# Smart PV Top 10 Trends

Combine PV and Energy Storage, Accelerating the Green and Smart PV to Become a Primary Energy Source for Every Home and Organization

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HUAWEI

# Foreword

Since the Paris Agreement entered into force in 2016, more than 140 countries and regions have made commitments on clean energy transformation. Over the past two years, carbon neutrality has become a global consensus, accelerating the use of clean and low-carbon energy. To achieve the carbon neutrality goals, clean energy generation and electrified energy consumption are indispensable.

Clean energy generation:

According to a report released by Ember, an independent climate think tank in the UK in 2022, to achieve the target of 1.5°C global temperature rise, wind and solar energy generation must maintain an annual growth rate of 20% by 2030. In 2021, the proportion of global wind-solar energy yield will exceed 10% of total energy yield for the first time. There is still plenty of room for development in the future. Therefore, many regions around the world have proposed future clean energy development plans. In May and June 2022, China and Europe issued the 14th Five-Year Plan for Renewable Energy and RepowerEU, respectively, laying out more specific plans for renewable energy development. International Renewable Energy Agency (IRENA) estimates that the installed PV capacity will reach 5200 GW in 2030 and 14,000 GW in 2050. PV is set to play a dominant role in the future of energy.

Electrified energy consumption:

According to IRENA, electricity is expected to surpass fossil fuels and account for more than 50% of global energy consumption in 2050, increasingly replacing coal, oil, and natural gas. PV is entering thousands of industries and households, combined with energy storage systems (ESSs) and electric vehicle (EV) chargers, accelerating the electrification of energy consumption. This enables us to build zero-carbon factories, buildings, campuses, and cities in the future.

However, amid the rapid development of the PV industry, there are still many challenges to be solved to make PV the most economical and reliable primary energy source.

### I. Continue reducing the levelized cost of electricity (LCOE) of PV and ESS.

We should continue reducing the LCOE through technological innovations to accelerate business closed-loop development of PV and ESS in more regions.

### II. Continue improving operation and maintenance (O&M) efficiency.

Utility plants are usually at a large-scale and in adverse environments such as high-altitude deserts or offshore areas, while distributed plants are too scattered to implement unified management and must comply with high safety standards. O&M is difficult in these scenarios.

### III. Enable high-proportion PV feed-in and consumption.

As the proportion of renewable energy increases, the stability of the power grid is deteriorated. In many countries and regions where renewable energy accounts for a high proportion, such as Australia and the UK, large-scale power outages have occurred due to grid disconnection of renewable energy. Therefore, how to improve the renewable energy consumption capability of the power grid and maintain the stability of the power grid is an industry challenge.

### IV. Place safety as the top priority.

In recent years, safety accidents occur frequently in PV and ESS plants, especially for those with high equipment power. Furthermore, rooftop PV systems and ESS application in industrial campus and residential buildings are popular. It is urgent to achieve system-level and end-to-end safety protection.

We are at a time of clean energy transformation. To address the preceding challenges, let's unveil the future of PV development.

# Content

# Trend 1
# PV+ESS Generator

## ▶ Background

PV and other renewable energy will replace fossil fuels to become primary energy sources in the future.

The International Energy Agency (IEA) estimates that the global installed renewable energy capacity will increase by 2400 GW between 2022 and 2027. PV will account for 60% of all newly installed renewable energy capacity, with an increase of nearly 1500 GW. By the beginning of 2025, PV energy yield will surpass coal and become the world's primary power source. Traditional power systems using synchronous generators will be replaced by new power systems featuring high proportion of renewable energy and power electronic equipment. However, it is difficult to ensure stable grid connection and consumption of renewable energy in new power systems.

