



StoREgio ZVEH



Safety Guidelines – Li-ion Home Storage Systems

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1. General Remarks

This document - safety guidelines for Li-ion home battery storage systems - was prepared with the participation of the following institutions: Bundesverband Energiespeicher e.V. (BVES - *German Energy Storage Association*), the German Solar Industry Association (BSW-Solar), Zentralverband der Deutschen Elektro- und Informationstechnischen Handwerke (ZVEH, *Association of German Electrical and Information Technology Contractors*), the International Solar Energy Society, German Section (DGS, *Deutsche Gesellschaft für Sonnenenergie e.V.*), and StoREgio Energiespeichersysteme e.V. The compilation of the guidelines was supported by TÜV Rheinland, the Association for Electrical, Electronic and Information Technologies (VDE - *Verband der Elektrotechnik, Elektronik, Informationstechnik e.V.*), CETECOM ICT Services GmbH, the Karlsruhe Institute of Technology (KIT) and the Zentralverband Elektrotechnik- und Elektronikindustrie e.V. (ZVEI – *Central Association of the Electrical Engineering and Electronics Industry*).

We make no claims as to the completeness of the specifications of this guide. In addition to the standards listed in the Section 6, other standards can be applied, provided they are based on the same or stricter criteria.

It is recommended that manufacturers take into consideration the safety objectives in Section 6 and that they also take general hazard sources into account in the context of a risk analysis (see Appendix 6.4 General safety objectives).

Beyond the specifications of this safety guide, other statutory requirements continue to apply, including the Low Voltage Directive, the Product Safety Act, the Battery Act, the EMC Directive, UN transport tests etc. and others.

The application of this safety guide is voluntary. An update of the guide to reflect the future state of technology is planned. Comments may be submitted to the offices of the participating organizations.

2. Scope

This catalogue identifies safety objectives for battery storage systems that function as stationary home storage systems and are based on rechargeable lithium-ion cells (secondary lithium-ion cells), with and without incorporation of converters, for example those used in combination with photovoltaic applications.

The term “lithium-ion cells” refers to rechargeable cells that utilize the intercalation of lithium-ions in suitable host materials (e.g. graphite or titanate) for energy storage purposes.

This safety guide does not apply to non-rechargeable batteries (so-called primary batteries) or to rechargeable batteries with cells not based on lithium intercalation. These include lithium metal cells (often referred to as LMP), so-called conversion systems using lithium, such as lithium sulfur and lithium air cells, nickel cadmium cells and lead-based cells, high temperature cells (e.g. sodium-sulfur, or NaS) and redox flow systems.

Note: Lithium-metal cells (LMP) are similar to lithium-ion cells and are characterized by a significantly higher energy density (capacity in Wh per unit of volume or weight), but utilize metallic lithium on the anode rather than intercalation. However, in energy storage systems a higher energy density and metallic lithium can lead to potentially critical conditions in the event of a fault. Since a high energy density is in many cases not the chief criteria for stationary storage systems, the selection of cell technology for certified stationary storage systems should be carefully considered. However, the safety objectives remain the same in all cases.

2.1 Details for the identification of lithium-ion systems

“Lithium-ion cell” is the generic term for a number of different systems that can be distinguished by, among other things, the composition of cathode, anode and electrolyte.

There is no unified nomenclature for the classification of Li-ion cells. Thus, the letters contained in the typical designation can refer primarily to the anode or cathode materials or compounds, or, alternatively, to doping or electrolyte forms. Even if “L” or “Li” is not included in the abbreviation, lithium is always included in lithium-ion cells. Other metals are often present as an oxide or phosphate compound (see Table 1).

Examples:

- Definition by cathode:
A cell with a graphite anode and a cathode made of lithium, nickel, manganese and cobalt can thus have different identifying names, or be identified by a chemical formula that usually refers to the composition of the cathode’s active material: NMC, NCA.
- Definition by anode:
A cell with a titanate anode can be identified by the abbreviation LTO (lithium titanate oxide). The cathode material (e.g. NCA, LFP) is not defined and may be specified separately.
- Definition by electrolyte:
Lithium-polymer, or LiPo in short, refers to a lithium-ion cell with a polymerized (solid or gel-form) rather than a liquid electrolyte. This describes neither a specific anode nor cathode material.

In many but not all cases, batteries are constructed on the basis of these lithium-ion cells:

- LFP or lithium-iron phosphate, also referred to as iron phosphate cells
- LMO or lithium manganese oxide
- LTO or lithium titanate oxide
- NCA or lithium nickel cobalt aluminum oxide
- NMC or lithium nickel manganese cobalt oxide,
- Exception: LMP is sometimes used for lithium metal polymer cells (not in the scope of application of this guide), as well as for lithium manganese phosphate.

Furthermore, some of the components contained in lithium-ion cells are combustible (e.g. electrolyte, graphite). For this reason, no lithium-ion cell type can be referred to as non-combustible per se.

