near the initial module M8 300 mm away from the vertical array each side, on instrumented wall A and wall B. See Figure 18.

Maximum temperature measured on instrument wall A was 24.3°C at TWA13, temperature curve see figure 19 for detail.

Maximum temperature measured on instrument wall B was 23.9°C at TWB3, temperature curve see figure 20 for detail.

Figure 18. Horizontal position of the thermocouples on the wall A and wall B

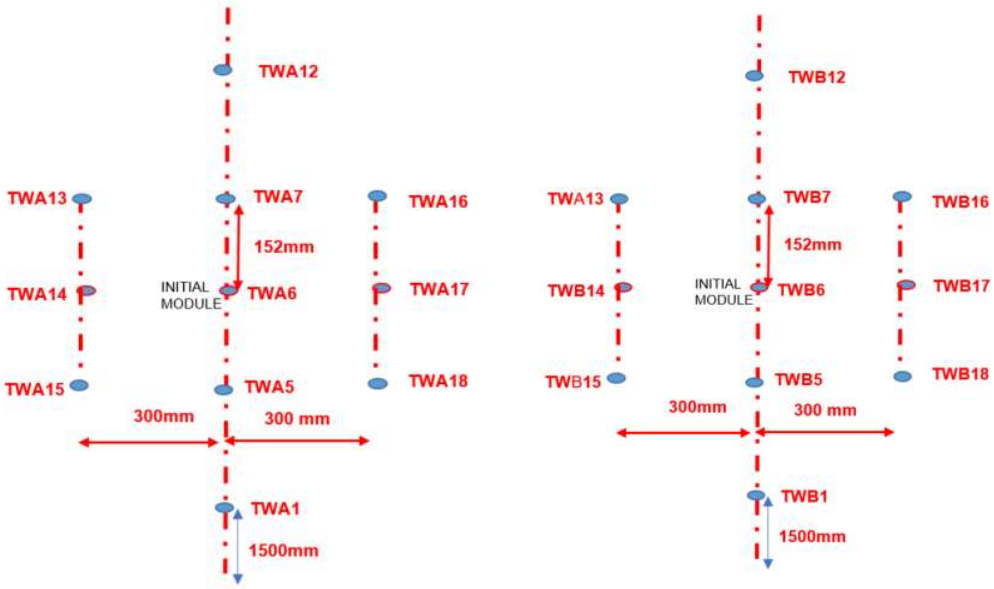


Figure 19. Temperatures on instrument wall A.

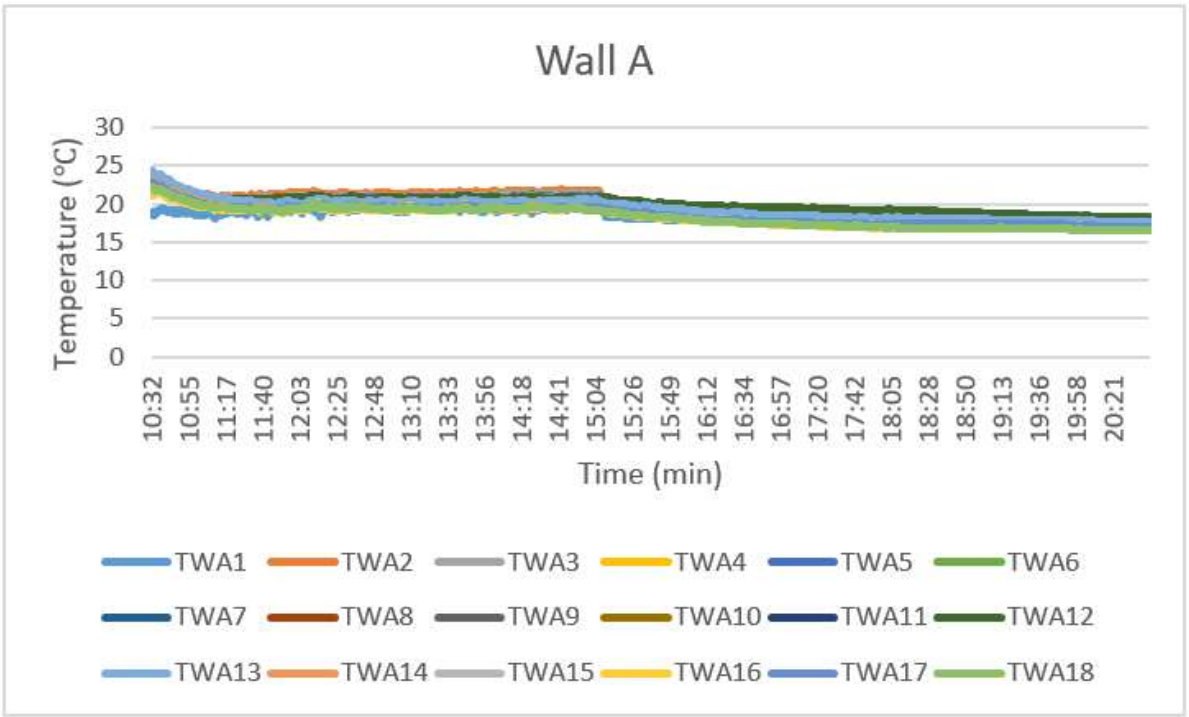
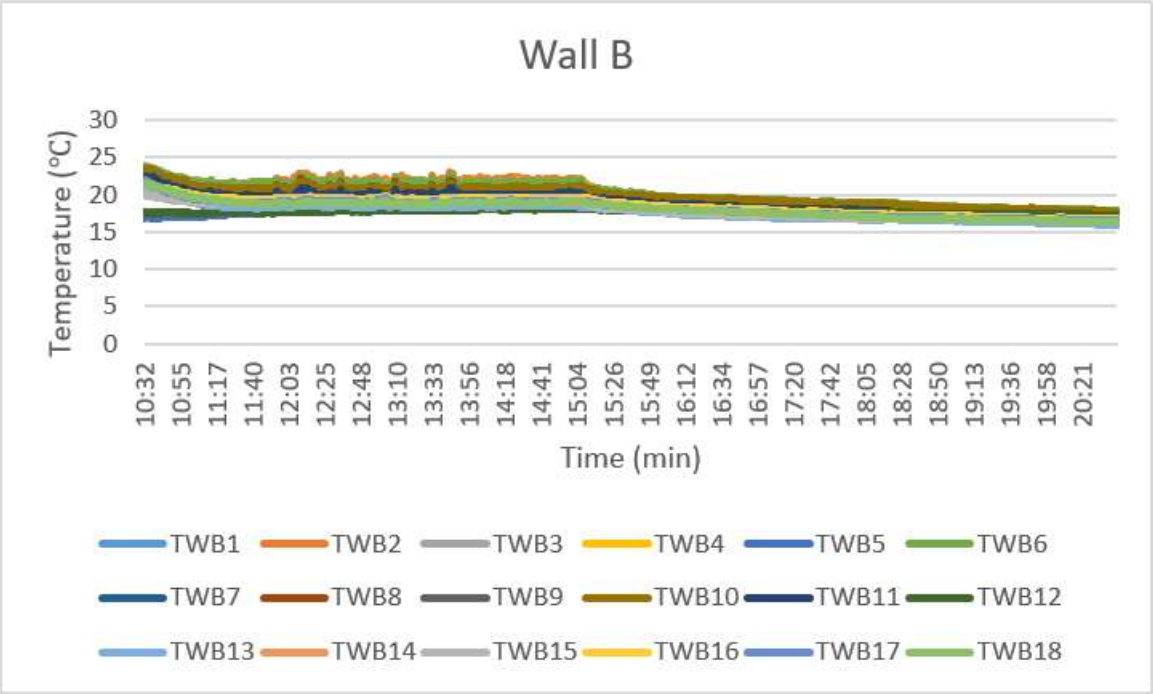