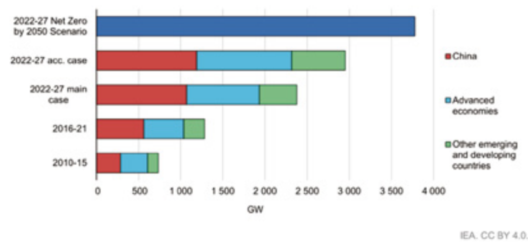



Figure 1 Renewables 2022
(Source: IEA Analysis and forecast to 2027)

Current power systems use turbines, synchronous generators, and multi-time-scale energy storage to build mechanical and electromagnetic power networks. These power networks feature storage of primary energy and controllability of secondary energy. However, as new power systems use increasingly more semiconductors, they will face complex technical problems such as system stability, power balance, and power quality. Power grid accidents have occurred in places around the world where a high proportion of renewable energy is used.

### Australia:

In the afternoon of September 28, 2016, strong typhoons and rainstorms occurred in South Australia, where the penetration rate of renewable energy reached 50%. As a result, the power grid experienced six voltage drops, and wind turbines were disconnected from the power grid on a large scale, which led to a 50-hour blackout in the state. This is the world's first large-scale blackout caused by extreme weather-induced grid-disconnection of renewable energy. It has also become a trigger for Australia's power grid to continuously tighten grid-connection standards, slowing down Australia's development of renewable energy.

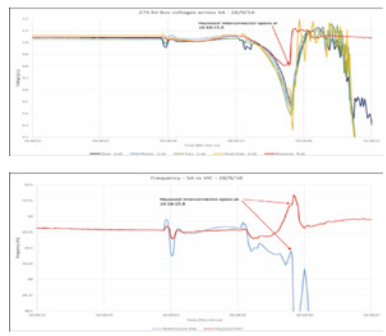


Figure 2 Frequency and voltage failure waveforms at fault
(Source: Integration, Interaction and Control of Renewable Energy Power Generation Equipment and Grid)

### UK:

At about 5 p.m. on August 9, 2019, a large-scale blackout occurred in the UK due to wind power grid-disconnection. The blackout originated in the middle east areas and northeast offshore areas of England, resulting in blackouts in most parts of England and Wales, affecting about 1 million people.

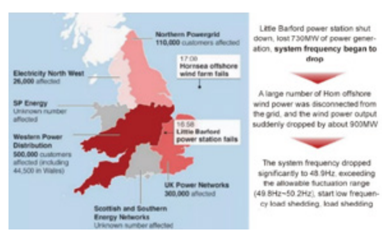



Figure 3 UK blackout analysis
(Source: PSD Power System Research Institute)

China:

By the end of 2021, Qinghai Province has installed 8.96 million kW wind power and 16.32 million kW PV power, accounting for 21.8% and 39.7% respectively. Renewable energy accounts for 61.5%, the highest in China, however, the peak load in this province is only 10.51 million kW. The surplus electricity needs to be transmitted to other areas. For example, the province has built the Qingyu DC power transmission line that transmits 100% renewable energy. However, DC power bipolar blocking will bring rapid voltage changes and reverse power flow, which lead to over 1.3 times overvoltage. This is the major challenge facing the Qingyu DC power transmission line.

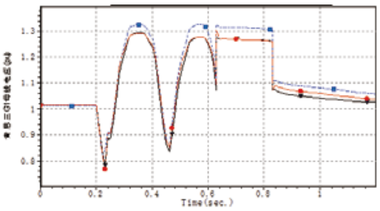


Figure 4 Transient overvoltage problem in the near-zone of Qingyu DC

## ▶ Trend

Looking back on the global development of renewable energy, the challenges for grid-connection in terms of consumption and technologies vary with the penetration rate of renewable energy.

01/ When the penetration rate is less than 30%, flexible resources for peak shaving and frequency regulation are required to balance the supply and demand. Lack of such resources will result in curtailment of PV and wind power.

02/ When the penetration rate ranges from 30% to 50%, the operating scenarios of the power system are more diversified. Due to fluctuation of renewable energy sources, traditional thermal power gensets have to quickly adjust their output to ensure the balance, requiring higher capabilities of peak shaving and frequency regulation. Therefore, power resources must be properly coordinated.

03/ When the penetration rate ranges from 50% to 60%, the system strength decreases continuously because the proportion of large thermal power decreases. As a result, the inertia of the synchronous power grid decreases greatly, and the difficulty of active and reactive power control increases. In this case, the system frequency and voltage fluctuations rise, and the transient stability problem is prominent. Grid supporting technologies and energy storage are the key.

