Draft standard document for stationary batteries

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° ENER/FP7/308896/STABALID and n° ENER/FP7/308800/STALLION.

CONTENTS

1 INTRODUCTION

1.1 Scope

The FP7 projects STABALID and STALLION deal with a risk assessment of large-scale, stationary, grid-connected Lithium ion storage systems. Such energy storage systems have intrinsic safety risks due to the fact that high energy density materials are used in large volumes. In addition these storage systems are possibly situated in a residential area. Since this application is still under development, only few relevant standards have been formulated until now on the specific application of electrical stationary storage. In both projects, test procedures are developed that protect against the most prominent risks defined in a prior risk assessment. The defined test procedures shall either ensure risks for which no test procedure is existing or shall describe present tests more stringently with a focus on the specific application.

1.2 Selected risks

Both the STABALID and STALLION projects have executed a thorough risk assessment of a large stationary Li-Ion battery. This has led to a quantification and priority ordering of the identified risks. When combining both lists, there was a significant overlap. Hence a combined list was presented for review to the International Advisory Boards of both projects, which led to the following list of representative scenarios and main risks for which a test procedure should be defined:

- Propagation of thermal runaway between cells or modules
- Internal short circuit in a cell
- Overcharge of a module
- Undercharge because of extended storage
- Rough handling of the battery container during transport or installation
- Module cycling without cooling
- Deformation of module due to an accident
- Flooding of the battery container
- External short circuit of a module
- Malfunctioning of the BMS

The following risks were also identified to be important, but for these risks design requirements were found to be a better option than the definition of a test procedure:

- Touchable external voltage
- Insulation failure due to moisture

1.3 Test protocol structure

Each of the defined test procedures is specified using the following structure:

1. Purpose: this describes the intention (i.e. the 'why') of the test procedure and the risks it is supposed to mitigate.
2. Approach: this describes how the test procedure is supposed to test for the identified risk (i.e. the 'how').
3. Items to be tested: this describes the device under test and in which stage of its lifetime it should be subjected to the test.
4. Test equipment: this describes the mandatory and optional test equipment that is needed to execute the defined test procedure. Test equipment is defined as mandatory when it is necessary to verify whether the device under test passes or fails the test. Optional test equipment may be used to gather additional information from the test that may be useful to improve the design.
5. Precondition: this describes the condition the device under test and the environment are in before the actual test procedure is started.
6. Test procedure: this describes the actual test procedure in a stepwise manner. It also indicates any pass-fail criteria linked to the executed test steps.
7. Post condition: this describes the condition the device under test is in after the execution of the test procedure. This post condition may depend on whether the device under test passed or failed the test.

1.4 Definitions

In all test procedures, the following definitions are used.

- Cell: a cell consists of a single cathode and anode, where electric energy is derived from the insertion/extraction reactions of lithium ions. The cell contains an electrolyte and is mechanically contained in a housing.
- Cell block: a cell block consists of one or more cells connected in parallel.
- Block assembly: a block assembly consists of one or several cell blocks in series and contains at least one temperature sensor.
- Module: a module consists of one or more block assemblies and it has a battery management system that reads data from the voltage and/or temperature sensors at lower levels. The BMS potentially communicates to a higher level battery management system.
- Pack: a pack consists of one or more modules and it has at least one current sensor. It has a BMS that reads this current sensor and potentially communicates with battery management systems at lower and higher levels.
- Fail-safe BMS[1]: A fail-safe BMS consists of separate control- and safety systems. The safety system shall be independent from and supervisory to the control system. This means that the internal functionality, external communications and actuators of the safety system shall not be

[1] Battery Management System

negatively impacted by a failure of the control system. In case of failure of the control system, the safety system informs a hierarchically higher system (i.e. not the control system), or a human operator of the failure. In case of failure of the safety system itself it will fail in such a way that the system it is supposed to guard is left in a safe state. All software that is part of the safety system is implemented as safety-critical software (e.g. according to IEC 60508 or IEC 62897).

- Leakage: visible escape of liquid electrolyte
- Venting: release of excessive internal pressure from a cell, module, battery pack, or battery system in a manner intended by design to preclude rupture or explosion
- Rupture: mechanical failure of a cell container or battery case induced by an internal or external cause, resulting in exposure or spillage but not ejection of materials
- Explosion: failure that occurs when a cell container or battery case opens violently and major components are forcibly expelled
- Fire: the emission of flames from a cell, module, battery pack, or battery system
- Hazardous event: fire, explosion or rupture.
- I_t: the current by which a battery cell or module is charged from 0% to 100% in exactly 1 hour.

2 GENERAL INSTRUCTIONS

2.1 Mandatory equipment

For all tests we expect any personnel involved in the test to use proper personal protection devices and tools for the handling of charged cells and modules (e.g. protection glasses for eyes, insulated hand gloves, electrically insulated tools etc.).

For tests that take some time we expect the use of a video camera to record the test results to make sure, that events will be captured even if the complete test can't be monitored by test personnel.

For all tests that may lead to a thermal runaway we expect the following equipment to be used:

- Test chamber able to withstand the effects of the thermal runaway/explosion of a module.
- Exhausting system, able to exhaust the maximal volume of escaping fumes, flames, vapors etc. This system shall be able to withstand high temperatures up to 900 °C for a longer time.
- Tissue paper to be placed under the device under test to detect flames escaping the enclosure of the system below the enclosure.

2.2 Preconditioning

Prior to testing, all active cells in the test will cycled three times at an ambient temperature of 25 °C ± 5 K using a CCCV charging profile:

- Charging to the specified maximum voltage with the maximum charge current specified by the manufacturer.
- The charging is continued at constant voltage until the charge current drops to 0,05 I_t A.
- Discharging to the specified minimum voltage with the maximum discharge current specified by the manufacturer.

After these cycles, the cells are charged for half an hour with a current of I_t.

This can be executed on individual cells or on a module.

After the cycling, wait for 6 hours until all cells have cooled down to the ambient temperature of 25°C ± 5 K.

2.3 BMS reset

In case the BMS contains an error register, it may be necessary to reset the register between test steps, when the battery has exceeded the safe operating range.

3 PROPAGATION OF THERMAL RUNAWAY

3.1 Purpose

The test shall make sure, that cells turning into a thermal runaway or another hazardous event will not propagate this event to cells in the neighborhood of the cell with the initial event.
Causes for a thermal runaway or another hazardous event within one cell could be, but is not limited to, one or more of the following reasons:

- Metal particles inside the cell due to contaminants during cell production
- Defective separator materials not detected during cell production
- Rising dendrites puncturing the separator material because of incorrectly charging and discharging cells in stationary batteries in case of Single Fault Conditions or poor construction of safety circuits.
- Mechanical damage to cell internal materials during or before production of the cell

3.2 Approach

The approach used in this test is initiating a thermal runaway in a single cell and then observing the effect. There are several methods to turn cells into a thermal runaway or another catastrophic event.

- Method A: external short circuit of the terminals of one cell with very low impedance
- Method B: internal heating element in the cell
- Method C: heating up one spot of one cell with an electric heater element. The initial temperature of the heater is 200°C. If this doesn’t trigger a thermal runaway, the temperature is increased with 100°C every 5 minutes until 600°C is reached or a thermal runaway is triggered.
- Method D: using a nail made of metal to puncture the cell and the separator and in that way cause a short circuit. Special caution has to be given to the setup of the module. The test on cell level must acknowledge the accessibility of the cell.
- Method E: overcharge of a cell. In this case the electrical connections between the treated cells, the adjacent cells and the other (dummy) cells shall be made in such a way that the initial overcharging only influences the treated cell.
- Method F: exerting external force on a cell using a blunt nail, without puncturing it, until separator shutdown. Special caution has to be given to the setup of the module. The test on cell level must acknowledge the accessibility of the cell.
- Method G: In cases where methods A to F could not be used due to construction limitations or safety features built into the cell, an appropriate method shall be found and agreed between test house and manufacturer of the cells leading to the aimed result (thermal runaway or other (catastrophic) failure). This method will be confirmed by applying it on three different cells prior the final test with the module to be sure this method works consistently.
  In case the cell manufacturer could not provide any acceptable method to reach this result, pre-tests shall be done on 10 single cells to find a way to turn the cell into a thermal runaway or other (catastrophic) failure. All 10 cells shall be tested with different methods. The test with

the worst case event in terms of exhausted gas volume or emitting of fire shall be used to confirm this method. The found method shall be confirmed on two further samples to make sure, that this method works consistently. The method found to be acceptable with this test will be used for the final test with the module or battery.