Figure 20. Temperatures on instrument wall B.



3.6 Heat flux measurement

Two sensors were placed on the surface of instrumented wall A, wall B and adjacent unit A that faces the initiating unit.

The sensors were collinear with the vertical thermocouple array. One was positioned at the height equivalent to module M8 top edge, which was estimated to receive the greatest heat flux due to the thermal runaway of the initiating module within the initiating unit. Another was positioned at the height equivalent to module M11 top edge, which was estimated to receive the greatest surface heat flux due to the thermal runaway of the initiating unit.

Figure 21 shows the positions of the sensors. Sensor H1 & H2 were positioned at unit A; H3&H4 were positioned at wall A, H5&H6 were positioned at wall B, All sensors were numbered from low to high.

Measured heat flux of target wall and target units are zero.

Figure 21. Heat flux sensor locations on unit

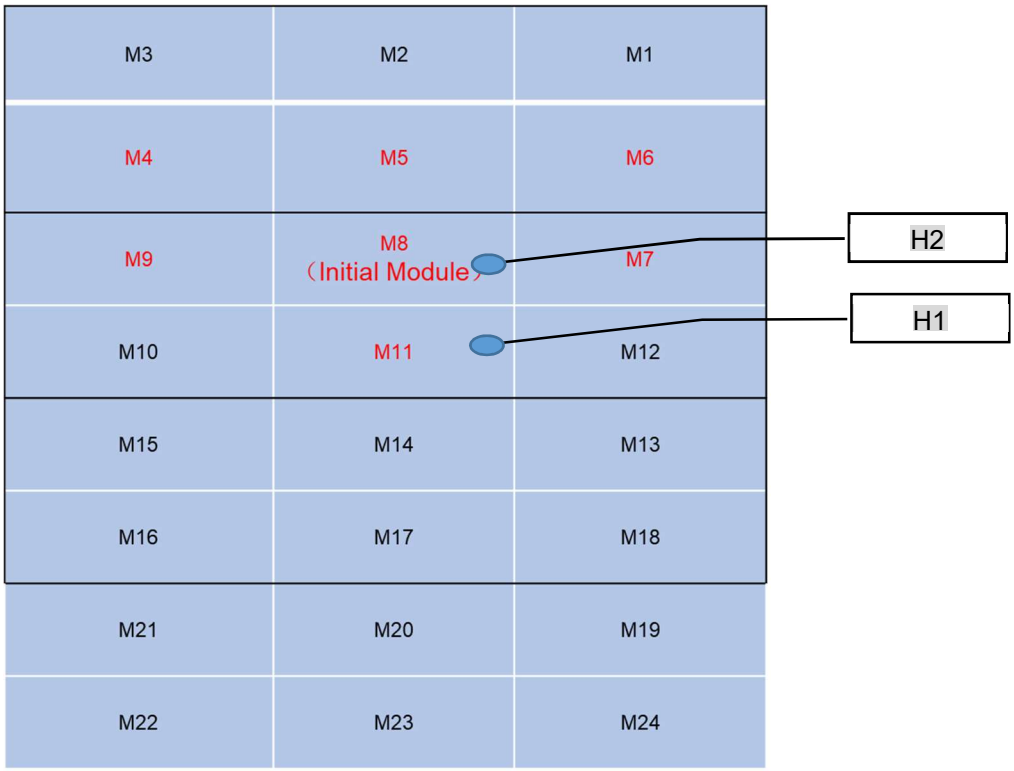
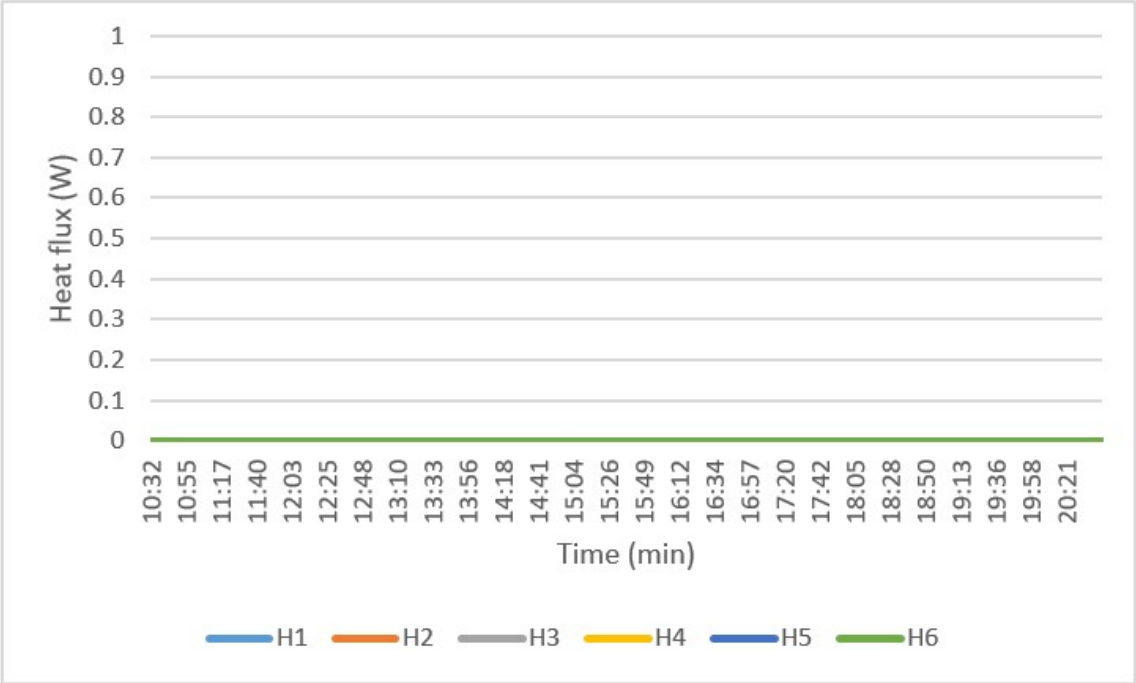