04 / When the penetration rate exceeds 60%, for example, in large-scale renewable energy base + ultra high voltage (UHV) output scenarios, new thermal power plants cannot be built or synchronous condensers cannot be configured in a high proportion due to policy restrictions and costs. The system is seldom synchronized or even has no synchronous power supply support, the conventional control logic of renewable energy cannot ensure stable power grid connection.

Therefore, a new control mode is needed to increase active and reactive control and response, actively mitigate frequency and voltage fluctuations. With the integration of PV and ESS as well as grid forming technologies, we can build Smart PV+ESS Generators that use voltage source control instead of current source control, provides strong inertia support, transient voltage stabilization, and fault ride-through capabilities. This will transform PV from grid following to grid forming, helping increase PV feed-in and make PV a primary energy source.

## ▶ Application

In 2021, China's State Grid Qinghai Electric Power Company, together with China Electric Power Research Institute, Tsinghua University, Zhejiang University, and Huawei Technologies Co., Ltd., set up a professional research team. It took the team more than four months to complete the Research on Large-Scale Energy Storage Supporting Safe and Stable Operation of Power Systems High-Proportion Renewable Energy. This research provides a comprehensive analysis on the mechanism and adaptability of battery energy storage systems (BESSs) with different performances, such as current-type and voltage -type, that support complex and AC/DC power grids. It proposes the optimized power allocation and control strategy of voltage active support energy storage (grid forming), and provides new technical means for exploring the capabilities of renewable energy generation and DC transmission.

In 2022, ACWA POWER, SEPCOIII, and Huawei jointly built the Red Sea Project in Saudi Arabia, the world's largest PV+ESS microgrid project (400 MW PV and 1.3 GWh energy storage) and a key project in Saudi Arabia's Vision 2030. The city where the project is located will become the first in the world that uses 100% renewable energy. The PV system supports the power grid and replaces traditional diesel generators to provide clean and stable power for 1 million people. The project helps Saudi Arabia build a global clean energy and green economy center, setting a great example for the world in terms of clean power supply with PV and energy storage.

# Trend 2 High Density and Reliability

02

## Background

In recent years, the LCOE of traditional fossil fuels is increasing with the resource depletion and the carbon taxes, but the prospect of renewable energy is promising. IRENA analyzes that the LCOE of PV has decreased by nearly 10 times since 2010, and is now far lower than that of traditional fossil fuels. This is driven by the emergence of innovative technologies.

