TrinaStorage

TÜVNORD

WHITE PAPER

Safety and Reliability for Energy Storage Systems

A Guide to Design, Analysis, and Validation

Introduction

Battery Energy Storage Systems (BESS) have become indispensable in the transition to a renewable energy future, addressing the challenges posed by the intermittent nature of solar and wind power. These systems enable grid stability by balancing supply and demand, providing critical services such as peak shaving, frequency regulation, and backup power. As renewable energy continues to scale, BESS will play an even greater role in supporting resilient, efficient, and low-carbon energy systems.

However, the rapid expansion of energy storage also highlights the critical importance of safety. Recent advancements in storage technologies have introduced complexities that demand rigorous safety measures across the lifecycle of these systems. From thermal runaway and electrical hazards to operational challenges, the safety of BESS directly impacts the reliability of energy storage assets, the protection of personnel, and the sustainability of renewable energy growth. Addressing these concerns requires not only innovative design but also adherence to strict validation and risk mitigation protocols.

Co-authored by Trina Storage and TÜV NORD, this white paper examines the evolving role of safety in the energy storage landscape, providing insights into market trends, emerging challenges, and advanced solutions for mitigating risks. With the Elementa platform, Trina Storage is advancing safety and reliability, ensuring that BESS not only meet market demands but also set new industry benchmarks for secure and sustainable energy solutions.

Prepared by: Trina Storage, TÜV NORD

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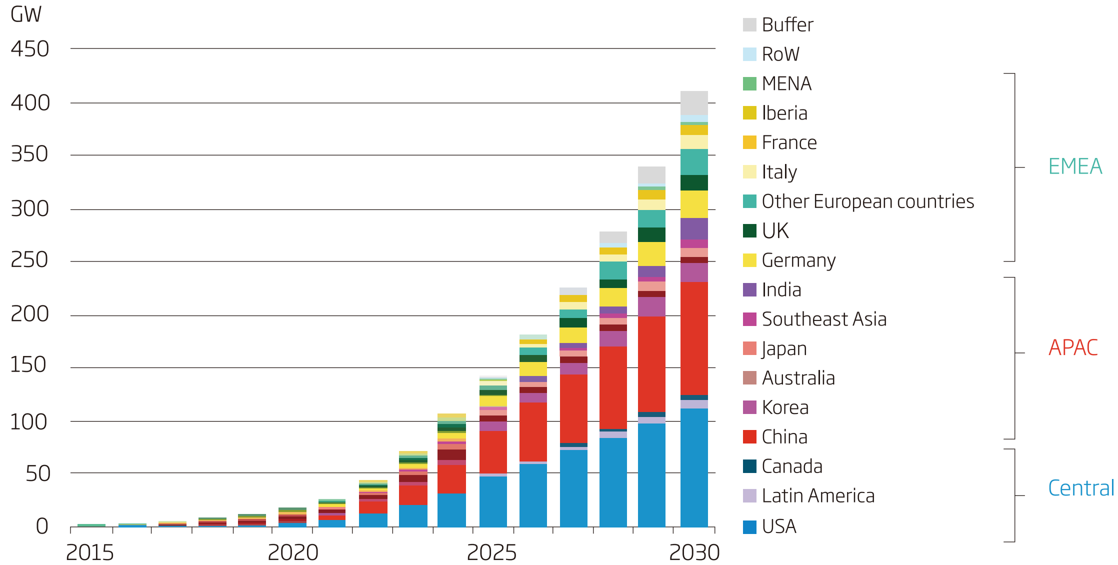
Current Status of Energy Storage Systems

1.1 Energy Storage Market Trends

As the global energy landscape rapidly shifts towards renewable energy sources, the energy storage market is experiencing unprecedented growth opportunities. Over the next few years, energy storage technologies will play a pivotal role in enabling large-scale integration of renewable energy into the grid, enhancing grid resilience, and promoting distributed energy management. Energy storage systems will be essential for applications such as frequency regulation, peak shaving, backup power, and diverse use cases on both the demand side and the transmission and distribution side of the grid. Advances in technology and cost reductions will drive the widespread adoption of energy storage systems, while the development of smart and digital technologies will further enhance their efficiency, safety, and economic viability. Overall, the market for energy storage is set to scale up, commercialize, and diversify, becoming a critical driver of the global energy transition.

According to data from BloombergNEF (BNEF), the global energy storage market nearly tripled in size in 2023, marking the largest year-on-year growth ever recorded. By 2030, global installed energy storage capacity is projected to reach 411 GW (1,194GWh), a 15-fold increase from 2021 levels. As businesses and industrial facilities continue to seek ways to reduce energy costs, improve efficiency, and enhance reliability, the global demand for commercial and industrial energy storage is expected to keep growing.



Source: BloombergNEF. Note: "MENA" refers to the Middle East and North Africa; "RoW" refers to the Rest of the World. "Buffer" refers to markets and use cases that BNEF could not forecast due to limited visibility.

Figure 1 (Global Cumulative Installed Energy Storage Capacity, 2015-2030)

From a regional perspective, the global energy storage market is still dominated by Asia-Pacific, North America, and Europe. Among these regions, China not only holds the largest market share in the Asia-Pacific region but also leads globally. The rapid growth of China's energy storage market is driven by its significant energy demand and strong policy support.

In the Asia-Pacific region, Japan's energy storage market is also noteworthy. The need for energy storage systems as backup power sources has become increasingly critical due to Japan's challenges in maintaining a stable power supply, especially with the frequent occurrence of natural disasters.

The North American energy storage industry is growing rapidly, spurred by a variety of federal and state-level incentives, such as tax credits, subsidies, and energy storage standards, which have effectively promoted the adoption and application of energy storage technologies. Additionally, North America's mature power market has facilitated broader commercialization of energy storage systems.

In Europe, early adopters such as Germany, the United Kingdom, and France have actively promoted the development and broad adoption of energy storage technologies, capitalizing on their leadership in the renewable energy sector.

Notably, the South African energy storage market has shown significant potential and growth opportunities overthe past year. As renewable energy projects increase and electricity market reforms advance, the demand for energy storage systems in South Africa continues to rise, opening new opportunities for market development.

Overall, the development of regional energy storage markets is influenced by local policies, energy demand, and market environments. The global energy storage market is evolving in a dynamic and diverse manner.

1. 2 Application Scenarios

From a power system perspective, the applications of energy storage can be categorized into three scenarios: power generation side, transmission and distribution side, and demand side. As a critical regulatory tool, energy storage systems enable the flexible deployment of power resources among generation, transmission, and consumption, improving energy efficiency and integrating "generation, grid, load, and storage".

1.2.1 Generation Side (Supply)

Energy storage systems are primarily used on the generation side for smoothing output, frequency regulation, and providing standby capacity:

– Smoothing Output: Renewable energy sources like wind and solar are intermittent and unstable. Energy storage systems can smooth out power generation, reducing fluctuations and stabilizing the grid.

– Frequency Regulation: Fluctuations in grid frequency can affect the safe and efficient operation of power generation and consumption equipment, shortening their lifespan. Energy storage systems quickly respond to grid demands, providing voltage and frequency regulation to enhance power quality and system stability.

– Backup Capacity: Energy storage systems serve as backup capacity, providing necessary active power reserves during peak loads, ensuring stable grid operation, and improving overall reliability and resilience.

1.2.2 Transmission and Distribution Side (Grid)

On the transmission and distribution side, energy storage systems help alleviate bottlenecks and enhance overall efficiency:

– Relieving Transmission and Distribution Bottlenecks: When transmission lines or substations face high loads, energy storage systems offer additional power support, easing congestion and preventing overloads, thus improving grid reliability and stability.

– Improving Transmission and Distribution Efficiency: Through charging and discharging, energy storage systems can optimize reactive power on transmission lines and correct the power factor, boosting the overall efficiency and stability of the power system.

1.2.3 Demand Side (Load)

The application of energy storage systems on the demand side can be categorized into two main types: photovoltaic (PV) and non-photovoltaic systems. As market demand continues to grow, the use of energy storage products has evolved from simple backup and emergency power reserves to a wider range of applications.

For non-photovoltaic energy storage systems, such as those used in homes, commercial buildings, and educational institutions – where large-scale PV installations are impractical – these systems can be independently configured to store energy during periods of low demand and release it during peak periods, effectively reducing peak loads. Thanks to favorable domestic electricity pricing policies and the widening gap between peak and off-peak rates, users can take advantage of this differential to lower their electricity costs. In scenarios such as base stations and data centers, energy storage systems serve as critical backup power sources, ensuring power stability and resilience during natural disasters and other disruptions.

Photovoltaic energy storage systems capitalize on the overlap between peak electricity consumption and peak PV generation. Through an integrated "solar-storage-charging" model, these systems combine PV generation, energy storage, and charging capabilities. Solar energy is converted into electricity by PV modules, and any excess power is stored in the energy storage system for later use, such as charging electric vehicles, enabling self-consumption energy management.

In regions with high penetration of renewable energy, such as islands, industrial parks, and remote areas, energy storage systems are paired with renewable power generation facilities to provide independent power solutions where grid coverage is unavailable. Establishing microgrid systems in such locations, combined with industrial and commercial energy storage, can significantly enhance the reliability and flexibility of the power supply.

Supply Side

– Power Peaking:

Energy storage systems enable peak shaving and valley filling of electricity loads. Power plants can charge the batteries during periods of low demand and release the stored energy during peak load periods.

– Capacity Provision:

Energy storage systems provide additional generating capacity to handle peak loads, enhancing the efficiency of conventional power generation units.

– Frequency Regulation:

Energy storage systems can quickly and flexibly switch between charging and discharging modes to regulate frequency, ensuring voltage and frequency stability on the supply side and improving overall power supply quality.

Grid Side

– Relieve Grid Congestion:

By installing energy storage systems upstream of the power lines, excess energy that cannot be transmitted due to congestion can be stored in the system. When the load on the line decreases to a level below its capacity, the stored energy can then be discharged back into the grid, alleviating congestion.

– Defer Expansion and Upgrading of Transmission and Distribution Equipment:

In transmission and distribution systems where the load approaches the capacity of the equipment, energy storage systems can be used to enhance the grid's transmission and distribution capacity without the need for significant infrastructure expansion. This allows for deferring the construction of new facilities, thereby reducing costs.

Demand Side

– Peak-to-Valley Price Arbitrage:

In electricity markets with peak and valley pricing, energy storage systems can be charged during periods of low tariffs and discharged during periods of high tariffs. This strategy capitalizes on the price difference to reduce overall electricity costs.

– Enhance Power Supply Reliability:

During power outages, energy storage systems can provide stored energy to end-users, preventing power interruptions while faults are being repaired and ensuring continuous power supply.

– Self-Consumption of Electricity:

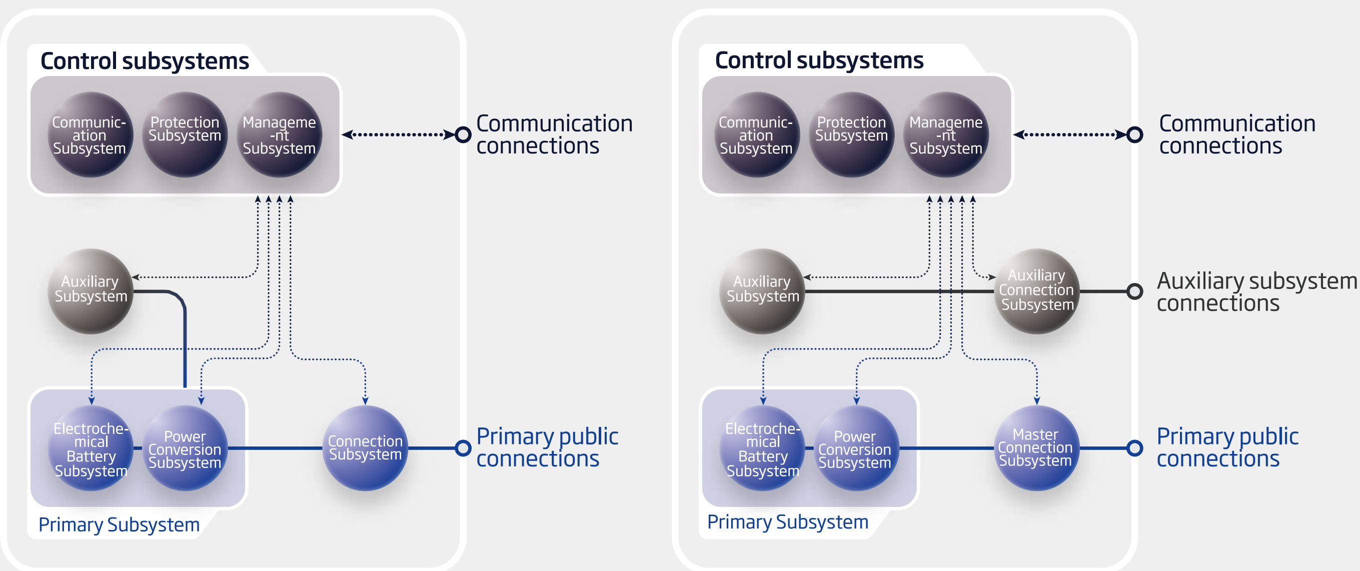
Commercial and industrial users with PV installations can optimize their use of PV power by integrating energy storage systems. This setup improves self-consumption levels and reduces electricity costs by storing excess solar energy for later use.

Figure 2

1.3 Energy Storage Systems

An energy storage system is a complex integration of multiple key subsystems and components, working together to ensure efficient, reliable, and safe operation. According to the IEC 62933-5-2 standard, the architecture of an energy storage system includes primary subsystems (electrochemical system, energy conversion system), control subsystems (communication system, energy management system, thermal management system, safety protection system), auxiliary subsystems, and more. Below is a detailed description of these subsystems:

Subsystems	Components
Management Subsystem	System control and/or energy management system
Communication Subsystem	Data transmission and information exchange between internal components and between the system and the external environment, including operator panels (human-machine interfaces), system communications and/or monitoring, and instrumentation communications
Protection Subsystem	Prevention and response to potential failures and abnormalities during system operation, including over-voltage protection, over-current protection, short-circuit protection, and overheating protection
Auxiliary Subsystem	Fire, heat, and/or smoke detection systems, fire suppression systems HVAC (heating, ventilation, and air conditioning) systems, auxiliary transformers, auxiliary power distribution switchgear, auxiliary uninterruptible power supply (UPS)
Auxiliary Connection Terminals	Connection terminals and cables (type, fire rating, thermal rating, chemical rating, size, and flexibility)
Electrochemical Battery Subsystem	Batteries (including battery management systems), communication equipment, protective devices, mechanical fixtures, and cables
Power Conversion System	Transformers, AC/DC converters, inverters, PCS controllers, switches
Main Connection Terminals	Connection terminals and cables (type, thermal class, chemical class, size, and flexibility)
Others	Room and/or building/enclosure, foundation, water supply building HVAC system, fuses, safety signage



Source: IEC 62933-5-2:2020.6.1.1 Figure 3

2 Safety Challenges in Energy Storage System

2.1 Safety Issues in Energy Storage System

With the advancement of renewable energy, the use of energy storage systems in power grids has become increasingly widespread. However, the safety issues associated with these systems have also become more prominent.

Energy storage batteries come in various types, including lead-acid batteries, lithium-ion batteries, sodium-ion batteries, flow batteries, and sodium-sulfur batteries. Each type has its own characteristics and is suited to different applications. Among these, lithium-ion batteries have emerged as the dominant technology in the energy storage field due to their high energy density, long lifespan, high efficiency, and rapid response capabilities. They are widely used in electric vehicles, consumer electronics, and large-scale energy storage systems, driving advancements in technology and application.