Table 1: Most frequently occurring letters or abbreviations in lithium-ion cell or battery designations.

Abbreviation in cell type	Element symbol	Meaning	A: Anode K: Cathode E: Electrolyte
A	Al	Aluminum	K
C	Co	Cobalt	K
F	Fe	Iron	K
L	Li	Lithium	K, A, E
M	Mn	Manganese	K
N	Ni	Nickel	K
O	O	Oxide of one or more cathode metals	K
P	P	Phosphate of one or more cathode metals	K
P / Po / Polymer		Electrolyte in polymerized rather than liquid form	E
S	Si	Silicon compound in anode graphite	A
T	Ti	Titanium or titanate compound	A
Y	Y	Yttrium	K

Lithium-ion batteries, if correctly labeled, can also be identified by their UN classification (UN3480 or UN3481) for hazardous materials transportation.

3. Definitions of terms used in this document

3.1. Shut-down

For the purposes of this guide, shut-down refers to the secure interruption of charging and discharging. The BMS (battery management system) may continue to operate for monitoring and diagnosis purposes.

3.2 Anode and cathode

The terms anode and cathode are used in this guide to refer to the electrodes of the individual lithium-ion cells; they follow the definition for electrochemical elements and should not be mistaken for the connection names of electronic components (e.g. a semiconductor diode), where the pole with the positive potential is referred to as an anode. In voltage measurement, the cathode of a lithium-ion cell is positive relative to its anode.

Note: With electrochemical elements, the electrode at which the oxidation reaction (electron release of an atom or ion to the conductor) takes place during the discharge of the cell is referred to as the anode. See also IEC 60050-482 International Electrotechnical Vocabulary – Part 482: Primary and secondary cells and batteries.

3.3 Battery

In this guide a battery is defined as a completely and intrinsically safe unit encasing an array of cells and safety devices.

Battery submodule: a submodule of cells connected in series or parallel, which is only intended for use in a battery assembly unit, but which must also be safe for transport (=> certain Safety devices for UN38.3, T.1-T.5, not T.7).

3.4 Battery management system (BMS)

With regard to battery safety, the BMS has three important tasks (among others):

- Measuring and monitoring of individual cell voltages and temperatures (see also section 4.4 Individual cell monitoring)
- Control of safety devices, e.g. relays
- Communication with other systems, e.g. converter and control systems

3.5 Dendrites

Dendrites are metallic lithium deposits that grow from the anode to the cathode and can thus cause cell-internal short circuits; these cannot be prevented by external measures and protective circuits. Depending on the kind, size and charging level of the cells, internal short circuits are among the most critical fault conditions. Significant dendrite growth is caused for example by plating (see 3.9), by inhomogeneities between the electrodes or by contamination of the electrode material during manufacturing or another error in the manufacturing process, or also by improper installation of the lithium-ion cell. Substantial local dendrite growth, also known as dendrite nests, can also cause significant mechanical changes in the cells. This is evident for example in an increase in thickness or the development of bulges in the cell casing.

3.6 Derating

Derating refers to the controlled power reduction in batteries, dependent upon other parameters (primarily temperature), in order to avoid damage to the cell, such as plating or overheating (see also 4.3 Operating window – Figure 1).

3.7 Intrinsically safe battery storage system

Intrinsically safe battery storage systems, batteries or inverters are constructed in such a way that one single fault cannot lead to an unsafe system. This includes faults that can result from external factors as well as from faults in the system during intentional or predictable use (e.g. internal short circuit, malfunction of an electronic component).

An unsafe condition exists when hazards (e.g. mechanical, chemical, thermal, electrical) can arise to persons or property. Situations in which hazards to persons or property can exist should be identified, and appropriate countermeasures to minimize the risk should be detailed described (e.g. in installation and operating manuals). If both the battery and the inverter/the charging device are used as intended and are each intrinsically safe, the system can also be considered intrinsically safe. See also 4.5 Measures for loss of intrinsic safety.

3.8 Short circuit internal/external

Depending on the section of the safety guide, internal and external short circuits refer to different faults.

Table 2

	Internal short circuit	External short circuit
Cell	A short circuit within one or more cells, e.g. through a defect of the separator, dendrite growth or perforation with a conducting object.	One or more cells are short-circuited at their poles.
Battery	A short circuit on one, several or all connected cells within a battery.	Short circuit at the external poles of a battery, at several battery modules connected in series or at one of the modules.
System	A short circuit of DC or AC lines within a combination of battery and inverter – e.g. through significant damage to a shared outer casing or a connection fault.	A short circuit at the system’s AC or DC output.

3.9 Plating

Plating, in the context of this guide, refers to the undesired effect of deposition of metallic lithium on the anode instead of the storage of the lithium ions in the anode material (e.g. graphite). It is primarily caused by charging rates that are too high for the respective graphite type, often in conjunction with low temperatures (see also 4.3 Operating window - Figure 1). The intrinsic safety of the lithium-ion cell is thereby significantly reduced and this results in further detrimental effects (e.g. increased dendrite growth, increased internal resistance, capacity loss).