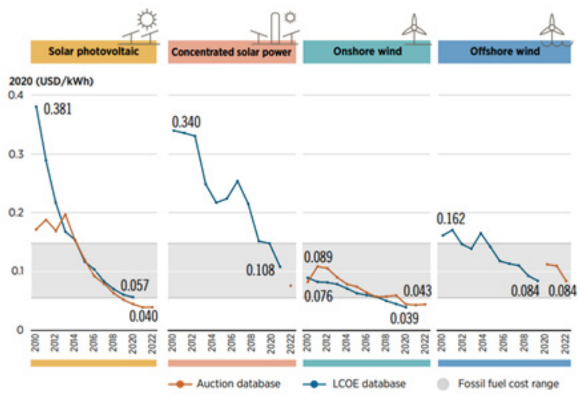
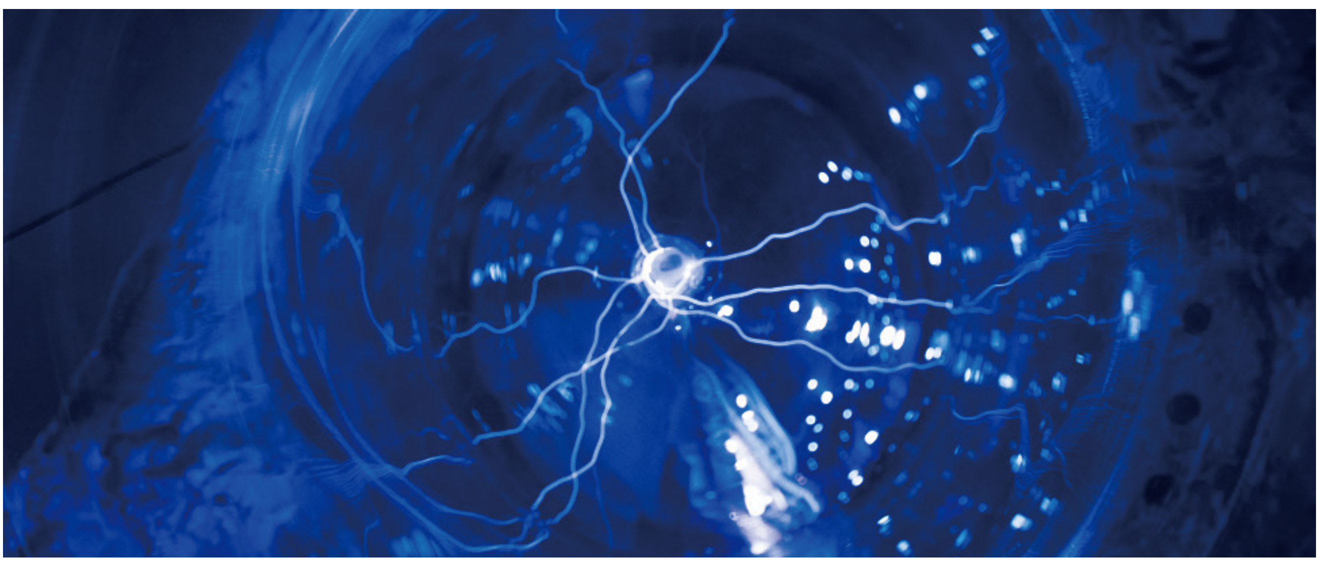



Figure 5 LCOE change of some renewable energy
(Source: IRENA WORLD ENERGY TRANSITIONS OUTLOOK 2022)



## Trend

High power density: The rapid decrease in the LCOE of PV greatly depends on the increase in the power density of equipment.

01/ The array power is increased from less than 1 MW to more than 3 MW.

02/ The power density of PV modules is increased from 200 W to over 500 W.

03/ The DC voltage of inverters is increased from 1100 V to 1500 V. With the emergence of materials such as high-density silicon carbide (SiC) and gallium nitride (GaN), it is estimated that the power density of inverters will increase by about 50% in the next five years.

High reliability: The high reliability of equipment is more important than ever at a higher power density. The magnetic integration technology, power distribution board integration technology, optimized layout of air channels for heat dissipation, modular design, and independent cabin design effectively improve equipment reliability. In addition, to verify its reliability, the equipment must be tested in extremely harsh environments, such as high salt mist, high temperature, high humidity, typhoon, and sandstorm.

After four years of research and development (R&D), testing, and verification, Huawei has increased the power of Smart PV Controllers from 200 kW to more than 300 kW, improving power density and ensuring higher reliability.

## Application

On September 30, 2020, the world's largest single-site PV plant — 2.2 GW ultra-high voltage (UHV) PV plant built by Huanghe Hydropower and Huawei — went live in Hainan Prefecture, Qinghai Province. The plant is 3100 m above sea level and has 9216 Huawei Smart PV Controllers running stably in this harsh environment. The total availability hours of the Smart PV Controllers exceed 20 million hours, and the availability reaches 99.999%. This plant supplies 5 billion kWh clean electricity to Zhumadian, Henan Province through the Qingyu DC power transmission line over a distance of 1500 km.