Nevertheless, lithium-ion batteries face significant challenges, particularly concerning thermal stability. Under extreme conditions such as high temperatures, overcharging, or short circuits, lithium-ion batteries can experience thermal runaway, potentially leading to fires or explosions. These safety risks make lithium-ion batteries a major cause of safety incidents in energy storage systems.

According to incomplete statistics, there have been dozens of fire or explosion incidents at energy storage stations globally over the past five years (2019 to 2024), with lithium-ion batteries responsible for up to 80% of these accidents. Such incidents not only result in property damage but also pose serious risks to personnel safety, prompting extensive attention and research into lithium-ion battery safety. To address these challenges, the industry is actively exploring technological solutions to improve the thermal stability of lithium-ion batteries and developing new battery technologies to achieve higher safety and reliability.

Region	Incident	Cause of Incident
USA	Fire at a battery storage facility built by AES, burned for five days and still not fully extinguished	Defective battery cells, causing lithium dendrites to form and lead to internal short circuits
Korea	Fire at SK Energy's battery storage building (50MW), Ulsan Nam-gu	Faulty electrical protection system; poor management of operating environment, negligent installation, and poor integration control system management
Korea	Fire at Gunwi-gun, Gyeongsangbuk-do. VCE	Internal short circuit in lithium-ion batteries caused by overcharging or defects
China	Explosion at Dahongmen Energy Storage Power Station, Beijing	Internal short-circuit failure in a single lithium iron phosphate battery, causing thermal runaway and fire spread to the battery modules
Germany	Fire in a lithium battery storage container, business district of Neermoor (Leer)	Internal short-circuit failure in batteries, resulting in thermal runaway and the spread of fire to battery modules
Germany	Fire in a containerized battery storage system during the Suncycle project test, Thuringia	Poor management of the operating environment; improper management of the energy storage system's integrated control (EMS, PCS) and protection systems
UK	Fire at Warwick energy storage project, University of Warwick, Warwickshire	Internal short-circuit failure in batteries, resulting in thermal runaway and the spread of fire to battery modules

Table 1

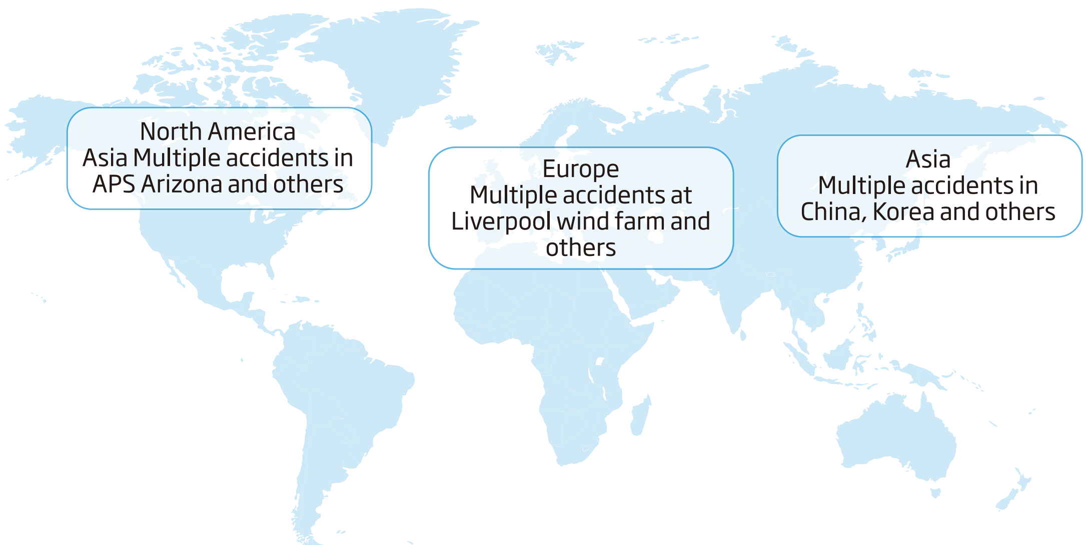


Figure 4

The investigation report on the fire and explosion accident at the energy storage power station in Fengtai District, Beijing, released by the China Electric Power Research Institute, states that the accident at the Beijing Jimei Dahongmen Power Station occurred on April 16. The report identifies the following eight causes of the accident:

1. Safety and quality of the energy storage batteries

2. Electrical topology of the energy storage system

3. Battery Management System (BMS)

4. Site layout of cables and wiring harnesses 5. Fire protection design of the power station

6. Monitoring, early warning, and fire extinguishing systems at the power station

7. Meteorological environmental factors

8. On-site personnel operations and management procedures

Figure 5 Photograph of the Beijing Dahongmen Accident

Source: Accident analysis report on the 25MWh DC photovoltaic-storage-charging integrated power plant project in Dahongmen, Jimei, Beijing, issued by the Electric Power Research Institute

From the analysis of past incidents, the causes of energy storage system safety accidents can be broadly categorized into the following four groups: intrinsic safety risks of the storage system, external safety risks, inadequate safety design protections, and operational management system factors.

1. Intrinsic Safety Risks of the Battery:

– Manufacturing Defects: Internal short circuits caused by issues such as metal burrs or poor coatings.

– Lithium Dendrites: The formation of lithium dendrites within the battery cell may puncture the separator, leading to internal short circuits.

– Battery Aging: The natural aging process of the battery can degrade its performance, potentially impacting the safety of the energy storage system.

2. External Safety Risks:

– Electrical Hazards: Risks like overcharging, over-discharging, and external short circuits.

– Mechanical Hazards: Physical damage resulting from compression or puncturing.

– Electromagnetic Hazards: Electromagnetic interference may disrupt system operations.

– Temperature Hazards: Overcooling or overheating can affect battery performance and safety.

– Explosion Hazards: Batteries may explode due to certain triggering factors.

– Unsuitable Environments: Inappropriate environmental conditions, such as excessive humidity or temperature extremes, may introduce safety risks.

3. Inadequate Safety Design Protection:

– Insufficient Insulation Detection: Inadequate insulation protection measures, such as the breakdown of DC contactors, failure of Busbar insulation, or burnout of AC input wires, can compromise the insulation of the battery's DC contactor, potentially leading to fires.

– Poor System Protection Coordination: When system protection measures fail to operate in harmony, overall safety may be compromised.

– System Control Failures: Faults in systems like thermal management can lead to hazardous situations such as battery fires.

– Auxiliary Equipment Failures: Malfunctions in auxiliary equipment can also undermine the overall safety of the energy storage system.

4. Operational Management System Factors:

– Inadequate Coordination Between Systems: For example, a lack of effective communication among the Battery Management System (BMS), Power Management System (PMS), and Energy Management System (EMS) can lead to operational issues. Additionally, failure to properly coordinate the operational sequences between the Power Conversion System (PCS) and the battery protection system may result in system conflicts. Restarting the system without checking the battery status after troubleshooting the PCS can cause conflicts between the AC and DC sides.

– Management System Failure: These include deficiencies in the management system itself, inadequate control of the operational environment, and excessive humidity or dust levels, all of which can degrade insulation and system safety. Incomplete reporting of anomalies can also hinder timely maintenance and repairs.

– Inadequate Management and Maintenance of Energy Storage Stations: Poor management and maintenance practices following the construction of energy storage stations can result in operational issues that go unresolved, leading to safety risks.

2.2 Safety Analysis of Energy Storage Systems

What is Safety? In general terms, safety is defined as the condition in which people are free from threats, dangers, hazards, or losses.

IEC 62933	Focuses on human safety in electrochemical energy storage systems, aiming to prevent unreasonable risks caused by system failures.
ISO 26262	Emphasizes the avoidance of unreasonable risks arising from the failure of electrical or electronic systems.

Injury

– Harm or damage to human health, property, or the environment.

Hazard

– A potential source of injury.

Risk

– A combination of the likelihood of injury occurring and the severity of the potential harm.

Safety

– A state in which unacceptable risks are eliminated.

The safety of energy storage systems must be addressed at the conceptual stage of product design, ensuring that system-level safety objectives are met and that the safety mechanisms developed comply with the safety requirements of this phase. Additionally, both software and hardware within the system must be validated to ensure they meet the criteria for minimum tolerable risk.

To effectively mitigate safety concerns in battery energy storage systems, potential risks need to be strictly managed throughout every stage of the system's lifecycle. According to the safety assessment and risk reduction guidelines outlined in the IEC 62933-5-1 standard, a comprehensive and effective risk assessment should be conducted, which includes three key steps: risk identification, risk assessment, and risk reduction.

First, all foreseeable hazards and accidents that the energy storage system may encounter during its expected lifetime must be identified. Next, the probability and potential severity of these hazards must be assessed. During the design phase, efforts should focus on eliminating or reducing the likelihood and severity of these risks, with a thorough evaluation of any residual risks. If the risk assessment shows that the level of risk exceeds the minimum acceptable standard, additional measures must be implemented to reduce the risk to an acceptable level. Finally, residual risks should be tested and verified to ensure that the energy storage system achieves the intended level of safety.

2.3 Risk Identification of Energy Storage System

2.3.1 Thermal Runaway Hazards

Thermal Runaway: This refers to the phenomenon where the rate of heat generation within a battery significantly exceeds its rate of heat dissipation, causing rapid heat accumulation within the system, which cannot be effectively released. This results in the system temperature spiraling out of control.

GBT36276	The phenomenon of uncontrollable temperature rise caused by the exothermic reactions inside the battery cell.
IEC62619	An uncontrollable, intense temperature rise triggered by exothermic reactions within the battery cell.
UL9540A	An event in which an electrochemical battery experiences self-heating, leading to an uncontrollable temperature increase. Thermal runaway occurs when the heat generated by the battery exceeds the amount it can dissipate. This can result in fires, explosions, and gas emissions.

The typical process of thermal runaway in a battery occurs as follows: A single battery cell produces excessive self-generated heat due to mechanical or electrical abuse. This overheating causes the battery temperature to rise, pushing it into a thermal abuse phase, eventually leading to thermal runaway. During this process, flammable gases and smoke are released, and the battery begins to burn, which may trigger a chain reaction. This can ultimately result in a fire or even an explosion at the energy storage power station.

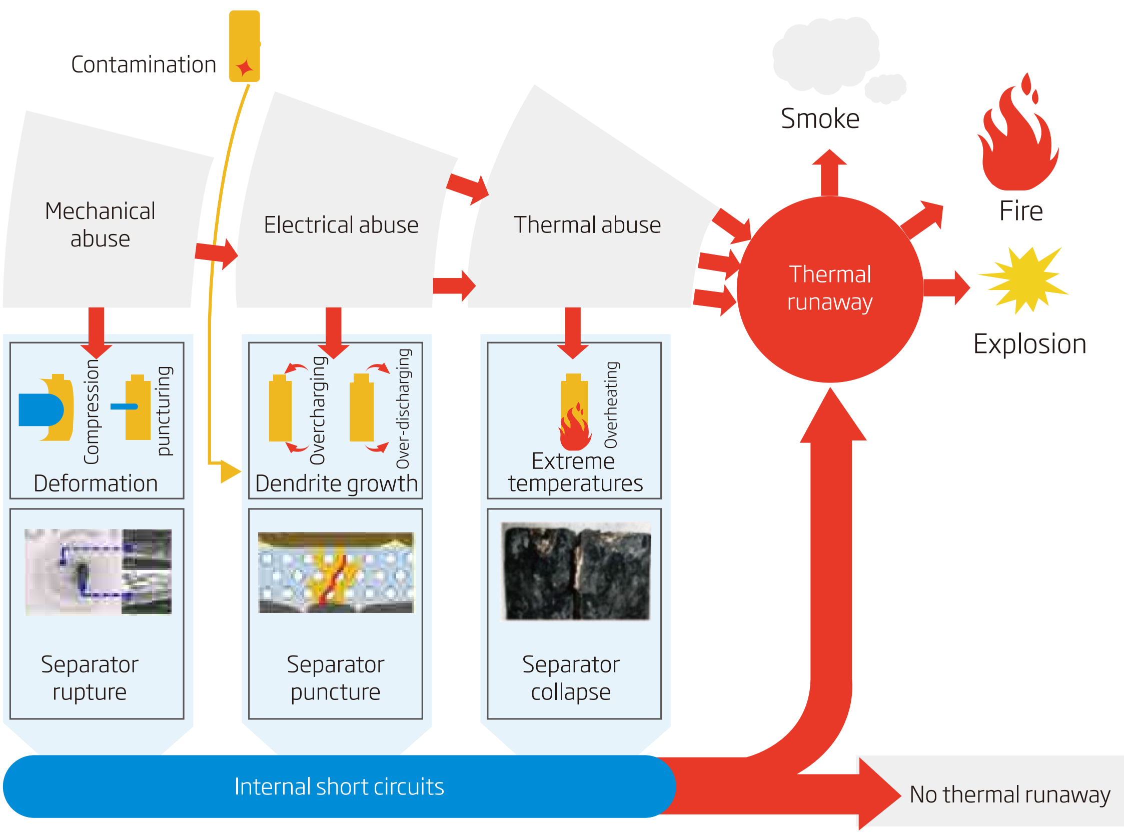


Image credit: Feng X. et al. Mechanisms of Thermal Runaway in Lithium-Ion Batteries for Electric Vehicles: A Review, Energy Storage Materials, 2018, 10: 246-267

In addition to battery aging and internal defects, the following factors may also contribute to thermal runaway:

– Overcharging or overdischarging: Charging or discharging the battery beyond its design parameters.

– Critical connection failure: Malfunction of an electrical connection point.

– Management system failure: Failure of the Battery Management System (BMS) to effectively monitor and control the battery's condition.

– Manufacturing defects: Issues such as internal short circuits or other production-related defects.

– Battery aging: As batteries age, their performance degrades, increasing the risk of internal short circuits.

– Failure of cell protection mechanisms: Deformation or malfunction of protective devices.

– Operation in extreme temperatures: High or low temperature conditions that compromise battery safety.

– Battery deformation and liquid leakage: Structural deformation of the battery shell or leakage of battery fluids.

– Gas leakage or release of combustible gases: Combustible gases are released when the battery burns.

2.3.2 Electrical Hazards

Electrical hazards represent one of the most critical safety concerns in energy storage systems. As the capacity of these systems grows, voltage levels have risen from earlier low-voltage systems to as high as 1500Vd.c. In electrical safety, any line exceeding 60Vd.c. is considered dangerous, and accidental contact with live components can result in electric shock.

Therefore, energy storage systems must incorporate effective electrical isolation measures to prevent direct or indirect contact with live circuits during operation. For instance, reduced insulation impedance poses a risk of electric shock. Insulation impedance is an indicator of the integrity of insulating materials, which can degrade due to issues such as damaged cables or aging insulation. In such cases, damaged insulation may expose the conductors inside the cables, leading to electrical leakage and increasing the risk of electric shock for maintenance personnel.

Moreover, energy storage systems typically include numerous ancillary electrical devices and are often installed in complex environments. Unexpected events such as high voltage, high current (e.g., lightning or surges), or the aging of equipment and cables can lead to the failure of protective devices or insulation breakdown, increasing the risk of electric shock and other electrical safety incidents.

2.3.3 Other Hazards

The energy storage system also contains mechanical hazards, explosion hazards, electromagnetic compatibility (EMC) hazards, temperature hazards, chemical hazards, unsuitable working conditions, and several other potential risks that are often overlooked.

– Mechanical Hazards: Moving parts, sharp edges, and weak mounting brackets can all pose mechanical risks.

– Temperature Hazards: During system operation, certain components, especially batteries, can generate high temperatures. If these temperatures exceed the component's tolerance limits, there is a risk of fire. Additionally, exposed surfaces may become dangerously hot, posing a burn hazard to personnel.

– Chemical Hazards: The operation of energy storage systems involves numerous chemical reactions, which can result in the release of hazardous substances. For example, in the event of capacitor or battery failure, electrolyte leakage and corrosion of conductive components due to electrochemical reactions may occur.