If there is none of the executed pre-tests results in a catastrophic failure, the cell and therefore the module or battery is considered safe in the terms of this propagation test.

The temperature at which this procedure is performed may have an impact, so the most appropriate temperature for triggering the thermal runaway should be chosen.

3.3 Items to be tested

This test is to be executed on one or several modules. These modules shall be mounted within their original enclosure to make sure, that the conditions of oxygen flow into the enclosure through openings will be the same as later in the field. Any change of oxygen volume within the enclosure and the ability of oxygen to enter the enclosure via openings of the enclosure of the system has direct influence on the concentrations of hazardous substances within the enclosure and therefore also outside the enclosure of the system, where persons could be harmed by these substances.

To have a representative situation of an installation later in the field, all components of the original system shall be part of this test. However, components with high costs can be replaced by dummies. But at least one module with active cells shall be part of the test setup. The cells in direct neighborhood of the cell that initiates the thermal runaway shall be active and fully charged in the same way as the initial cell, even if they are in a different module from the one that houses the initial cell. All other cells may be volume dummies (same enclosure but not filled by active materials) or fully discharged cells (voltage 0 V) to reduce the amount of energy involved when a thermal runaway or other event occurs. All dummy or fully discharged cells will have their terminals short-circuited to allow charging via the standard module terminals.

3.4 Test Equipment

3.4.1 Mandatory equipment

3.4.1.1 General equipment

- Test chamber with the ability to control the ambient temperature within the operational boundaries of the module under test.
- Temperature measuring system (measuring range 0 °C up to 1200 °C) for measuring temperatures at specific points on the device under test e.g. on the terminals, the enclosure, the venting area.
- Cycling equipment capable to drive the currents and voltages according to the manufacturer's specifications or the operation region for the cells under test according to the test requirements.

3.4.1.2 Additional test equipment for method A

- Short circuit device capable of at least 3000 A short circuit current where the maximum loop resistance of the external device including connection leads (excluding the contact resistance between the leads and the terminals of the cells) doesn't exceed 0,3 mOhm while a current of 3000 A is flowing (e.g. short circuit by relay, knife switch or electronic device, in all cases remotely activated). Special attention shall be given to the fact, that wire resistance as well as contact resistance could be changed based on heating up the materials due to high currents. Special attention shall also be given to the fact that those high currents will lead to high forces on the wires and components of the short circuit device, depending on the construction. See IEC 61660-1 for short circuit current calculations in DC circuits and IEC 61660-2 for calculation of forces between current carrying conductors.

3.4.1.3 Special additional test equipment for method B

- A heating element capable to heat up until a separator within a cell will become instable and create a hole in the separator. The heating element shall be constructed in such a way, that it will not impair the uniformity of layers (conductive foils and separators) within the cell. The heat shall be concentrated to a spot not exceeding a surface of 10 mm².
- A power supply to heat up the heating element, adapted to the technical parameter in terms of voltage and available power of the heating element.

3.4.1.4 Special additional test equipment for method C

- An electric heater to heat up a cell. This heater shall provide heat at a local area of one cell in such a way, that this heat will lead to a shutdown of the separator in this area and therefore a thermal runaway or other event will start. The contact area to the cell shall not exceed 5 mm in diameter. The temperature of the contact area shall be regulated to its intended temperature between 200 °C and 600 °C with a max. deviation of ± 5 K.

3.4.1.5 Special additional test equipment for method D

- Equipment of driving a metal nail through a battery cell.

3.4.1.6 Special additional test equipment for method E

See test procedure 'Overcharge of a module', §0.

3.4.1.7 Special additional test equipment for method F

- Equipment for exerting force on a battery cell using a blunt nail, without puncturing the cell.

3.4.2 **Optional equipment**

3.4.2.1 Equipment when testing system for residential use

- Measurement system capable to measure the exhausted amount of gas, fumes, vapors (compared to the existing volume within the chamber minus the volume taken by the construction of the system).

- Chemical analysis system to make a measurement of the chemical content of the exhausted fumes and vapors of the cell or module.

3.4.2.2 Additional test equipment for method A:

- Current measuring device capable of measuring currents up to 3000 A DC with high accuracy and sample rate. A sample rate of 100 readings per second or an oscilloscope are considered acceptable. The device is necessary to detect the current with sufficient accuracy and make sure the test procedure was performed correctly.

3.5 Precondition

Thermocouples are placed on the cell to be treated, such that sufficient temperature results are generated to get an overview of the temperature distribution on all sides of the cell (see Annex B for example). An extra thermocouple is mounted in the area where the vent of the cell is located to get temperature readings from the exhausted gases, vapors, etc.
On cells in the direct neighborhood of the cell to be treated thermocouples are mounted on corresponding areas (direct opposite the thermocouples on the cell to be treated).
The exhausting system of the chamber shall not be active at the start of the test. A gas sampling shall take place at this time (zero reading).
The temperature of the test chamber is set at the most appropriate temperature to trigger thermal runaway in the treated cell, as explained in paragraph 3.2. All active cells are charged to 100% +0/-5% SOC.

3.6 Test procedure

#	Action	Pass/Fail
1	Put the modules into the test chamber, connect all necessary charging and monitoring cables. Wait 6 hours for temperature stabilization or until the temperatures of the active cells differ by maximum 2K. Start all monitoring equipment.	
2	Initiate the thermal runaway of the initial cells, by using any of the indicated methods.	If another cell, except for the initial cell turns into a thermal runaway or any hazardous event, the module fails the test.
3	When testing systems for residential use, the exhausted gas volume shall be measured. After the event is initiated a gas analysis shall be performed again between 2 and 5 minutes after the event was triggered.	

4	The test is finished six hours after the initiation of the thermal runaway or when the temperature of all monitored cells is within 5K of the ambient temperature, whichever is longer.	If another cell, except for the initial cell, turns into a thermal runaway or any hazardous event, the module fails the test.

3.7 Post condition

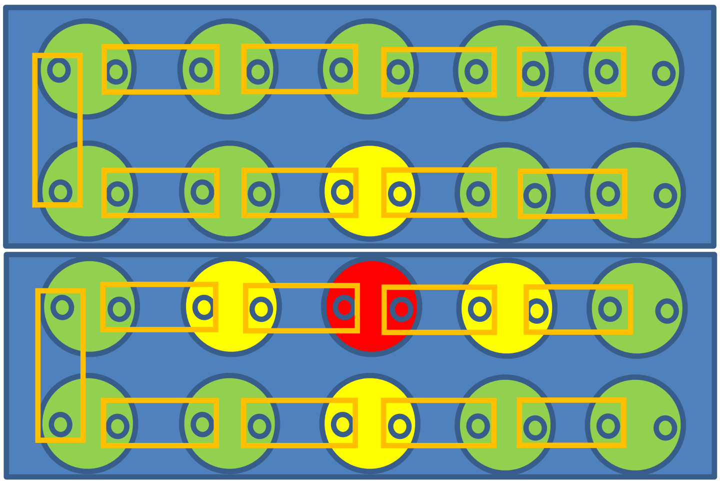
After the gas analysis is finished the test chamber shall be purged by means acceptable for this kind of fire. At the same time the exhausting system will be switched on. The analysis of the exhausted gas, vapor, fumes and flames and the measurement of the exhausted volume of gas could provide information about circumstances under which the cells might be used even if the test is unsuccessful.
In all cases, independent which method is used to trigger the thermal runaway, the modules tested are handled with extreme care and always using protection devices.
The modules tested are regarded as dangerous good according to UN regulations.
Any transport shall be done according to the existing rules for dangerous goods.
Disposal shall only be done according to the legal local regulations for this kind of waste material.

