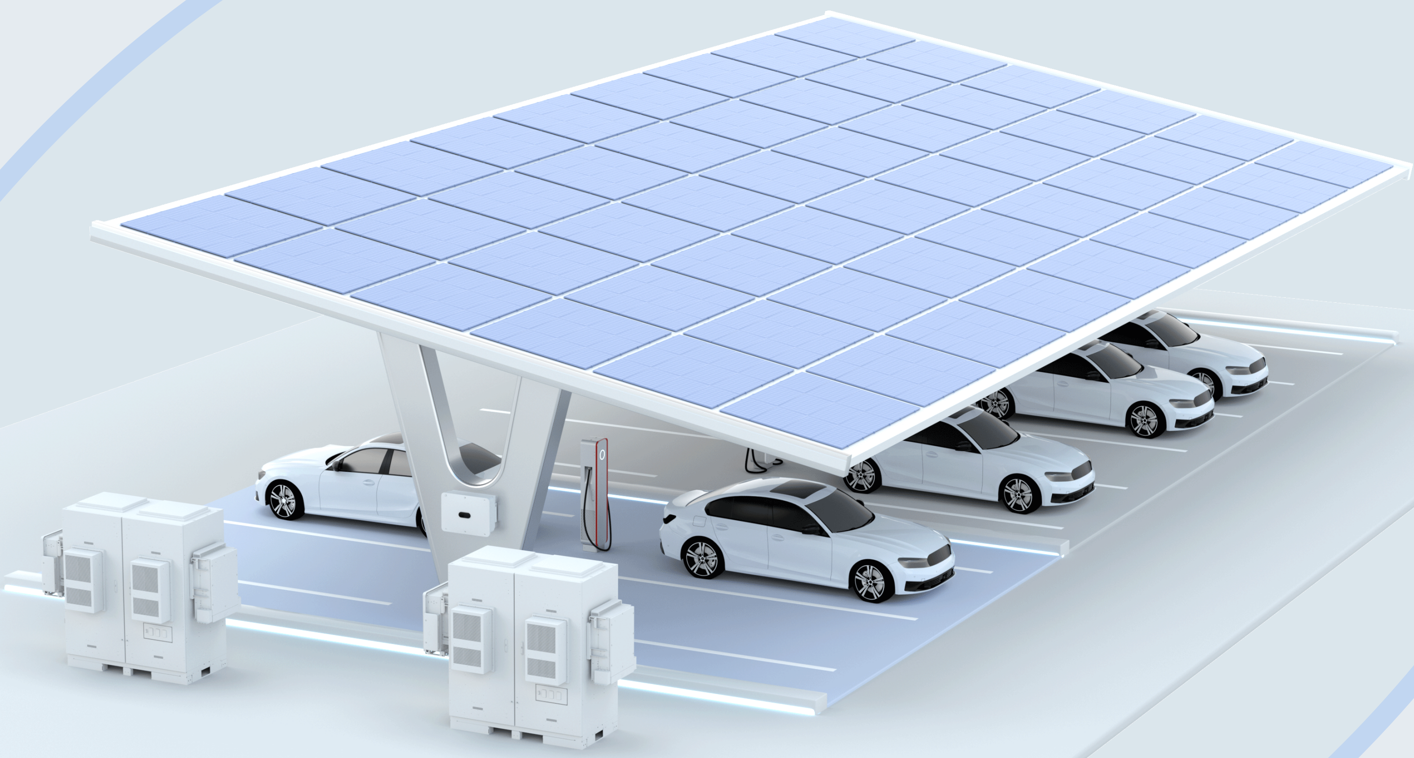
C&I ESS Safety White Paper



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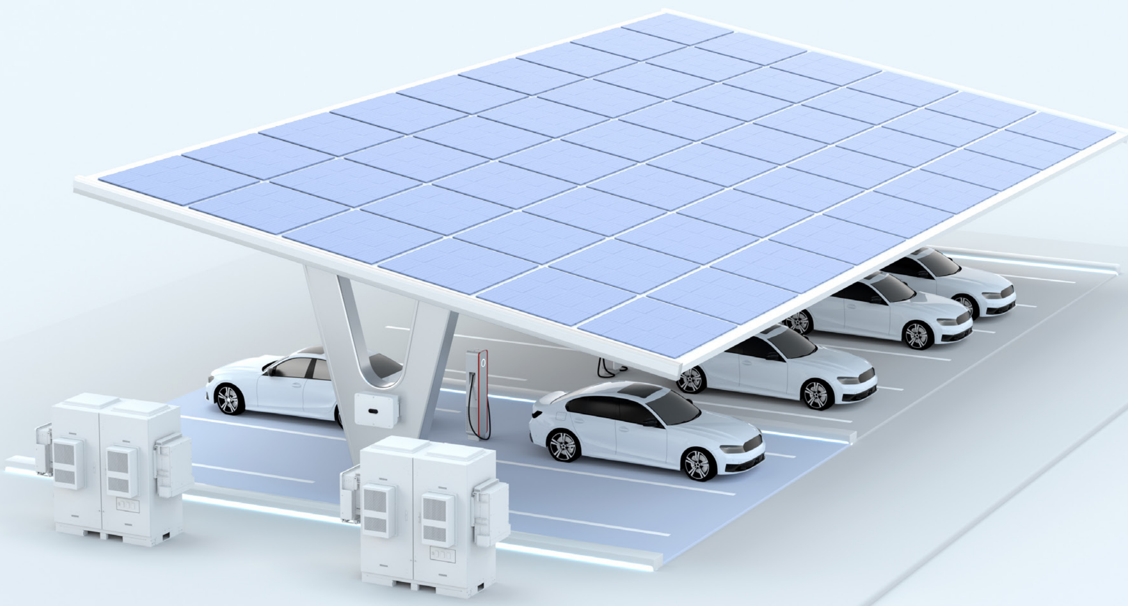
Precisely Right.