– Noise Hazards: Excessive noise may be generated during system operation. Noise reduction measures should be implemented to ensure that personnel and the surrounding environment are not negatively impacted.

– Electromagnetic Compatibility (EMC) and radio hazards: The electromagnetic waves emitted and received by the energy storage system may interfere with nearby electronic and electrical devices, and the system itself may be affected by surrounding equipment. In complex electromagnetic environments, subsystems can interfere with each other, preventing the energy storage system from functioning properly. Adverse electromagnetic environments can also have negative effects on both humans and the ecosystem.

– Functional Safety Hazards:Functional safety is a critical component of energy storage system safety. It addresses the risks posed by controlled equipment and associated systems in the event of malfunction or failure.

– Unsuitable working environments:

Electrochemical Energy Storage System Hazard Considerations

- ·Electrical
- ·Mechanical
- ·Explosive
- ·Electromagnetic compatibility
- ·Fire
- ·Temperature
- ·Chemical
- ·Unsuitable working environments
- ……

2.4 Risk Assessment of Energy Storage Systems

The safety of energy storage systems is a comprehensive and complex subject, encompassing the entire life cycle of electrochemical energy storage systems. This includes the concept design and development phase, system manufacturing phase, product operation and use phase, service and maintenance phase, and finally, the decommissioning and retirement phase.

Design & Manufacturing → Transportation & Installation → Operation & Maintenance → Changes & Upgrades → Decommissioning & Recycling

The safety risks of energy storage systems depend on multiple factors, including the installation location, chemical composition, and size/scale (e.g., power capacity). Therefore, a corresponding risk assessment is necessary. Energy storage systems may be installed in various environments, ranging from residential applications to commercial and industrial uses, and large-scale grid systems. Each of these scenarios requires its own risk assessment.

Classification Characteristics	Category Code	Description
System Connection Point Voltage	V-L	Low Voltage: V≤1 kV AC or 1.5 kV DC
	V-H	High Voltage: V>1 kV AC or 1.5 kV DC
Energy Capacity	E-S	Small: E≤20 kWh
	E-L	Large: E>20 kWh
Site of Electrochemical Battery Subsystem	S-O	Residential Area
	S-U	Non-Residential Area
Electrochemical Battery Subsystem Chemistry	C-A	Non-Aqueous Electrolyte Battery
	C-B	Aqueous Electrolyte Battery
	C-C	High-Temperature Battery
	C-D	Fluid Flow Battery
	C-Z	Others

Source: IEC 62933-5-2:2020

When performing system risk analysis, IEC 62933-5-1 offers various approaches, including both top-down and bottom-up methods such as the widely used Failure Mode and Effects Analysis (FMEA), Fault Tree Analysis (FTA), HAZOP analysis, and STAMP. These methods help identify potential risks, and through safety system design and the development of electronic circuits, protective mechanisms are implemented to mitigate these risks to an acceptable level.

Bottom-up Risk Analysis

– Failure Mode and Effects Analysis (FMEA), refer to IEC 60812.

Top-down Risk Analysis

– Fault Tree Analysis (FTA), refer to IEC 61025.

Combined Risk Analysis

– Hazard and Operability Studies (HAZOP), see IEC 61882.

– Systems-Theoretic Accident Model and Processes (STAMP).

2.5 Measures for Reducing Energy Storage System Risks

Safety is a non-negotiable aspect of product quality. Ensuring the safety of energy storage systems has become a significant challenge for the sustainable development of the industry. Given the unique nature of energy storage products, ensuring their safety requires integrating multiple safety features. As outlined in ISO/IEC Guide 51, risk mitigation measures in energy storage design are classified as "inherent," "safe design," "protective devices," and "end-user information". ISO/IEC Guide 51 also discusses additional safety management measures for the utilization phase, addressing life cycle safety management.

The design of energy storage systems must not only focus on the technical aspects of system and component design but also emphasize proactive risk management – predicting and identifying potential risks early, implementing preventive measures, and resolving failures at the source. Even in extreme scenarios, the system should provide fail-safe mechanisms to protect both people and property.

Inherent safety design

– Proper selection of subsystems .

– Protection function design.

– System functional safety design.

– Structural design.

– Eletrical design– Fire protection system design.

– Ventilation and explosion relief design, etc.

Safeguards and Protective Measures

– Faults occurring within any subsystem must be contained and not extend beyond their boundaries.

– High-voltage systems must be safeguarded to prevent hazardous remote control operations.

– In compliance with relevant standards, Any component exposed to dangerous voltages due to insulation faults must be grounded and assessed for lightning protection.

– Overcurrent protection must be installed at the external connections of battery subsystems.

– Subsystem connection failures should not pose safety risks, and batteries must be handled with appropriate lifting equipment during installation and removal.

– Enclosures or supports for the system must be constructed of non-combustible materials; fire zones must be established within the system to separate battery compartments, charging equipment, and disconnection/discharge circuits.

– Auxiliary, control, and communication systems must be designed to fail safely, ensuring no danger occurs even during power interruptions or fluctuations.

– Environmental protection is crucial; outdoor energy storage systems must at least meet IPX4 standards, with additional salt spray resistance for coastal installations.

– Ground fault protection and alarm systems must be provided on both the DC and AC sides.

– Audible and visual alarms must activate if the battery becomes overcharged, and any overcurrent within the battery subsystem must be promptly reported.

– A combustible gas detection system with both audible and visual alarms must be integrated into the system.

– The system must include a ventilation system that ensures proper temperature regulation within the enclosure; forced ventilation should be available when natural airflow is insufficient. The ventilation openings must also prevent fire spread and water ingress.

Operation, Maintenance, Staff Training, and User Information

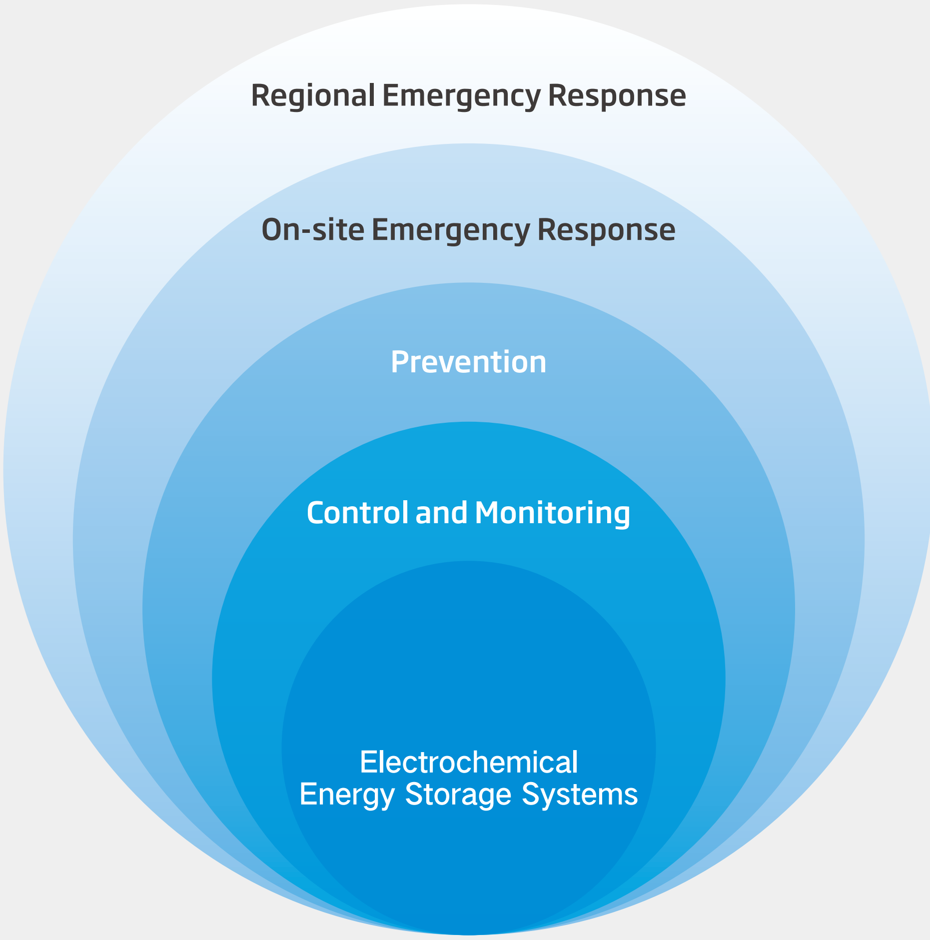
– End users must receive comprehensive safety information, including warning signs and signals, labels identifying hazardous components, audible and visual alarm systems, and safety design flowcharts.

– On-site operations should always take priority over remote operations to ensure the safety of personnel working on-site. Safety contingency plans must be developed, and overcurrent protection must be provided for all external connections to battery subsystems.

– Operation and maintenance manuals must be supplied to the system owner, and manufacturers or system integrators are responsible for establishing a regular maintenance schedule,

– Manufacturers must provide detailed guidelines on the qualifications and authorization requirements for personnel operating the equipment or safety systems.

From a process control perspective, the first step is to identify and monitor potential risk points, followed by the implementation of preventive measures. If issues have already arisen, immediate mitigation actions should be taken. Should these measures prove ineffective, an emergency response plan must be initiated. This plan encompasses immediate on-site reponses and larger-scale regional emergency actions, ensuring that protective measures form a complete, closed-loop system.



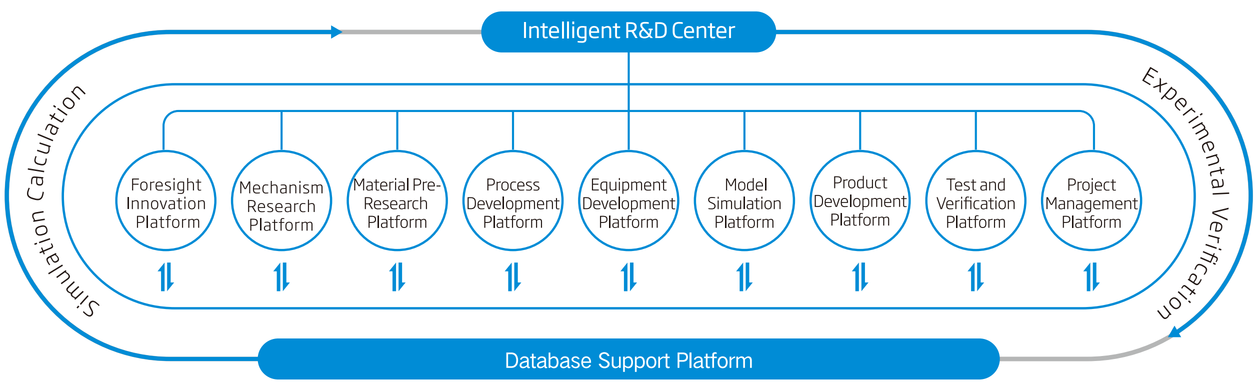
Sources: IEC 62933-5-2:2020

Trina Storage System Safety Solutions

3.1 Product Safety

3.1.1 Safety of Trina Cells

The intrinsic safety of battery cells is the foundation of energy storage system safety. Achieving intrinsic safety requires a seamless integration of multiple factors: selecting the appropriate electrochemical system, structural design, environmental control during the manufacturing process, and detection of defective battery cells. Trina Storage is committed to full-stack, in-house development of battery cells. From product development through mass production and delivery, the R&D and manufacturing teams have established rigorous Trina processes and standards. With a foundation of nine key platforms – forward-looking innovation, mechanism research, material research, product development, process development, equipment development, model simulation, testing and validation, and project management the team focuses on three critical technological areas: mechanism research, key material studies, and battery cell design. This is further supported by two core safeguards: simulation and testing. Together, these efforts form a robust R&D capability summarized as "9 platforms + 3 technologies + 2 guarantees". The team has mastered the core technologies of lithium-ion battery electrochemical systems, cell structures, and manufacturing processes, ensuring the delivery and deployment of ultra-safe cells with the highest quality standards.



a) Intrinsic Safety (Materials)

Developing the electrochemical system is a critical technological pathway to achieving the intrinsic safety of battery cells. Based on an in-depth analysis of safety failures in high-capacity energy storage battery cells, Trina's R&D team has established the intrinsic structure-property relationships among the physical properties of $LiFePO_4$, electrolytes, and separators, and their safety under misuse. This research has led to the development of exceptionally safe active materials, separators, and electrolytes, driven by mechanism-based studies.

The team has implemented key technologies such as resistance to decomposition at 800°C in inert atmospheres and adjustable double-layer structures at the "cathode material-electrolyte" interface. These advancements are made possible through atom-scale interface regulation techniques, including heteroatom doping, surface modification, and coating of cathode materials. By designing formulations with appropriate ratios and particle sizes, the team has optimized the cell's over-voltage charging response, significantly reducing the production of hazardous gases during overcharging and eliminating the risk of thermal failure caused by overcharging.

The development of high thermal stability electrolytes and high rupture temperature separators is critical to enhancing the intrinsic thermal safety performance of battery cells, reducing the likelihood of thermal runaway in events such as abuse or fires. During thermal runaway, the intensity of the exothermic side reactions between the electrolyte and the fully charged negative electrode directly impacts the cell's temperature rise and the proportion of combustible gases generated. To address the high-risk combustible gases such as CO, H_2, and C_2H_4 generated during thermal runaway, along with the heat generation mechanisms of side reactions, Trina Storage has established a comprehensive database focused on high-temperature heat generation from electrodes and electrolytes. This effort has allowed us to identify the critical factors contributing to heat generation and gas production during thermal runaway. By optimizing the intrinsic physical properties of materials and regulating the interface design, the team has achieved ultra-high stability in fully charged positive electrodes under high-temperature reducing gas atmospheres. This has led to ppb-level oxygen release during thermal runaway, significantly reducing heat and combustible gas generation. Improving the heat-resistant shrinkage and rupture temperature of the separator is an effective way to reduce the likelihood of internal short circuits during thermal abuse. The new composite-coated separator design enhances heat shrinkage resistance by 40°C compared to conventional separators, greatly lowering the risk of internal short circuits due to separator rupture.

b) Abuse Safety (Testing)

Internal short circuits caused by mechanical, electrical, or thermal abuse are the primary cause of thermal runaway. Enhancing the voltage and heat resistance of the battery cell to prevent fire and explosion under abuse conditions is key to achieving intrinsic safety. Safety testing and verification serve as the strongest evidence of this safety. Trina's battery testing center has earned authoritative certifications from CNAS, CQC, UL, TÜV SÜD, and IEC laboratories. The center is equipped to conduct safety performance tests in compliance with domestic and international standards such as GB/T 36276, UL 1973, IEC 62619, JISC 8715-2, UN 38.3, and UL 9540A. These tests cover various abuse scenarios, including nail penetration, overcharge, thermal runaway, over-discharge, short circuits, extrusion, and drop tests, validating the safety performance of the battery under different abusive conditions.

CNAS CQC TÜVNORD IEC UL

Through the optimization of the electrochemical system and battery structure, and detection of ppb-level defects in the manufacturing process, the team ensures extreme safety from design to production, delivery, and use. Trinasolar's cells have passed domestic and international certifications such as GB/T 36276, UL 9540A, UL 1642, UL 1973, UN 38.3, and IEC 62619 from authoritative organizations including UL, TÜV NORD, and the China Electric Power Research Institute. In tests simulating mechanical, electrical, and thermal abuse scenarios – such as overcharge, over-discharge, overload, external and internal short circuits at high/normal temperatures, extrusion, drop, impact, nail penetration, and adiabatic temperature rise – Trina cells have demonstrated intrinsic safety by not igniting or exploding. This performance has been widely recognized by domestic and international customers. According to international overpressure standards for casualty prevention, Trina cells provide the maximum safety distance, ensuring personnel safety during extreme accidents.

