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PowerTitan Energy Storage System

White Paper

February 2023

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Preface

To achieve the great vision of carbon neutrality, clean energy will become one of the top low-carbon energy resources. With the increasing application of new energy systems, the power grid must be more flexible and stable to meet the increasing power demand of new energy systems connected to the grid. As an important regulator, energy storage facilities can effectively reduce the spatial and temporal mismatch between the new energy output and the grid power load, fully use and consume the new energy output; thereby ensuring the safe power supply, improving the operation efficiency of the power system, and supporting high-quality new energy development.

It has become one of the key issues in the energy storage industry to improve the overall performance and efficiency of the energy storage system, such that it can better play its important role in energy transfer, matching and optimization in the new energy system.

This white paper aims to analyze the value of electrochemical energy storage systems in new energy power grids and provide feasible reference solutions for the industry by studying innovative applications of new energy storage systems to facilitate the high-quality development of clean energy.

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CONTENTS

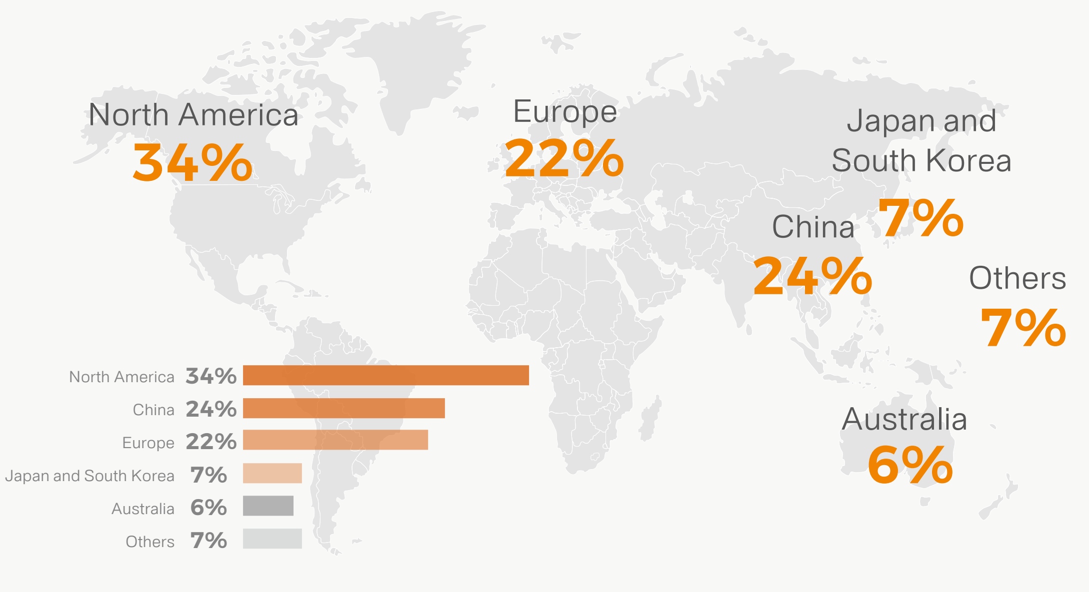
01 Research Background

1.1 Development Prospects of Electrochemical Energy Storage

With the global popularization and application of power generation with renewable energy resources and the rapid development of smart power grid, the global energy storage industry has also entered a rapid development era. By the end of 2021, the cumulative global installed capacity of energy storage projects in operation had reached 209.4 GWh, a year-over-year increase of 9%. The installed capacity of lithium-ion battery projects has reached 25.4 GWh, a year-over-year increase of 67.7%. This indicates that lithium-ion battery projects dominate the new energy market, with a market share of over 90%. Among new energy applications, the lithium-ion battery develops the fastest and has the best industrial foundation, other than pumped-storage applications.

Despite the COVID-19 pandemic global effects, since 2020, both the energy storage industry and installed capacity thereof have risen against this adverse situation. With respect to the increased capacity of electrochemical energy storage projects in service, increases in China, North America, and Europe are 24%, 34%, and 22% respectively, leading the large-scale development of the global energy storage market.

Regional Increase of Global Installed Capacity of Electrochemical Energy Storage System in 2021



*Source: China Energy Storage Alliance (CNESA)

Compared with pumped energy storage, electrochemical energy storage has greater advantages in response speed, site selection conditions, environmental impact, and construction period, and has more abundant and flexible application scenarios, including the following aspects.

Power Generation

Power generation in terms of renewable energy resources such as wind and solar power can be intermittent and uncertain, and connection of large renewable energy into the grid is likely to have an impact on the grid, making it unable to fully meet the power grid schedule. The energy storage system stabilizes active power fluctuations, reduce the difficulty of scheduling renewable energy units by the grid, and improve the utilization rate of renewable energy power generation. After the power grid system fails, the thermal power unit cannot start. As such, the energy storage system can also be used as a black start power supply to assist the power recovery of the entire system if and when the grid collapses.

The Grid

For real-time fluctuations in power supply and load and periodic changes in load, the energy storage system can respond to the grid's frequency modulation and peak shaving and other auxiliary service needs, increase the system's reserve capacity, and maintain the stability of the power system voltage and frequency.

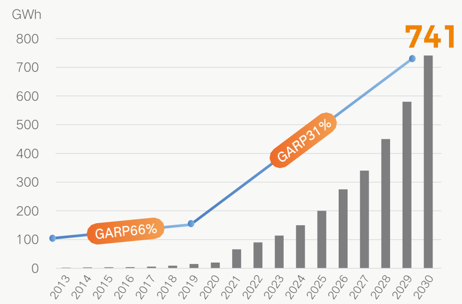
The User

In the micro-grid application with distributed energy units, the energy storage system can adjust the output power of the power supply, solve the voltage fluctuations, perform harmonic control, improve the stability of the power grid, and improve the power quality. It is also possible to use the peak-valley electricity price difference to conduct peak-valley electricity price arbitrage, as the business model is becoming more and more mature.