Introduction

As renewable energy technologies develop and become increasingly popular, battery energy storage technologies are widely used in fields such as power systems, transportation, and agriculture. Energy storage has become an important part of clean energy. Especially in commercial and industrial (C&I) scenarios, the application of energy storage systems (ESSs) has become an important means to improve energy self-sufficiency, reduce the electricity fees of enterprises, and ensure stable power supply.

However, the development and application of battery energy storage technologies pose safety challenges. Once an ESS safety accident occurs, the surrounding environment and personal safety will be seriously threatened. C&I ESSs are deployed in factories, hospitals, shopping malls, and campuses. Compared with traditional plant ESSs, C&I ESSs are used in more complex scenarios with more difficult fire fighting, and denser personnel and assets. Therefore, higher safety requirements are imposed on C&I ESSs. To address safety issues, C&I ESS safety solutions in the industry are gradually enhanced. However, it is still difficult to accurately identify risks before an accident occurs. In addition, the C&I ESS safety solutions have defects and limitations and cannot absolutely guarantee equipment, asset, and personal safety in extreme cases.

To help industry players better understand the safety design of C&I ESSs, Huawei and TÜV Rheinland jointly released the *C&I ESS Safety White Paper*. This white paper describes C&I ESS safety challenges and current status of develoopment of its safety solution. It also provides future-oriented innovative technology concepts and directions for industry reference.



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01 Necessity of C&I ESS Safety Design

Energy storage technologies can be applied to the power side, user side, and grid side. On the user side, ESS is mainly used with renewable energy systems such as PV systems to improve self-consumption rate, implement peak staggering, manage demand charges, and improve power supply reliability. C&I scenarios are important ESS application scenarios on the user side. Compared with a utility energy storage plant, C&I scenarios have higher and more unique requirements on device safety. The necessity of strengthening the safety of C&I ESSs comes from the following three aspects.

1.1 Dense Personnel and Assets, Resulting in Great Loss in Case of Accidents

C&I ESSs are deployed in factories, hospitals, shopping malls, and campuses where there are a lot of people and assets. An accident can cause serious economic losses and casualties. According to the investigation report of Beijing Emergency Management Bureau, an energy storage fire and explosion incident on the user side caused multiple casualties and a property loss of US$ 234 million.

Figure 1. Energy storage accidents can cause serious casualties and property losses

1.2
Complex Scenarios, Non-standard Site Selection, and Difficult Fire Suppression

Typical C&I scenarios include shopping malls, supermarkets, factories, and official parks. The scenarios and site types are complex. Due to this complexity, it is difficult for firefighters to access the equipment on fire although they usually arrive at the sites quickly. As a result, firefighters cannot effectively put out the fire. In addition, different from utility energy storage plant, C&I ESS is a relatively new field, and related design specifications and standards are still in an early stage. As a result, it is difficult to restrict the planning and design of the installation scenarios, which further increases the difficulty of fire extinguishing. Due to the lack of guidance, owners usually pay more attention to the use of idle land and economy during site selection, but lack consideration and design for subsequent accidents. Therefore, the safety ability of the equipment itself becomes particularly important.

Factory Logistics Supermarket

Figure 2. The typical installation scenarios for C&I ESSs, site types are complex

1.3
High Safety Concerns of Owners, Discouraging C&I ESS Deployment

Safety concern is a major factor that hinders the continuous growth of energy storage in C&I scenarios. According to a survey conducted by TÜV Rheinland, most owners regard "safety" a top concern about ESSs.

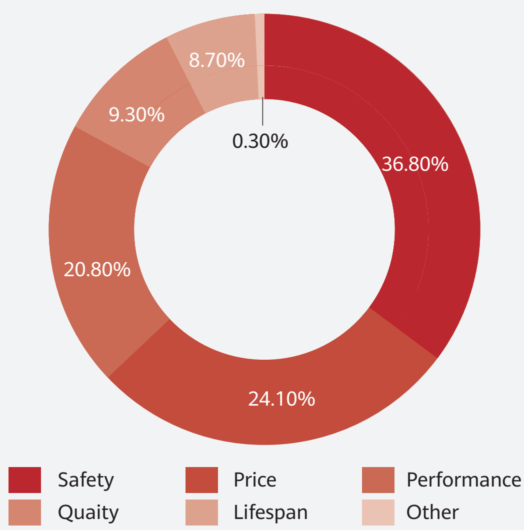


Figure 3. Key indicators of ESSs that owners are most concerned about (Source: TÜV Rheinland)

02 Challenges of C&I ESS Safety Design

The stages of a typical ESS failure path include risk source introduction, thermal runaway occurrence and spread, and ESS fire and explosion in extreme cases. Each phase corresponds to different safety technical challenges. To safeguard C&I ESS safety, the key is to address the following safety technical challenges and provide protection across the failure path.