Figure 6 Trina Cells Obtain Authoritative Testing and Certification

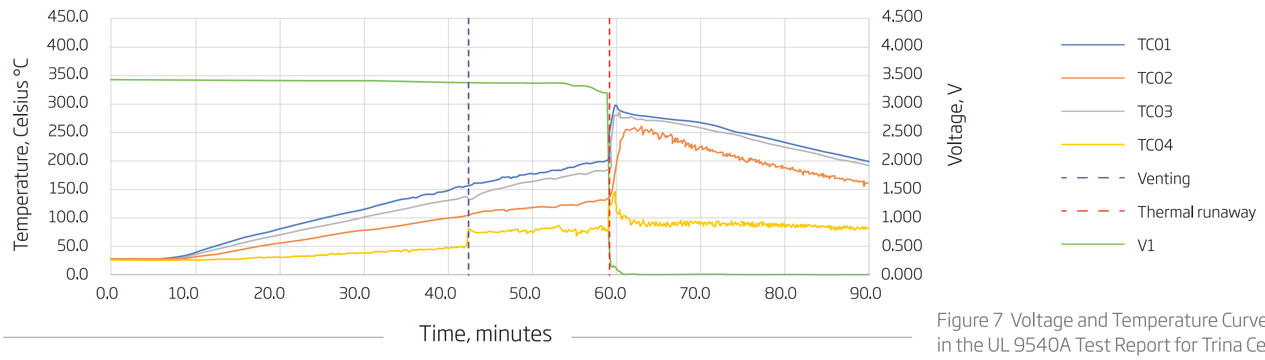


Figure 7 Voltage and Temperature Curves Displayed in the UL 9540A Test Report for Trina Cells

3.1.2 Safety of Trina Battery Cabinets

3.1.2.1 Electrical Safety

a) Arc Flash Protection and Coordination Analysis

An arc flash occurs when a faulty resistive connection within an electrical system discharges across the atmosphere to another voltage phase or to ground. When an arc flash occurs in energy storage electrical equipment, it can cause significant damage due to the effects of extreme temperature, pressure, radiation, and arc roots. High-temperature and high-pressure gases, combined with the arc, produce hot metal and non-metal particles that can escape the equipment enclosure, potentially leading to personal injury and even triggering fires.

Arc flashes can result in electrical fires, pressure waves, flying debris, and other severe hazards. Trina Solar has conducted an in-depth analysis of the common causes of arc flashes in energy storage systems, as this is critical to ensuring the safe operation of electrical equipment.

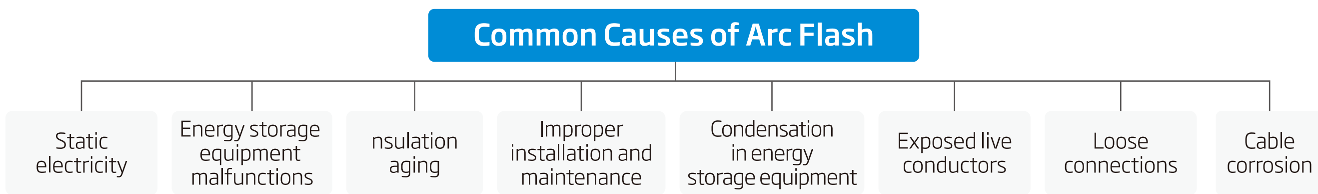


Figure 8 Common Causes of Arc Flash

Arc flash risks are directly linked to the overall safety of energy storage systems. Trina Storage's products implement comprehensive electrical safety and coordination analysis. This includes identifying and addressing line faults, short circuits, grounding issues, and other failures within various sub-systems. Through this analysis, Trina Storage ensures coordinated protection between different system components, including current-limiting, selective protection, and rapid circuit disconnection, all aimed at ensuring optimal product safety.

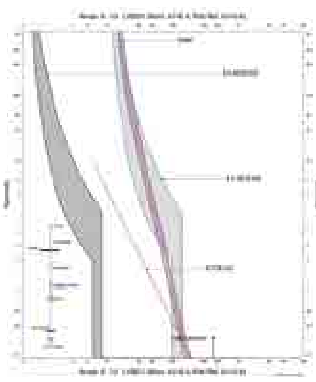


Figure 9 Matching of Different Circuit Breakers and Fuses

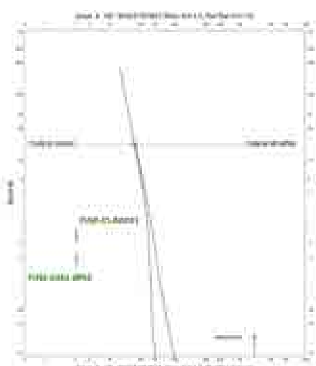


Figure 10 Short-Circuit Matching of Upper and Lower Level Fuses

Traditional energy storage systems often neglect proper arc flash analysis, failing to account for the personal safety of nearby personnel during the design process. They also tend to lack clear warning labels and do not provide appropriate protective equipment. In extreme cases, the effects of an arc flash can pose serious risks to both operational personnel and firefighters.

Trina Storage evaluates its products according to the strict NFPA70E and IEEE1584 standards, assessing high-voltage electric arc hazard distances and incident energie. The products include warning labels and safety recommendations across five key dimensions:

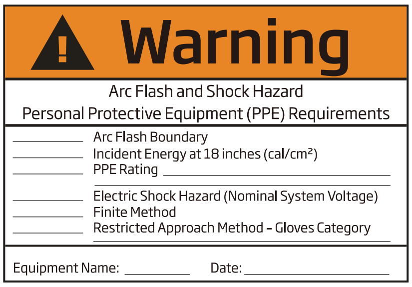


Figure 11 Arc Flash Analysis Label Figure

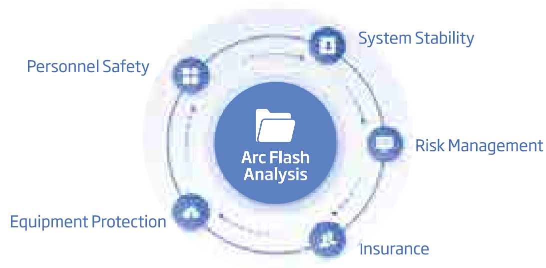


Figure 12 Benefits of Arc Flash Analysis

b) Condensation Safety Design

During operation, energy storage systems may be exposed to extreme environmental conditions such as high temperatures and humidity. If humidity inside the energy storage cabinet exceeds safe limits, condensation may occur. This moisture accelerates equipment corrosion, thereby shortening the lifespan of the energy storage cabinet. Moreover, condensation can severely impact the electrical components within the system, degrading insulation performance and increasing the likelihood of leaks and short circuits. To mitigate these risks, Trina's energy storage systems are equipped with intelligent dehumidification devices. These systems optimize dehumidification points based on operating conditions and airflow characteristics within the cabinet. They feature a 3D air circulation design to ensure comprehensive coverage. Additionally, the systems are outfitted with high-quality fire-retardant materials and include multiple safety features, such as low-temperature protection, over-temperature protection, and overload auto-shutdown functions. The cabinet environment and humidity levels are continuously monitored and adjusted to maintain optimal conditions, ensuring first-class environmental control.

c) DC Short Circuit Protection

As energy storage systems increase in capacity, the number of battery racks connected in parallel grows, leading to higher short-circuit currents during system failures. This puts increased demand on the fuse's interrupting capacity. The dynamic and thermal stability of switching devices is also tested by these higher currents. To address these challenges, Trina Storage uses rack-level controllers, which effectively reduce the maximum fault current by isolating faulty racks quickly, thus improving system stability. Additionally, the rack-level controller helps resolve issues related to circulating currents in parallel DC connections, preventing the "weakest link" phenomenon in battery groupings and extending the product's lifecycle.

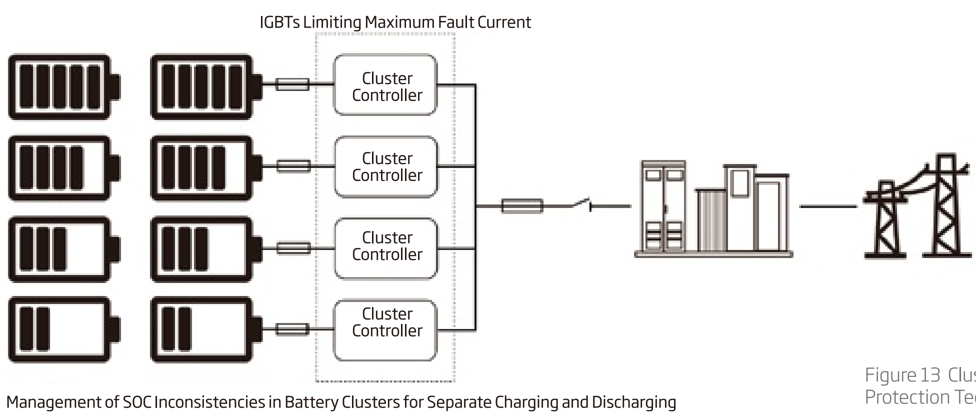


Figure 13 Cluster Controller Control Protection Technology

d) Three-Level Electrical Protection and Multi-Level Isolation

Frequent short-circuit faults pose significant safety challenges to the electrical equipment in energy storage systems. To better control fault currents and mitigate safety risks, Trina storage has implemented a three-tiered short-circuit protection system that spans from battery modules to battery racks and the overall energy storage system. This ensures that fault current incidents are contained and prevented from escalating. Additionally, isolation devices are installed from the battery module level to the energy storage system, with each level adhering to designated safety isolation breakpoints. These multiple insulated safety breakpoints ensure protection duringassembly, transportation, and maintenance, providing multi-layered personal safety safeguards.

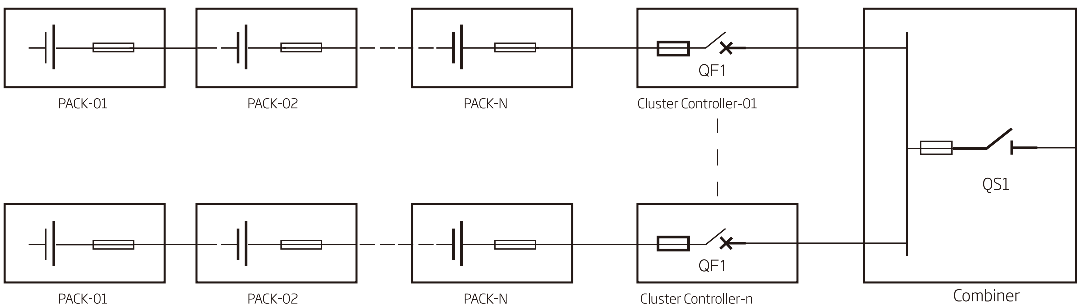


Figure 14 Three-Level Short-Circuit Protection and Isolation Safety Measures

e) Lightning Protection System

Energy storage systems are exposed to various external environments, which can result in direct lightning strikes, induced lightning, conduction from lightning, and ground potential surges caused by inrush currents. Internally, operational over-voltage and electromagnetic pulse interference from short-circuit faults can lead to irreversible damage to energy storage equipment. Trina Storage's battery cabinets are equipped with surge protection and grounding devices at both AC and DC interfaces, as well as communication ports, ensuring the safety and stable operation of key equipment.

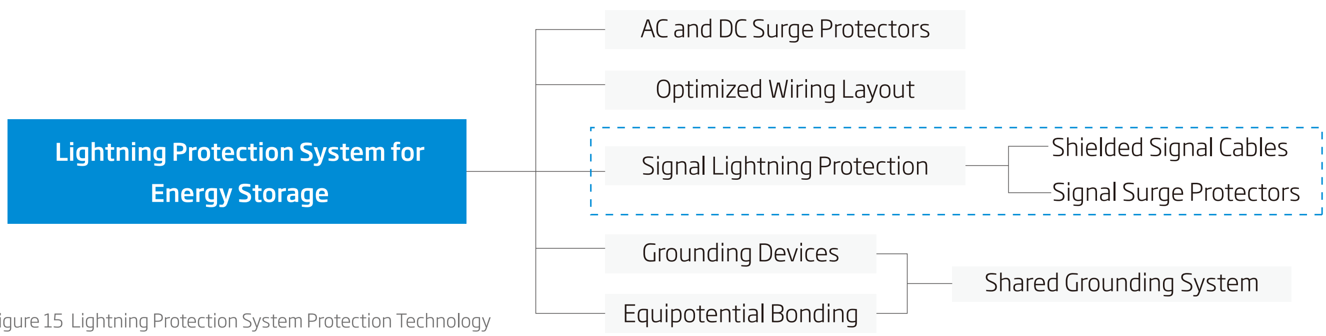


Figure 15 Lightning Protection System Protection Technology

3.1.2.2 Structural Safety

a) Waterproof Protection

Energy storage systems are often deployed outdoors, where preventing external water ingress is critical. Conventional battery cabinets must meet at least IPX4 protection standards. Trina Storage enhances this by incorporating a multi-layered labyrinth waterproof structure and a waterproof sealing design, achieving an IPX5 rating. This allows the system to operate safely and reliably even in heavy rainfall. Additionally, the cabinet features a unique sloped design, promoting water repellency and drainage, effectively removing water vapor or condensation under abnormal conditions.

b) Anti-Corrosion Protection

To ensure the long-term durability of the energy storage system in extreme climates, including cold, heat, high temperatures, and humidity, Trina's energy storage system employs a multi-layer protection strategy, from the battery module to the system framework. High-weather-resistant, high-strength steel is used, with anti-corrosion coatings applied to both inside and outside the cabinet. These protective measures have been rigorously tested for salt spray resistance, aging, and adhesion to ensure the reliability of the protective layer. The system meets the C5-VH corrosion protection standard according to ISO 12944, ensuring a service life of 15 to 25 years for the cabinets.

c) High-Strength Safety

Trina Storage's battery cabinets and modules are designed using high-strength steel. Simulation tools are flexibly applied during the design to select the optimal lifting method, ensuring that the stress and strain levels meet all necessary requirements. These designs are validated through actual load-bearing, lifting, and road tests. Under fully loaded conditions, the mechanical strength satisfies the demands of seismic activity up to level 8, ensuring safety during assembly, transportation, and on-site installation, as well as the reliable operation of the equipment.

d) Fireproof Design

Fireproofing is a crucial aspect of energy storage system safety. Trina Storage's prefabricated battery cabinets are arranged according to strict fire spacing regulations to prevent the "heat island" effect and to limit the spread of fire. The cabinet's outer shell is filled with heat-resistant and thermal insulation materials, while the battery and electrical compartments are separated by fire-resistant barriers, so that the fire-resistance limit exceeds the requirements of the relevant standards. At the battery module level, a fire-resistant insulation technology is used, capable of withstanding temperatures over 1,200°C. The heat-resistant cell material improves thermal stability, while the six-fold protection includes: Reliable sensor-based safety monitoring and warning systems; Thermal insulation between cells; Heat-resistant insulation between modules; Specific channels for thermal runaway exhaust; Explosion-proof valves and air pressure balancing; Rapid exhaust systems within the module under specific pressure conditions. These integrated safety measures, combined with liquid cooling panels and high thermal conductivity materials, ensure effective active cooling. This design ultimately significantly reduces thermal propagation from the battery modules.

3.1.2.3 Thermal Safety

a) Liquid Cooling System: Anti-Leakage and Liquid Shortage Safety Design

The safe operation of energy storage systems relies heavily on the stable functioning of various auxiliary systems, with the thermal management system being a crucial component. It serves as a key foundation for ensuring the overall safety of the system. Currently, liquid cooling technology is widely adopted due to its high level of integration and uniform temperature regulation. However, the application of liquid cooling systems presents potential risks such as fluid leakage and liquid shortage, which can lead to system failure. The prevention of leaks and protection against liquid shortages are critical benchmarks for evaluating the reliability of liquid cooling systems. If these safeguards fail, the malfunctioning liquid cooling system would lead to uncontrolled temperature increases in the battery cells, thereby threatening the safety of the entire energy storage system.