Figure 22. Measured heat flux of target wall and target units



3.7 Chemical heat release rate measurement

The chemical heat release rates were measured by an oxygen consumption calorimeter measurement system consisting of a paramagnetic oxygen analyzer, non-dispersive infrared carbon dioxide and carbon monoxide analyzer, velocity probe, and a Type K thermocouple.

The instrumentations are located in the exhaust duct of the heat release rate calorimeter.

The chemical heat release rate was calculated at each of the flows as follows:

$$HRR_1 = \left[E \times \varphi - (E_{co} - E) \times \frac{1-\varphi}{2} \times \frac{X_{co}}{X_{O_2}}\right] \times \frac{\dot{m}_e}{1+\varphi \times (\alpha - 1)} \times \frac{M_{O_2}}{M_a} \times (1 - X^o_{H_2O}) \times X^o_{O_2}$$

In which:

HRR_t = total heat release rate, as a function of time (kW)

E = Net heat released for complete combustion per unit of oxygen consumed (adjusted for oxygen contained within cell chemistry, 13,100 kJ/kg)

E_{CO} = Net heat released for complete combustion per unit of oxygen consumed, for CO (adjusted for oxygen contained within cell chemistry, 17,600 kJ/kg)

φ = Oxygen depletion factor (non-dimensional), where:

$$\varphi = \frac{X^o_{O_2} \times [1 - X_{CO_2} - X_{CO}] - X_{O_2} \times [1 - X^o_{CO_2}]}{X^o_{O_2} \times [1 - X_{O_2} - X_{CO_2} - X_{CO}]}$$

X_{CO} = Measured mole fraction of CO in exhaust flow (non-dimensional)

X_{CO_2} Measured mole fraction of CO_2 in exhaust flow (non-dimensional)

$X°_{CO_2}$ = Measured mole fraction of CO_2 in incoming air (non-dimensional)

$X°_{H_2O}$ = Measured mole fraction of H_2O in incoming air (non-dimensional)

X_{O_2} = Measured mole fraction of O_2 in exhaust flow (non-dimensional)

$X°_{O_2}$ = Measured mole fraction of O_2 in incoming air (non-dimensional)

α = Combustion expansion factor (non-dimensional; normally a value of 1.105)

M_a = Molecular weight of incoming and exhaust air (29 kg/kmol)

M_{O_2} = Molecular weight of oxygen (32 kg/kmol)

$\dot{m}_e$ = Mass flow rate in exhaust duct (kg/s), in which:

$$\dot{m}_e = C \times \sqrt{\frac{\Delta p}{T_e}}$$

or

$$\dot{m}_e = 26.54 \times \frac{A \times k_c}{f(\mathrm{Re})} \times \sqrt{\frac{\Delta p}{T_e}}$$

C = Orifice plate coefficient (in $kg^{1/2}m^{1/2}K^{1/2}$)

Δp = Pressure drop across orifice plate or bidirectional probe (Pa)

T_e = Combustion gas temperature at orifice plate or bidirectional probe (K)

A = Cross sectional area of the duct (m^2)

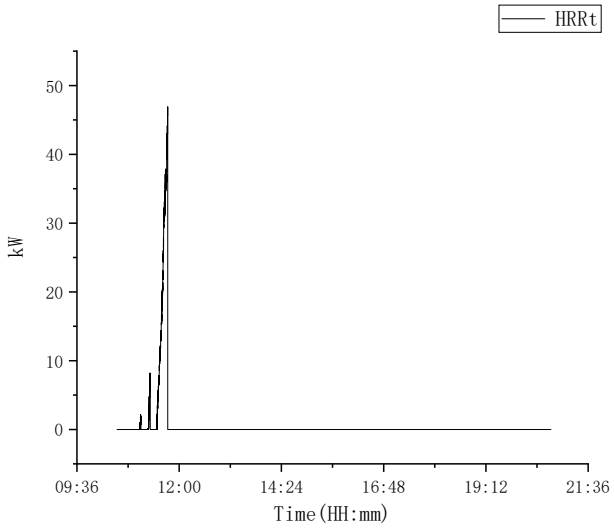
k_c = Velocity profile shape factor (non-dimensional)

$f(Re)$ = Reynolds number correction (non-dimensional)

The heat release rate measurement system was calibrated at 50kW and 70kW heat release rate using a standard propane burner before the test. The calibrations were performed using flows of 1078mg/s and 1510mg/s of propane.