3.8 ANNEX A

3.8.1 **Example A**

Module A with one cell to be treated (Red), 4 cells which are active as well (yellow) and all others are dummies or fully discharged cells (green).

The terminals of the modules are used to charge the active cells (in Module A 4 cells) in Module B 1 cell).

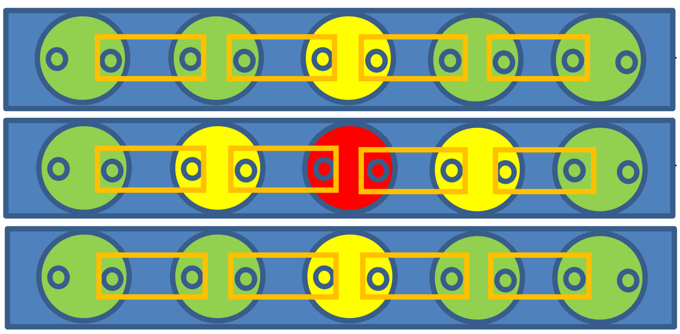


All dummy cells (green) are short circuited between its cell terminals to allow charging over the + and – terminals of the modules.

3.8.2 **Example B**

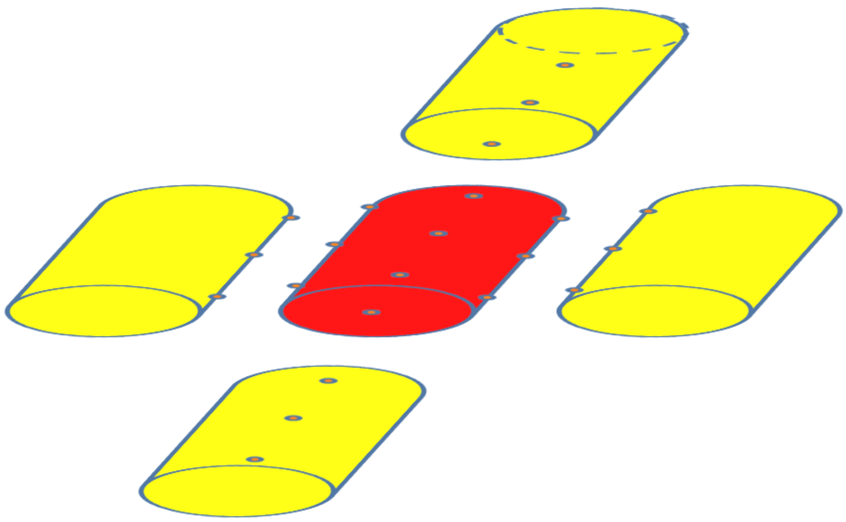
Module B with three cells to be treated (Red and yellow), each one cell in the Modules A and C which are active as well (yellow) and all others are dummies or fully discharged cells (green).

The terminals of the modules are used to charge the active cells (in Module A and C 1 cell) in Module B 3 cells).



All dummy cells (green) are short circuited between its cell terminals to allow charging over the + and – terminals of the modules.

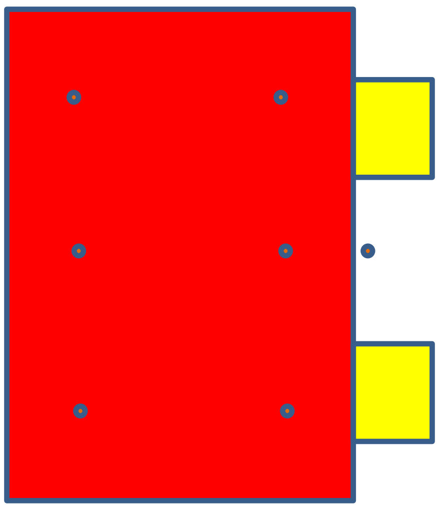
3.9 ANNEX B: Example of mounting thermocouples for temperature measurements:



On a cylindrical cell to be treated (red) there shall be mounted 13 thermocouples to get a temperature distribution of the surface temperature of the cell. 12 thermocouples on the cylindrical surface, 4 mounted around the diameter and three of such “rings” distributed over the longitudinal axis. The thermocouple 13 will be located where the venting area is located.

On the neighboring cells (yellow) thermocouples shall be mounted opposite to the thermocouples on the treated cell. On each neighboring cell 3 thermocouples shall be mounted.

The mounting shall be in such a way, that the temperatures will not impair the position of the thermocouple even the temperature is up to 900 °C.
On prismatic cells the distribution of the thermocouples shall be as follows:
The drawing assumes that neighboring cells are facing the treated cell with the greatest surface. If the placement is different, the placing of the thermocouples shall be aligned by taking the actual configuration into account, so that the intended result will be reached.
6 thermocouples will be distributed on each side with the greatest surface. One thermocouple should be placed in the area of the venting opening.
For the neighboring cells the same principle shall be used as described at the cylindrical cells.
(yellow are the terminals of the cell)



4 OVERCHARGE OF A MODULE

4.1 Purpose

This procedure shall make sure, that overcharge happening during single fault conditions within the charging circuits or the BMS system will not lead to a hazardous situation.

4.2 Approach

A module and a cell are overcharged until 2 times the maximum charge in Ah is charged into the module or cell or until they reach twice the specified maximum voltage. No cell should go into thermal runaway during the test or during an inspection period.

4.3 Items to be tested

One module and one cell shall be tested using the procedure described below.
If the module is equipped with a fail-safe BMS it may be permitted to waive the overcharge test procedure. For this purpose it is necessary to verify previously the conformity of the BMS being fail-safe by performing the overcharge test procedure with the BMS enabled. In case of a positive test result further overcharge procedures on cell or module level may then be carried out but are not stringently required.

4.4 Test Equipment

4.4.1 Mandatory

- Test chamber with the ability to control the ambient temperature within the operational boundaries of the module under test.
- Cycling equipment capable to drive the currents and voltages according to the manufacturer's specifications or the operation region for the cells under test according to the test requirements.

4.4.2 Optional

- Thermal imaging and recording system for measuring the temperature distribution of the surface of the cell during the test.
- Temperature measuring system (measuring range -200 °C up to 1200 °C) for measuring temperatures at specific points on the sample e.g. on the terminals, the enclosure, the venting area. These temperature measuring system acts at the same time as reference for the thermal imaging system.

4.5 Precondition

The temperature of the test chamber is set at the minimum operating temperature of the module -0K +5K. The module and cell should be charged to 100% -5% +0% SOC.

4.6 Test procedure[2]

#	Action	Pass/Fail
1	Put the preconditioned test samples (cell and module) into the test chamber, connect all necessary charging and monitoring cables. Wait 6 hours for temperature stabilization or until the temperatures of the active cells differ by maximum 2K.	
2	Overcharge the cell and module with a current of I_t either to a voltage twice the cell/module voltage or the max available voltage in the charging circuit even under single fault condition, whichever is higher, while charging a maximum of 2 times the maximum charge in Ah into the cell and the module.	If the cell or any cell inside the module catch fire or explode, the test is failed.
3	The overcharging shall be made until 2 times the maximum charge in Ah is charged into the cell and module.	If the cell or any cell inside the module catch fire or explode, the test is failed.
4	The test is finished six hours after the initiation of the thermal runaway or when the temperature of all monitored cells is within 5K of the ambient temperature, whichever is longer.	If the cell or any cell inside the module catch fire or explode, the test is failed.

4.7 Post condition

Destroy the module directly after the test e.g. by immersing it in salt water.
Regardless of the test result the module and the cell shall be handled after the test with extreme care and always using personal protection devices.
Regardless of the test result the module and the cell should be regarded as a defective dangerous good according to UN regulations.
The transport shall be done according to the existing rules for dangerous goods.
Disposal shall only be done according to the legal local regulations for such kind of waste material.