Figure 6 Hainan Qinghai 2.2 GW UHV project (inverter availability survey)

# Trend 3 Module-Level Power Electronics (MLPE)

03

## ▶ Background

Driven by industry policies and technology advancement, distributed PV has witnessed vigorous development in recent years. According to IHS statistics, the global annual newly installed capacity of distributed PV increases rapidly from 24% in 2016 to 47% in 2021. However, with the rapid growth of the total installed capacity, the rooftop resources for large-scale PV installation become more and more scarce. We are facing challenges such as how to install PV on rooftops with shaded areas or multiple orientations and how to improve the utilization of rooftop resources while ensuring high energy yield. In addition, distributed PV systems are mainly installed on rooftops, and safety risks related to high voltage on the DC side need to be addressed. Furthermore, as distributed PV plants are scattered around wide areas, it is difficult to implement refined O&M and management relying on manual work. Therefore, we need to further improve the power generation and O&M efficiency of distributed PV, ensure power consumption safety, and implement refined management and O&M through innovative technologies.

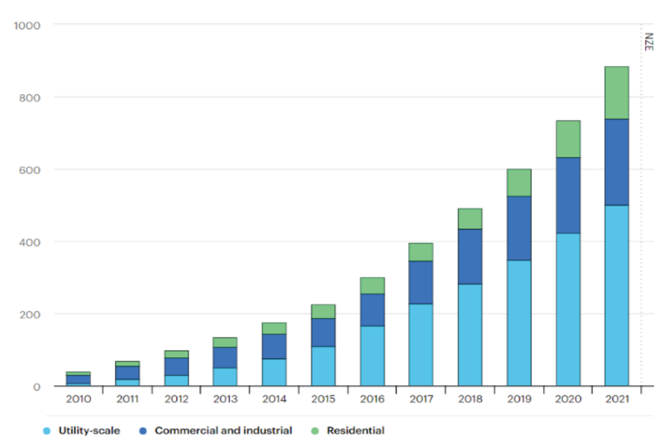



Figure 7 Distributed PV installation growth

## Trend

In a PV system, module-level power electronics (MLPE) refer to power electronic equipment that can perform refined control on one or more PV modules, including micro inverters, power optimizers, and disconnectors. MLPE brings unique values such as module-level power generation, monitoring, and safe shutdown. As more customers attach importance to features such as safety and high energy yield, the market value of MLPE is further explored. Therefore, its market acceptance and market share increase rapidly. Take power optimizers as an example. According to IHS statistics, the global annual shipment of optimizers in 2021 is 8.2 GW, accounting for 7.47% of the installed distributed PV capacity that year. By 2027, the global annual shipment of optimizers is expected to increase to 77 GW, and the penetration rate of optimizers is expected to reach 20% to 30%. Looking back on the development path of PV power electronics, we can see a trend from central inverters to string inverters. The system-level maximum power point tracking (MPPT) is upgraded to the string-level MPPT, improving the energy yield by more than 3%. In the future, string inverters will evolve toward micro inverters to achieve module-level optimized power generation and monitoring. The energy yield and safety of the PV system are expected to be further improved. The granularity of a PV system is continuously refined by more intelligent power generation and higher safety features.