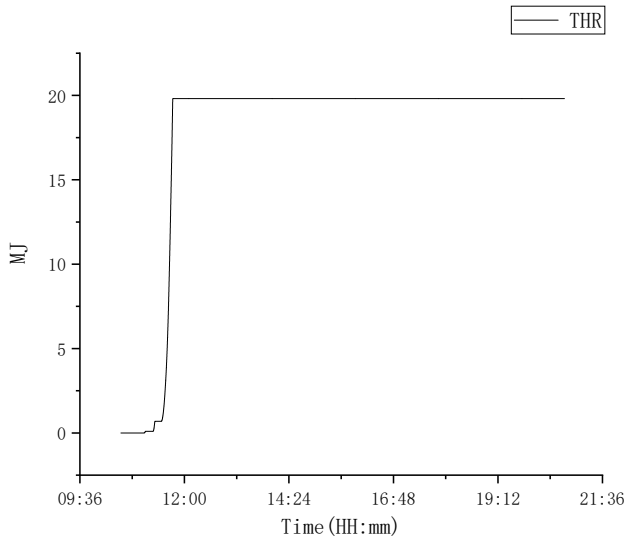
Measured peak chemical heat release rate HRR_t was 46.91kW

Figure 23. HRRt curve



Measured total heat release THR through the test was 19.814 MJ

Figure 24. THR curve



3.8 Convective heat release rate measurement

The convective heat release rate was measured using thermopile, a velocity probe, and a Type K thermocouple, located in the exhaust system of the exhaust duct.

The convective heat release rate was calculated at each of the flows as follows:

$$HRR_c = V_e A \frac{353.22}{T_e} \int_{T_o}^{T} C_p dT$$

Where:

HRR_c = *The convective heat release rate (kW)*

V_e = *The exhaust velocity (m/s)*

A = *The exhaust duct cross sectional area (m^2)*

T_e = *The temperature at the location where exhaust velocity is measured (K)*

$353.22/T_e$ = *The density of air at the velocity measurement location (kg/m^3)*

T_o = *The ambient temperature (K) in the test room*

T = *The thermopile temperature (K)*

$$\int_{T_o}^{T} C_p dT = A_0(T - T_o) + A_1/2(T^2 - T_o^2) + A_2/3(T^3 - T_o^3) + A_3/4(T^4 - T_o^4)$$

Cp = Specific heat of air (kJ/kg-K), given as $\boldsymbol{C_p = A_0 + A_1 T + A_2 T^2 + A_3 T^3}$, where:

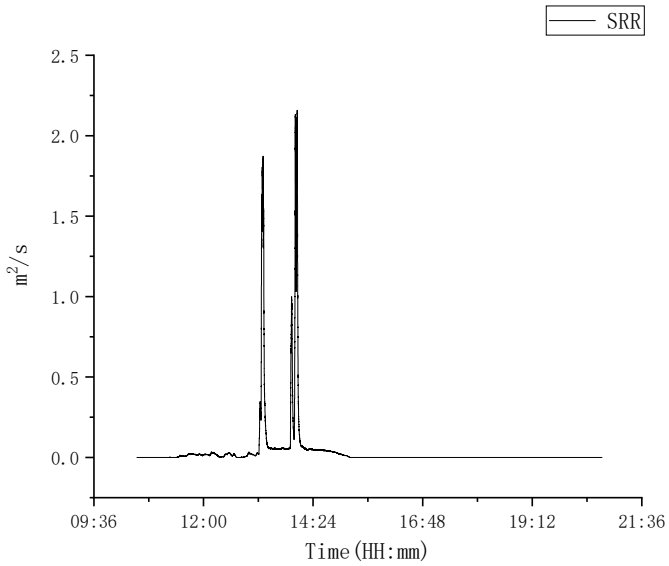
A_0 = *0.9950*

A_1 = *-5.29933E-05*

A_2 = *3.21022E-07*

A_3 = *-1.22004E-10*

Figure 25. Peak smoke release rate SRR: 2.16 m2/s



3.9 Gas generation measurement

The composition, velocity and temperature of the vent gases were measured within the calorimeter's exhaust duct.

Gas compositions were measured using a Fourier-Transform Infrared Spectrometer with a resolution of 1 cm^{-1} and a path length of 4.2 m within the calorimeter's exhaust duct.

The total hydrocarbon content of the vent gas was measured using flame ionization detection.

Hydrogen gas was measured with electrochemical method.

Composition, velocity and temperature measurement instrumentation were collocated with heat release rate calorimetry instrumentation.

3.9.1 Total gas release

The flow rates of various gases were integrated over the test duration and the total cumulative volume of gas calculated for the total test duration (10:32 ~ 20:43) was presented in the below table.

The total cumulative volume of gases before cell venting (10:21 ~ 12:46) was also presented in the table for reference. Which may be considered as ambient gases background before the test.

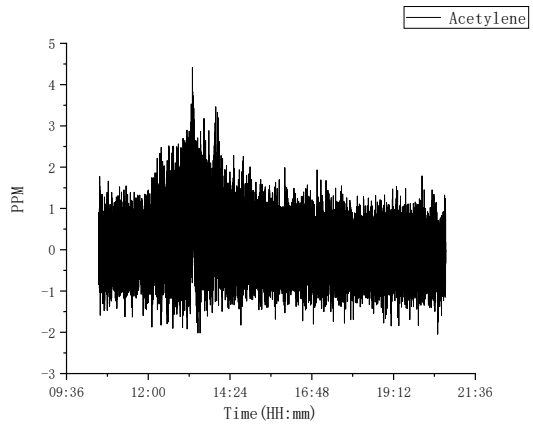
Gas type	Gas components		Total volume of gas (L)	
			Before cell venting	Throughout the test
Hydrocarbon species	Methane	CH4	0	45.5
	Acetylene	C2H2	0.1	6.4
	Ethylene	C2H4	0	35.4
	Ethane	C2H6	0	14.8
	Propylene	C3H6	0	71.6
	Propane	C3H8	0.1	25.5
Hydrogen halide species	Hydrogen Fluoride	HF	0	61.1
Nitrogen containing species	Nitrogen Monoxide	NO	0.1	29.1
Others	Carbon Monoxide	CO	0	152.3
	Carbon Dioxide	CO2	23096.8	80258.1
	Hydrogen	H2	0	466.9
	Oil as octane	--	0	25.3
	Methanol	CH4O	0	69.5
	Diethyl carbonate	C5H10O3	0	5.8
	Ethylmethyl carbonate	C4H8O	0	73.7
	Dimethyl carbonate	C3H6O3	0	362.1
Total Hydrocarbons				363.9

Note:
1) The collection time is from 10:32 to 20:43;
2) The carbon dioxide in the air during this period1) was also counted;
3) Total hydrocarbon gas volume was measured by flame ionization detection (FID);
4) Total volume of carbon monoxide (CO) and carbon dioxide (CO2) was measured using nondispersive infrared spectroscopy (NDIR);
5) The volume of hydrogen (H2) was measured using electrochemical with MODEL5000 sensor.