3.10 Separator

The separator is an ion-permeable membrane that electrically separates the anode from the cathode. Defects in the separator, such as shrinking under exposure to significant levels of heat, or dendrites that perforate the separator, can lead to cell-internal short circuits.

Safety is ensured by the use of separators that retain their stability under high temperatures and in the event of internal short circuits, and that safely separate anode and cathode.

3.11 SoC and SoH

SoC – State of Charge is the value for the charge state of cells and batteries. It is usually expressed in % of available capacity, which decreases over time through aging. In stationary battery systems, the percentage is often translated into kWh.

SoH – State of Health is the term used for the age condition of batteries and cells. It is used inter alia to indicate the performance of the aged cell relative to its new condition.

Neither value can be measured directly; they are rather calculated by the battery management system using existing measured data such as current, voltage difference and temperature.

3.12 Deep discharge

Deep discharge respectively depth of discharge tests are defined differently according to various standards:

- a) A cell or battery is discharged with a load down to a voltage below its end-of-discharge voltage (see also 4.3 Operating window – Figure 1).
- b) A cell is discharged by a voltage source with reversed polarity, e.g. in order to test its ability to withstand a reversed polarity (forced discharge).
- c) a) or b), depending on cell behavior.

Under certain circumstances, a deep discharge according to a) is possible in application of a series product.

A forced deep discharge, even to the point of reversed polarity, is possible within a battery, despite the correct polarity of all cells.

Example: One or more cells in a serial connection have significantly less capacity than the other cells (e.g. through inconsistent aging effects) and therefore will be exposed to a reversed polarity charge, because the battery is discharged until the cells with greater capacity are empty.

In this guide, therefore, option a) refers to the deep discharge as a fault to be avoided, although tests on deep discharge behavior according to b) can be carried out.

Note: Lithium-ion cells can, even after a complete deep discharge, re-establish an open circuit voltage (OCV) that is within the allowable operating window. For this reason, a voltage measurement alone when switching on the BMS cannot always rule out whether one or several cells were exposed to a deep discharge. In order to safely prevent recharging, the cell can be tested, for example through a short discharge.

3.13 Overcharge

An overcharge is defined differently according to different standards:

- a) One or more cells of a battery system are charged with a higher voltage than the end-of-charge voltage (see also 4.3 Operating window – Figure 1).
- b) A cell or battery is charged with a greater current than specified by the cell manufacturer. More than is the case during discharge, the temperature dependency of the maximum charging current must be taken into account (see 3.14 Overcurrent).

In this guide, a) is referred to as overcharge and b) as overcurrent.

3.14 Overcurrent

In many datasheets, maximum currents for pulsed and continuous current are only provided as individual values throughout the entire operating temperature range. If only those specifications are followed, plating can still occur in the cells during the charging process (see 3.9 Plating), for example if charging takes place in the lower range of cell temperature (at low temperature limit) using the maximum current allowed according to the datasheet – and depending on cell and specification, the plating can occur even with lower currents than the maximum specified. In many cases, therefore, more detailed values for the cells must be taken into consideration than those provided on the datasheet. This is especially true for the charging process.

Overcurrent during charging refers to a pulsed or continuous current that is too high for the respective cell temperature. Particularly during the charging process in the lower range of the temperature window for lithium-ion cells, charging currents have to be reduced for most kinds of cells (see 3.6 Derating) in order to avoid plating (see 3.9 Plating).

Overcurrent during discharge is less temperature-critical. It occurs when the maximum values specified by the manufacturer for pulsed and continuous current are exceeded.

3.15 Safety mechanisms in cells

Some lithium-ion cell types have safety mechanisms incorporated in the cell casing, which are not necessary for all technologies, but which can significantly increase safety, also for cells connected in parallel. These include, for example:

- **PTC** (positive temperature coefficient):
The electrical resistance of this component increases with rising temperatures in order to limit the charge or discharge current.
- **CID** (circuit interrupt device or current interrupt device):
In the event of a build-up (increase) of gas pressure within the cell (e.g. through the start of overcharging and increasing temperature), the electrical contact to one of the poles is interrupted to prevent further faults (e.g. fire).

Nearly all cells also have a safety feature that serves to protect against the cell's uncontrolled rupture or exploding; this can be a burst disk, a safety vent or another pre-determined breakpoint. At excessive temperatures and/or intensive degradation, the electrolyte builds up more gas pressure in the lithium-ion cell than the cell housing or cell casing can withstand. With completely encapsulated battery casings, not only the cells but also the cases themselves should have a mechanism for avoiding excessive overpressure.

3.16 System

Battery, converter and control system including casing.

3.17 Cell

Lithium-ion cell as an individual electrochemical unit.