[2] It is allowed to perform this test on a cell first and only perform the module test if the cell test is successful

5 DEEP DISCHARGE

5.1 Purpose

The purpose of this test procedure is to evaluate the danger arising from the battery, when it becomes deeply discharged due to false handling or extended storage without use.

5.2 Approach

A cell is discharged to 0V and after the deep discharge the cell is cycled to see the effect of any damage caused by the deep discharge.

5.3 Items to be tested

This procedure is to be executed on a cell. This test is a type test and should be executed at design time to prove the robustness of the design.
If the module the cell will be used in is equipped with a fail-safe BMS and the BMS has passed the BMS voltage protection test, this test can be waived.

5.4 Test Equipment

5.4.1 Mandatory

The following testing equipment is needed:

- System to apply a discharge to a cell down to 0V.
- Cycling equipment capable to drive the currents and voltages according to the manufacturer's specifications or the operation region for the cells under test according to the test requirements.
- Voltage sensor that measures the voltage of the cell with an accuracy of 5mV (can be included in the cycling equipment).
- Temperature measuring system (measuring range 0 °C up to 1200 °C) for measuring temperatures at specific points on the device under test e.g. on the terminals, the enclosure, the venting area.

5.4.2 Optional

- Thermal imaging and recording system for measuring the temperature distribution of the surface of the cell during the test.

5.5 Precondition

The cell shall be working correctly. The cell shall be tested at 100% +0% -5% SOC. The ambient temperature shall be 25°C ± 5°C. The cell shall rest at this temperature for minimum 6 hours before start of the test, unless it was stored at ambient temperature.

5.6 Test procedure

#	Action	Pass/fail
1	Put the preconditioned cell into the deep discharge system, connect all necessary charging and monitoring cables.	
2	Discharge the cell with I_t for 2 hours or until the cell voltage reaches0V, whichever is reached earlier.	The cell fails the test if any hazardous event occurs.
3	The cell shall rest for minimum 2 hours and until all temperatures are within 25°C±5°C.	The cell fails the test if any hazardous event occurs.
4	Put the preconditioned cell into the cycling equipment, connect all necessary charging and monitoring cables.	
5	Charge the cell up to 100% SOC with a charge current of $I_t/3$.	The cell fails the test if any hazardous event occurs. If the cell prevents charging, it passes the test[3].
6	Cycle the cell for 100.5 full cycles. Use the specified recommended charge and discharge current at 25°C. Stop charging at the charging voltage limit at $I<I_t/20$. Stop discharging at the discharge voltage limit. After each charging and discharging step there shall be a pause of 10 seconds. The test must be stopped after a discharge to make the handling after the test safer.	The cell fails the test if any hazardous event occurs. If the cell prevents cycling, it passes the test.

5.7 Post condition

After the test, the cell shall be handled with extreme care, always using personal protection devices.
In case of fire, explosion or venting the cell is regarded as a defective dangerous good according to UN regulations.
If the cell passes the test, it is not considered to be OK. In any case it needs to be handled with care, become discharged and shall not be used for further tests.
The transport shall be done according to the existing rules for dangerous goods.
Disposal shall only be done according to the legal local regulations for such kind of waste material.

[3] The cell can prevent charging or cycling by internal chemical reactions or internal safety features. No external safety devices like BMS control are considered in this test.

6 ROUGH HANDLING OF THE BATTERY CONTAINER

6.1 Purpose

The purpose of this test procedure is to evaluate the harmful effects of a drop of (or bump against) the battery energy storage system container on the battery modules inside a module rack inside the container. Such a drop or bump may occur during transport and handling.

The scenario to be tested is the following: during a 'normal' drop of the container, e.g. when the container is put into its place from the transport vehicle[4], the battery modules should not fall out of the module racks. This means that the locking mechanisms[5] (locks, bolts, latches, hooks, …) must stand such a container drop. No module should fall out of the module rack, because that would create an unsafe situation for the people who have to go inside the container to commission the system.

6.2 Approach

The drop of the battery container is translated into a drop test of a rack containing several modules. The pass criterion is that no modules shall fall out of the rack during the drop test.

The test could be performed with dummy modules to minimize the hazards when testing. The only purpose is to check that such an event doesn't result in mechanical or electrical hazards. In the drop test, the rack will have all dummy modules mounted to check the module locking mechanisms and the rack construction itself. The drop height of the rack is 1 meter. This value is selected to test a rather severe scenario, e.g. container falling from the carrying vehicle.

6.3 Items to be tested

This procedure is to be executed on a rack containing all modules that are normally inside the rack[6]. The modules should be dummies[7] that have the same outer dimensions, weight and weight distribution as a fully functioning module. The module locking mechanisms on the rack (including the fixing structure of the modules) should be of the same type that is used in the storage systems to be marketed. Also, the backplanes and/or busbars of the rack electrically connecting the modules to the system must be present in their original state.

This test is a type test and should be executed at design time to prove the robustness of the design.

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[4] This does not include an accident with the vehicle carrying the container, because we cannot make rules for a container that is tumbling over the side or rolling over.

[5] The modules might be disconnected and isolated from the rack backplane during transport, e.g. by positioning them a few centimeters forward inside the rack and fixing them by a locking mechanism.

[6] An empty rack with only modules at the top may collapse easier than a full rack.

[7] With dummy modules, no safety precautions with respect to shock or drop of a module (possibly initiating a hazardous event) are needed. Therefore, dummies are required or at least strongly advised. The use of dummies should not significantly change the electrical safety characteristics (e.g. insulation resistance) of the modules.

6.4 Test Equipment

The following testing equipment is needed for the test:

- Equipment (lift-and-release set-up) to let a heavy sample drop from a specified height on a concrete floor.
- Insulation resistance measurement device

6.5 Precondition

The manufacturer shall prepare and deliver dummy modules for testing, showing proof (e.g. measurements and calculations) of proper dimensions, weight and weight distribution. The manufacturer shall deliver a rack. The dummy modules shall be properly locked in the rack. All places available in the rack should be occupied. The backplanes and/or busbars of the rack must be present in their original state. The environment shall be at 25°C ±5°C.

6.6 Test procedure

#	Action	Pass/fail
1	Gently put DUT beneath lift-and-release equipment on concrete floor.	No lock shall open Locks shall not release any module
2	Lift DUT with lift-and-release equipment, until lowest point of DUT is 1.0 m above the floor	No lock shall open Locks shall not release any module
3	Stabilise DUT in such a way that the lower front edge is the lowest point and DUT is tilted 30° from the vertical position (see Annex A).	No lock shall open Locks shall not release any module
4	Release DUT from lift-and-release equipment (DUT falls on the floor)	No lock shall open Locks shall not release any module
5	Visually inspect module locks in rack	No lock shall open or have loose parts Locks shall not have released any module
6	Measure the insulation resistance between the back housing and the conductors.	Insulation resistance should still be in line with basic insulation.

6.7 Post condition

Since the test is performed with dummy modules, there will be no chemical or thermal hazards. The materials might be reused or recycled by the manufacturer.

6.8 **Annex A: Orientation of DUT before release.**

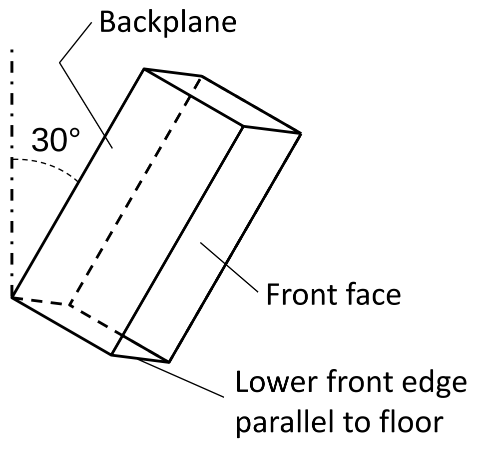


Figure 1. Orientation of DUT before release in drop test. The front face is the face facing the user during normal operation.

7 MODULE CYCLING WITHOUT COOLING

7.1 Purpose

The purpose of this test procedure is to evaluate the functionality and robustness of the battery in conditions where the battery becomes cycled without active cooling (e.g. due to a failure of the cooling system).