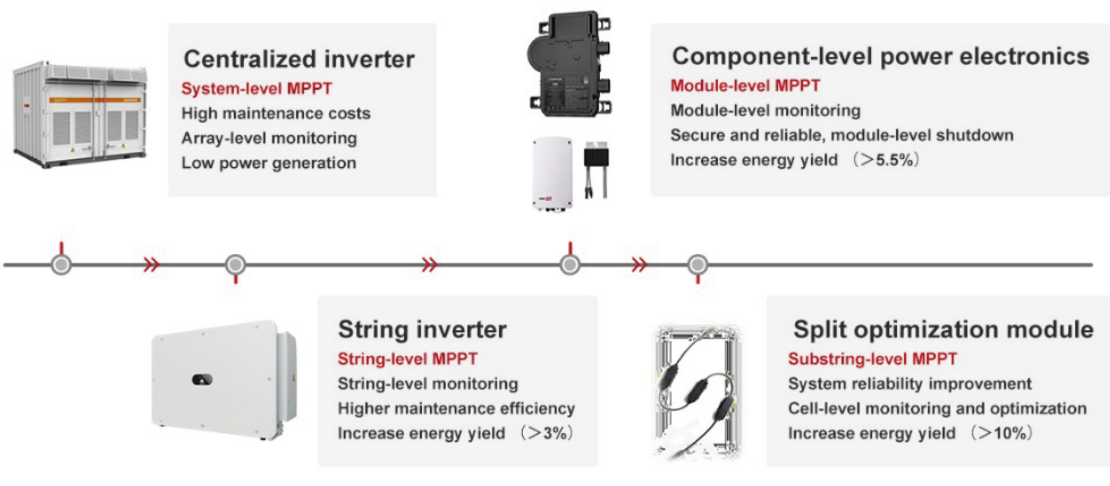



Figure 8 Evolution trend of PV power electronics

### Module-level power generation:

A string inverter tracks the maximum power point at the string level. The operating point of the PV modules affected by mismatch deviates with the decrease of the current. As a result, the output power of the entire string decreases. Based on the MLPE technology, the maximum power point of each PV module can be independently tracked to eliminate energy yield loss caused by module-level mismatch. Compared with conventional PV solutions, the MLPE technology brings considerable energy yield increase and higher benefits.

### Safety shutdown:

In a rooftop PV project, the DC voltage of PV modules connected in series ranges from 600 V to 1100 V. When an emergency such as a fire occurs, high voltage exists in the PV array and firefighters cannot put out the fire directly, causing more personal injury and property loss. In recent years, PV rapid shutdown (RSD) standards have been released and implemented in various countries. The US UL 1699B stipulates that the system should be shut down within 2 seconds when arcing is detected. The European VDE-AR-E 2100-712 safety standard has been enforced. Australia AS 5033:2020 and Thailand EIT Standard are being implemented. MLPE provides module-level rapid shutdown to eliminate safety risks caused by high DC voltage. It also detects cable terminal temperatures in real time to identify common faults such as cable short-circuit and damage in advance, implementing active safety protection.

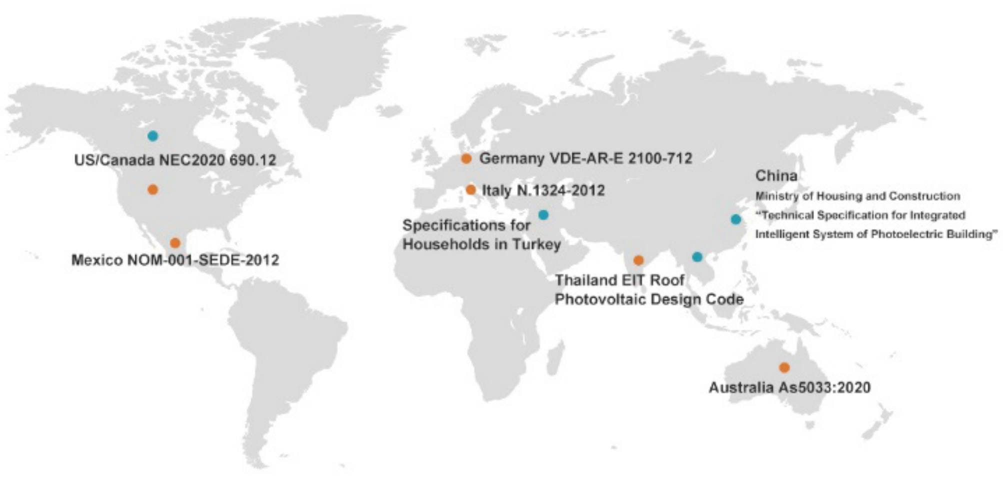



Figure 9 Global RSD standard status

Module-level monitoring:

The MLPE also provides refine management in terms of performance monitoring and fault diagnosis. The management system displays the PV module positions and power as well as optimizer input and output current and voltage, implementing intelligent module-level monitoring and visualized management. In addition, the PV module layout of the plant can accurately reflect the actual installation positions. The equipment data is uploaded in real time and the status is reported in real time, helping users accurately locate the fault and locate the faulty device.

## ▶ Application

The 300 MW whole-county rollout of distributed PV in Xiangcheng County, Xuchang City, Henan province, China-helps revitalize the local economy. The PV system in Kuzhuang Middle School adopts the full-configuration optimizer solution, which has the following features:

• Compliance with the NEC 2020 safe shutdown standard and all-round safety protection for power consumption, equipment installation, and system O&M.