To prevent such risks, Trina Storage adheres to a leak-proof design philosophy throughout the development of its liquid cooling systems. This approach includes the selection of highly reliable materials and connection methods, such as multi-layer piping made of premium materials with excellent water and glycol resistance and adaptability to a wide temperature range. The inclusion of a bionic wave structure further enhances reliability and extends the system's lifespan. In addition, the liquid injection process is carefully monitored to ensure precise control of every litre, allowing comprehensive management of all parameters throughout production. The system is equipped with real-time monitoring capabilities for key performance indicators, with data continuously uploaded to the energy storage decision-making and control platform, ensuring leak-free performance over the entire lifecycle of the system.

Building on the foundation of the leak-proof design, Trina Storage's liquid cooling system addresses liquid shortage risks right from the production stage. Trina Storage precisely calibrates and quantitatively controls the coolant volume. In addition, real-time monitoring of coolant pressure ensures maximum consistency in production. The liquid cooling system is further equipped with an intelligent replenishment mechanism, featuring a coolant reserve system, a one-way check valve, an intelligent filling system, and a comprehensive control and protection system. These components work together to enable online smart replenishment, providing real-time control of system pressure. This effectively prevents liquid shortages and ensures the safe and efficient operation of the liquid cooling system.

b) Temperature Control Safety Design

Temperature control is a key indicator of the energy storage system's thermal management capabilities. Effective temperature regulation not only prevents thermal runaway in battery cells, safeguarding system operation, but also enhances the temperature uniformity of battery cell racks. This, in turn, extends the lifespan of the energy storage system, resulting in higher reliability and better economic returns.

Trina Storage's thermal management system ensures safe and efficient performance throughout the product lifecycle. The system is optimized through design features such as pipe diameter adjustments, piping configurations, and valve and fitting adjustments to improve flow distribution uniformity. In terms of operational strategy, Trina Storage's system surpasses conventional temperature control methods by integrating a self-developed decision-making program. By monitoring the performance of the battery cell's thermal field and differentiating between various operating conditions, the system can provide tailored operation modes and optimal coolant temperatures for each scenario. This ensures precise control over every degree of water temperature with real-time response and adjustment. Furthermore, the thermal management monitoring system is linked to the fire safety system, allowing for predictive analysis of battery safety status. This proactive approach ensures that potential risks are detected and mitigated early, ensuring long-term, risk-free operation.

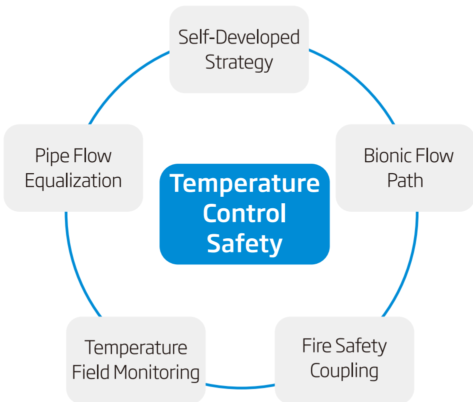


Figure 16 Multi-Faceted Thermal Management System Design

3.1.2.4 Fire Safety

Traditional space-level fire protection systems often react too late. The fire safety system in energy storage should respond immediately to thermal runaway in battery cells, intervening to vent and extinguish fires at the early stage to minimize system losses. Trina Storage's fire protection system leverages multi-sensor, multi-level detection to identify thermal runaway incidents early and deploy gas extinguishing measures to provide targeted protection, reducing potential damage.

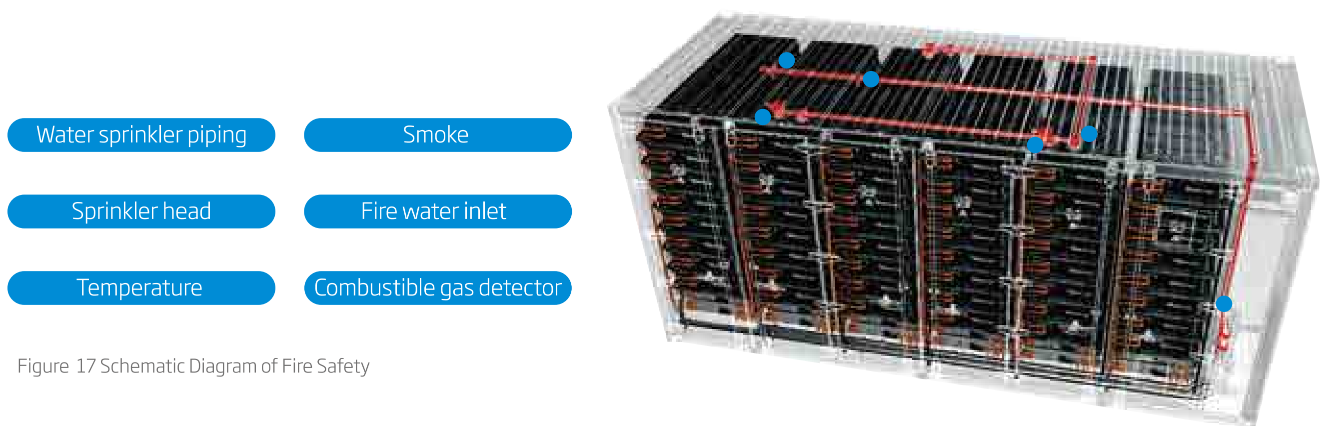


Figure 17 Schematic Diagram of Fire Safety

a) Multi-Sensor Detection and Signal Extraction for Protection

Using a multi-sensor, tiered detection system, Trina's fire protection system continuously monitors electrolyte leaks and thermal runaway data within the battery boxes of the energy storage station. This ensures comprehensive surveillance of battery performance, with data stored locally and remotely for big data analysis. The system detects temperature, smoke, and combustible gases at both the module and cabinet levels. When a composite detector identifies a fire within a module, it triggers the exhaust system and fire suppression system, allowing for rapid and accurate fire control at the module level. In the event of a fire within the energy storage cabinet, multiple detectors can trigger space-level suppression using a fully-flooded extinguishing system, ensuring comprehensive fire safety for the energy storage container.

b) Targeted Protection

To meet the growing fire safety demands of the energy storage industry, Trina Storage's fire protection system incorporates a new lithium battery fire suppression device equipped with a large-capacity extinguishing agent. This system ensures rapid and long-lasting suppression of fires at the module level. Composite detectors are installed inside the modules, enabling high-precision fire protection. Trina Storage's fire protection system treats the module as the smallest protective unit, ensuring accurate detection and targeted fire suppression. When thermal runaway occurs, the composite detector sends an alert to the fire control unit, activating the module's extinguishing system for quick fire suppression and continuous containment.

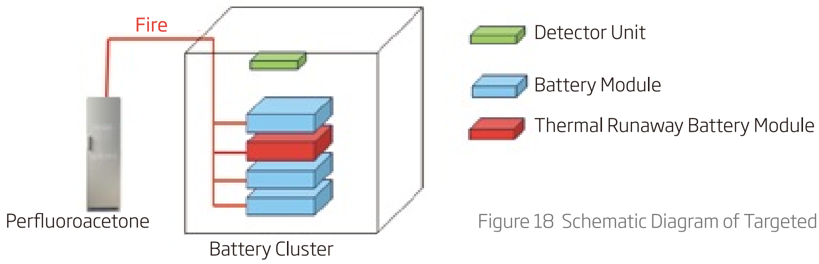


Figure 18 Schematic Diagram of Targeted Fire Extinguishing

c) Explosion Protection

During lithium battery thermal runaway, a significant amount of combustible gases (CO, H_2, methane, VOCs) can be produced. If the concentration of these mixed gases reaches a certain level, it poses a risk of combustion or explosion. Trina Storage's energy storage containers are equipped with an explosion-proof exhaust system, which features ventilation, insulation, explosion protection, and fire safety integration that can close external airflow channels and discharge hazardous gases.

The exhaust system in the energy storage container is linked to a combustible gas detection system. When the concentration of combustible gases inside the container reaches a threshold, the explosion-proof exhaust module is activated to reduce the gas concentration within the energy storage battery cabinet. Additionally, the system's exhaust and explosion-proof ventilation functionality can be simulated and evaluated based on the characteristic gas emissions during thermal runaway events. This explosion-proof ventilation system must ensure that, upon triggering the combustible gas detector and initiating the exhaust process, the concentration of combustible gases inside the enclosure of the electrochemical energy storage system remains below 25% of the Lower Flammable Limit (LFL).

Figure 19 Combustible Gas Concentration in the Cabinet Minutes after Mechanical Exhaust System Activation

d) Explosion Venting Protection (completed in 2025)

In extremely flammable conditions, energy storage containers pose a significant threat to nearby battery prefabricated cabinets and maintenance personnel. Trina Storage containers are equipped with explosion vent panels, designed in compliance with NFPA 68 safety standards. If initial explosion-proof ventilation and fire suppression strategies fail to contain the fire, the system's explosion relief mechanism will create a directional pressure release, preventing the disintegration of the storage container and protecting adjacent units. Trina Storage also simulates and analyzes the risks of combustible gas ignition and explosion due to thermal runaway. This analysis models the gas and pressure distribution within the container, helping to optimize the size and placement of explosion relief panels.

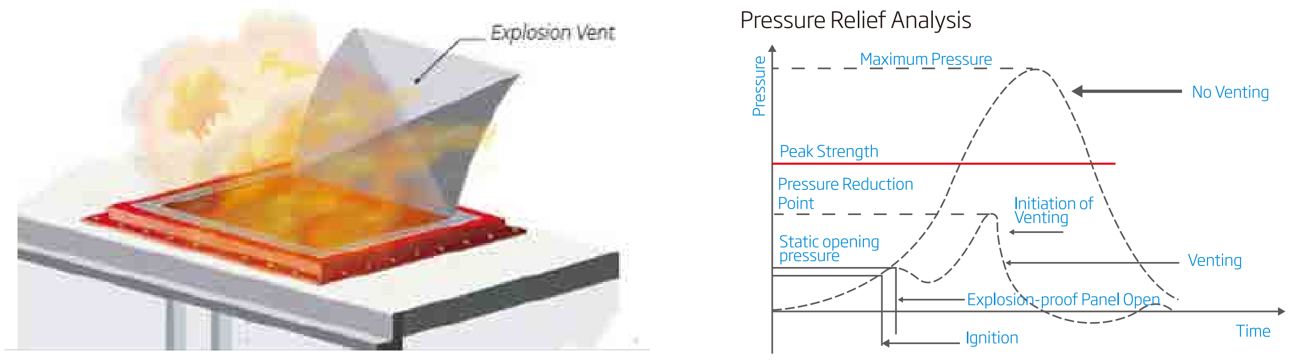


Figure 20 Explosion Venting Schematic

e) Water Fire Safety Design

Due to the characteristics of lithium-ion battery thermal runaway, fire suppression chemicals can cool the battery surface, but internal chemical reactions may continue. Simply spraying extinguishing agents may not fully prevent the spread of thermal runaway, and large-scale fires could still occur. To ensure comprehensive fire safety at energy storage stations, Trina Storage is equipped with external water firefighting interfaces. Water pipelines are installed on top of the container to enable diffusion-based fire suppression, providing a rapid response to extinguish any fire.

3.1.2.5 Data Function Safety

a) Outlier Cell Detection

As the fundamental unit of the battery, cell failure can degrade the overall performance of the battery pack or even cause safety incidents. Even cells from the same production batch may have minor differences. Outlier cells typically exhibit noticeable deviations in voltage, internal resistance, and other parameters compared to their counterparts. Over time, these differences can intensify, leading to an imbalance within the battery pack. This can trigger issues such as overcharging, overdischarging, and overheating, severely compromising battery safety. Detecting and addressing these abnormal cells through outlier detection is crucial in preventing potential safety hazards.

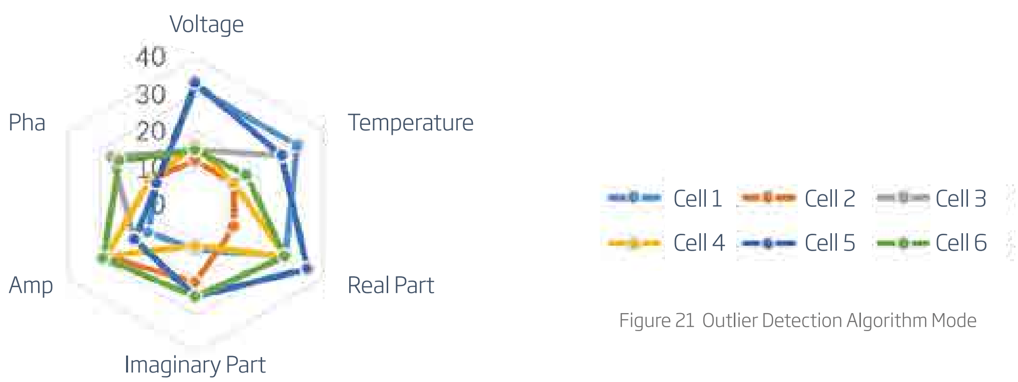


Figure 21 Outlier Detection Algorithm Mode

The Battery Management System (BMS) utilizes outlier detection methods based on electrochemical impedance detection and other advanced technologies. With the support of online impedance detection equipment, the system enables intelligent early warning for abnormal cell behavior, allowing potential issues to be addressed in the early stages. This proactive approach ensures the safety of the entire new energy system throughout its lifecycle.

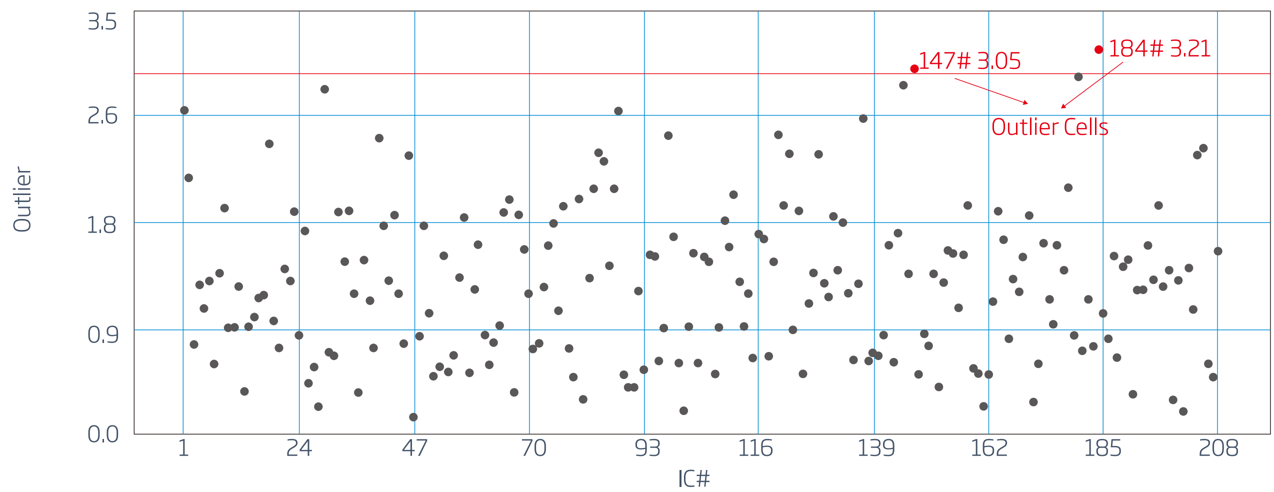


Figure 22 Outlier Cell Detection Results

The outlier detection algorithm, integrated within the BMS, continuously monitors the status of the battery pack. By employing clustering analysis to group cells based on their impedance characteristics, the process of detecting outliers is simplified, making it more accurate in identifying differences in the status and performance of individual cells. Outlier detection can be performed both before the battery modules are dispatched and during operation, enabling the identification of abnormal cells. Necessary actions, such as isolating faulty cells, can then be taken, providing strong support for the optimization and management of battery packs.

b) BMS Safety Warning Algorithm

As lithium-ion batteries age, they experience capacity degradation and an increase in internal resistance. This aging process can negatively impact battery performance and lifespan, affecting the entire system and potentially leading to safety risks. The Battery Management System (BMS) must continuously monitor the battery's condition and adapt its charging strategies and load distribution according to the State of Health (SOH) changes. SOH prediction algorithms provide crucial data to the BMS, offering real-time insights into the internal condition of the battery. These algorithms help manage the charge/discharge process, trigger safety alerts, and predict the battery's remaining lifespan. Accurately predicting the SOH of battery cells plays a critical role in guiding the design of battery management systems and optimizing battery usage and maintenance strategies.