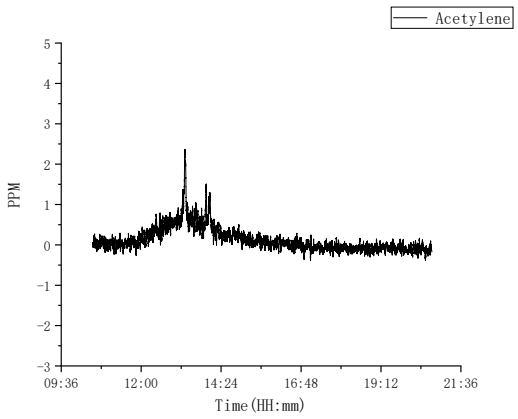
3.9.2 Gas components

Concentrations of the gases were scaled based on the measured flow rate of the exhaust system and were presented in the standard volume flow rate of gas ventilated in below figures.

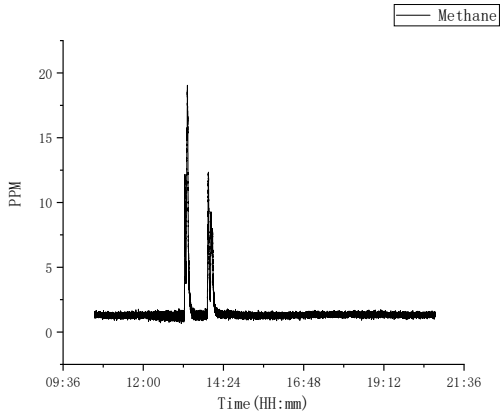
Figure 26. Hydrocarbon species



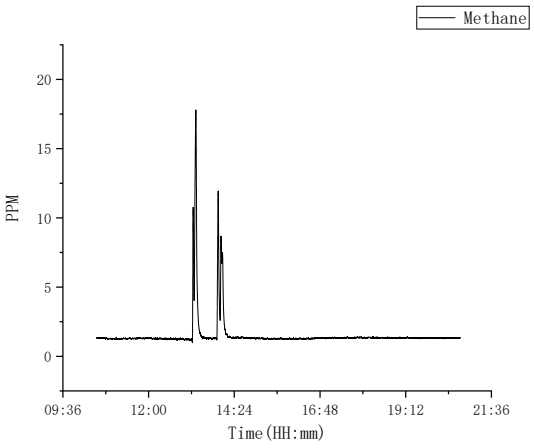
Raw original data



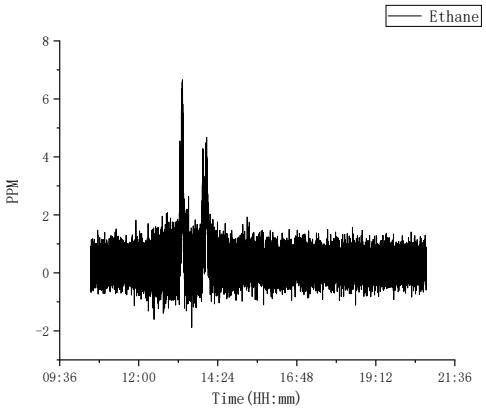
Savitzky-Golay filtered data



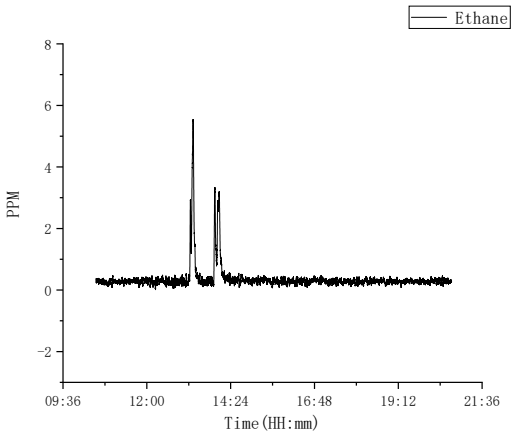
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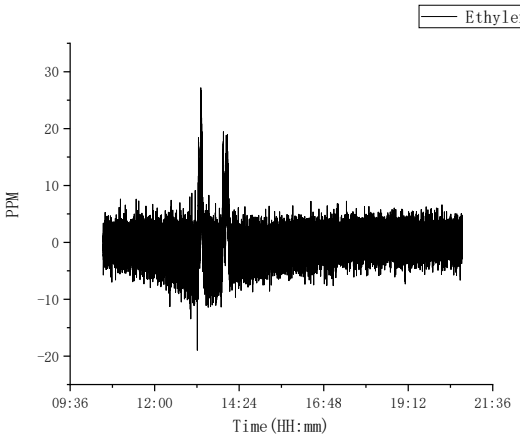
Savitzky-Golay filtered data