1.2 Development Trend of Electrochemical Energy Storage

The research firm Wood Mackenzie forecasts that the global installed capacity of electrochemical energy storage will hit a record high. By 2030, the installed capacity of electrochemical energy storage projects worldwide will reach 741 GWh. Market demand is always the biggest driving force for technology development. With the gradual maturity of existing application scenarios and the continuous emergence of innovative and composite application scenarios, the electrochemical energy storage technology shows the following development trends.

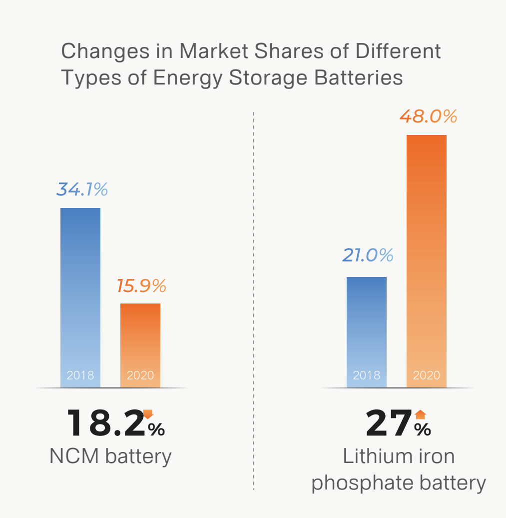
Cumulative Installed Capacity and Forecast of Electrochemical Energy Storage Systems



A. Continuous Optimization and Innovation of Battery Technology

There are many battery cell technology routes suitable for energy storage applications. Currently, lithium-ion batteries have an absolute leading market share, and key materials such as cathodes account for the main cost of batteries. In the future, the industry will see further reduced costs due to material and process improvements, new products with high power/energy density, and further improved battery life and cycle efficiency.

In addition to improving the performance of the battery itself, it is also necessary to break through the physical boundaries of the batteries and the upper limit of battery performance through innovative empowerment, systematic integration, and refined management of the energy storage system.



B. More Integrated Systems

The footprint and applicable scenarios of energy storage systems are determined by the power and energy characteristics. The development trend of the new energy industry has stimulated the huge potential of large-scale application of energy storage systems, and the integration scale of energy storage systems has continuously exceeded the upper limit. Power units at all levels such battery packs and racks in the energy storage system will be further modularized and compacted, further improving the degree of integration and systematization of the main components of the energy storage system, and the refined management of each unit’s energy and temperature control.

02 Research Background

The electrochemical energy storage industry has also ebbed and flowed. There are still many restrictive factors, including the key restrictive factors such as system cost, efficiency, and safety.

2.1 System Efficiency

Although the electrochemical energy storage industry has developed rapidly in recent years, for investors, the slow decline in the levelized cost of energy (LCOE) is still one of the important reasons hindering the rapid development of the industry.

To reduce the LCOE of the energy storage life cycle, costs in the initial investment stage need to be reduced, and it also helps to optimize efficiency in the usage, prolong the life cycle, and reduce operation and maintenance costs.

$$\text{LCOE}\left[\frac{\$}{\text{MWh}}\right]=\frac{\text{Investment cost}+\sum_{n}^{N}\frac{\text{O\&M cost}}{(1+r)^{n}}+\sum_{n}^{N}\frac{\text{Charging cost}}{(1+r)^{n}}+\frac{\text{End-of-life cost}}{(1+r)^{N+1}}}{\sum_{n}^{N}\frac{\text{ElecDischarged}}{(1+r)^{n}}}$$

*Note: N — Current year n — End of life cycle r — Discount rate

A. Energy Efficiency

During the charging and discharging process of the battery, the internal resistance of the battery and the chemical reaction cause energy loss, and the difference in the consistency of the battery leads to a low conversion efficiency of the series/parallel battery packs. This difference in consistency includes not only unavoidable inconsistency in voltage and capacity, but also the attenuation caused by inconsistency in temperature, current, and voltage during use. As the integration of the energy storage system increases, the number and levels of battery series and parallel connections increase, and the energy conversion efficiency further decreases. With respect to economy of energy storage systems, it is important to improve the level of refined battery management, improve capacity mismatch, reduce system loss, and improve conversion efficiency.

B. System Life

To reduce the LCOE of the energy storage system, it is important to ensure that the battery has a high cycle life. As the temperature of the battery itself and the ambient temperature are closely related to the battery life, unsuitable temperatures will accelerate the attenuation of battery life and performance.

In a test, battery packs of the same batch with the same capacity were placed in a constant 25°C, 20°C, and 15°C environment and four charge-discharge cycles were performed. The test results show that within a certain temperature range, the capacity and power of the battery pack decrease with temperature. Compared with 25℃, the test result of 15℃ proved that the battery capacity decreased by about 6%, and the power decreased by about 6.5%.

However, in a test, the temperature of two battery packs made in the same batch that are connected in series were set to (25°C, 25°C) and (15°C, 25°C) respectively and four cycles of charge and discharge were performed. The test result showed that, compared with the zero-temperature difference, the capacity and power of the battery pack both decreased by about 5% when the temperature difference was 10°C.

*Note: The test was designed based on specific working conditions to verify the effect of temperature difference on the discharge capacity, and the test data is not representative of all working conditions.

Due to the difference in batteries, the overall life of the series system is constrained by the battery cell with the worst performance, and the unfavorable effect of temperature difference further degrades the cycle life of the overall system.