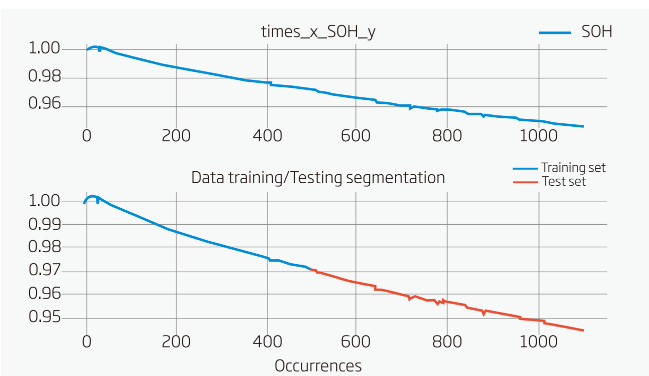


Figure 23 SOH Prediction Model

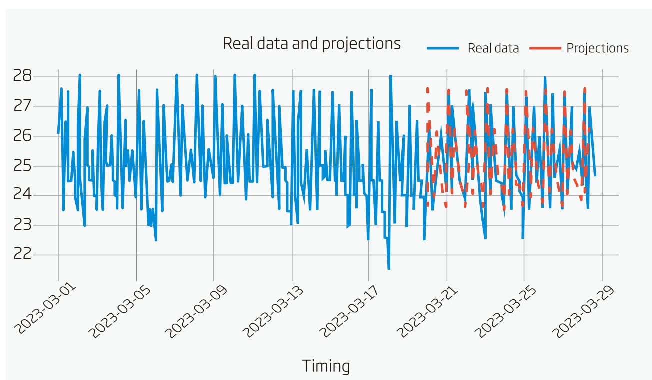
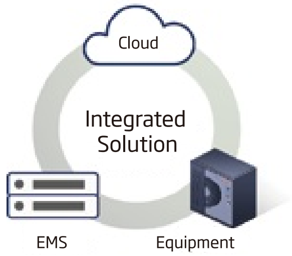


Figure 24 Actual vs. Predicted Temperature

BMS employs a data-driven approach, generating predictive models using machine learning algorithms. By integrating with the cloud platform, this enables real-time forecasts of key data, such as the predicted temperature of battery cells for the next 24 hours and the State of Health (SoH) of the cells.

c) Intelligent Equipment Monitoring

To enhance safety management from the ground up, Trina Storage implements a comprehensive "three-in-one" solution, integrating the local controller, Energy Management System (EMS), and cloud platform. This multi-layered approach ensures data security, station safety, and energy reliability. The system provides real-time, all-encompassing data monitoring, utilizing cloud-based digital twin technology for dynamic visualization. With robust data collection and analysis capabilities, it continuously uploads cell-level data, offering precise and efficient monitoring of critical equipment parameters. This facilitates early detection of operational anomalies or malfunctions, supporting a complete lifecycle of safety monitoring for energy storage systems.



d) Fault Alarm Diagnosis

To expedite the resolution of safety issues in energy storage systems and prevent faults that may escalate into serious incidents, Trina Storage employs real-time, comprehensive data monitoring. The system immediately triggers alarms upon detecting abnormalities or potential failure indicators. Through data analysis, it quickly identifies the fault's type, location, and potential impact. Enhanced by the cloud's powerful data processing and analysis capabilities, it conducts in-depth evaluations of alarm details. Utilizing historical data, equipment status, and environmental conditions, the system pinpoints faults with accuracy. The fault diagnosis expert system generates a detailed report, promptly notifying the relevant operation and maintenance personnel to prevent fault escalation. This approach minimizes malfunctions, simplifies operation and maintenance, and significantly reduces associated costs.

e) Integrated Multi-Endpoint Warning and Protection (available in certain markets)

To ensure equipment safety and improve the overall security and stability of energy storage systems, Trina Storage's EMS and cloud platforms utilize advanced statistical analysis, machine learning, and deep learning techniques to perform in-depth analysis of big data and train predictive warning models. Complemented by intelligent algorithm-driven control strategies, the system provides multiple layers of protection, identifying potential safety risks or operational irregularities before they manifest. This proactive warning mechanism allows the operations team to address potential issues before they escalate, effectively preventing safety incidents. Additionally, the system breaks down information silos, enabling data sharing and collaborative management across subsystems, optimizing resource allocation, and improving response times. In emergency scenarios, precise risk localization significantly reduces response times, safeguarding the overall system's stability and safety.

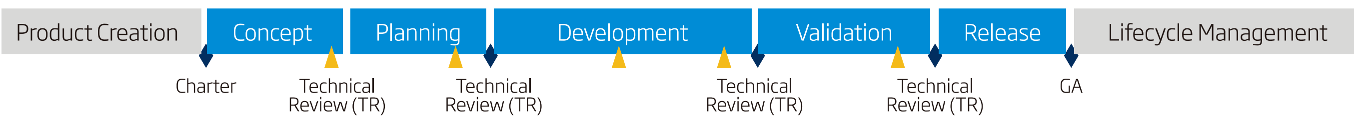
3.2 Quality Management System

3.2.1 System Overview

Trina Storage has achieved the international ISO9001 certification for quality management systems. Following the requirements of this standard, Trina Storage has benchmarked its processes against the HW system, continuously improving the quality management framework for the entire lifecycle of its energy storage products. The laboratory has also been accredited with the ISO17025 certification for laboratory management systems, ensuring that testing services are conducted in a standardized and regulated manner. Additionally, Trina Storage has been certified under ISO45001 for Occupational Health and Safety Management, ISO14001 for Environmental Management, and ISO27001 for Information Security Management. These certifications enhance internal management practices and overall performance, enabling the company to meet customer expectations and regulatory requirements, thus laying a solid foundation for promoting sustainable organizational growth.

3.2.2 Quality Management Process in R&D

During the development process, the company incorporates best practices from the IPD development management process of leading companies while tailoring it to its own industry characteristics and expertise. The updated project development process is divided into five stages: concept, planning, development, validation, and release/mass production.



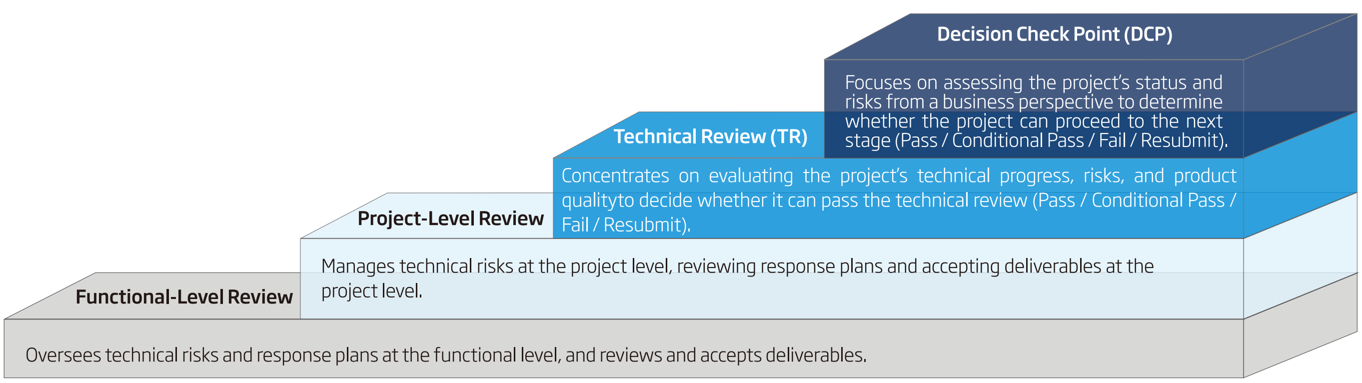
Concept Stage: The Product Development Center initiates the preliminary design based on input from the Marketing Department and MU. This stage focuses on assessing product design requirements, reviewing feasibility reports and risk assessments, identifying key technical risks, and devising solutions.

Planning Stage: The new product development plan is defined, and quality objectives are finalized. This stage emphasizes reviewing the completeness and accuracy of the project plan and objectives.

Development Stage: The specific design plan is refined, and A/B samples are trial-produced. This stage focuses on evaluating the success of the A/B samples, analyzing technical risks, and deciding whether to proceed to the next stage based on current test and quality data.

Validation Stage: The design is optimized, and the C-sample is validated on the mass production line. This stage focuses on evaluating the adaptability of the design to the production line as well as the production line's capabilities.

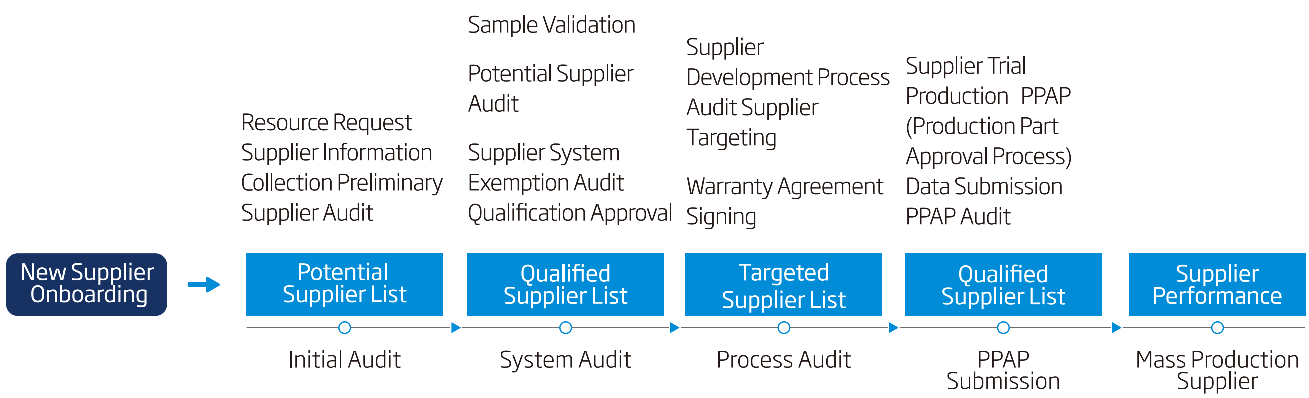
Release Stage: The design is finalized, and mass production begins. This stage emphasizes evaluating and analyzing technical risks and determining whether to ramp up production capacity based on current test and quality data.



3.2.2.1 Product Certification

Components	Cell	Battery Cluster	Battery Cabinet
Standards	IEC 62619:2022	IEC 60529:2013	IEC 60529:2013
	UL 1973:2022	IEC 60730-1:2013	IEC 60730-1:2013
	UL 9540A	IEC 62477-1:2012	IEC 61000-6-2/-4:2019
	UN38.3	IEC62619:2022	IEC62619:2022
	Rohs	IEC63056:2020	IEC 62933-5-2:2020
	GB/T 36276-2018	UL 1973:2022	IEC63056:2020
		UL 9540A	UL 1973:2022
		UN38.3	UL9540:2020
		GB/T 36276-2018	UN38.3
		CE	CE

3.2.3 Supply Chain Quality Management



New Supplier Onboarding:

1. Initial Audit:

Conduct an investigation through the Potential Supplier Development Questionnaire to further confirm the qualifications of potential suppliers and assess whether further development is required.

2. System Audit:

After identifying potential suppliers for development, the Purchasing Department convenes a cross-functional team meeting to establish the evaluation method. The cross-functional assessment team includes representatives from Purchasing Management, Energy Storage Quality Management, and the Advanced Energy Storage Products Research Institute.

3. Process Audit:

Primarily focuses on signing warranty agreements and approving new parts/materials, which includes sample evaluations, third-party certifications, and batch trial production, among other related processes.

4. PPAP Submission:

Once the sample evaluation, batch production, and reliability verification are complete, and the PPAP audit is approved, the relevant functional departments co-sign to finalize the supplier's qualification as a qualified supplier.

5. Mass Production Supplier Management:

1) Supplier Performance Evaluation and Management: Includes monthly and annual supplier performance assessments, performance improvement measures, and 8D management.

2) Annual Supplier Audit: The Quality Department develops and implements an annual on-site audit plan. If issues arise, audits and guidance are arranged as necessary.

3) Supplier Change Management: Supply chain management acts as the sole interface for supplier changes. Changes are initiated by the Energy Storage Quality Management department through a Change Request Form process and handled by Trina Storage's Supply Chain Management team.

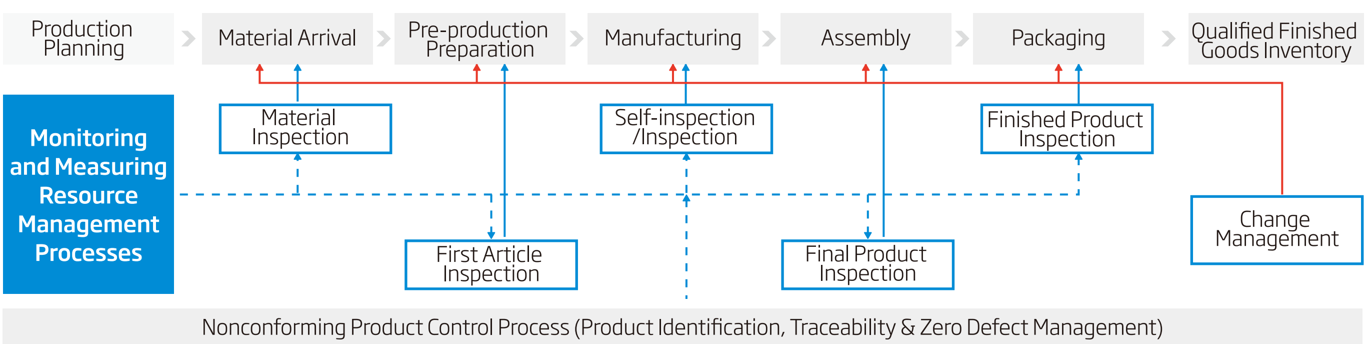
4) Supplier Reliability Management: Reliability requirements are defined in product specifications and technical agreements. Suppliers must submit an annual reliability report to the Advanced Energy Storage Products Research Institute (AESPRI). The AESPRI then organizes R&D, R&D quality, and supplier quality departments to review and file the report with Energy Storage Lab Management.

5) Supplier Development Management: To help suppliers provide lower-cost products, while ensuring better quality, delivery, and service, the Supplier Quality team works with suppliers through a collaborative process, providing guidance to foster improvements.

3.2.4 Process Quality Control

The Trina Storage Quality Center has developed a comprehensive process quality management system. Quality inspections and controls are conducted in stages, from material receipt to the storage of finished products, with quality monitoring and measurements integrated throughout the manufacturing process. These are carried out at five key checkpoints: incoming material inspection, first-piece inspection before production, in-process self-inspection and patrol inspection, product inspection after assembly, and finished product inspection before packaging and warehousing. During manufacturing, Trina strictly adheres to processes for product monitoring and measurement, process change, and defective product control, ensuring optimal product quality.