4 Cell selection, system design and operation

The existing standards and operating manuals for the respective systems contain many mainly electrical safety specifications that must be observed. To ensure maximum safety of the system, the electrochemical characteristics and hazard potentials of the installed cells (including possible damages and their effects) must also be taken into consideration. These include, among other factors, proper (safe) mode of operation, appropriate safety measures and the appropriate selection of components.

4.1 Cell selection and cell processing

The selection of lithium-ion cells that are incorporated into battery systems is one of the most important decisions in the manufacturer's selection of components.

Cell damage and fires that result from external influences on the cell (e.g. malfunction) can be avoided by good battery construction, proper mode of operation and use of appropriate safety devices. However, problems within the cell that are caused by deficits in manufacturing and/or material quality, possibly augmented by construction type, cannot be limited - or can only be limited to a minimal degree - by safety mechanisms outside the cells.

Maximum safety in the production of lithium-ion cells can be ensured, however, by the use of high-quality and optimally matched electrode materials with a high grade of purity, as well as by the choice of manufacturing method and type of casing.

Manufacturing

Nowadays, high-quality cells are almost exclusively manufactured in fully automated production processes and under strictly controlled environmental conditions (e.g. very low humidity). The reasons for this include:

- Semi-finished products (including coatings and foil thicknesses of the electrodes of the separator in the micro-millimeter range) that can be easily damaged outside of the cell packaging/cell casing, must be manufactured with great care.
- Homogeneity, precision (e.g. exact alignment between anode and cathode) and avoidance of contamination (e.g. through skin oils from touching) are important prerequisites for producing cells that are as safe as possible.

Greater care must be taken in particular in semi-automated manufacturing methods, since e.g. small defects in the separator or other defects do not always show up in quality control, but can have a critical effect on safety in operation. In any case, suitable quality management as well as a clear labeling of individual cells (e.g. batch number etc.) are necessary in order to prevent safety-critical events as well as to limit and prevent negative impacts in the event of a fault.

Note: The impacts of an internal short circuit increase with increasing cell capacity and/or energy density.

Type of casing

In lithium-ion cells, humidity must be kept to an absolute minimum, as it not only accelerates aging, but also has safety-critical impacts (e.g. premature gas formation). The cell and all of its casing components must have a high resistiveness to moisture intrusion, i.e. they must have a metal casing, an outer foil with an aluminum layer or an appropriate thickness of the casing wall. In general, for every type of casing and every variation of design, especially heat dissipation must be taken into account in order to avoid heat accumulation and its effects in the event of internal or external short circuit, among other things.

4.2 Mandatory information provided by the cell manufacturer for the battery manufacturer

Lithium-ion cells differ according to, for example, the composition of anode and cathode used (see Table 1), the type of construction (see 4.1 Cell selection), the additives in the electrolyte and other components. Therefore, information on voltage ranges and temperature windows for charging and discharging, including maximum currents, which are necessary to ensure compliance with the operating window (see also 4.3 Operating window – Figure 1), are mainly specific to cell respectively manufacturer. The manufacturer's cell specifications and processing/handling information, which are necessary for the assembly of batteries and the safe operation in all temperature ranges specified for the cells, extend far beyond the often simplified and abridged information provided on the cell datasheets.

The cell manufacturer is obliged to supply the battery manufacturer with all safety-relevant information. This information can include:

- End-of-charge voltage and end-of-discharge voltage
- Expected mechanical changes to the cells due to aging during operation under the expected charging and load profiles within the stipulated temperature range in the battery module. This includes, for example, local increase in thickness at certain points of the cell casing or in the cell packaging; these factors must be taken into consideration in the design of the battery module.
- Parameters or data and dependency curves for incorporated safety measures/ mechanisms such as PTC or CID
- Recommended and maximum charge rate and discharge current for different cell temperatures (derating table)

4.3 Operating window

Lithium-ion cells have manufacturer's specifications regarding the operating window (current, temperature, power) and storage conditions (in particular temperature and SOC if not in operation), which must be adhered to. Otherwise, the cells can be irreversibly damaged and can undergo changes, which even after returning to their operating window can become unsafe. In this case, their behavior is no longer as safe as during previously passed tests, and under continued operation the cells themselves can become a cause of defect (e.g. internal short circuits, release of gas, fires). For this reason, a lithium-ion battery used in the residential application must be shut down after damage has occurred to the cell, and may not be turned operational until a professional test and overhaul (performed by a specialist authorized by the system manufacturer) have been performed.

Note: The quality management of system, battery and cell manufacturer should also ensure that the lithium-ion cells are not transported or stored/warehoused under conditions outside of the permissible temperature range.