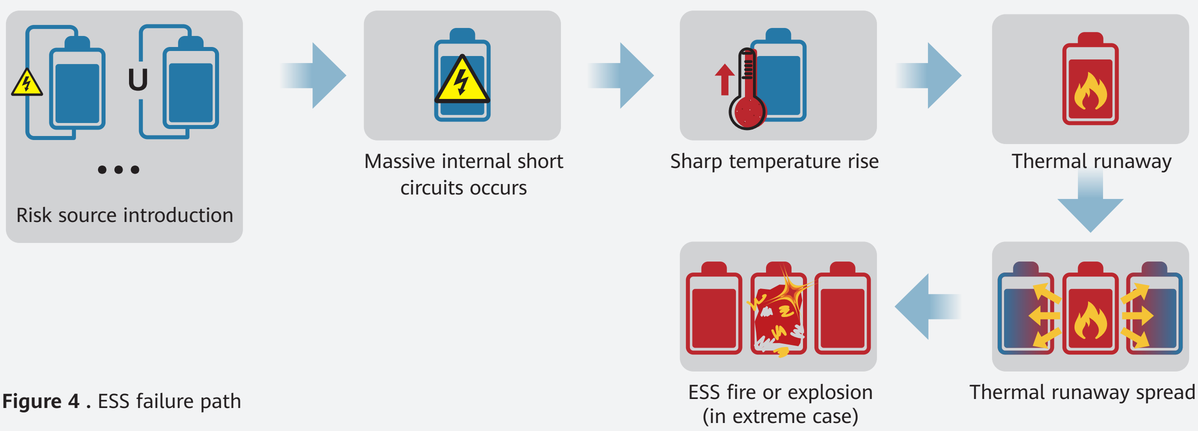


Figure 4 . ESS failure path

2.1 Battery Intrinsic Safety

The intrinsic safety of an ESS is directly related to its battery cell performance. The battery is still the core that determines ESS safety. Lithium batteries have many potential exothermic side reactions during the process of charging and discharging, making them unstable. ESS integrators need to impose higher requirements on battery materials, battery selection, and production techniques to enhance ESS safety from the source.

2.2
Early ESS Safety Management that Integrates Pre-warning

Based on the ESS failure path, safety management can be conducted in the early pre-warning phase and the fault and thermal runaway alarm phase. In the fault and thermal runaway alarm phase, the internal reaction of the ESS is formed, and the thermal runaway of the cell or pack is irreversible. In the early pre-warning phase, technologies such as real-time management of battery cells' running data, smart prediction of battery cell risks, and hierarchical fault pre-warning can be used to warn about thermal runaway in advance, saving time for O&M personnel and fundamentally preventing thermal runaway risks.

2.3
Comprehensive Risk Source Prevention Methods

There are many and complex factors that induce battery thermal runaway, including non-battery thermal risks, external and environmental risks, electrical risks, internal defects, and control failure risks. These factors can cause overheating and short circuits when an ESS is running, resulting in thermal runaway and fire. Different risk sources have different causes and therefore require different prevention methods. For example, electrical risks need to be prevented through multi-level measures of electrical isolation and system shutdown, and control failure risks need to be prevented through sampling exception detection algorithms. Therefore, a comprehensive multi-level safety design is required for ESSs to cover different risk sources and accurately identify risk factors.

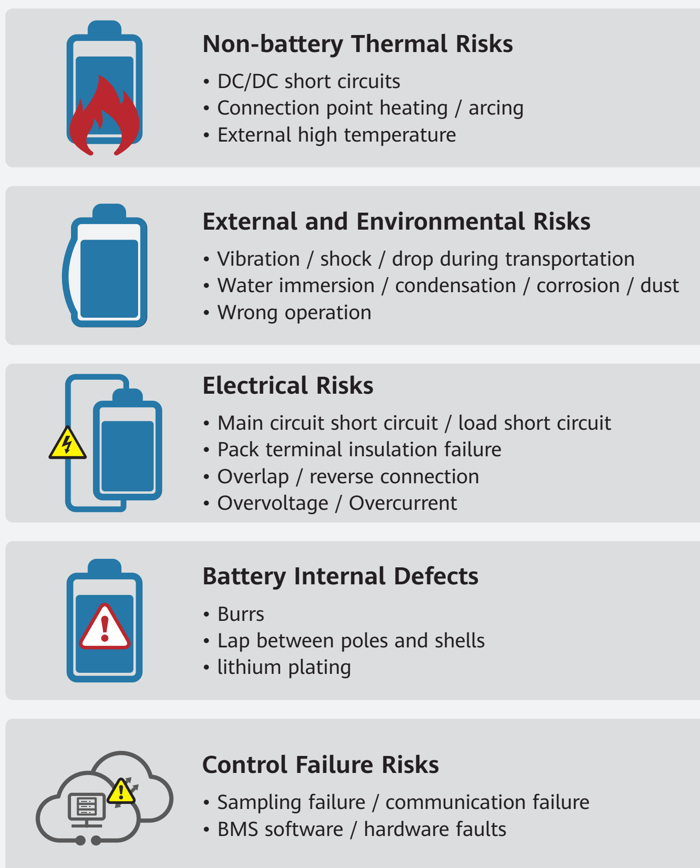


Figure 5. Complex risks of batteries

2.4
Quick Isolation of Thermal Runaway Spread

In an ESS, thermal runaway first occurs in a single battery cell. And it spreads to the battery pack and then to adjacent packs. It is difficult to stop thermal runaway once it starts and recover the caused loss. However, further loss can be minimized if the spread of thermal runaway can be quickly isolated. Therefore, a multi-level isolation design needs to be added to an ESS. When parameters such as the current, voltage, and temperature of some components are abnormal, the faulty components can be quickly shut down or isolated.

2.5
Fundamental Guarantee Capabilities for Personal Safety in Extreme Cases

Personal safety is critical. In extreme cases where an ESS explosion occurs, employees who are performing maintenance and routine inspection nearby may get injured. If an ESS explodes, the door may be blown out, the shell may disintegrate, and the air conditioner on the top may be blown out, which directly poses safety threats to O&M personnel and firefighters around the ESS. The shock wave caused by the explosion will create secondary hazards such as window shattering of surrounding facilities, bringing more personal safety risks to personnel in surrounding facilities.