In both the production and shipping phases, product flow is effectively managed through MES-integrated process routes, allowing for the precise control of energy storage products at critical process control points. Additionally, the MES system enables real-time traceability management, ensuring full product traceability. The implementation of the Quality Center's nonconforming product management and change management systems addresses challenges in storing and statistically analyzing data related to manufacturing quality abnormalities and process changes. Automated quality report generation, as well as automatic updating and preservation of change histories, ensure traceability of quality anomalies and process changes, while also enhancing data security.



3.2.4.1 Process Quality Management (Factory Testing)

The Quality Center is equipped with extensive factory testing capabilities, allowing for the independent creation of tailored testing environments for various products. The center is outfitted with three 35kV power stations, numerous high-precision power quality analyzers, safety testing instruments, air tightness testing equipment, and other auxiliary testing tools. The center can independently conduct a range of standard factory tests and system function tests, including safety testing, auxiliary function testing, joint testing, power quality testing, and aging testing.

1. System List
- Containers
- Energy Storage Inverters
- Batteries
- Battery Holders
- Air Conditioning Units
- Low Voltage Cabinets
- Fire Protection Systems
- Lighting Systems

2. Test Environment
- Containers
- Energy Storage Inverters
- Batteries
- Battery Holders
- Air Conditioning Units
- Low Voltage Cabinets
- Fire Protection Systems
- Lighting Systems

3. Routine System Testing
- Containers
- Energy Storage Inverters
- Batteries
- Battery Holders
- Air Conditioning Units
- Low Voltage Cabinets
- Fire Protection Systems
- Lighting Systems

4. Safety Tests
- Containers
- Energy Storage Inverters
- Batteries
- Battery Holders
- Air Conditioning Units
- Low Voltage Cabinets
- Fire Protection Systems
- Lighting Systems

5. Auxiliary System Function Tests
- Lighting Systems
- Emergency Lighting Systems · Air Conditioning System Test
- Fire Protection Function Test
- Limit Switches
- Cameras
- EXIT
- Temperature and Humidity Probe Test

6. Energy Storage System Function Tests
- Lighting Systems
- Emergency Lighting Systems
- Air Conditioning System Test
- Fire Protection Function Test
- Limit Switches
- Cameras
- EXIT
- Temperature and Humidity Probe Test

7. Power Quality
- Air Conditioning System Test
- Harmonics
- Voltage Deviation
- DC Component

8. Traceability Information
- Air Conditioning System Test
- Harmonics
- Voltage Deviation
- DC Component

3.2.5 Delivery Quality Management

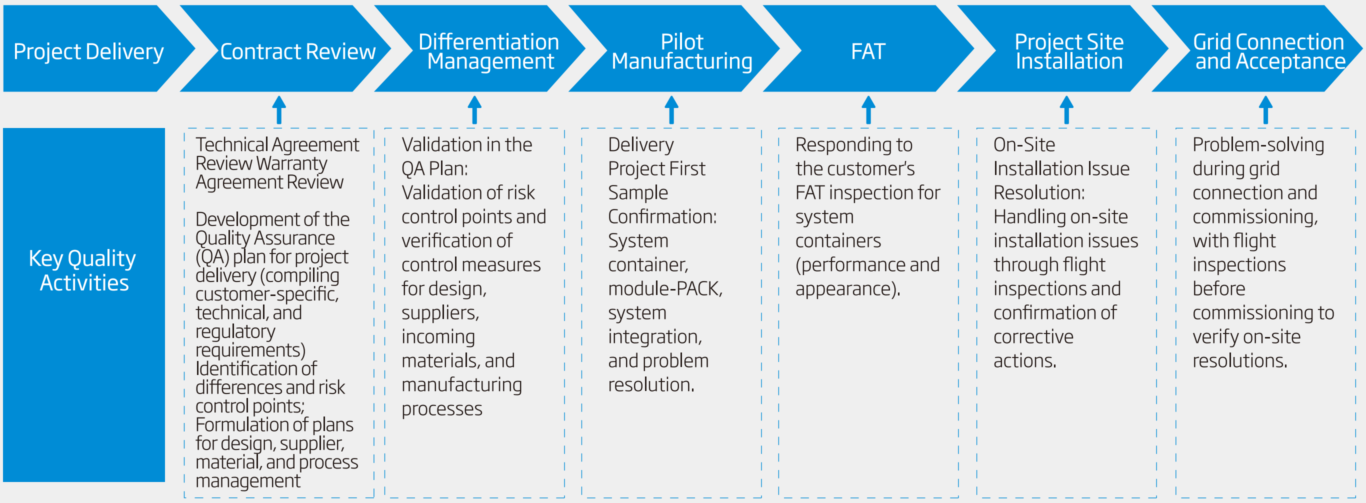
Client's New Project Introduction:

1. Contract Review:
During the early stages of project initiation, Trina Storage conducts a quality review of the bidding and project agreements in accordance with Trina's contract evaluation process, and provide feedback.

2. Differentiation Identification for Project Introduction:
Once the project is confirmed, the commercial department schedules internal production based on the customer's delivery timeline. The system design department identifies key differences between the customer's project and the standard platform. The quality department organizes input from design, suppliers, incoming materials, and production to formulate control plans for these differences.

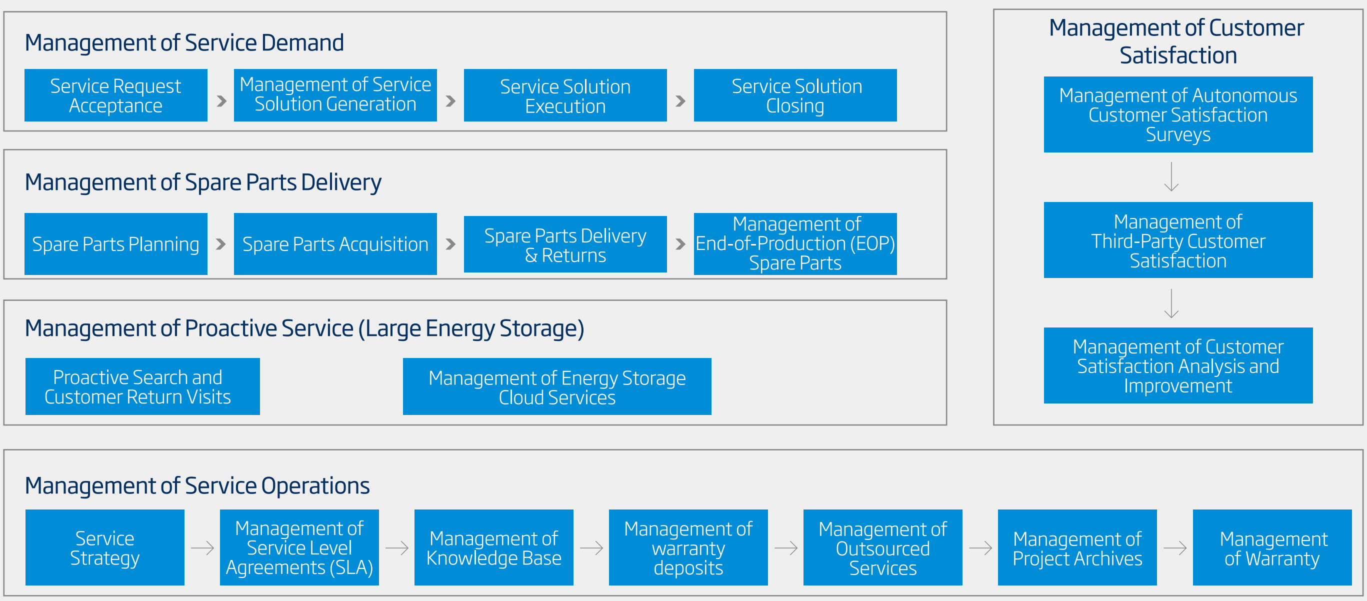
3. FAT:
Prior to shipment, products undergo inspection according to the FAT checklist, approved during the contract review.

4. On-site Issue Resolution:
Problems during installation are handled via a streamlined process, including on-site inspections and confirmation of issue resolution at the project site.



3.2.6 Customer Quality Management

Classification	First Response	On-site Arrival Time (if needed)	Solution Provided
Parts Consultation / Remote Support	2 days	/	/
General Complaints	1days	2 days	5 days
Customers with Special Needs	ccording to the sales contract	ccording to the sales contract	ccording to the sales contract
Critical Complaints	Immediate response	Decision made with customer	Expedited based on the situation



4 Trina Storage Safety Verification

With the rapid development of the industry, energy storage systems are becoming increasingly complex. To prevent potential safety function failures, Trina Storage adheres to IEC 61508 "Functional safety of electrical/electronic/programmable electronic safety-related systems". This standard governs the design, validation, and management processes at every stage of the product lifecycle, from both hardware and software perspectives, to ensure product safety and reliability.

4.1 Cell Safety Validation

Trina conducts rigorous "mechanical safety", "electrical safety", and "thermal safety" tests on cells. These tests ensure that the cells perform safely under various operating conditions, providing a secure foundation for their widespread use in different application scenarios.

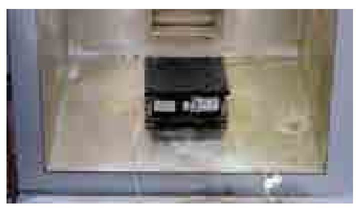
Overcharge thermal runaway performance test

Overcharge non-thermal runaway electrical performance test

Short circuit performance test

Impact test

Crush performance test



Spray test

4.2 Electrical Safety Verification

Ensuring insulation and voltage withstand capabilities is essential for the safe operation of energy storage systems. These tests help prevent potential electrical failures, prolong equipment lifespan, and protect personnel. Trina Storage performs insulation and voltage withstand tests across battery modules, clusters, cabinets, as well as electrical equipment and wiring. Additionally, to mitigate risks such as leakage, static electricity, and electric shocks, Trina Storage conducts grounding continuity tests on battery cabinets. These tests ensure that all conductive components are reliably connected to the grounding point and that the grounding system complies with safety standards, ensuring both user safety and proper equipment function.

4.3 Structural Safety Verification

4.3.1 IP Protection Level Testing

The IP protection rating consists of two digits, representing dustproof and waterproof capabilities, which are core indicators of the safety and reliability of energy storage systems. Trina Storage's battery cabinet has successfully passed the IP55 protection level test. Furthermore, the battery modules have achieved an IP67 or higher protection level, effectively resisting dust and moisture. This ensures that even in harsh working environments, the battery cabinet maintains excellent safety, reliability, and performance, creating added value for customers.

Figure 25 Battery compartment IPX5 waterproof product evaluation for IEC 60529 testing

Figure 26 Battery compartment IP5X dust test

4.3.2 Transportation Safety

Transportation safety is a crucial aspect of delivering energy storage systems. In China, energy storage systems are typically transported via freight trucks, with all equipment inside the container securely installed and fixed before transport. No special tooling is required during the journey. The container's bottom corners are fastened with straps to ensure structural stability, eliminating the risk of damage during transportation. Trina Storage has also verified transportation safety through vibration and road tests.

Figure 27 Battery Module Vibration Test (Photo credit: Trina Storage)

Trina Storage ensures that its energy storage systems comply with global transportation safety standards as well, including UN Recommendations on the Transport of Dangerous Goods, Part III: Lithium Batteries (UN38.3), the IMO International Maritime Dangerous Goods Code (IMDG CODE), and the Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR). Through rigorous testing, the energy storage systems have demonstrated their ability to withstand the challenges of sea transport, including salt spray, temperature and humidity fluctuations, and rough handling. Additionally, their design adheres to the requirements of the ADR for road transport, ensuring compliance with stringent safety protocols across Europe. These comprehensive measures guarantee the safe and reliable delivery of Trina Storage systems to global markets, safeguarding product integrity from the factory to the final destination.

4.3.3 Lifting Safety

Energy storage systems frequently involve lifting operations during transportation. If the structural rigidity and strength design are inadequate, it can lead to issues such as container deformation or difficulty in opening cabinet doors post-lifting. To prevent such problems, Trina Storage has conducted lifting tests on containers. By reinforcing the transverse and longitudinal stiffness with diagonal bracing, the system ensures smooth, stable lifting without tilting, while maintaining reliable structural strength, minimal elastic deformation, and no permanent distortion.

4.3.4 Seismic Resistance

In addition to basic structural safety, seismic resistance is a critical performance requirement. As a global product, Trina Storage rigorously verifies the seismic performance of its energy storage systems according to the standards of various overseas regions. The systems have passed seismic requirements in North America, Europe, and other regions, ensuring the structural safety of the system.

For domestic systems, Trina Storage also conducts seismic performance verification, adhering to the GB 50260 standard and other regulations. The systems are designed to withstand seismic events with up to an 8.0 magnitude intensity, allowing them to be deployed across various regions in China.

4.4 Thermal Runaway Safety Verification

a) Test Objective: The goal is to simulate a single-point failure within the battery system to observe whether thermal runaway propagation, ignition, or explosions occur inside the energy storage battery cabinet. This test is conducted to verify the safety and reliability of the battery cabinet;

b) Test Conditions: The test takes place outdoors at room temperature, using a heating method to simulate the failure of a single cell within the energy storage system;

c) Test Setup: The test is designed to closely replicate thermal conduction scenarios inside the battery cabinet, ensuring a high degree of realism;

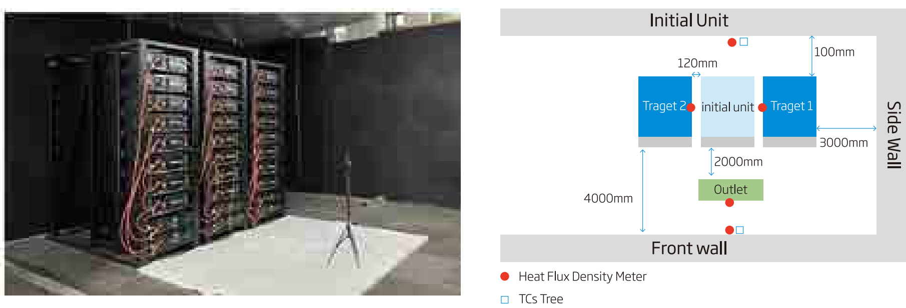
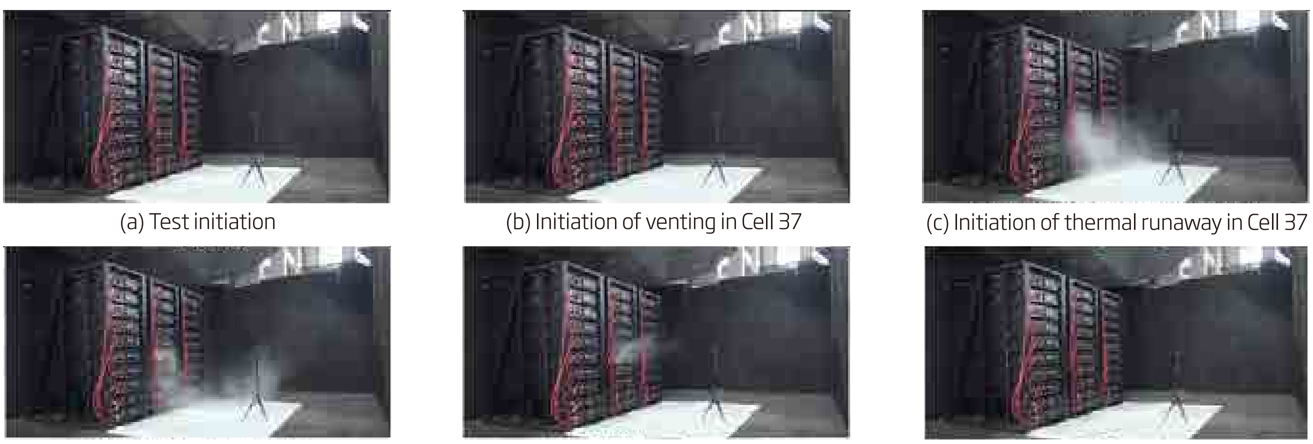


Figure 28 Schematic Diagram of Thermal Runaway Test Setup (Image Source: Trina Storage)

d) Test Performance: When thermal runaway occurs in a cell, the battery pack's pressure relief valve is triggered, successfully venting any explosive gases. The thermal runaway does not propagate further, and no incidents of sparking, ignition, or explosions were observed.