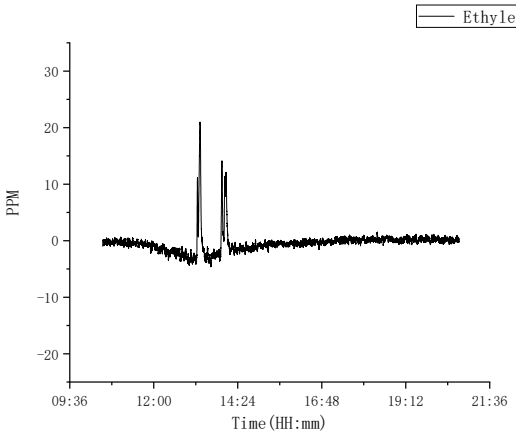
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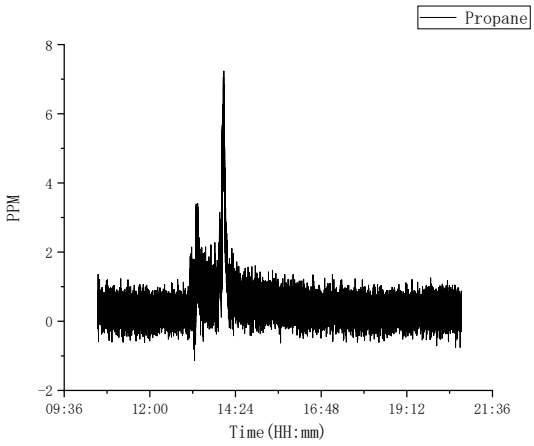
Savitzky-Golay filtered data



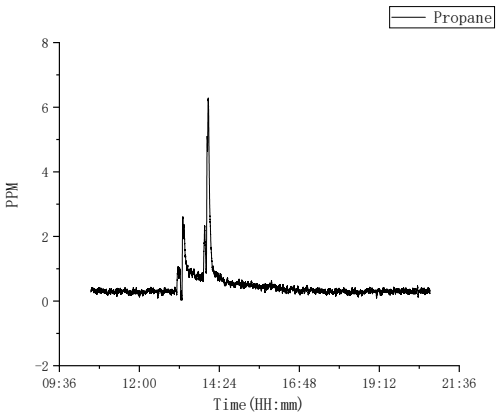
Raw original data



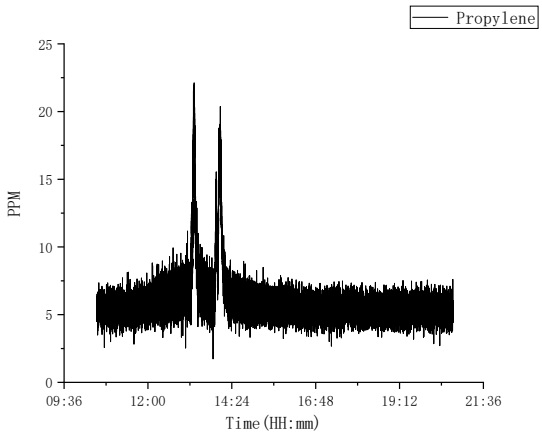
Savitzky-Golay filtered data



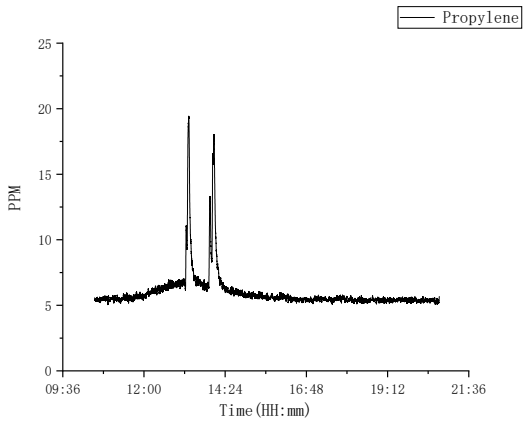
Raw original data



Savitzky-Golay filtered data

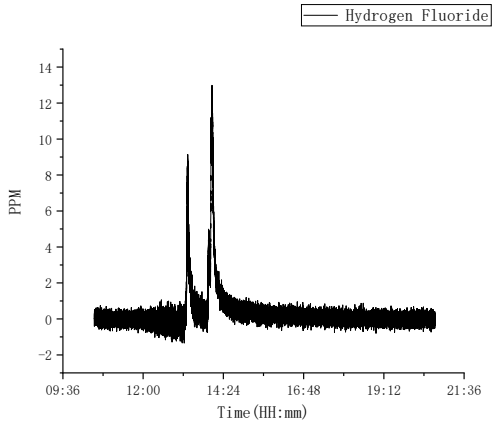


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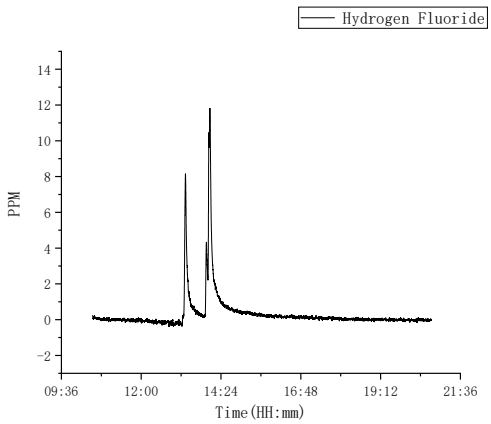