7.2 Approach

The approach is to impose a cycling to a module with cooling switched off. The cycling represents the worst possible use case.

7.3 Items to be tested

This procedure is to be executed on a module.
This test is a type test and should be executed at design time to prove the robustness of the design.
If the module is equipped with a fail-safe BMS and the BMS has passed the BMS temperature protection test, this test can be waived.

7.4 Test Equipment

7.4.1 Mandatory

The following testing equipment is needed:

- Test chamber with the ability to control the ambient temperature within the operational boundaries of the module under test.
- Cycling equipment capable to drive the currents and voltages according to the manufacturer's specifications or the operation region for the cells under test according to the test requirements.
- Temperature measuring system (measuring range 0 °C up to 1200 °C) for measuring temperatures at specific points on the device under test e.g. on the terminals, the enclosure, the venting area.

7.4.2 Optional

- Monitoring equipment to monitor the external communication channels of the module.
- Current sensor that measures the current through the module with an accuracy of 10mA (can be included in the cycling equipment).
- Voltage sensor that measures the voltage of the module with an accuracy of 5mV (can be included in the cycling equipment).

7.5 Precondition

The module shall be working correctly. All monitoring and control systems that are part of the module shall be properly powered. The temperature control system shall be disabled in a way that detected over-temperature may not stop the cycling. This can be realized by disabling the part on the BMS that tracks the temperatures, by disassembling the temperature sensors, by deactivating the safety controls which prevent the cycling or other comparable means. Any cooling system of the module shall be disabled in a way that the module is still working[8].

The SOC of the module shall be adjusted to 100% +0% - 5% SOC. The ambient temperature should be the highest allowed working temperature +0°C -5°C, the device under test shall be stored at this temperature for at least 6 hours before the start of the test. The temperature stabilized box must keep the surrounding temperature within the above mentioned limits.

7.6 Test procedure

#	Action	Pass/fail
1	Put the preconditioned module in the test chamber and connect all necessary charging and monitoring cables.	
2	Discharge the module with maximum allowed continuous discharge current down to the minimal module voltage or until one cell reaches the minimum cell voltage.	No leakage, venting or any hazardous event may occur.
4	Charge the module with maximum allowed continuous charge current until the maximum module voltage or until one cell reaches the maximum cell voltage.	No leakage, venting or any hazardous event may occur.
5	Repeat from step 3 without any pause until the module reaches a thermally stable state (the overall temperature of the module does not rise from one cycle to the other (step 4 to step 4, measurements of each sensor compared to itself) by more than 1°C), at least for 20 cycles.	No leakage, venting or any hazardous event may occur.

[8] There may be battery systems that have a redundant cooling system. These systems may get the opportunity to skip this test under still to be defined circumstances, e.g. proof that each cooling system can provide enough power to keep the storage within the operation temperatures. This issue will be covered in the next steps of the projects Stallion and Stabalid.

7.7 Post condition

In case the module or at least one cell within the module turns into fire, explodes, ruptures or vents, the module shall be handled after the test with extreme care, always using personal protection devices. In case of fire, explosion, rupture or venting the module itself is regarded as a defective dangerous good according to UN regulations.

If the module passes the test, it is considered to be OK and can be used for further testing; nevertheless the tested module is considered as an used one that will behave different than a new one in respect to the performance.

The transport shall be done according to the existing rules for dangerous goods.

Disposal shall only be done according to the legal local regulations for such kind of waste material.

8 EXTERNAL SHORT CIRCUIT OF A MODULE

8.1 Purpose

The purpose of this test procedure is to evaluate the danger arising from the battery, when it becomes short circuited due to an accident.

8.2 Approach

The approach is to short circuit one module with a resistance less than 5mΩ with fuse and other passive short-circuit protection elements enabled.

8.3 Items to be tested

This procedure is to be executed on a battery module.
This test is a type test and should be executed at design time to prove the robustness of the design.
The test should only be performed if a short circuit on module level is possible, i.e. by absence of double insulation, touchable terminals, creepage / clearance distances are inadequate (traces of conductive dust may cause a short circuit) or vermin intrusion.
Higher level safety (e.g. system level) is not covered in this test, but is part of the design review that is specified in IEC 62619. The individual safety of system level components (e.g. inverters) is part of other standards.

8.4 Test Equipment

8.4.1 Mandatory

The following testing equipment is needed:

- Test chamber with the ability to control the ambient temperature within the operational boundaries of the module under test.
- System to apply short circuits to batteries. The system shall be designed to handle short circuit currents.
- Voltage sensor that measures the voltage of the module with an accuracy of 5mV and with a sampling frequency or bandwidth of at least 1000Hz for the moment of short circuit (during the observation period a lower frequency can be used).
- Current sensor that measures the current of the module with an accuracy of 1A and with a sampling frequency or bandwidth of at least 1000Hz for the moment of short circuit (during the observation period a lower frequency can be used).
- Temperature measuring system (measuring range 0 °C up to 1200 °C) for measuring temperatures at specific points on the device under test e.g. on the terminals, the enclosure, the venting area.

8.4.2 Optional

- Thermal imaging and recording system for measuring the temperature distribution of the surface of the cell during the test.

8.5 Precondition

The module shall be working correctly. All monitoring and control systems that are part of the module shall be properly powered. Any cooling system of the module shall be disabled, as the cooling will not affect the result. The ambient temperature should be at the maximum operating temperature of the module +0°C -5°C. The module shall rest at this temperature for minimum 6 hours before start of the test. If applicable, fuses shall be in place. The state of charge of the module shall be adjusted to 100% +0% -5% SOC. The internal resistance shall be measured by suitable equipment or a pulse according to the IEC 62620.

8.6 Test procedure

#	Action	Pass/fail
1	Put the module in the short circuit system. Connect all necessary charging and monitoring cables.	
2	Apply a short circuit with a resistance equal to the internal resistance of the DUT ± 10% with a maximum of 5mΩ to the module. Apply this short circuit for 10 minutes after the current stops flowing (e.g. because the fuse blows) with a maximum of 2 hours.	The module fails the test if any hazardous event occurs. Venting is allowed.
3	The module shall rest for 6 hours or until all temperatures are equal to the ambient temperature, whichever is shorter.	The module fails the test if any hazardous event occurs. Venting is allowed.

8.7 Post condition

In case the module or at least one cell within the module turns into fire, explodes, ruptures or vents, the module shall be handled after the test with extreme care, always using personal protection devices. In case of fire, explosion or venting the module itself is regarded as a defective dangerous good according to UN regulations.

If the module is equipped with a fuse and passes the test, it is considered to be OK and can be used for further testing. If the module is not equipped with a fuse, it is not considered to be OK and it needs to be handled with care, become discharged and shall not be used for further tests.

The transport shall be done according to the existing rules for dangerous goods.

Disposal shall only be done according to the legal local regulations for such kind of waste material.

9 DEFORMATION OF MODULE

9.1 Purpose

The purpose of this test procedure is to evaluate the danger arising from the battery, when it becomes deformed by a force from outside the housing (e.g. by an accident during transportation or during operation).

9.2 Approach

The approach is to impose a force to a module by letting a weight fall on it.

9.3 Items to be tested

This procedure is to be executed on a battery module.
This test is a type test and should be executed at design time to prove the robustness of the design.

9.4 Test Equipment

9.4.1 Mandatory

The following testing equipment is needed:

- System to apply a defined impact with measurement equipment.

9.4.2 Optional

- High speed video monitoring system.
- Thermal imaging and recording system for measuring the temperature distribution of the surface of the module during the test.

9.5 Precondition

The module shall be working correctly. The module shall be in a state of 100% +0% -5% SOC. All monitoring and control systems that are part of the module shall be properly powered. Any cooling system of the module shall be disabled, so the cooling will not affect the result[9]. The ambient temperature should be 25°C ± 5°C. The module shall rest at this temperature for minimum 6 hours before start of the test, unless it was stored at ambient temperature. The module must be stabilized in a way as it is in the final case, so any displacement into areas that are already filled by other modules must be prevented.