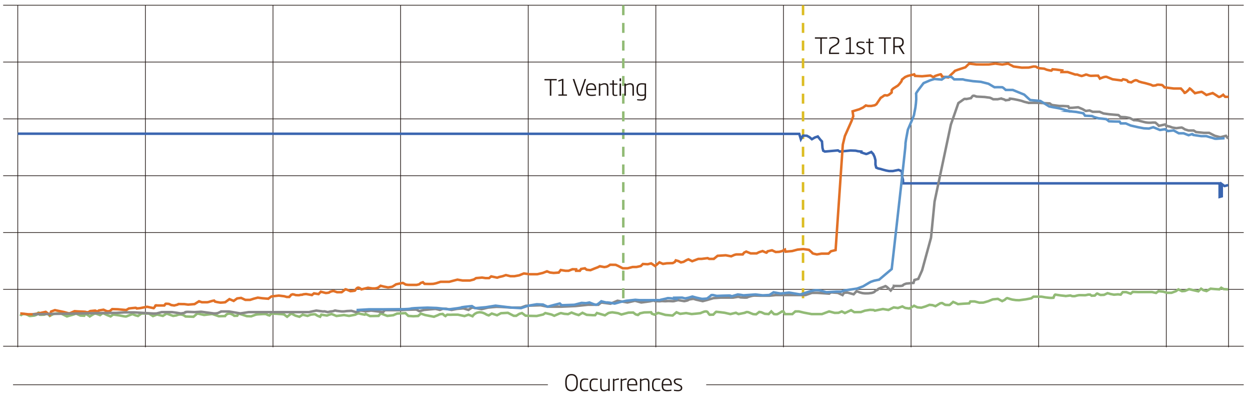


(a) Test initiation (b) Initiation of venting in Cell 37 (c) Initiation of thermal runaway in Cell 37

(d) Thermal runaway in Cell 38 (e) Thermal runaway in Cell 36 (f) Test conclusion

Figure 29 Thermal Runaway Test Process Illustration (Image Source: Trinastorage)

e) Temperature Data:



f) Test Results: Under the scenario of a single component failure at the system level, there are no incidents of fire, explosion, or large-scale thermal runaway propagation.

4.5 Fire Suppression System (FSS) Verification

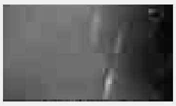
The fire protection system plays a critical role throughout the entire lifecycle of energy storage products, designed to protect lives and property.

It incorporates three key components: fire detection, alarm, and suppression. Given the numerous subcomponents and multi-device interactions, ensuring the overall reliability of the fire protection system is of utmost importance.

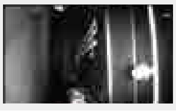
Trina Storage has developed a comprehensive range of tests for the fire protection system. By rigorously evaluating fire protection equipment and systems, potential safety hazards can be promptly identified and mitigated, significantly reducing the risk of fire incidents. The process begins with early detection and response, issuing fire alerts, and triggering connected equipment. Finally, through logical decisions, the fire suppression system is automatically activated. Trina Storage conducts these full-system linkage tests by simulating real fire scenarios for the most accurate assessment.

Additionally, Trina Storage recommends validating the reliability of fire protection designs through live fire testing. In these tests, battery modules are deliberately placed in a thermal runaway condition to trigger automatic fire suppression. By continuously monitoring the temperature inside the battery modules and cabinet, it is determined whether the fire protection system can effectively control and suppress thermal runaway.

Burn Cabinet Test



Monitoring at the upper end of the pressure relief valve



Smoke monitoring at the middle layer of the battery pack (Point 1)

When the pressure inside the PACK reaches the explosion-proof valve threshold, the valve

The active exhaust system engages, rapidly venting combustible gases and reducing their concentration

Heat flux meter readings indicate no impact on the surrounding area of the energy storage cabinet

The fire is fully extinguished with no risk of re-ignition.

4.6 Trina System Verification Platform

Trina Storage focuses not only on the research and development of key components such as battery products, system integration, software, and cloud platforms but also places great importance on laboratory validation to ensure the safety and reliability of its products.

The Energy Storage Product Testing Center of Jiangsu Trina Storage Co., Ltd. (hereinafter referred to as the Testing Center) upholds strict standards in both management systems and technical capabilities. It has established a robust laboratory management system, equipped with state-of-the-art testing equipment, and assembled a highly skilled technical team to guarantee the precision and reliability of test results.

Figure 30 Testing Center

The Testing Center offers comprehensive testing capabilities across the entire product chain, covering energy storage cells, battery modules, battery clusters, BMS, and battery cabinets. Its capabilities span a wide range of domestic and international standards, including GB/T 36276, GB/T 34131, IEC 62619, IEC 63056, and IEC 62477-1. This demonstrates the breadth and sophistication of its testing technologies, which have helped the center gain increased collaboration opportunities and a competitive edge in the global energy storage market.

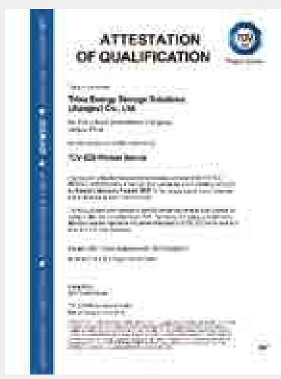
Cell → Battery Module → Battery Cluster → Battery Cabinet

Figure 31 Product Chain Testing Capabilities

In January 2023, the Testing Center received accreditation from the China National Accreditation Service for Conformity Assessment (CNAS). By June of the same year, it became the first energy storage witness laboratory accredited by the China Quality Certification Centre (CQC). In August, it earned recognition as the first TMP witness laboratory in the energy storage industry from TÜV SÜD, along with witness laboratory certification from Underwriters Laboratories (UL). These certifications signify that the Testing Center is fully qualified to provide energy storage product testing services that comply with international standards, ensuring comprehensive protection for its global clients.

CNAS Accreditation Certificate

CQC On-Site Testing Laboratory Certification



TÜV SÜD TMP Witness Test Laboratory Certification

UL Witness Test Laboratory Certification

Third-Party Organizations and Industry Experts' Perspectives

5

5.1 TÜV NORD Testing Supporting Energy Storage Safety

Approach to Safety Assessment of Energy Storage Systems

Hazard identification	Identifiable hazards in energy storage systems encompass a wide range, including electrical hazards, mechanical hazards, electromagnetic hazards, explosion hazards, electromagnetic compatibility (EMC) hazards, thermal hazards, fire hazards, chemical hazards, environmental hazards, and communication hazards...
↓ Risk Assessment	Bottom-up Risk Analysis Top-down Risk Analysis Combined Risk Analysis
↓ Validation and Testing	The primary methods for verifying the safety of energy storage systems include structural design inspections, simulations and modeling, type testing, and routine testing, among others.
↓ Documentation	Technical documentation, such as product manuals, plays a crucial role in enhancing the integrity of safety management processes and reducing risks during installation, maintenance, and operation.

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Dimensions of Safety Evaluation for Energy Storage Systems

Electrochemical Energy Storage Systems

Safety Indicators					Performance Indicators			Environmental Indicators		
Subsystem and Component Safety	Installation and Structural Safety	Firefighting Safety	Functional Safety	Transportation Safety	Key Parameters	Functional Verification	Grid-Connectivity	Energy Storage Performance	Battery Compatibility	Special Environmental

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Full Life Cycle Safety Management of Energy Storage Systems

R&D and Design
- 01 Application Scenario Analysis
- 02 Standards Compliance Review
- 03 Design Evaluation

Manufacturing
- 01 Pre-Production Factory Audit
- 02 Manufacturing Process Monitoring
- 03 Testing – Factory Witness / Third-Party Lab
- 04 Pre-Shipment Inspection

Key Stages in Product Safety Control

Deployment and Installation
- 01 Arrival Inspection
- 02 On-Site Evaluation
- 03 System Performance Evaluation

Operation and Maintenance
- 01 Regular Inspections
- 02 Troubleshooting

End-of-Life and Recycling
- 01 Compliance with Recycling Standards
- 02 Material Reutilization

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5.2 Quality Control and Product Testing Solutions

Implementing effective safety testing and management protocols can significantly mitigate potential risks and ensure the safe operation of energy storage systems. As a leading technical service provider, TUV NORD offers comprehensive global certification services, including CE, IEC, and CB system certifications. These services ensure that batteries and energy storage systems meet international safety and compliance standards, helping clients improve their products' global competitiveness and market acceptance.

Global Market Access Requirements for Energy Storage Products

Test Category	Europe (IEC System Countries)	North America	Australia	China
Safety	IEC62619 IEC63056	UL 1973 UL 2743 UL 9540 UL 9540A	AS IEC 62619 UL 1973	GB/T 36276
Performance	IEC 62620 IEC 62933-2-1	– –	– –	GB/T 18278
Safety Standards	IEC EN 62477-1 IEC EN 62040-1 IEC 62933-5-2 VDE-AR-E 2510-50	UL 1642 UL 2054	AS IEC 62040-1	GB/T 36558
EMC	IEC 61000-6-x series	FCC	IEC 61000-6-x series	GB/T 36558
Transportation		UN38.3 IMDG Code IATA Code		
Installation	VDE-AR-N 4105(Germany) PGS 37-1(Netherlands) NFC15-100(France) BS 61427(UK))	NFPA 70 NFPA 855	AS/NZS 3000 AS/NZS 3011	
Functional Safety	IEC 60730-1 IEC 61508	UL 991 UL 1998		GB/T 34131
Environment	RoHS REACH			

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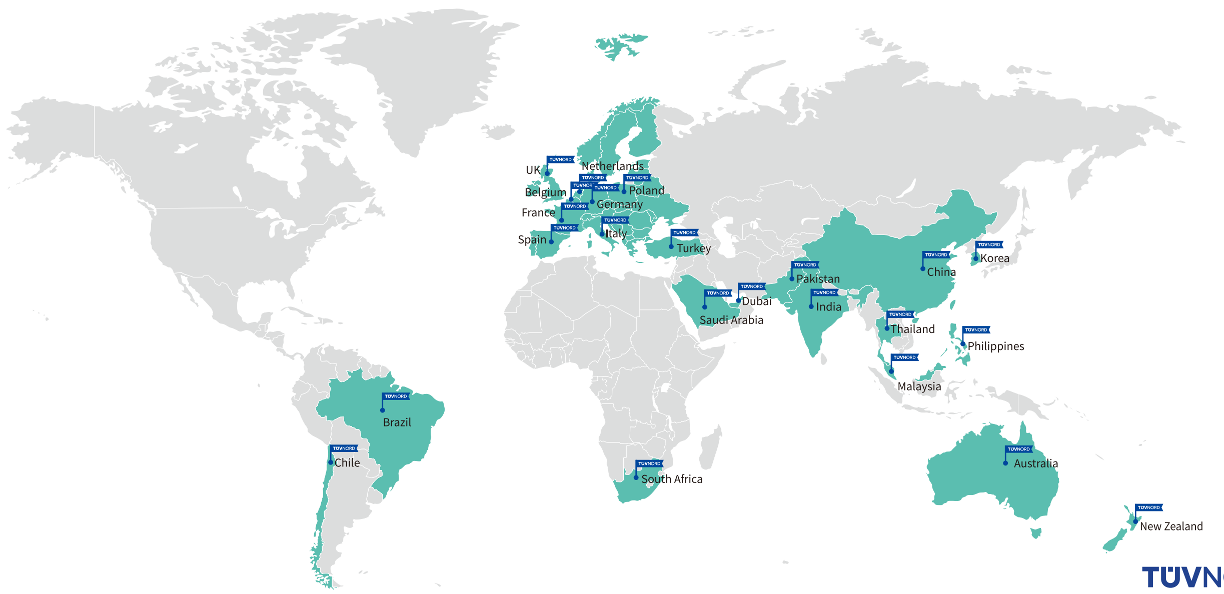
TÜV NORD's Global Energy Storage Market Access Services



In recent years, the trend of integrating electrochemical energy storage with new energy develops rapidly and it is common to transition from household energy storage to large-scale energy storage power stations. Currently, electrochemical energy storage systems are widely applied in generation side, grid-connected side and user side. Due to the complexity of its application scenarios, there are many challenges in design, operation and maintenance. Based on extensive experience in on-site inspection of the energy storage system and components, TÜV NORD can minimize the probability of operational failures during product delivery to the site or in use, and avoid connection failures, large capacity attenuation and damage during the transportation and installation. TÜV NORD offers one-stop solutions to ESS clients, from testing, inspection and certification, to feasibility & bankability evaluation, risk analysis and mitigation solutions, performance evaluation, project certification, and O&M support, which cover the entire project life cycle.

Pre-Sales Services

– Technical Services: Provide detailed interpretations of standards and regulations, helping customers navigate the specific requirements of their target markets; develop tailored compliance strategies and certification plans based on product characteristics.

– Training Services: Offer training on standards, certification process, and relevant personnel qualifications.

– R&D Support: Provide product design reviews services to ensure compliance with relevant standards. We also provide technical support and guidance in resolving R&D challenges.

In-Sales Services

– Testing Services: Provide testing for product safety, performance, and compliance with safety regulations.

– Inspection Services: Supervise production processes, conduct factory audits, and perform on-site witnessing.

– Certification Services: Provide certification services that align with global market access requirements.

After-Sales Services

– Follow-Up Services: Provide continuous certification support for product updates and iterations, ensuring customers stay informed about and responsive to evolving market regulations.

Comprehensive Standards Coverage

√ EU Certification

√ CB Mutual Recognition

√ North American Certifications

√ Australia Certification

√ Japan Certification

√ National Standards Certification

√ Market Listing

√ Battery Regulations

...

Comprehensive Product Coverage

√ Lithium-Ion Battery Cells

√ Mobile Energy Storage

√ Residential Energy Storage

√ Commercial and Industrial Energy Storage

√ Containerized Energy Storage

√ Energy Storage Power Stations

√ Charging Piles

√ Battery Management System

√ Energy Conversion System

√ Fire Safety System

...

Full Lifecycle Support

√ R&D Support

√ Factory Audits

√ Manufacturing Process Monitoring

√ Product testing

√ Pre-Shipment Inspection

√ Arrival Inspection

√ On-Site Evaluation

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Conclusion

6

Energy storage is a key enabling technology driving the energy transition, contributing to the creation of a clean, low-carbon, safe, and efficient energy system.

Against the backdrop of the global push for carbon neutrality, the energy storage industry has been experiencing rapid growth worldwide. As a cornerstone of the new energy sector, energy storage technology plays a crucial role. Its diverse applications and close integration with renewable energy provide powerful support in addressing the imbalance between energy supply and demand, improving energy efficiency, reducing reliance on traditional energy sources, and facilitating the sustainable development of energy. It holds pivotal strategic significance for stabilizing the power grid and enhancing overall energy efficiency. However, alongside the strong growth of energy storage technology, the increasing number of installations has brought a higher risk of accidents. Safety incidents in energy storage systems, particularly fires and explosions, have emerged as critical technical challenges that the industry must urgently address.

Safety is at the core of the new energy industry's development. This white paper emphasizes the importance of energy storage safety, exploring the essential aspects of safety design, safety analysis, and safety validation for these systems. It also delves into the safety challenges and solutions posed by the rapid advancement of energy storage technology. We hope that this white paper will help promote the healthy development of the energy storage industry.

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