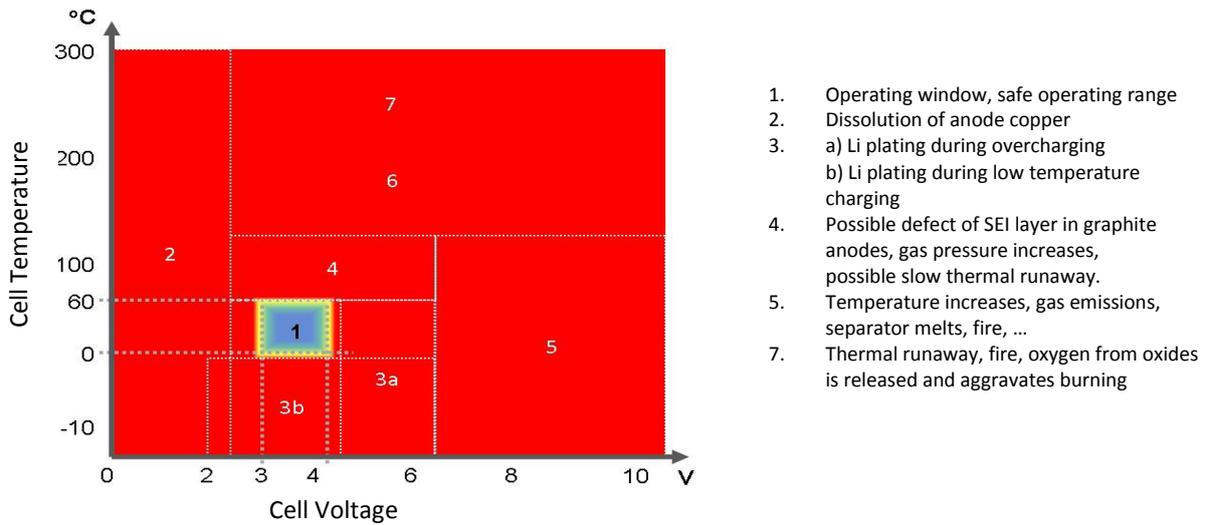


Figure 1: Schematic operating window for an example of a lithium-ion cell (NMC) with graphite anode (actual values may differ)

The numbered fault ranges 2-7 are divided only for clarity purposes. In practice, they are not clearly differentiated but rather merge into or overlap with each other.

4.4 Single cell monitoring

Problems with batteries often begin within a single lithium-ion cell, and the failure can spread within the battery. In order to ensure the safe adherence to the operating window (see 4.3 Operating window), it may be necessary to monitor the temperature and voltage of every single cell in a battery.

Depending on construction type and installation site, it is not always guaranteed that all the cells within a battery have the same temperature. Cell voltages of in series-connected cells can vary for a number of different reasons (e.g. differing aging effects).

4.5 Measures in case of loss of intrinsic safety

Every fault that leads to the loss of intrinsic safety means that the system may no longer be operated. A fault also exists if one or more cells are no longer within the safe operating window specified by the manufacturer and cannot be deactivated.

5. Documentation of compliance to these safety objectives in a battery system by accredited laboratories

If conformity with this safety guide is declared and advertised, then this must be confirmed with respective test reports supplied by accredited laboratories.

Tests already administered with accredited testing laboratories within the context of other battery tests (e.g. transport tests pursuant to UN38.3, EMC tests of the battery management system) are taken into account in the relevant safety objectives and do not need to be re-evaluated.

6. Catalogue of safety objectives

6.1 Safety objectives for the cell

No.	Hazard sources	Intended safety objective	Which standards cover this	Possible preventive measures	Possible corrective measures	Are measures at the next level up necessary?	Are measures at the next level up compulsory?
6.1.1	External short circuit	In case of external short circuit no fire etc. may occur (described by: Hazard Level 4 under EUCAR may not be exceeded)	UN38.3	Selection of technology/cell with corresponding certificates, CID, coated separators ...	Additives in the electrolyte as fireproofing, limitation of impact radius of chemically aggressive substances, emergency vents, burst disk etc. Balancing of internal pressure conditions	Collection of electrolyte fluid Casing must have vents for gas release Measures for preventing external short circuits are mandatory	Yes
6.1.2	Internal short circuit	Avoid negative impacts of an internal short circuit. (Internal short circuit at cell level cannot be avoided and not preventatively detected in a safe way)		Selection of materials, quality management system of the manufacturer (fully automated production), mechanical construction of the cells, coated separators, thickness and type of separators	Additives in the electrolyte as fireproofing, emergency vents, burst disk etc. Balancing of internal pressure conditions	Precautions at the next level are compulsory (e.g. casing), Operation must be performed so that internal short circuits are avoided as far as possible	Yes
6.1.3	Overcharging	Avoid negative impacts of overcharging (this cannot be solved at cell level alone)		Triggering of "breakpoint" upon pressure build-up, if needed with CID; overcharge capability of the cell must be listed in the safety concept.	Additives in the electrolyte as fireproofing, emergency vents, burst disk etc. Balancing of internal pressure conditions	Overcharge protection at pack or system level	Yes
6.1.4	Deep discharge	Avoid negative impacts of a deep discharge. (this cannot be solved at cell level alone)	Forced discharge under UN38.3		Emergency vents, burst disk etc. Balancing of internal pressure conditions	Deep discharge protection at pack or system level	Yes