[9] Most failures of this type will occur during transport, where the cooling system is supposed to be switched off.

9.6 Test procedure

#	Action	Pass/fail
1	Put the module in the impact system. The side to be impacted shall be the one that faces the walls of the enclosure. If several sides face the wall of the case, the side shall be impacted that may result in the worst effect. The impact shall be in the area where the worst effect is expected.	
2	Conduct the impact on the module. The impact mass is equal to the module mass ±10% and the height is 1000mm. The impactor has a hemispherical form with an radius of 150mm[10]	The module fails the test when it catches fire or leads to a thermal runaway that spreads across the whole module.
3	Observe the module for 2 hours.	The module fails the test when it catches fire or leads to a thermal runaway that spreads across the whole module.

9.7 Post condition

In case the module or at least one cell within the module turns into fire, explodes, ruptures or vents, the module shall be handled after the test with extreme care, always using personal protection devices. In case of fire, explosion, rupture or venting the module itself is regarded as a defective dangerous good according to UN regulations.

If the module passes the test, it is not considered to be OK and cannot be used for further testing. In any case it needs to be handled with care, become discharged and shall not be used for further tests. The transport shall be done according to the existing rules for dangerous goods.

Disposal shall only be done according to the legal local regulations for such kind of waste material.

[10] As defined in IEC 62660-2, step 2

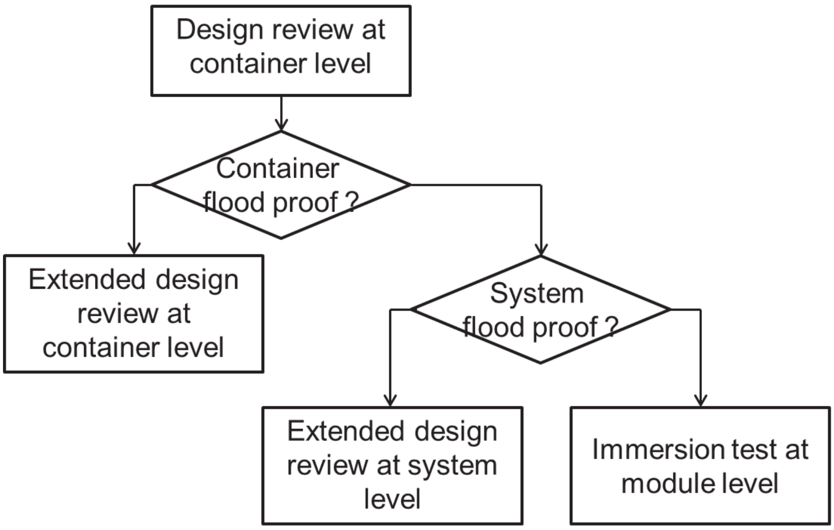
10 FLOODING OF BATTERY CONTAINER

10.1 Purpose

The purpose of this procedure is to evaluate the physical measures against the risk of flooding of the battery container. These measures should prevent flooding of the container or harmful effects on the system components inside.

10.2 Approach

The overall approach is shown in the flow chart below.



The first step in the procedure will be a design & construction review, depending on the specifications of the (sub)system manufacturers or the system integrator. The main barrier against flooding of the storage system is the container. Design and installation requirements are prescribed, to minimize the risk of flooding. It is recommended that the containerized storage system is placed in such a way that the probability of flooding is less than 1 in 1000 years.

If the container manufacturer or system manufacturer specifies that his equipment is flood-proof (i.e. immersion-proof), an extended design review is specified in this test procedure.

If none of the higher levels is flood-proof, the effects of flooding on the module will be evaluated through a flooding type test. Depending on the specification of the module manufacturer, the expected outcome of this flooding test will be either that no hazardous events occur or that the module is still functional.

10.3 Design review

10.3.1 Design review at container level

This review encompasses all relevant design and testing documents and also a physical inspection of a complete containerized storage system both on the inside and the outside. The storage system must be switched off, BMS's must be on, and the battery modules must be in a safe state. Specific items to be considered:

- The container, including the door seals and all other seals, shall be rainwater-proof (IPX4). This must be proven by standardized IP construction design reports or IP testing reports. The necessary measures should be taken that the container remains rainwater-proof for its entire projected lifetime.
- Condensation inside the container should be prevented (e.g. by an air conditioning system). In case of eventual condensation, drip water damage (e.g. from the container roof) should be prevented.
- The risk of hydrogen production, concentration and subsequent explosion (in the unlikely event of water ingress and hydrolysis) must be evaluated and mitigated. Possible measures could be:
  - Measures for hydrogen venting
  - A blowout device for hydrogen explosion
- The risk of chlorine production must be evaluated and mitigated.

10.3.2 Extended design review at container level

In case the container manufacturer mentions extra specifications for flooding-proofness, an enhanced design and construction review shall be executed to prove these extra specifications. If the manufacturer claims that the complete containerized system meets IPX7 requirements (full immersion), the system must be able to still operate after the flooding.
Items of the enhanced design and construction review may be:

- Ingress protection higher than IPX4 may be required (IPX7 for full immersion)
- Additional requirements for the constructional strength of the container to withstand the water pressure at full immersion
- Additional requirements for the air conditioning system, e.g. it must be watertight by having the heat pump outside of the container with closed piping through the container wall.

10.3.3 Extended design review at system level

In case the battery manufacturer mentions extra specifications for flooding-proofness, an enhanced design and construction review on the battery (i.e. without converter and other system components outside of the battery containment box) shall be executed to prove these extra specifications. If the manufacturer claims that the battery meets IPX7 requirements (full immersion), the system must be able to still operate after the flooding.
In this case the standard IEC 61427-2, which has an immersion test for batteries in sea water (complete battery immersion for 3 days), might be applicable.

10.4 Items to be tested

This procedure is to be executed on a battery module, in the case indicated in §10.2.
This test is a type test and should be executed at design time to prove the robustness of the design.

10.5 Test equipment

10.5.1 Mandatory

The following test equipment is needed

- Vessel that can contain the salt water and the DUT, including a system to measure the water depth.
- Salt water supply (5%±0.5% salt content in weight) with a water temperature of 25°C±5°C.
- Measurement system capable to measure the exhausted amount of gas (hydrogen, chlorine…).
- Chemical analysis system to make a measurement of the chemical content of the exhausted gas.
- Insulation resistance measurement device.
- Cycling equipment capable to drive the currents and voltages according to the manufacturer's specifications or the operation region for the module under test according to the test requirements.

10.5.2 Optional

- Current sensor that measures the current through the module (can be included in the cycling equipment or as part of the BMS).
- Voltage sensor that measures the voltage of the module (can be included in the cycling equipment or as part of the BMS).
- Temperature measuring system for measuring temperatures at specific points on the device under test e.g. on the terminals, the enclosure, the venting area.

10.6 Precondition

The module shall be working correctly. The module shall be in a state of 100% +0% -5% SOC. Any cooling system of the module shall be disabled, so the cooling will not affect the result[11]. The ambient temperature should be 25°C ± 5°C. The module shall rest at this temperature for minimum 6 hours before start of the test, unless it was stored at ambient temperature.

[11] Most failures of this type will occur during transport, where the cooling system is supposed to be switched off.

10.7 Test procedure

#	Action	Pass/fail
1	Put the module at the bottom of the water vessel	
2	Add salt water in the water basin at a rate of 2cm±0.5cm water height per 10 minutes until the complete module is 5cm±1cm below the water surface. Leave the module submerged for one hour.	The module fails the test if any hazardous event occurs. There should be no significant hydrogen or chlorine production.
3	Remove the module from the water and wait 1 hour.	The module fails the test if any hazardous event occurs. The insulation resistance between the live parts and the module housing should still be in line with basic insulation.
If the module manufacturer claims that the module is flooding proof, perform the following steps		
4	Discharge the module with maximum allowed continuous discharge current down to the minimal module voltage	The module fails the test if any hazardous event occurs.
5	Charge the module with maximum allowed continuous charge current until the maximum module voltage	The module fails the test if any hazardous event occurs.
6	Open the module and perform a visual analysis of the state of the cells.	None of the cells in the module should have vented nor should there be any leakage.