According to public information in the industry, we summarized major fire and explosion accidents in global energy storage projects from 2018 to 2023. In the past five years, 55 energy storage safety accidents have occurred, among which six were explosion accidents. Explosions in Fengtai, Beijing and Arizona, US caused casualties.

Figure 6. An explosion causes threats such as shell disintegration and door panel blown out

No.	Time	Country	Location	Fault Severity
1	2019.04	US	Arizona	Explosion; eight people injured
2	2020.09	UK	Liverpool	Explosion
3	2021.04	South Korea	Chungnam	Explosion
4	2021.04	China	Beijing	Explosion; three people died
5	2022.03	Germany	\	Explosion; roof blown off
6	2022.05	Germany	\	Explosion; doors and windows destroyed

Figure 7. Reference cabinet not affected (Source: CEEIA)

03 FusionSolar C&I ESS Safety Solution

3.1 C&I ESS Safety Design Concept: Active Safety for Device, Asset, and Personnel

Based on its deep understanding of ESS safety, Huawei proposes C&I ESS active safety solutions in three dimensions: Device safety, Asset safety, and Personal safety, covering the entire ESS failure path.

Device safety

The device safety design includes battery cell safety, Real-Time Management of Cell Parameters, safety pre-warning, power terminal temperature detection, and multi-linkage isolation and shutdown. The design ensures stable running of ESSs in four phases: the source (battery cells), status management, accident pre-warning, and fault isolation.

Asset safety

The asset safety design includes the safety of PV+ESS systems and the safety of surrounding buildings and materials. Huawei C&I ESSs use multi-linkage active fire suppression systems to mitigate thermal runaway spread and fire risks and reduce asset loss in case of accidents.

Personal safety

The personal safety design is the safety redline in C&I scenarios. Huawei C&I ESSs support top explosion venting and can generate audible and visual alarms to protect personnel, especially O&M personnel around the ESSs, in extreme cases.

3.2 Device Safety Design, Ensuring Stable Operation

3.2.1 | Cell Safety-Strict Access & Mass Production Standards

The intrinsic safety of an ESS is directly related to its battery cells. The battery is still the core that determines ESS safety. Low-quality cells are prone to internal defects, such as scraps, burrs, and lap between poles and shells.

The selection of cells mainly includes two phases: cell access and mass production. Huawei controls ESS safety from the source through strict cell access tests and mass production management standards. In the cell access phase, Huawei conducts more than 100 tests on candidate cells to fully cover global certification standards. The cell cycle test takes more than 10 months to fully evaluate the cell performance. The crush test and nail penetration test are conducted to evaluate the safety performance of cells in harsh working conditions and unexpected faults. In the mass production phase, Huawei provides onsite control standards (CTQ* or CTS*) of more than 200 articles for suppliers to ensure cell safety in manufacturing processes.

Cell Selection Process	Huawei	Traditional
Cell access tests	• **24** safety tests, **20** long-term electrical performance tests, **25** short-term electrical performance tests, and **37** white-box tests, fully covering global certification standards • Cell cycle test lasting for more than **10 months** to fully evaluate the performance	• Basically no tests. Cells are accessed based on the specifications and warranty of vendors • No strict requirements on cell specifications, with delivery as the main focus
Cell mass production management	• Onsite control standards (CTQ* or CTS*) of more than 200 articles to continuously improve production quality • Key process data sent back (required CPK of key processes: higher than **1.33**; yield rate: higher than **90%**)	• Production quality not controlled

Figure 8. Huawei strictly controls cell safety and leads the industry in terms of access and mass production

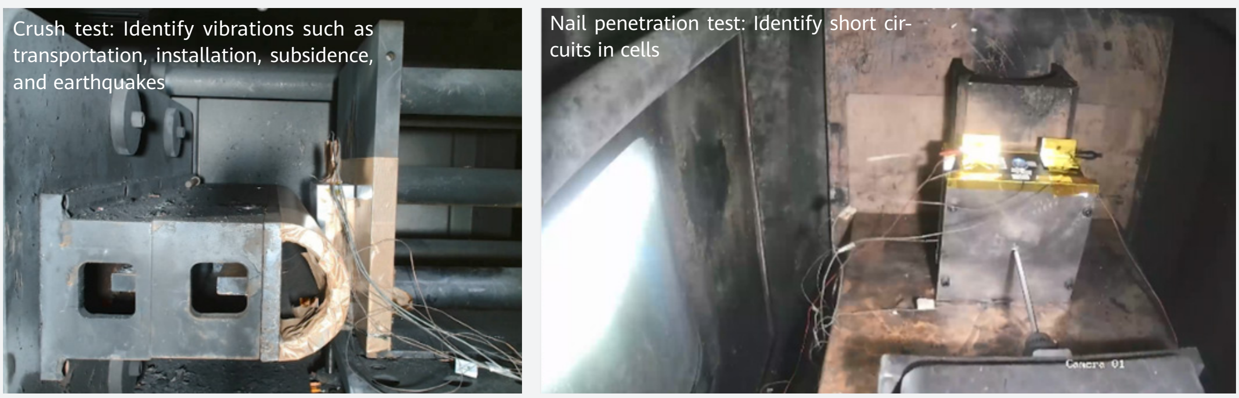


Figure 9. Multiple cell tests during the access

*Critical to quality: key characteristics of a component that has a fatal impact on important quality attributes such as performance, skills, and safety
*Critical to safety

3.2.2 | Real-Time Management of Cell Parameters

Cell status management is the core of battery management. Multiple standards have raised requirements for this capability. An ESS must be able to obtain key parameters such as the voltage, current, and temperature of each cell in real time and transmit the data to the management system in real time for analysis and processing through management devices.