C. Operation and Maintenance Costs

To reduce LCOE, in addition to reducing initial investment costs, it is also necessary to consider how to reduce installation costs, operation and maintenance costs, and auxiliary power losses during long-term operation. Currently, components such as the Battery Management System (BMS), Energy Management System (EMS), and Power Conversion System (PCS) of energy storage systems in the industry are supplied by different companies, generating problems such as difficult on-site installation, long system commissioning cycle, poor operation adaptability, frequent on-site operation and maintenance, and difficulty in defining responsibilities in the later stage, thereby impacting the LCOE of the energy storage system. In addition, the auxiliary power consumption of the energy storage system is mostly supplied by external power supplies, and the loss of auxiliary power in the entire life cycle will directly affect the income of the energy storage power plant. Therefore, building an energy storage system solution with high integration, easy installation, simplified operation and maintenance, and low auxiliary power loss will become one of the development directions of the industry.

2.2 System Safety

The rapid development of the energy storage industry has brought about explosive growth in market demand, and there are many market entrants, many of which are weaker in power electronics and energy storage technology. The electrochemical energy storage system is mainly composed of battery PACK, BMS, EMS, PCS, and other electrical devices. The low integration of energy storage systems, inconsistent design standards and quality control, lack of experience in managing energy storage systems throughout the life cycle, and improper understanding and implementation of standards have led to frequent occurrence of energy storage safety accidents in the industry.

A. Electrical Safety

In the energy storage system, an integration of power electronics and electrochemistry technologies, deterioration of some batteries that cannot be warned in time may cause battery failures. To ensure that the energy storage facilities can deal with failures such as short circuits, arcing, and arc flashes, and build system-level energy security protection, not only do the electrochemical processing capabilities need to be further improved, but also a deep understanding of power electronics is required, which constitue an important part of the power system.

B. Fire Safety

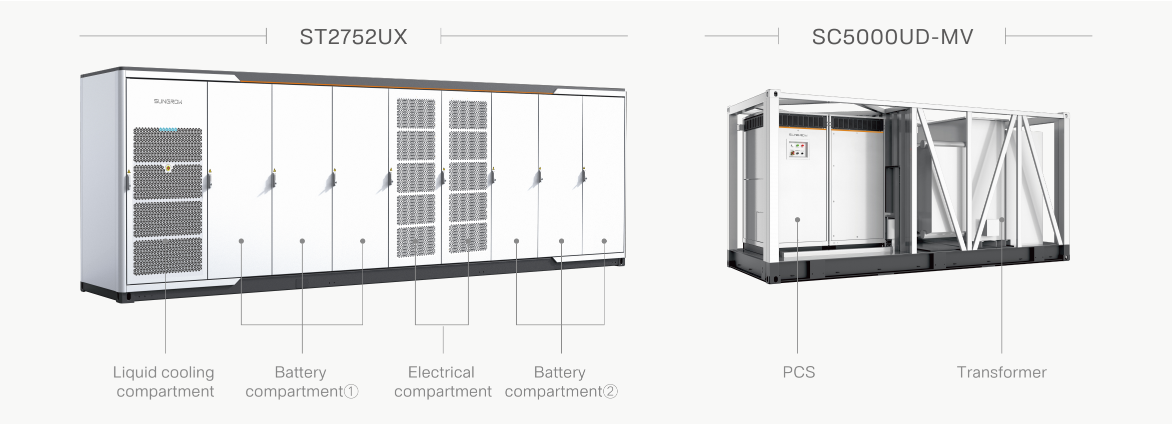
Large energy storage terminals are mostly prefabricated compartment products. It imposes a test for the comprehensive strength of energy storage manufacturers to ensure that energy storage terminals can accurately identify fires, effectively suppress thermal runaway, and build safer energy storage systems through integrated combustible gas detection, pressure relief, ventilation, and anti-explosion measures.

The safety design of each component of the energy storage system and the overall system has become the cornerstone of the long-term and healthy development of the energy storage industry.

03 ⁄ The PowerTitan Energy Storage System Solution

3.1 Design Schemes

Based on over 25 years of power electronic conversion technology, SUNGROW has innovatively integrated electrochemistry, power electronics, and power grid support technologies, and developed a new generation of liquid-cooled energy storage systems featuring professional integrations. Through the integrated design of one set of products, one data system, one control system, and one link logic, the system works holistically. It can shorten the distance between electrochemistry and the power grid, and effectively links the units in the system, thereby supporting the three key requirements of safety, efficiency, and grid-connection. Through the patented flow channel design scheme, it can provide a balanced temperature in the system battery packs and battery cells. In addition, through the holistic design which utilizes the EMS, PCS, DC-DC controller, and BMS, it improves system compatibility and adaptability. Further, as a result of the the modular component design and integrated pre-installation structure, it also facilitates a seamless transportation and installation.



Key features:

Balanced Heat Dissipation

The system uses a patented liquid cooled heat dissipation scheme, with a ≤2.5°C temperature difference in the battery cells, delivering a balanced system temperature, which alleviates large battery temperature differences caused by traditional heat dissipation methods.

Modular Installation

The modular design of the main components such as the DC-DC controller and the battery pack and the pre-installed internal wiring of the energy storage system greatly save the construction time and costs, and facilitate the operation, maintenance, and replacement.

Professional Integration

The DC-DC controller integrates BMS functions, reducing system control levels and providing rack-level battery management. The integrated design of PCS and DC-DC controller provide higher system compatibility and adaptability, which greatly reduces the difficulty of system commissioning and adaptation.