10.8 Post condition

The module shall be handled after the test with extreme care, always using personal protection devices. In case of fire, explosion, rupture or venting the module itself is regarded as a defective dangerous good according to UN regulations. The transport shall be done according to the existing rules for dangerous goods. Disposal shall only be done according to the legal local regulations for such kind of waste material.

Only a flooding-proof module that passes the test can be considered to be OK after the test and can be used for further testing.

11 BMS TEMPERATURE PROTECTION

11.1 Purpose

The purpose of this test procedure is to evaluate the functionality and robustness of the temperature protection of the battery management system.

11.2 Approach

The approach is to impose all possible error conditions in sequence and check the behavior of the battery management system.

11.3 Items to be tested

This procedure is to be executed on a battery module. This test is a type test and should be executed at design time to prove the robustness of the design.

Higher level safety (e.g. system level) is not covered in this test, but is part of the design review that is specified in IEC 62619. The individual safety of system level components (e.g. inverters) is part of other standards.

11.4 Test Equipment

11.4.1 Mandatory

The following testing equipment is needed:

- Test chamber with the ability to control the ambient temperature within the operational boundaries of the module under test.
- Cycling equipment capable to drive the currents and voltages according to the manufacturer's specifications or the operation region for the cells under test according to the test requirements.
- Monitoring equipment to monitor the external communication channels of the module.
- Temperature measuring system, separate from the BMS temperature monitoring system for measuring temperatures at least near all the block temperature sensors and if needed at specific points on the device under test e.g. cells, the enclosure, the venting area.

11.4.2 Optional

- Thermal imaging and recording system for measuring the temperature distribution of the surface of the module during the test.

11.5 Precondition

The module should be working correctly. All monitoring and control systems that are part of the module should be properly powered. The SOC should be 50%±5%.

11.6 **Test procedure**

#	Action	Pass/fail
1	Set the test chamber at least 5°C below the specified minimal charging temperature of the module. Put the module in the test chamber. Connect the module to the cycling equipment. Wait until the temperature of one of the blocks drops below the specified minimal charging temperature. Charge the module with a current of $I_t/2$ or half of the allowed current, signaled by the BMS, whichever is lower.	Once one of the block temperatures drops 2°C or more below the specified operating temperature for more than 1 minute, the battery management system should either disconnect the module from the power source or communicate this information via its external communication channels. There should be no hazardous event, leakage or venting.
2	The temperature of the test chamber is set to a value within the operating range of the module. The module is discharged to an SOC of 50%±5%	
3	Set the test chamber at least 5°C below the specified minimal operating temperature of the module. Wait until the temperature of one of the blocks drops below the specified operating temperature. Discharge the module with a current of $I_t/10$ or half of the allowed current, signaled by the BMS, whichever is lower.	Once one of the block temperatures drops 2°C or more below the specified operating temperature for more than 1 minute, the battery management system should either disconnect the module from the power source, limit the current flow to a safe value or communicate this information via its external communication channels. There should be no hazardous event, leakage or venting.
4	The temperature of the test chamber is set to a value within the operating range of the module. The module is discharged to an SOC of 50%±5%	
5	Set the test chamber at least 5°C above the specified maximal operating temperature of the module. Wait until the temperature of one of the blocks rises above the specified operating temperature. Discharge the module with a current of $I_t/10$ or half of the allowed current, signaled by the BMS, whichever is lower.	Once one of the block temperatures rises 2°C or more above the specified operating temperature for more than 1 minute, the battery management system should either disconnect the module from the power source, limit the current flow to a safe value or communicate this information via its external communication channels. There should be no hazardous event, leakage or venting.

6	The temperature of the test chamber is set to a value within the operating range of the module. The module is discharged to an SOC of 50%±5%	
7	Disconnect a single temperature sensor from the central block in the module and leave it suspended above the module such that it measures the ambient temperature. Keep its signal lines connected to the BMS. Set the temperature chamber at least 5°C below the maximum specified temperature. Alternatingly charge the module at maximum continuous charge power until it reaches the maximum specified voltage and discharge the module at maximum continuous discharge power until it reaches the minimum specified voltage[12]. Run this test for 20 hours.	The battery management system should either disconnect the module from the power source, limit the current flow to a safe value or communicate this information via its external communication channels once one of the block temperatures (in which the temperature sensor is properly connected) rises 2°C or more above the specified operating temperature for more than 1 minute or earlier. If the module detects the disconnection of the temperature sensor and does not allow charging or discharging at all or limits the current flow to a safe limit, it passes the test. There should be no hazardous event, leakage or venting. Nor should the maximum specified cell temperature be exceeded for any of the cells.
8	The temperature of the test chamber is set to a value within the operating range of the module. The module is discharged to an SOC of 50%±5%	

[12] In step 3 and 4 temperature change is induced by current flowing through the battery since we want to have a difference between the ambient temperature (which could still be measured by the disconnected sensor) and the cell temperature.

9	Reattach the temperature sensor to the central block of the module. Disconnect its signal lines from the BMS. Set the temperature chamber at least 5°C below the maximum specified temperature. Alternatingly charge the module at maximum continuous charge power until it reaches the maximum specified voltage and discharge the module at maximum continuous discharge power until it reaches the minimum specified voltage. Run this test for 20 hours.	The battery management system should either disconnect the module from the power source, limit the current flow to a safe value or communicate this information via its external communication channels once one of the block temperatures (in which the temperature sensor is properly connected) rises 2°C or more above the specified operating temperature for more than 1 minute or earlier. If the module detects the disconnection of the temperature sensor and does not allow charging or discharging at all or limits the current flow to a safe limit, it also passes the test. There should be no hazardous event, leakage or venting. Nor should the maximum specified cell temperature be exceeded of any of the cells.

11.7 **Post condition**

In case the module or at least one cell within the module turns into fire, explodes, ruptures or vents, the module shall be handled after the test with extreme care, always using personal protection devices. In case of fire, explosion, rupture or venting the module itself is regarded as a defective dangerous good according to UN regulations.

Otherwise the module is considered to be aged and cannot be used for further testing.

The transport shall be done according to the existing rules for dangerous goods.

Disposal shall only be done according to the legal local regulations for such kind of waste material.

12 BMS CURRENT PROTECTION

12.1 Purpose

The purpose of this test procedure is to evaluate the functionality and robustness of the current protection of the battery management system.

12.2 Approach

The approach is to impose all possible error conditions in sequence and check the behavior of the battery management system.

12.3 Items to be tested

This procedure is to be executed on a battery pack or a battery module (if this module contains at least a single current sensor).

This test is a type test and should be executed at design time to prove the robustness of the design.

Higher level safety (e.g. system level) is not covered in this test, but is part of the design review that is specified in IEC 62619. The individual safety of system level components (e.g. inverters) is part of other standards.

12.4 Test Equipment

12.4.1 Mandatory

The following testing equipment is needed:

- Test chamber with the ability to control the ambient temperature within the operational boundaries of the module under test.
- Cycling equipment capable to drive the currents and voltages according to the manufacturers specifications or the operation region for the cells under test according to the test requirements.
- Monitoring equipment to monitor the external communication channels of the module.

12.4.2 Optional

- Thermal imaging and recording system for measuring the temperature distribution of the surface of the cell during the test.
- Temperature measuring system, separate from the BMS temperature monitoring system for measuring temperatures at specific points on the device under test, e.g. cells, the enclosure, the venting area.

12.5 Precondition

The module should be working correctly. All monitoring and control systems that are part of the module should be properly powered. The SOC should be 20% ± 5%. The ambient temperature should be 25°C ± 5°C.