Savitzky-Golay filtered data

Figure 27. Hydrogen halide species

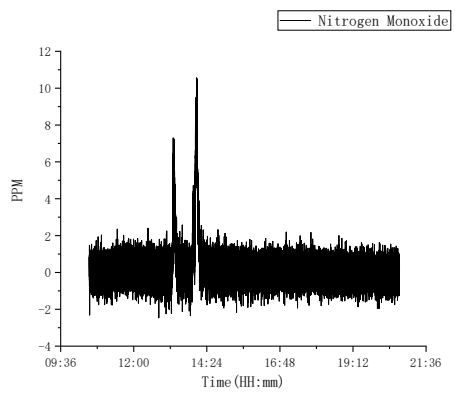


Raw original data

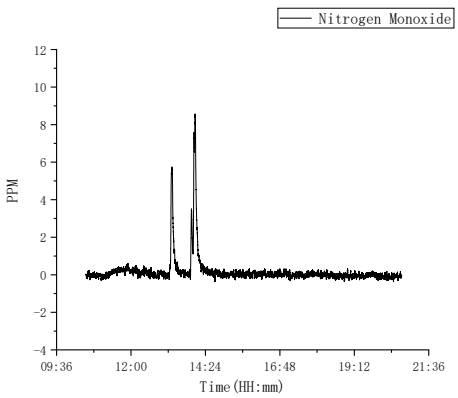


Savitzky-Golay filtered data

Figure 28. Nitrogen containing species



Raw original data



Savitzky-Golay filtered data

Figure 29. H_2 containing species

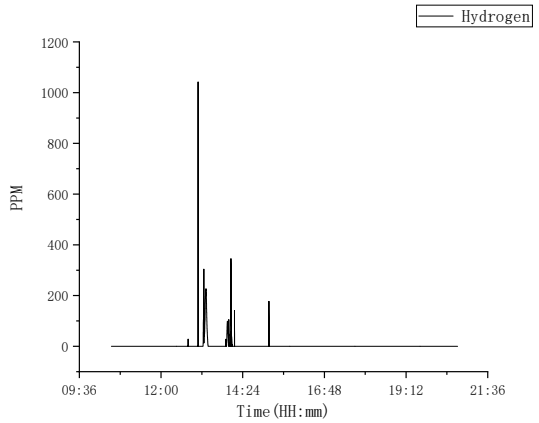
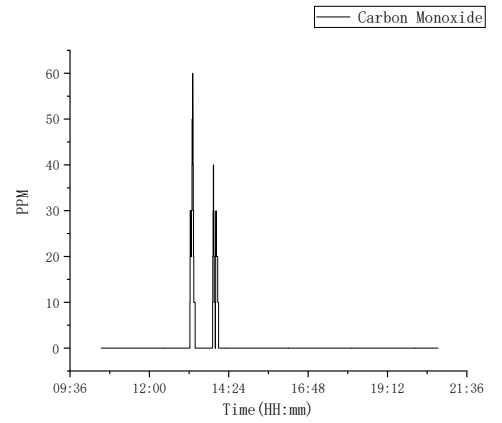
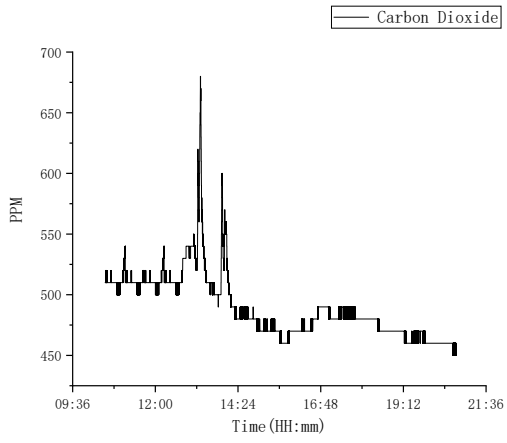


Figure 30. CO, CO_2 containing species

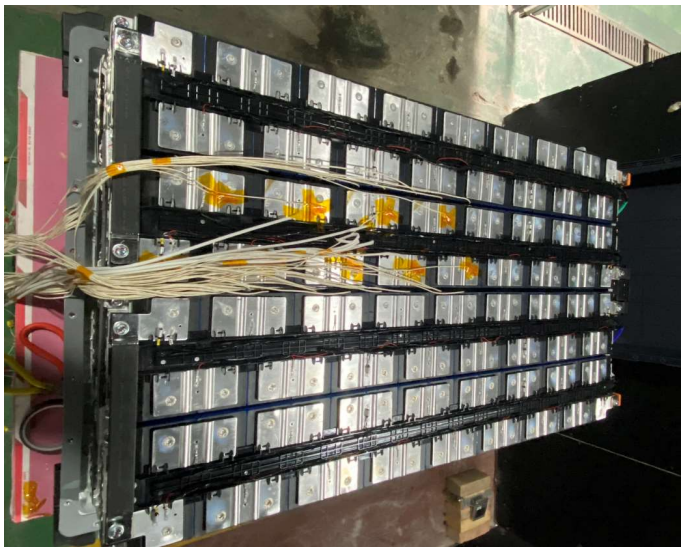




Note: Since raw original data is hard to interpret. Savitzky-Golay filtered data is also provided as this smooths the data and increases the precision of the data without distorting the signal tendency.