Refined Management

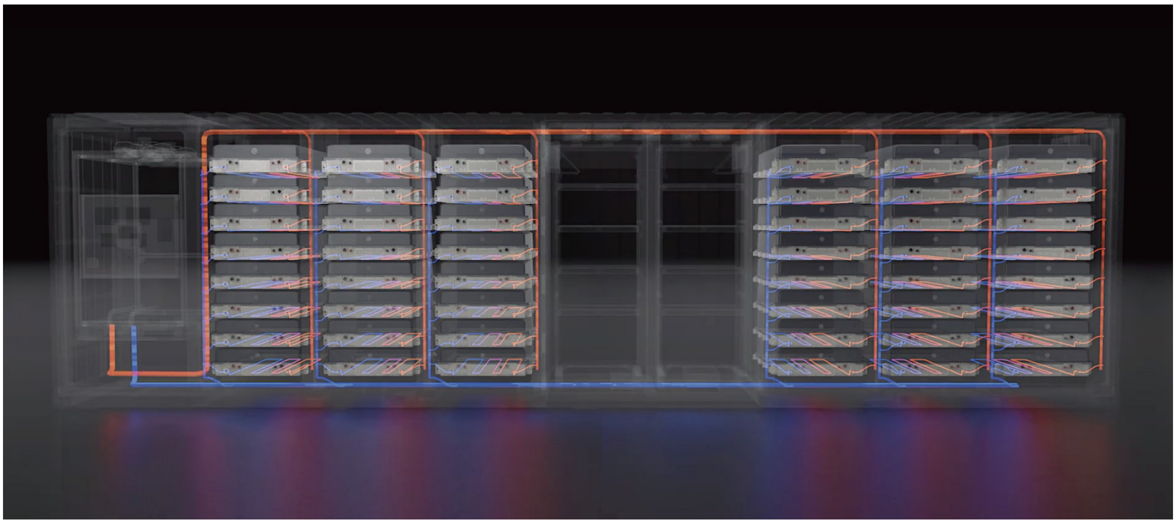
The system adjusts the charge-discharge ratio through the DC-DC controller, thereby providing full charge and discharge and solving the parallel barrel effect between racks. It also reduces the battery SOC (state of charge) error through SOC automatic calibration, eliminating downtime and manual on-site operation and maintenance.

System Safety

Early detections of unhealthy batteries are possible as a result of battery health AI monitoring. It also comes with four-level overcurrent protection and battery rack AI arcing detection to ensure the power safety, and various anti-leakage designs, power battery compartment design, and meets NFPA 855/69/68/15 and IEC63933-5-2 safety requirements.

3.2 Liquid-Cooled Heat Dissipation Technology

Liquid-cooled technology is widely used in energy storage, electric vehicles, and other energy fields due to its high energy efficiency ratio and temperature uniformity. Since 2009, SUNGROW has applied liquid-cooled technology to wind power converter products, and has developed a number of patents on liquid-cooled technology. As a result of its long and successful history in the power electronics field, SUNGROW has developed the PowerTitan energy storage system.

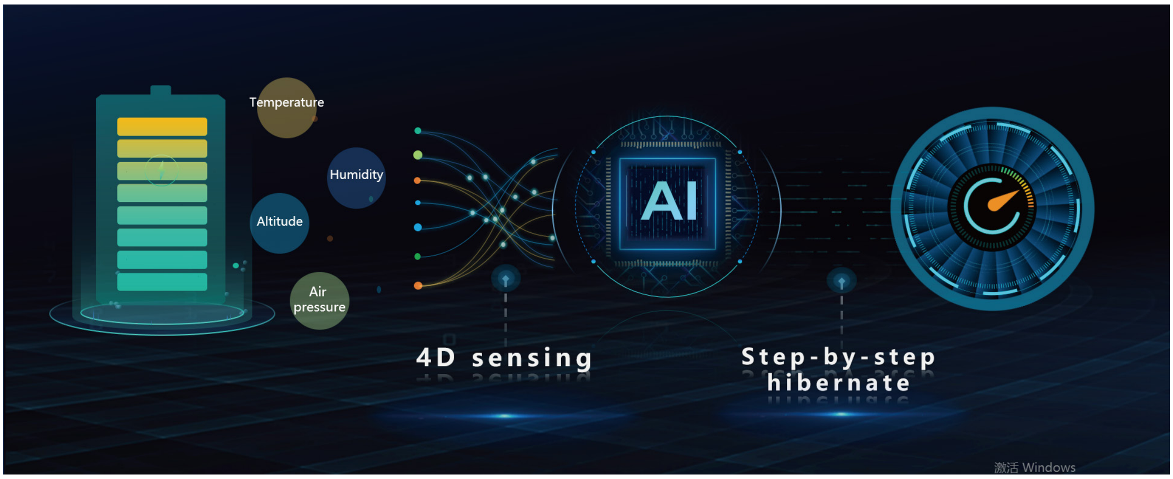


Inlet pipe   Outlet pipe

The performance of liquid cooled heat dissipation technology has advantages over conventional heat dissipation technologies, but generally, such liquid cooled technology faces pain points such as leakage, difficult and increased frequency of operation and maintenance. The PowerTitan energy storage system uses a multi-level protection system to improve efficiency, ensure system safety, and reduce operation and maintenance costs.

A. Intelligent Temperature Control Technology

In the energy storage system, the cooling system is mostly powered by an external power supply, and the plant owner needs to pay the electricity fee for such external power supply. Therefore, the loss of the cooling system will directly affect profits. The PowerTitan energy storage system uses 4D sensing technology to obtain internal data such as cell temperature and operating conditions, as well as external meteorological data such as humidity and air pressure. Through intelligent calculation and progressive standby technology, it accurately matches the cooling capacity required by the battery, reducing heat loss by 3% to 5% compared with that in the conventional liquid-cooled systems. The coolant passes through the system-level variable-diameter flow channel and the patented micro-channel in the pack. Compared to air-cooled heat dissipation, it can maintain a temperature difference in the battery cells of less than 2.5°C, a two-year increase in battery life, and an increase in the discharge capacity of the entire life cycle by 15%.



B. Tiered Leak-proof Design

- The PowerTitan energy storage system is equipped with IP65 liquid-cooled connecting pipes, electrical aviation plugs, pack shell and leakage diversion design. The test results show that in the case of external coolant spray and internal coolant leakage, the battery pack has no thermal runaway.
  *Note: The test is designed based on specific working conditions to verify the effect of temperature difference on the battery pack and even the whole energy storage system, and the test data is not representative of all working conditions.

- The liquid cooled system pipeline uses the independently-developed patented joint (patent number: ZL201420402974.8), which has passed multi-scenario environmental and vibration tests to verify reliability. Over 100,000 such joints have been placed into service, and no leaks have occurred.