6.1.5	Overcurrent	In case of overcurrent no fire etc. may occur (described by: Hazard Level 4 under EUCAR may not be exceeded)		Selection of corresponding high-quality, tested technology/cell, CID, coated separators Manufacturer's derating curves must be provided in the safety concept.	Additives in the electrolyte as fireproofing, limitation of impact radius of chemically aggressive substances, emergency vents, burst disc etc. Balancing of internal pressure conditions	Derating curve must be taken into consideration	Yes
6.1.6	Excess temperature	The cell may never be exposed to temperatures above those allowed by the manufacturer.	UN38.3 DIN EN 62619 5.5/6.1 (Manufacturer's data may differ from UN tests)	Triggering of "breakpoint interruption" at excess temperature e.g. PTC, CID; temperature-controlled transport chain	Additives in the electrolyte as fireproofing, emergency vents, burst disc etc. Balancing of internal pressure conditions	Monitor excess temperature at pack level, if needed initiate measures (recuperation according to manufacturer's data)	Yes
6.1.7	Too low temperature	Cell may never be exposed to temperatures below those allowed by the manufacturer.	UN38.3 DIN EN 62619 6.1.4.4 (Manufacturer's data may differ from UN tests)	Storage conditions/warehousing, heating, etc.		Monitor low temperature at pack level, if needed initiate measures (recovery according to manufacturer's data)	Yes
6.1.8	Mechanical damage	Mechanically damaged cells may not be installed in the system. The handling of used cells is not covered by the guide	UN38.3-defined impact/crush test (handling of cells is critical)	Proper handling, transport, storage/warehousing, assembly	QM system for identifying damaged cells	Mechanical protection must be provided	Yes
6.1.9	Production and design flaws	Avoidance of safety-relevant production and design flaws	E DIN EN 62619 Chap. 5.6 (quality control plan)	Procedures and process for the inspection of materials and components. Requirements for qualitative handling (assembly), including qualification (of persons carrying out assembly) must be established. Regular quality audits are necessary.	Recurring quality audits	The same measures are necessary	Yes

6.2 Safety objectives for the battery

No.	Hazard sources	Intended safety objective	Which standards cover this	Possible preventive measures	Possible corrective measures	Are measures at the next level up necessary?	Are measures at the next level up compulsory?
6.2.1	External short circuit	Safe, fast shutdown of the battery No restart without verification through protective circuits/measures and/or by trained specialist	DIN EN 61427-2 ADR for transport DIN EN 62109-1 para. 14.8	Constructive measures to avoid external short circuits, e.g. pack is de-energized, transport caps	Safety concept, taking into account cell characteristics	Measures are useful and, depending on construction, necessary. Single-fault safety is necessary, either at pack level or in the system as a whole.	No
6.2.2	Internal short circuit	Constructive avoidance, safe and fast shutdown of battery, no restart		Constructive measures to avoid internal short circuits, insulation coordination and IP protection classes	Safety concept, taking into consideration cell characteristics; safety concept for cells connected in parallel	No	No
6.2.3	Overcharge Overcurrent	Safe and fast shutdown of battery No restart without checking cell voltages	DIN EN 62619 para. 5.5.2	Single cell monitoring is mandatory (taking into consideration ripple current that occurs); cells connected in parallel can be monitored via single voltage measurement	Shutdown upon overvoltage; prevention via communication with the charging device	Charging device should prevent occurring of this failure	No
6.2.4	Deep discharge	External: Safe and fast shutdown of the battery following final discharge voltage (single cell voltages). No restart after deep discharge and without checking cell voltages, taking into account the fact that OCV may be in the permissible range despite previous deep discharge (see 3.12, last paragraph); Internal: recognize, prevent, communicate; no restart	DIN EN 61427-2 para. 8.3	Manufacturer's specifications for restart must be followed; BMS (e.g. redundant, with BMS monitoring) and system should prevent deep discharge	Protect against restart according to manufacturer's specifications.	Shutdown and no restart in the case of communication breakdown	No
6.2.5	Overcurrent	Safe disconnection of the battery according to manufacturer's derating instructions	DIN EN 62619 para. 6.1.4.2	Temperature-dependent current monitoring and cut-off in the event of overcurrent	Shutdown upon overcurrent	Charging and discharging current reduction	No