3.10 Photos

Initial module





Test setup





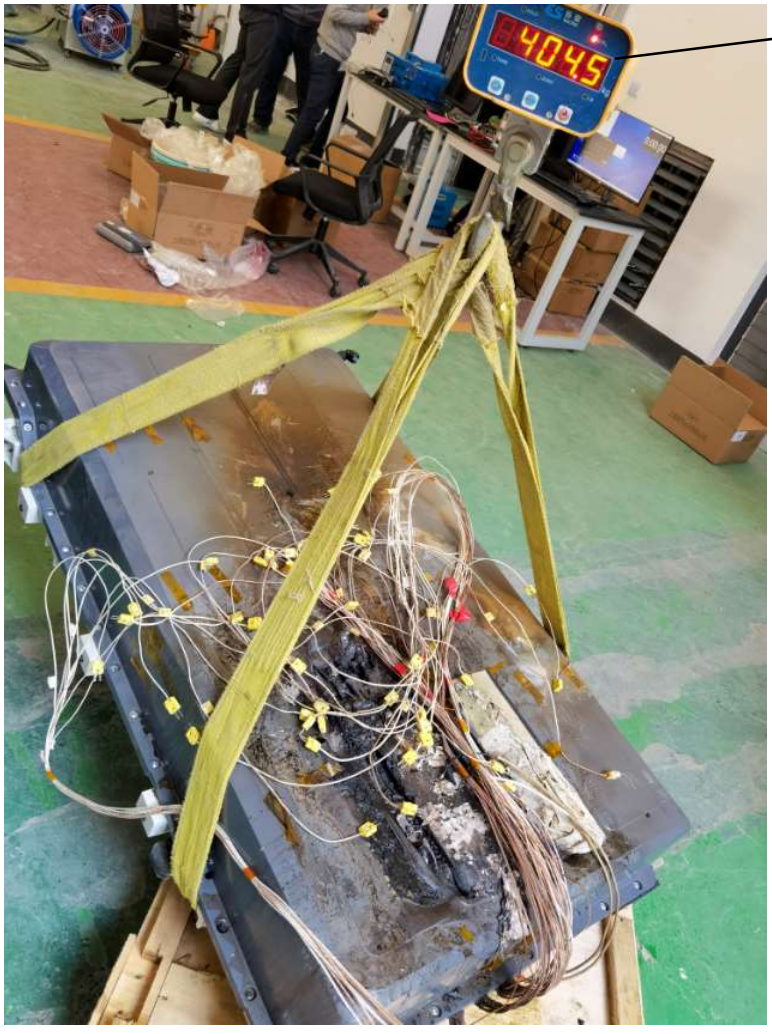
Smoke release during the test





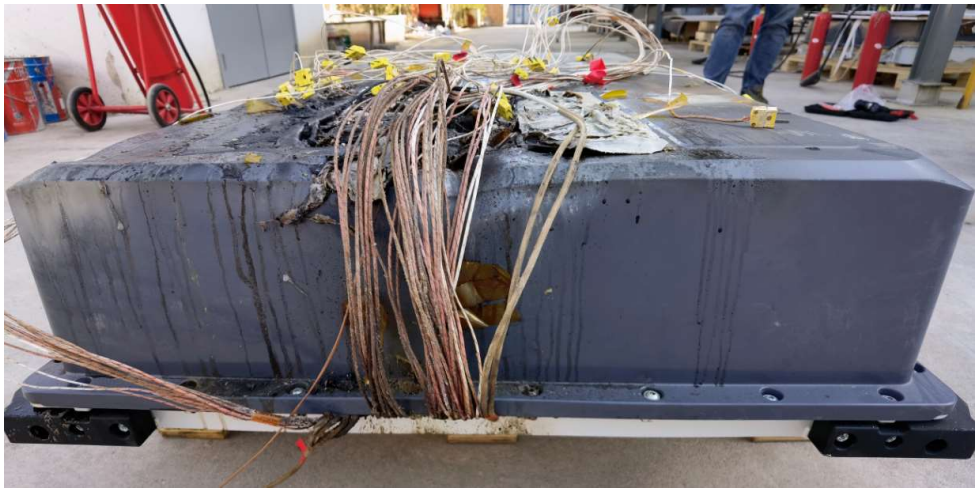
Photos after the test







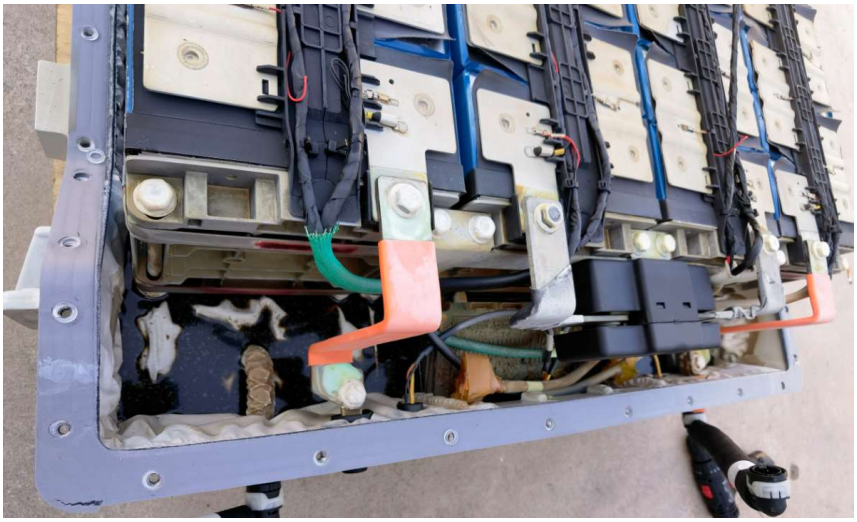

BAT-
COMM2
IN
COMM1
BAT+
OUT



Initial module after test







4 List of Test and Measurement Instruments

No.	Equipment		Model	Rating	Inventory no.	Last Cal. date
1	Ambient monitor		WSB-2-H1	0-40°C，10-90%RH	T-125	2021.07.24
2	Ambient monitor		WSB-2-H1	0-40°C，10-90%RH	S-050	2021.05.31
3	Data acquisition equipment		DTM	0-1000°C	S-029	2021.04.19
4	Data acquisition equipment		ADAM-4117 ADAM-4118 MT4W DTB4824	0-10V 0-1000°C 0-100V 0-1000°C	S-028-3 S-028-4 S-030-(5~8) S-046-2	2021.04.19 2021.05.06 2021.07.19 2021.07.20
5	Digital multi-meter		FLUKE101	0-600V	S-038	2021.04.22
6	Tape		1000mm 5000mm	0-1000mm 0-5000mm	S-040 S-042	2021.04.22 2021.04.22
7	Electronic scale		TCS-500	0-500kg	S-039	2021.04.19
8	Oxygen consumption calorimeter measurement system	Paramagnetic oxygen analyzer	SERVOMEX MultiExact 4100	O_2: 0-21% CO_2: 0-10% CO: 0-1%	S-024	2021.03.20
		CO and CO2 sensor				
		Velocity probe	WIKA	0~0.4MPa	S-024-5	2021.03.08
		Photo detector	DP101MD	-100~100Pa	S-024-4	2021.03.08
		Light filter	——	25%、50、75%	S-024-6 S-024-7 S-024-8	2021.03.12
9	Palladium-nickel thin-film solid state sensor		H2scan 740B MODEL5000 OMD-650	500ppm-100% 0-4% <20%	S-023-1 S-023-2 S-023-3	2021.03.20
10	Fourier-Transform Infrared Spectrometer		MG6000	0.01ppm-100%	S-019	2021.03.20
11	Flame Ionization Detector		ABB AO2000	0-3000ppm	S-025	2021.03.20
12	Thermopile		OMEGA TT-K-24	0-260℃	S-026	2021.04.01

13	Heat flux measurement equipment	Schmidt-Boelter, 64-5-20	0-50kW	S-031 S-032 S-033 S-034 S-035 S-036 S-037 S-065	2021.06.21

End of Test Report