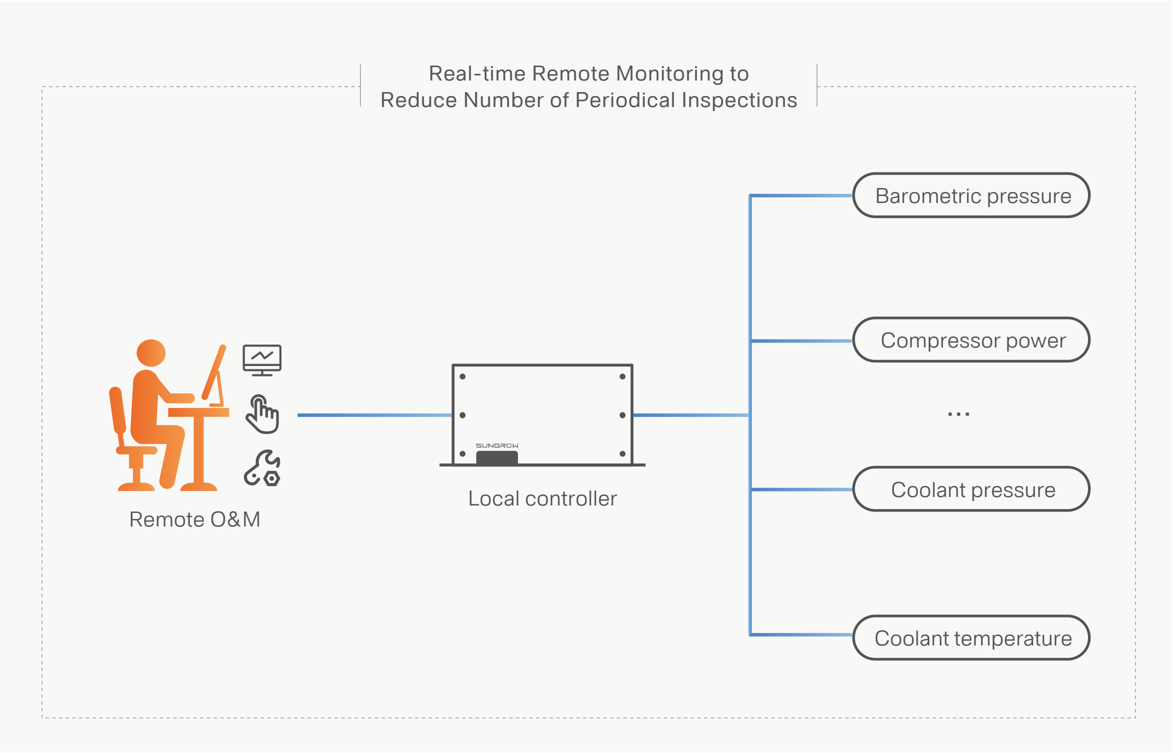
- The system is equipped with a liquid level hydraulic sensing device, which monitors the operating status of the cooling system in real time via big data analysis, pinpoints the leakage faults, and notifies the operator to perform maintenance in time to avoid further leaks.

- The energy storage system is equipped with a one-way breathing valve and an intelligent temperature control system. In addition, it monitors the temperature difference between the inside and outside of the system in real time, and intelligently controls the operation of the liquid cooling unit to reduce the temperature difference between the inside and outside of the system, thereby reducing the frequency of condensation, and improving the system reliability.

C. Intelligent Operation and Maintenance Design

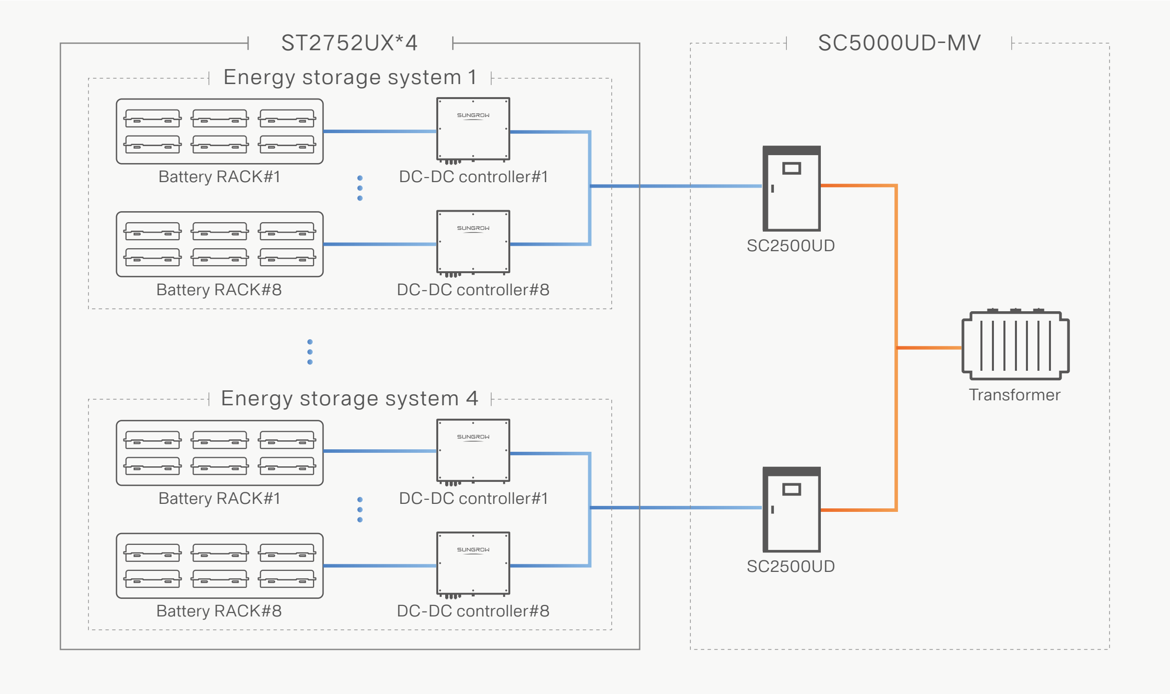
The large energy storage system features long pipelines and multiple interfaces. Even if the liquid cooled system does not leak, with the long-term operation of the liquid cooled system, hydraulic pressure of the coolant will slowly drop due to natural volatilization. Statistical data shows that over 60% of the liquid replenishment in the liquid cooled system is caused by the volatilization of the cooled liquid at the molecular level. The PowerTitan energy storage system is innovatively equipped with an automatic coolant replenishment system, which automatically replenish the coolant when liquid level decreases. Compared with manual regular coolant replenishment, the number of replenishment times is reduced by 60%, which reduces operation and maintenance costs and provides dynamically balanced and stable liquid levels, ensuring efficient heat dissipation.