Equipped with multiple types of sensors in battery packs, Huawei C&I ESSs can manage key parameters such as the cell voltage, current, and temperature in real time, accurately estimate cell SOC and SOH based on the preceding data, and continuously manage the ESS safety status to identify potential risks. In addition, the management platform visualizes key data, effectively improving users' awareness of the running status and safety status of the ESSs.

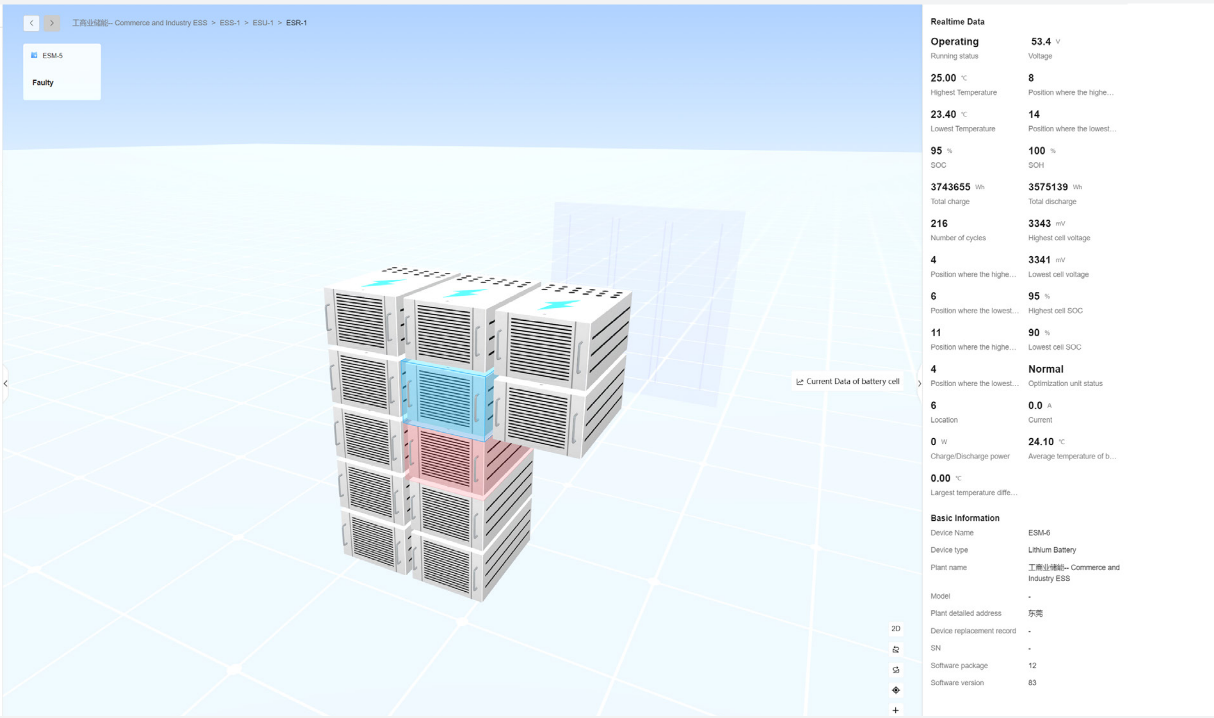


Figure 10. Real-time running data of a battery pack

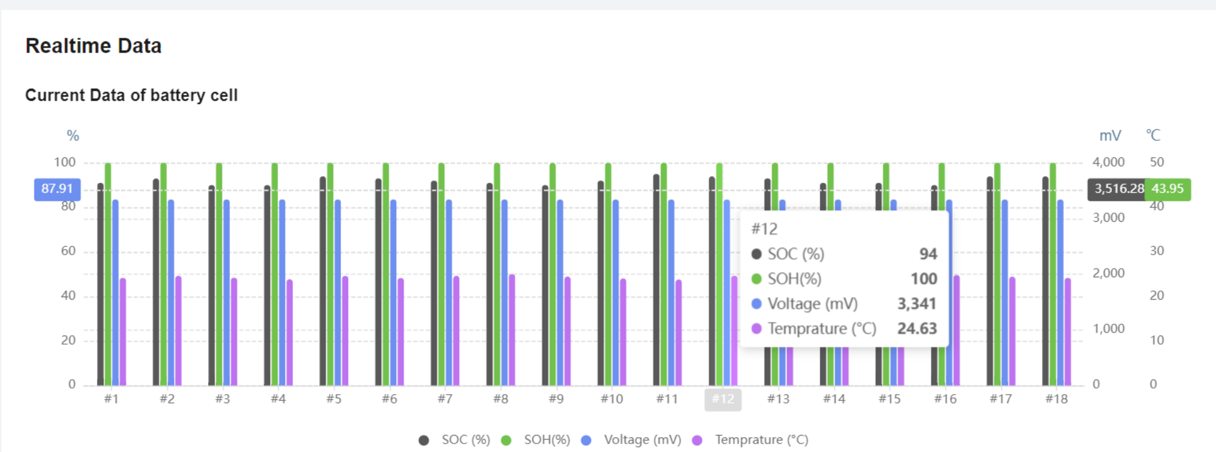


Figure 11. Real-time running data of cells in the battery pack shown in the preceding figure

3.2.3 | Smart Safety Pre-warning

Smart Safety Pre-warning is used to identify gradual failures. Across the failure path, the pre-warning function can identify potential faults. For example, if cell inconsistency is identified, short circuits of a large number of cells can be prevented in a timely manner.