6.2.6	Excess temperature	Safe shutdown of the battery during operations upon exceeding maximum allowable temperature (according to manufacturer's specifications) in order to avoid damage to the cell. No restart if maximum temperature has been exceeded.		Environmental/Ambient conditions must be identified and taken into account.	Shutdown when excess temperature is reached	Shutdown of charge/discharge operations	No
6.2.7	Too low temperature	Safe shutdown of battery and no restart of battery if a temperature below the minimum allowable temperature (according to manufacturer's specifications) is reached, which leads to a damage of the cell	DIN EN 61427 (storage)	Environmental/Ambient conditions must be identified and taken into account.	Shutdown when temperature is too low	Shutdown of charge/discharge operations	No
6.2.8	Mechanical damage	No startup of visible/suspected damaged modules/packs		Packaging instructions, handling, mechanical construction	Quality management system must enable identification of defective modules		No
6.2.9	Defective cell in pack	A defective cell in the pack may not lead to a fault that spreads.	DIN EN 62619 8.3.3	Detection of defective cell and shutdown (for an internal short circuit and high SOC, forced discharge can also be useful) Cells connected in parallel can be treated like a single cell.	Containment of possible spread at system level	Containment of further spread through construction	No
6.2.10	Production and design flaws	Avoidance of safety-relevant production and design flaws	E DIN EN 62619 Chap. 5.6 (quality control plan)	Procedures and process for inspection of materials and components, in particular of the cell, see 6.1.9.	Recurring quality audits		

6.3 Safety objectives for the system

No.	Hazard sources	Intended safety objective	Which standards cover this	Possible preventive measures	Possible corrective measures
6.3.1	External short circuit (battery side)	Avoidance of external short circuits, and maintenance of safe condition in the case of a short circuit.	UN38.3, EN 50272-2, IEC 62619, DIN EN 62109-1	Covering contact poles, shutdown and securing, against restart during transport, insulated tools, removal of body jewelry (information in instruction manual), casing with appropriate IP protection, sealing of conductive system components with electric shock protection (IPXXB internal)	Overcurrent protection
6.3.2	Overcharge /overvoltage (battery side)	Overvoltage and overcharge must have redundant prevention (single-fault safe) within the system	UN38.3, EN 50272-2, IEC 62619, DIN EN 62109-1	Monitoring of cell voltages and prevention of overcharging or overvoltage through battery management system (BMS), BMS must also switch to safe mode when a fault in BMS occurs Supervision of communication in order to safely prevent overcharge. Multi-stage monitoring in charge/discharge device	
6.3.3	Deep discharge	Prevention of deep discharge to maintain safe state. After deep discharge, charging must be prevented. Safe operating range of modules/packs must be observed.	UN38.3, EN 50272-2, IEC 62619, DIN EN 62109-2	Monitoring of cell voltages and prevention of deep discharge through the battery management system (BMS), BMS must also switch to safe mode when a fault in BMS occurs. Supervision of communication in order to safely prevent overcharge. Multi-stage monitoring in charge/discharge device	Shutdown of battery or charger
6.3.4	Overcurrent	Prevention of overcurrents from outside sources, DC and AC (home power grid, inverters, inductive loads) as well as cross-currents between modules/packs	UN38.3, IEC 62619	Balancing between cells and between modules/packs to avoid cross-currents, information in operating manual to select overcurrent protection. Supervision of current and prevention of overcurrent e.g. through shutdown of battery or charging/discharging device. Derating in dependence of the temperature range of the cell specified by the use of the charging/discharging device.	Overcurrent protection, shutdown of battery or charger
6.3.5	Excess and too low temperature	The same safety objectives apply as at the battery level	DIN EN 62619 6.1.4.4	Derating through reduction of charging or discharging current, heating of battery, cooling of battery, selection of installation site (indoor, outdoor, shaded etc.)	Shutdown at too high or too low temperatures
6.3.6	Mechanical damage from outside	Sufficient durability of construction against oscillations, vibrations, shock	UN38.3, DIN EN 50272, DIN EN 62109-1, impact test IK pursuant to IEC 62262	Suitably stable construction of casing, transport handles, fixation points, shock absorbing mounting of critical components in the system, shock indicators for transport, warning labels on equipment, information in operating manuals regarding safe transport and installation	