The PowerTitan energy storage system uses remote intelligent monitoring to monitor the status of key components. Compared to the periodical inspection of the conventional liquid-cooled system, PowerTitan reduces the number of inspections and related operation and maintenance costs by 30%.



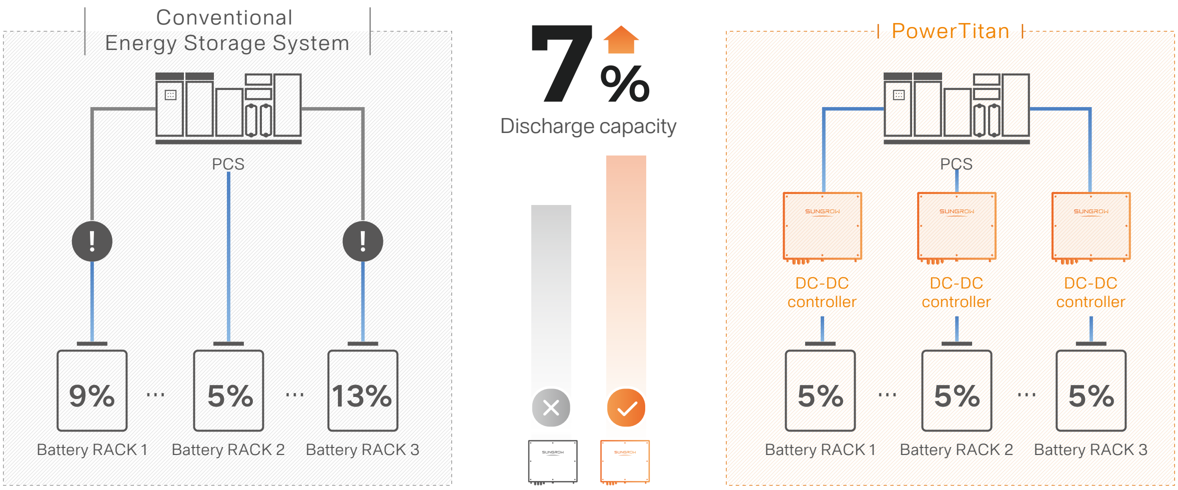
3.3 Refined Battery Management

There are 3,072 battery cells in the PowerTitan energy storage system. Compared to the traditional energy storage systems where one PCS manages all battery cells, the PowerTitan energy storage system innovatively integrates the independent control of the DC-DC controller. The battery racks are connected in parallel through the DC-DC controller to adjust the voltage of the battery racks and the charge and discharge rate to achieve consistent charge and discharge between racks and increase the system discharge capacity.



A. Reducing Parallel Mismatch

Charge and discharge performance of parallel battery racks are inconsistent due to differences in the internal resistance of the cells, and as the system capacity depends on the weakest module, a "barrel effect" may occur. Studies have shown that the power loss increases by 2.5% per year when eight racks are connected in parallel compared to non-parallel connections. The test data shows that for the case where two battery racks are connected in parallel and the SOC differs by 8%, after a complete charge-discharge cycle, the total discharge capacity of the energy storage system with a DC-DC controller is increased by about 7%.