The ESS reports data every 10 seconds. Based on this real-time data, mechanism condition model, and a large amount of live-network battery pack data, Huawei's safety pre-warning can detect internal and external short circuits caused by foreign objects in cells and external contact, and detect battery impedance inconsistency caused by loose bolts in a timely manner. The pre-warning function generates warnings about thermal runaway 24 hours before it occurs to ensure ESS safety. In addition, the system uses the sampling exception detection algorithm to identify voltage and temperature sampling exceptions caused by BMS board, NTC sensor, and communication link failures, ensuring warning accuracy and reducing O&M loss caused by false positives.

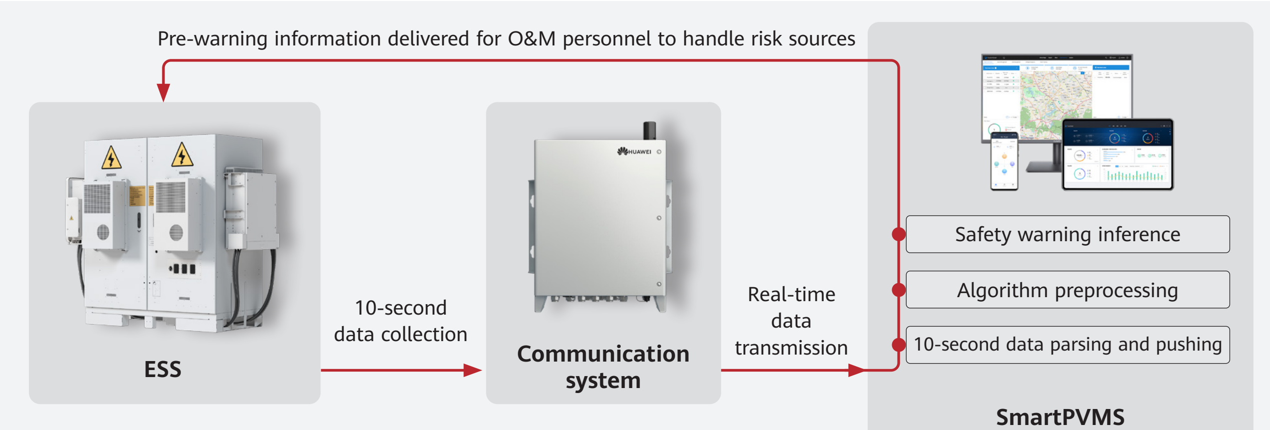


Figure 12. Implementation process of safety pre-warning function

*Expected delivery time is 2023 H2

3.2.4 | Multi-Level Power Terminal Temperature Detection

An ESS has complex structure. When it is running, electrical energy flows to other components through power distribution components such as cables and junction boxes. The connection points between cables and components are the weakest links in the entire process. Power terminals in an ESS are usually connected using copper terminals and bolts. This connection mode requires high-precision assembly. Unreliable connections can cause local overheating of cable harnesses and even lead to fire.

Therefore, Huawei adds NTC temperature detection circuits to power terminals of battery packs, rack controllers, and PCSs to identify terminal overtemperature in real time. Through the temperature detection circuits, the terminal temperature can be converted into electrical signals and the temperature change data is transmitted to the signal processor. Based on the electrical signal change, terminal overtemperature of devices at each level can be identified, and alarms can be sent to users to notify electrical risks such as loose connection of power cable wiring bolts in a timely manner, preventing thermal abuse.

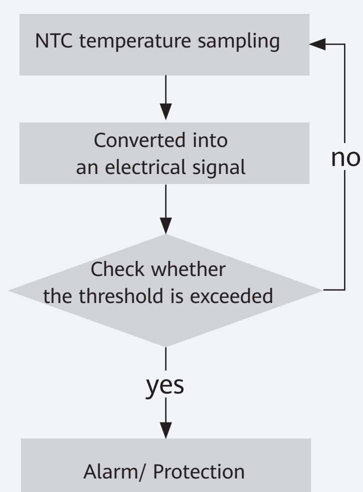


Figure 13. Implementation process of power terminal temperature detection

3.2.5 | Multi-Level Overcurrent Protection, Active Shutdown & Quick Isolation

To prevent thermal runaway spread at the system level, one important measure is to set up multiple isolation and shutdown mechanisms. When the current, voltage, or temperature of a circuit is abnormal, the circuit can be quickly and accurately disconnected. Traditional solutions usually use fuses, whose failure rate increases and reliability decreases over time. In addition, as the threshold is high, fuses cannot detect minor overcurrent and perform shutdown.

Huawei provides four levels of active shutdown and two levels of passive isolation for battery packs, battery racks, and the system to disconnect faulty internal circuits and avoid the spread of thermal runaway. The following figure shows the logical diagram of multi-level active isolation and shutdown of Huawei C&I ESSs.