6.3.7	Mechanical damage from inside	Influences during operation (e.g. thermal, mechanical) may not result in loosening, unfastening of construction components and unsafe conditions.	UN38.3, VDE AR 2510-2/-50, IEC 62619,	Proper selection of component fixation, taking into account relevant thermal, chemical and mechanical influences (growth of cells must also be taken into account) and intrinsic weight; markings to detect detached screw connections, use of thread-locking agents, self-locking nuts	
6.3.8	Faulty installation	Faulty installation must not lead to unsafe conditions (e.g. reversed polarity, incorrect fastening); this should be avoided through constructive measures and fault-tolerant design.	VDE AR 2510-2/-50, IEC 62619	Instructions in the operating manual and on equipment, constructive avoidance of reverse polarity, clear labeling of all connections, product training	
6.3.9	Incorrect operation	Incorrect operation must not lead to unsafe conditions. Operation should be fault-tolerant and self-explanatory.	VDE AR 2510-2/-50, IEC 62619	Instructions in the operating manual and on equipment, fault-tolerant and self-explanatory operation, risk analysis of predictable incorrect operation	
6.3.10	Hazardous touch-voltage	Hazardous touch-voltages may not come about in single-fault cases!	VDE AR 2510-2/-50, VDE 0100/410, EN 50272-2, IEC 62619, DIN EN 62109-1	Installation, adherence to normative clearance and creepage distances, safety ladder must be installed so that it is disengaged last when cable tension occurs, grounded casing, protection against contact for components with hazardous touch-voltages.	FI-protection
6.3.11	Misuse	Sealing and cleaning methods must be executed in a way that prevents misuse.	UN38.3, VDE AR 2510-2/-50, VDE 0100/410, EN 50272-2, BATSO 02, IEC 62619	(warning) information in the operating instructions and on the equipment, risk analysis of predictable faulty operation, constructive avoidance of misuse, opening of equipment only with special tools	If necessary, shutdown upon unauthorized opening of equipment
6.3.12	Unclear operating condition	Unclear operating conditions must be avoided in the design.	VDE AR 2510-2	Information in operating instructions and on the equipment as to how to respond to error messages or unclear operating conditions	
6.3.13	Harmful emissions (gaseous, liquid, solid)	Contaminant-laden liquids must not be released from the system. Hazardous gases must (in the case of an accident) be appropriately discharged/released.	UN38.3, VDE AR 2510-2/-50, EN 50272-2, BATSO 02, IEC 62619	Constructive measures to contain, collect or discharge hazardous substances in a contained manner (collection pans, drip protection, events etc.); if necessary, dilution by way of active ventilation; casing with appropriate IP protection	
6.3.14	Inadequate functional safety. Error in risk analysis and/or risk assessment	Correct hazard analysis, risk assessment and establishment of security integrity level (SIL), correct dimensioning of shutdown elements, single-fault safety for safety-relevant functions.	E DIN EN 62619, DIN EN 61508	Test laboratory should conduct tests of functional safety	Product revision (e.g. software and/or hardware updates), recalls for very critical faults

6.3.15	Production and design flaws	Avoidance of safety-relevant production and design flaws	E DIN EN 62619 Chap. 5.6 (Quality assurance plan)	For procedures and process for inspection of materials and components, in particular of the cell, see 6.1.9.	Recurring quality audits
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6.4 General safety objectives

No.	Hazard sources	Intended safety objective	Which standards cover this	Possible preventive measures	Possible corrective measures
6.4.1	Inadequate mechanical processing	Safe and stable mechanical design (no sharp corners and edges, crushing points) for safe installation, handling and operations as well as checks during installation for mechanical stress factors.	IEC 62619,		QM system
6.4.2	Vandalism	Basic protection against attempts to break in and against external mechanical or physical forces, including the use of simple tools (RC2 = screwdriver, pliers, wedge etc.) insofar as the system is public or accessible by third parties, or if such access is planned.	EN 50272-2, Impact test IK IEC 62262	Stable casing, use of locks, selection of materials, selection of installation site (lockable rooms etc.). Clear information/requirements on the installation site in the operating manual.	
6.4.3	Fire	Fire from inside and outside; basic resistance against heat/fire, prevention of spreading of fire from inside to outside, as well as of bursting. Prevention of transmission of external fires	EN 50272-2, EN 61010-1; BATSO 02, E-VDE AR 2510-50, at al	Prevention of fire acceleration, selection of appropriate designs (casing, partitions etc.), requirements on installation site in the installation manual, selection of materials for the casing, construction according to fire safety regulations as found in state building code.	
6.4.4	Lightning/electrical surge	Short-term/transient overvoltage/-over current may not have an influence on system safety, consideration of selectivity	VDE 0100/440, VDE 0185-305, IEC 62619	Overvoltage/surge protection (coarse, medium, fine) (safety-relevant BMS can require fine protection grade)	
6.4.5	Contamination	Avoidance of unsafe operating conditions through contaminations such as dust, liquids and foreign objects	IEC 62619 E-VDE AR 2510-50	Clearance and creepage distances, depending on the expected degree of contamination, labeling, must be permanently visible, air intake filters and regular maintenance, casing with appropriate IP protection	Filter changes, cleaning, visual inspections

6.4.6	Pressure	If pressure builds up within the system, there must be possibility to collect/compensate or release this pressure in a controlled manner; no unsafe operating condition must come about through external air pressure/changes in air pressure.	UN38.3, EN 50272-2, IEC 62619	Use of pressure relief valves or other measures to regulate pressure, information on the installation site in the installation manual (elevation)	
6.4.7	Special environmental requirements (corrosion, gases, flooding)	For intended installation conditions in a corrosive atmosphere or where there is the risk of flooding, special requirements must be taken into account in the design of the system.	E-VDE AR 2510-2, BATSO 02	Clear information regarding installation site in the installation manual, proper selection of insulation depending on the environmental conditions	
6.4.8	Compliance with regulatory requirements	Compliance with Low-voltage-directive, product safety law, battery law, EMC directive, UN transport regulations, dangerous good regulations and others			