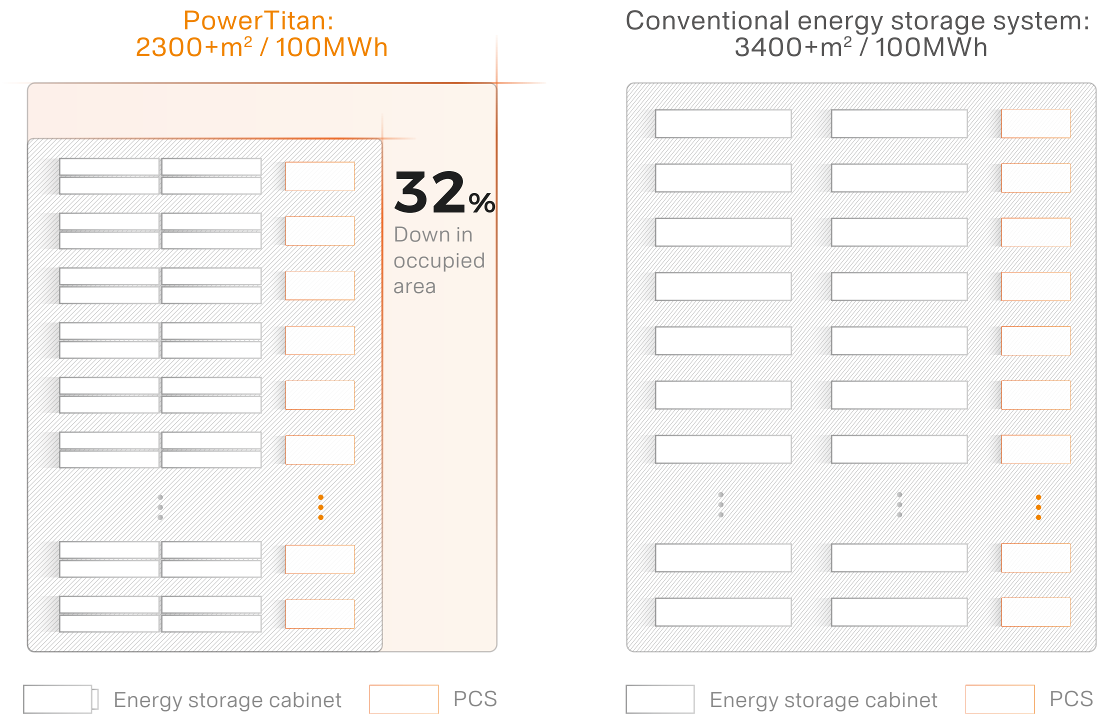


*Note: The test is designed based on specific working conditions to verify the effect of DC-DC controller on the discharge capacity, and the test data is not representative of all working conditions.

As the charge and discharge of each rack is controlled independently, battery racks with different numbers of packs can be combined, and new and old batteries can also be combined, allowing them to be replaced and extended. Therefore, in the subsequent system-level expansion of new batteries, additional PCSs are not needed, making the configuration more flexible, and reducing the costs.

A. Improving System Energy Density

The PowerTitan energy storage system uses less heat dissipation channels and a one-way door opening design, which can support "back-to-back, side-by-side" installation, further reducing the footprint and initial investment cost.



B. Reducing System Short Circuit Current

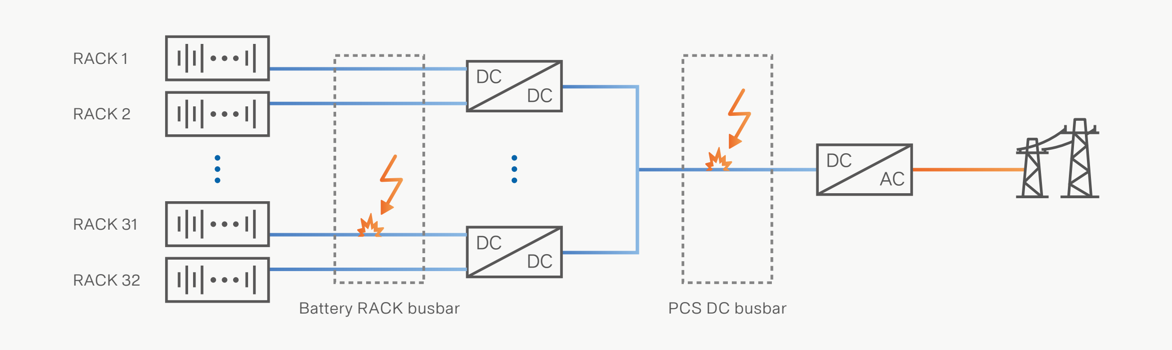
The four-hour energy storage system includes an increased number of batteries connected in parallel. This may lead to linear rise of short circuit current when the DC circuit is shorted. In addition, a safety risk is posed since the limit of the breaking capacity of the DC fuse is 250 kA, which no longer covers the short-circuit current when the batteries are connected in parallel, there is a safety risk.

- **When the system has no DC-DC controller:**

  When the busbar of a single battery rack is short-circuited, the current of other battery racks and PCS flows back to the short-circuit point, generating a short-circuit current of 13.6kA*30 + 15.4kA > 250kA.
  When the DC bus side of the PCS is short-circuited, the current of all battery racks in the system goes to the short-circuit point, generating a short-circuit current of 13.6 kA*32 + 15.4 kA > 250 kA.

- **When the system is equipped with the DC-DC controller:**

  Whether the short circuit occurs on the single battery rack busbar or the PCS DC bus side, the DC-DC controller cuts off the battery current loop within 10 microseconds, reducing the short circuit current by 75%, so that the maximum short circuit current at the short circuit point is within the fusing range of the DC fuse to ensure system safety.



As the DC-DC controller is pre-installed into the energy storage system, it reduces the hardware redundancy configuration cost and on-site installation cost in the system, and reduces the initial investment cost of the system compared with other independent DC-DC controller designs.

3.4 Battery Refined Management

A. Intelligent Detection and Early Warning

- Battery Health AI Monitoring

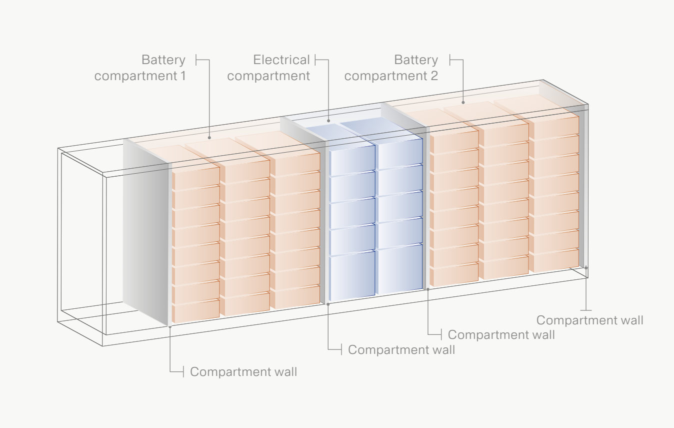
  By using the energy storage operational datasets, intelligent inter-rack online diagnosis, internal resistance discrete algorithms, and lithium plating state calculation, SUNGROW can accurately identify the degree of deterioration of batteries and provide early warnings, while controlling the system to adjust the charging and discharging current and the ambient temperature of the battery cells, thereby eliminating the thermal runaway of the battery cells in the early stage.

- AI Arcing Detection

  Based on the DC arcing detection technology used in the PV industry for many years, the product uses an innovative AI outlier detection algorithm to intelligently identify the electrical connection and other abnormalities of the battery rack circuits caused by conditions such as moisture, aging, and insulation damage. Through the detection of arcing phenomena, it intelligently determines circuit faults and gives information feedback, thereby fully identifying arcing at the millisecond level and shutting down the arcing at the second level, and increasing system safety.