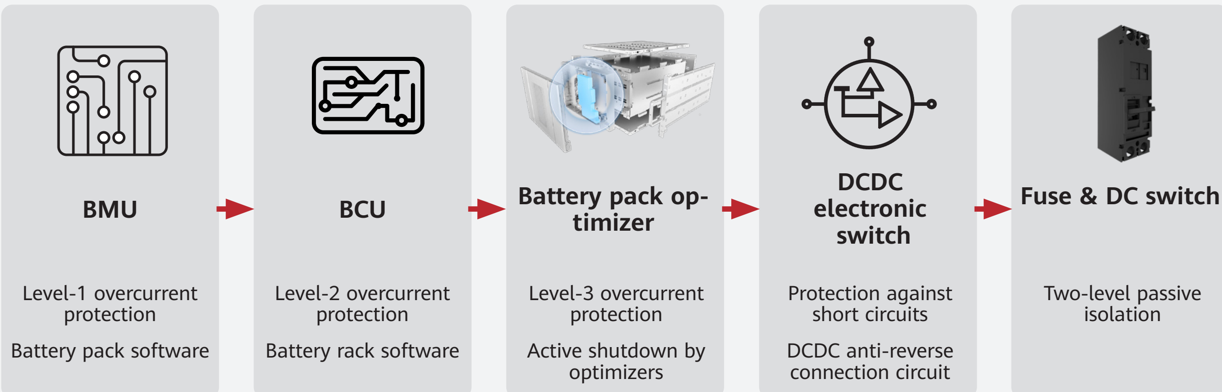


Figure 14. Working logic of multi-level active isolation and shutdown

At the battery pack level, Huawei uses the board BMS and energy optimizer to isolate the faulty pack by software and hardware. At the battery rack level, Huawei uses the BCU and rack controller electronic switch to implement active shutdown and isolation. At the system level, Huawei uses circuit breakers and fuses to implement passive isolation. In this way, protection against overcurrent is provided at different levels to quickly respond to faults and prevent faults from spreading.

3.3 Asset Safety Design, Reducing Loss Caused by ESS Failure

3.3.1 | Active Fire Suppression, Multiple Linkages for Early Involvement

Instead of the passive way of suppressing an open flame, the fire suppression system of an ESS should act when the cell valve is opened or thermal runaway occurs to reduce system loss. Huawei C&I ESSs use fire suppression systems that actively suppress fire in three dimensions: multiple sensors, timely exhaust, and early fire suppression, reducing faults and loss.

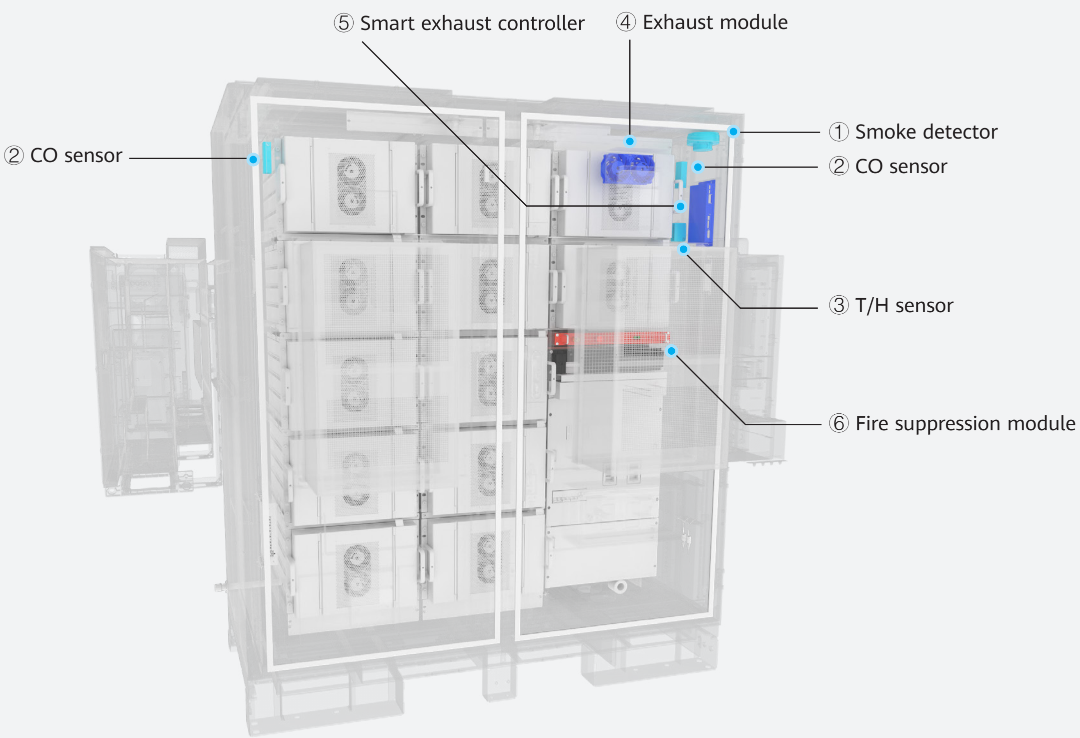


Figure 15. Active fire suppression system

1

Multiple Sensors

An ESS is equipped with multiple sensors, such as smoke detectors, temperature and humidity detectors, and CO detectors, to accurately detect the internal temperature and combustible gas concentration and detect the ambient environment in real time.

2

Active Exhaust System

The exhaust system is based on the combustible gas detection system. When detecting that the battery valve is opened and combustible gas is released, the exhaust module runs to reduce the combustible gas concentration in the battery compartment. During gas exhaust, the heat dissipation fan on the battery pack becomes an auxiliary power source, which can exhaust all combustible gas at the rear of the battery pack out of the cabinet. Compared with traditional solutions, the exhaust system with multiple power sources can effectively avoid problems such as obstructed air ducts between air intake and exhaust, high exhaust resistance, and blind spots for gas exhaust.

3

Active Fire Suppression Module

When detecting that the internal environment of the cabinet is abnormal, the active fire suppression module acts in advance to suppress thermal runaway by releasing inert gas that meets the concentration requirements for cooling. When detecting an open flame, the active fire suppression module acts in a timely manner to extinguish the open flame.