• Efficient and intelligent power generation and 25.9% higher installed capacity than traditional solutions, greatly improving the space utilization and aesthetic appearance of rooftop PV modules. In addition, the optimizers can effectively reduce series-parallel mismatch loss and increase the energy yields in the first year and throughout the lifecycle by 6.65% and 9.7%, respectively.

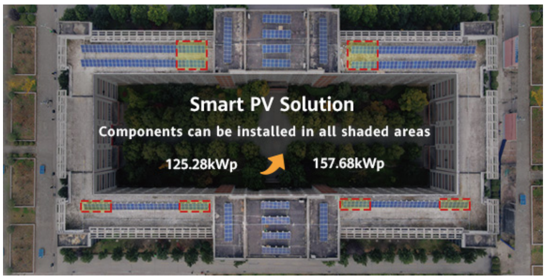



Figure 10 Comparison of installed PV capacity on the roof of Kuzhuang Middle School

In terms of safety, Wuhan built the first "highly safe gas station" of China National Petroleum Corporation. The system adopts the full-configuration optimizer solution, which can quickly shut down the rooftop voltage to 0 V and shut down the PV module output in case of emergency, allowing firefighters to rescue and fully meeting the strict safety requirements of the gas station.

Figure 11 Distributed PV at China National Petroleum Corporation Gas Station in Wuhan

# Trend 4
# String Energy Storage System

04

## Background

Similar to the development from central inverters to string inverters for refined string-level management, an ESS consisting of more than 2000 battery cells requires more refined and intelligent management to improve the available capacity and safety standards. Currently, most centralized ESSs consist of battery cells directly connected in series and parallel, which cannot implement refined charge and discharge and temperature management. Due to the impact of series-parallel mismatch and temperature difference between battery cells, capacity is wasted. In addition, the system cannot identify faults and implement protection in a timely manner. Internal and external excitation sources cause safety risks such as thermal runaway, which adds gray to the healthy development of the energy storage industry.

## Trend

An ESS is not just about battery cells. The Smart String ESS integrates digital, power electronics, and energy storage technologies. It adopts string, intelligent, and modular design to implement refined and intelligent management of battery cells and improve the charge and discharge capacity and system safety throughout the lifecycle.

String design: Battery pack optimizers help achieve full charge and discharge of battery packs, and battery rack controllers balance the capacity of battery racks during charge and discharge, preventing circulating current between battery racks and improving the available capacity of the ESS. The ESS also uses a distributed smart cooling architecture, reducing the temperature rise difference between battery cells and extending system service life..

Intelligent technologies: We apply digital technologies such as AI and cloud, and build prediction models to predict battery health and service life, reducing the initial battery configuration. The ESS will compare parameters such as the charge and discharge curves, temperature, internal resistance, and voltage to detect short circuits in battery cells. This helps it accurately locate and warn of battery fire risks before they occur. In addition, the battery pack optimizers and battery rack controllers help implement automatic SOC calibration at the battery pack level during routine charge and discharge, eliminating the need for site visits.

Modular design: If a single battery pack is faulty, the optimizer isolates the faulty pack without affecting other normal ones in the rack. Spare parts are installed in plug-and-play mode, eliminating the need for manual SOC balancing. If one or more power conversion systems (PCSs) are faulty, the system can continue working.