12.6 Test procedure

#	Action	Pass/fail
1	Put the pack in the test chamber. Connect all necessary charging and monitoring cables.	
2	Set the charge current to 110% of the maximum specified peak charge current ($C_{p,ch}$, in A) and charge the module for 20 seconds.	When the current rises above the specified maximum peak charge current for more than the specified peak time duration, the BMS should either disconnect the pack from the power source limit the current to a safe value or communicate this information via its external communication channels. There should be no hazardous event, leakage or venting.
3	Increase the charge current to 120% of the maximum specified peak charge current ($C_{p,ch}$, in A) and charge the module for 20 seconds.	When the current rises above the specified maximum peak charge current for more than the specified peak time duration, the BMS should either disconnect the pack from the power source limit the current to a safe value or communicate this information via its external communication channels. There should be no hazardous event, leakage or venting.
4	Increase the charge current to 130% of the maximum specified peak charge current ($C_{p,ch}$, in A) and charge the module for 20 seconds.	When the current rises above the specified maximum peak charge current for more than the specified peak time duration, the BMS should either disconnect the pack from the power source limit the current to a safe value or communicate this information via its external communication channels. There should be no hazardous event, leakage or venting.
5	Increase the charge current to 140% of the maximum specified peak charge current ($C_{p,ch}$, in A) and charge the module for 20 seconds.	When the current rises above the specified maximum peak charge current for more than the specified peak time duration, the BMS should either disconnect the pack from the power source limit the current to a safe value or communicate this information via its external communication channels. There should be no hazardous event, leakage or venting.

6	Increase the charge current to 150% of the maximum specified peak charge current ($C_{p,ch}$, in A) and charge the module for 20 seconds.	When the current rises above the specified maximum peak charge current for more than the specified peak time duration, the BMS should either disconnect the pack from the power source limit the current to a safe value or communicate this information via its external communication channels. There should be no hazardous event, leakage or venting.
7	Charge the pack with a current of $I_t/5$ until it reaches the maximum specified voltage. Wait for 1 hour.	
8	Set the discharge current to 110% of the maximum specified peak discharge current ($C_{p,d}$, in A) and charge the module for 20 seconds.	When the current rises above the specified maximum peak discharge current for more than the specified peak time duration, the BMS should either disconnect the pack from the power source limit the current to a safe value or communicate this information via its external communication channels. There should be no hazardous event, leakage or venting.
9	Increase the discharge current to 120% of the maximum specified peak discharge current ($C_{p,d}$, in A) and charge the module for 20 seconds.	When the current rises above the specified maximum peak discharge current for more than the specified peak time duration, the BMS should either disconnect the pack from the power source limit the current to a safe value or communicate this information via its external communication channels. There should be no hazardous event, leakage or venting.
10	Increase the discharge current to 130% of the maximum specified peak discharge current ($C_{p,d}$, in A) and charge the module for 20 seconds.	When the current rises above the specified maximum peak discharge current for more than the specified peak time duration, the BMS should either disconnect the pack from the power source limit the current to a safe value or communicate this information via its external communication channels. There should be no hazardous event, leakage or venting.

11	Increase the discharge current to 140% of the maximum specified peak discharge current ($C_{p,d}$, in A) and charge the module for 20 seconds.	When the current rises above the specified maximum peak discharge current for more than the specified peak time duration, the BMS should either disconnect the pack from the power source limit the current to a safe value or communicate this information via its external communication channels. There should be no hazardous event, leakage or venting.
12	Increase the discharge current to 150% of the maximum specified peak discharge current ($C_{p,d}$, in A) and charge the module for 20 seconds.	When the current rises above the specified maximum peak discharge current for more than the specified peak time duration, the BMS should either disconnect the pack from the power source limit the current to a safe value or communicate this information via its external communication channels. There should be no hazardous event, leakage or venting.

12.7 **Post condition**

In case the pack or at least one cell within the pack turns into fire, explodes or vents, the pack shall be handled after the test with extreme care, always using personal protection devices.

In case of fire, explosion or venting the pack itself is regarded as a defective dangerous good according to UN regulations.

If the pack passes the test, it is considered to be OK and can be used for further testing.

The transport shall be done according to the existing rules for dangerous goods.

Disposal shall only be done according to the legal local regulations for such kind of waste material.

13 BMS VOLTAGE PROTECTION

13.1 Purpose

The purpose of this test procedure is to evaluate the functionality and robustness of the voltage protection of the battery management system.

13.2 Approach

The approach is to impose all possible error conditions in sequence and check the behavior of the battery management system.

13.3 Items to be tested

This procedure is to be executed on a battery module.

This test is a type test and should be executed at design time to prove the robustness of the design. Higher level safety (e.g. system level) is not covered in this test, but is part of the design review that is specified in IEC 62619. The individual safety of system level components (e.g. inverters) is part of other standards.

13.4 Test Equipment

13.4.1 Mandatory

The following testing equipment is needed:

- Test chamber with the ability to control the ambient temperature within the operational boundaries of the module under test.
- Cycling equipment capable to drive the currents and voltages according to the manufacturer's specifications or the operation region for the cells under test according to the test requirements.
- Voltage monitoring equipment, separate from the BMS voltage measurement that measures the voltage of each of the cells in the module with an accuracy of 5mV (can be included in the cycling equipment).
- Monitoring equipment to monitor the external communication channels of the module.

13.4.2 Optional

- Thermal imaging and recording system for measuring the temperature distribution of the surface of the module during the test.
- Temperature measuring system, separate from the BMS temperature monitoring for measuring temperatures at specific points on the device under test, e.g. cells, the enclosure, the venting area.

13.5 Precondition

The module should be working correctly and the block voltages should be properly balanced. All monitoring and control systems that are part of the module should be properly powered. The SOC should be 50% ± 5%. The ambient temperature should be 25°C ± 5°C.

13.6 Test procedure

#	Action	Pass/fail
1	Put the module in the test chamber. Connect all necessary charging and monitoring cables.	
2	Discharge the module with a current smaller or equal to the maximum specified continuous discharging current.	The battery management system should either disconnect the module from the power source or communicate this information via its external communication channels once one of the block voltages drops more than x[13]V below the specified minimum operating voltage for more than 5 seconds or earlier. There should be no hazardous event, leakage or venting.
3	Charge the module with a current smaller or equal to the maximum continuous charging current.	The battery management system should either disconnect the module from the power source or communicate this information via its external communication channels once one of the block voltages rises more than xV above the specified maximum operating voltage for more than 5 seconds or earlier. There should be no hazardous event, leakage or venting.
4[14]	Disconnect a single voltage sensor from one of the blocks in the module. Keep its signal lines connected to the BMS.	
5	Repeat steps 2 and 3	The battery management system should either disconnect the module from the power source or communicate this information via its external communication channels once one of the block voltages (with a properly connected voltage sensor) exceeds the specified operating voltages by more than xV for more than 5 seconds or earlier. If the module detects the disconnection of the voltage sensor and does not allow charging or discharging at all, it passes the test. There should be no hazardous event, leakage or venting.
6	Reattach the voltage sensor. Disconnect its signal lines from the BMS.	

[13] x is a voltage threshold, dependent on the cell chemistry

[14] In case a module consists of a single block, the steps 4-7 do not have to be performed

7	Repeat steps 2 and 3	The battery management system should either disconnect the module from the power source or communicate this information via its external communication channels once one of the block voltages (with a properly connected voltage sensor) exceeds the specified operating voltages by more than xV for more than 5 seconds or earlier. If the module detects the disconnection of the voltage sensor and does not allow charging or discharging at all, it passes the test. There should be no hazardous event, leakage or venting.

Voltage thresholds to be used

Chemistry	Threshold (x in V)
Lithium-iron-phosphate	0.1V
Other	0.1V

13.7 Post condition

In case the module or at least one cell within the module turns into fire, explodes or vents, the module shall be handled after the test with extreme care, always wearing personal protection devices.
In case of fire, explosion or venting the module itself is regarded as a defective dangerous good according to UN regulations.
Otherwise the module is considered to be ok and can be used for further testing.
The transport shall be done according to the existing rules for dangerous goods.
Disposal shall only be done according to the legal local regulations for such kind of waste material.