3.4 Personal Safety Design, Protecting Personnel Safety

3.4.1 | Top Explosion Venting

Traditional C&I ESSs are usually not equipped with pressure-relief or explosion-relief devices and lack of consideration and design for safety of surrounding personnel. In extreme cases, explosions can seriously threaten the safety of O&M personnel and firefighters.

Huawei C&I ESSs are equipped with top-mounted explosion vent panels that comply with the NFPA 68 standard, and adopt five-point door locks and innovative hook design on the front doors. When an uncontrolled explosion happens, the top explosion venting system can guide the pressure and fire inside the ESS upwards. This can prevent personal injury caused by cabinet disintegration, shock waves, and thermal radiation, and limiting the impact of fire and explosion within a small range around the ESS.

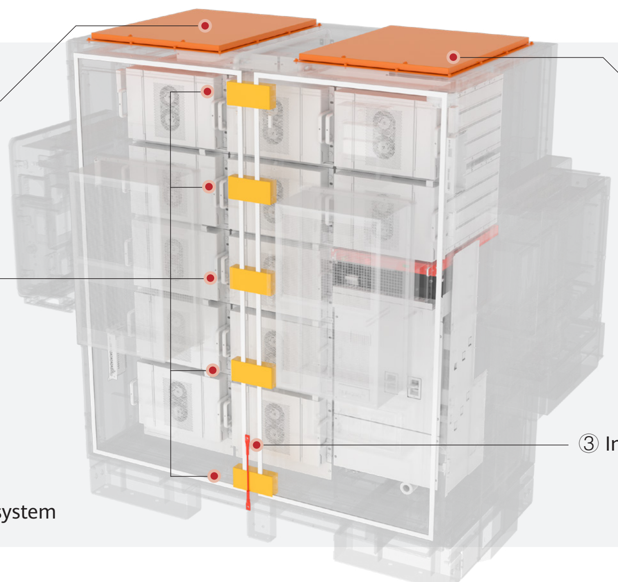


Figure 16. Top explosion venting system

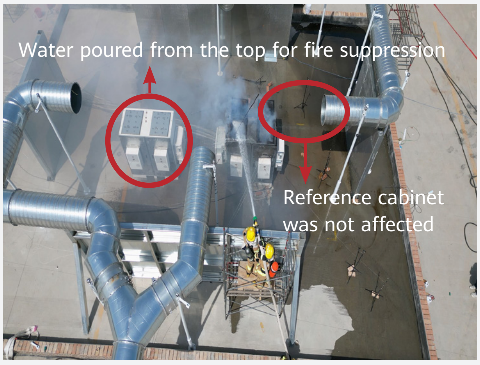
Personal safety is the redline in C&I scenarios. To accurately evaluate the performance of Huawei's top explosion venting, Huawei commissioned TÜV Rheinland to set up a verification team. In April 2023, the team performed tests to comprehensively evaluate the performance.

Context	On April 16, 2023, Huawei commissioned TÜV Rheinland to test the top explosion venting design of Huawei C&I ESSs at the National Hazardous Chemicals Emergency Rescue Base in Puyang, Henan to verify the safety capability of the design.
Test Method	The thermal runaway was triggered by overcharge of a single battery pack . When the thermal runaway spread to cells and after a certain period of time, ignition was performed to trigger explosion. A reference cabinet was placed near the tested cabinet according to the ESS layout requirements. Multiple observation methods, such as internal cameras, external box cameras, high-speed cameras, drones, and infrared thermal imager, were used to check whether the top explosion venting design can protect surrounding facilities and personnel.

Figure 17. Multiple observation devices used to accurately capture test results
Left: test site layout; **Right:** tested cabinet

Test Result

The test results met the expectation. The Explosion vent panels on the top of the tested cabinet was completely opened, and water could be directly poured from the top to avoid burning. The reference cabinet was not affected by the explosion and kept safe in its position.



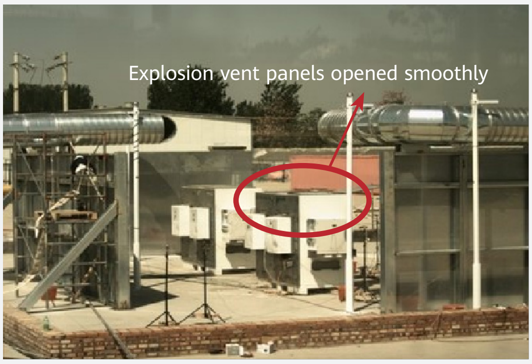


Figure 18. The test result is good, with the surrounding environment well protected
Left: image captured by a drone; **Right:** image captured by a high-speed camera

Based on the technical evaluation and actual test results of TÜV Rheinland, Huawei's top explosion venting technology is advanced and reliable and can ensure the safety of O&M personnel.

04 Summary and Prospects

Continuous deployment of C&I ESSs is a key to achieve green and low-carbon transformation. In this process, safety is undoubtedly an important prerequisite and basic requirement. As the C&I ESSs are booming, it is an urgent task to improve the safety design to safeguard their wide application. In the current and future exploration, Huawei is committed to systematic safety design for C&I ESSs in three dimensions: device, asset, and personal. Huawei uses industry-leading safety protection technologies to cope with complex ESS safety challenges in scenarios and provide more reliable solutions for property owners.

Continuous exploration is indispensable for building a better C&I ESS. Huawei will work with the industry to provide safer and more reliable ESS products and make green electricity available to every industries and business.

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