B. Compartment Design

The conventional design schemes mainly integrates the batteries in one compartment; however, in the extreme event of a fire, all the batteries will be damaged. However, the PowerTitan energy storage system has two battery compartments. The electrical compartment and the battery compartment are separate, and the compartment wall has a fire resistance capability of ≥1 hour. It can effectively avoid the chain effect of fire caused by thermal runaway, prevent the spread of fire, and reduce fire losses.



C. Overcurrent Protection Design

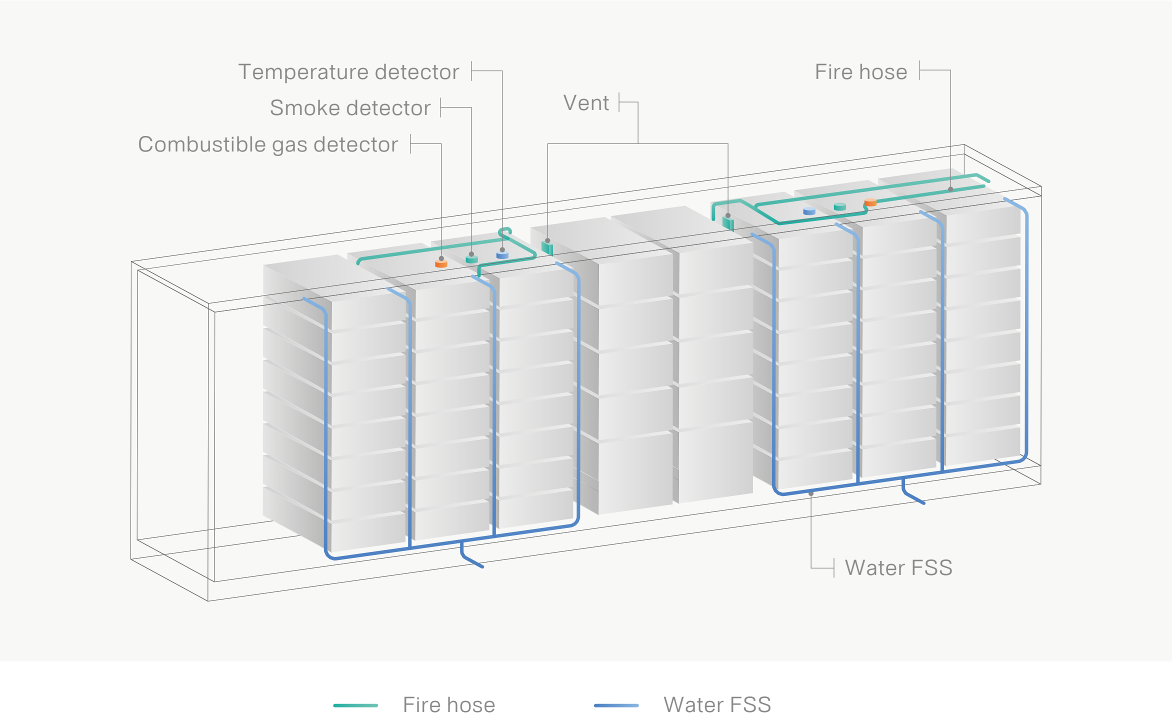
With respect to conventional energy storage systems, if any fault occurs on the DC side, all fuses will be disconnected. With a single gPV fuse, such systems cannot protect the battery rack from overload faults. As multiple cables are connected in parallel between the DC wiring cabinet of the battery collection cabinet (BCP) and the PCS DC side, due to the differences in technology and cables, there will be uneven current between cables. When a short circuit occurs on the DC side of the PCS in a large-capacity energy storage system, the short-circuit current will reach hundreds of kA. Due to the improper configuration of the overcurrent protection system, the system will ignite, break down, and have other serious failures.

In response to the above problems, the PowerTitan energy storage system uses a multi-level fuse protection method. While not changing the fuse configuration in the energy storage system, a multi-level protection, hierarchical current limiting protection architecture is designed to ensure that the fuses can be accurately matched to the corresponding layer's fault current, providing reliable breaking.

D. System-level FSS Design

Combined with the failure mechanism of the battery, the PowerTitan energy storage system is equipped with a high-precision combustible gas detector and an intelligent exhaust system that comply with the world's highest standard NFPA69, to provide active detection, timely pressure relief, and timely discharge of combustible gas during the early exhaust process of the battery thermal runaway, thereby reducing flammable gas concentration and preventing conflagration.

In addition, it is also equipped with a water fire suppression system (FSS) which meets the NFPA 15 standard and a compartment wall with fire resistance greater than one hour, as the final line of defense against thermal runaway of the energy storage system, reducing the impact of energy storage system fires. The system meets the relevant applicable requirements of NFPA 855, NFPA 68, UL 9540A, and UL 9540.



04 ⁄ Summary and Outlook

Looking to the future, under the general trend of carbon neutrality and driven by market demand and policy encouragement, the new energy industry is rapidly developing. Globally, the installed capacity of new energy systems will continue to rise, and the new energy storage industry will be one of the high-growth tracks in the future.

With the development of industry and technologies, the competitive advantages of energy storage systems will change from the batteries, which currently takes the core position, to the energy management and integration efficiency of the overall system. In the future, efficient system integration technologies will become the commanding heights of the energy storage industry. The system integration not only requires the integration of technologies in many fields such as electrochemistry, power electronics, power grids, and AI intelligence, but also requires a deep understanding of the application of power grids and energy storage in different industries and scenarios. With the intensification of competition, the threshold will only increase in the future.

SUNGROW will continue to innovate, deeply integrate power electronics and new energy power generation and storage technologies, and provide reliable green power solutions to create a zero-carbon world.

Clean power for all

Precisely Right.