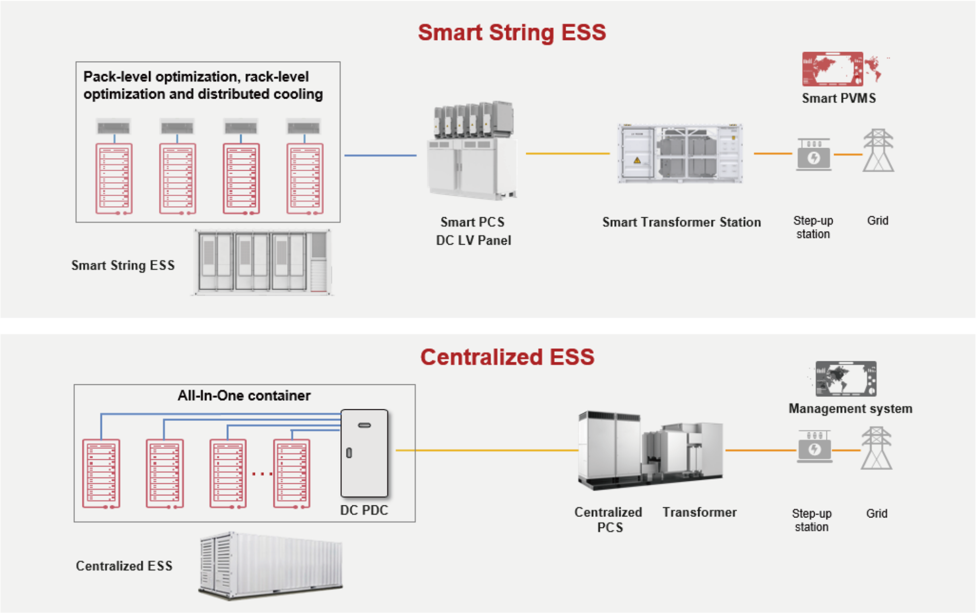



Figure 12 Comparison between Smart String ESS and centralized ESS

## Application

In the Singapore 200 MW/200 MWh project, the largest energy storage plant project in Southeast Asia, the Smart String ESS implements refined charge and discharge management to achieve constant power output for a longer time and ensure frequency regulation benefits. In addition, the automatic SOC calibration function at the battery pack level reduces labor costs and greatly improves O&M efficiency.


In the 1.3 GWh Red Sea project in Saudi Arabia, the world's first GWh-level off-grid project powered by 100% renew able energy, the Smart String ESS solution uses the grid forming feature to build a stable power grid and uses distributed cooling architecture to ensure reliable system operation in high temperature. The ESS can be transported with boards installed. No internal installation or cable connection is required onsite, saving the construction time by three months.

# Trend 5
# Cell-Level Refined Management

## Background

In a lithium battery energy storage system (BESS), the lifecycle comprehensive energy efficiency and system safety are the most important. With deep integration of power electronics, electrochemical, thermal management, and digital technologies in the energy storage field, the management granularity of the ESS has evolved from extensive management for centralized systems to refined management at the battery rack and pack levels. Even so, lithium BESSs still have a long way to go in the pursuit of higher energy efficiency and safety.

In the past two years, we've seen occasional ESS safety accidents. However, internal short circuits due to lithium plating cause thermal runaway, which is difficult to detect in the early stage. We need to find a solution to detect and warn of safety risks to prevent accidents.

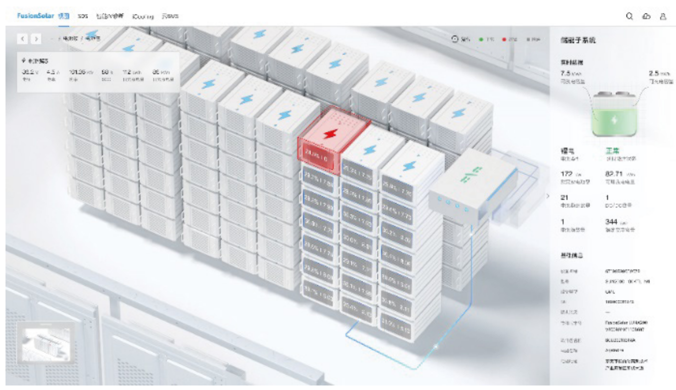


Figure 13 Cell-level refined management

## Trend

Similar to PV systems shifting towards MLPE, lithium BESSs are set to develop towards smaller management granularities. Only refined management of battery cells can help cope with the preceding efficiency and safety problems. Currently, the traditional battery management system (BMS) can only summarize and analyze limited data, and it is almost impossible to detect faults and generate warnings in the early stage. Therefore, BMS needs to be more sensitive, intelligent, and even predictive. This depends on the collection, computing, and processing of a large amount of data, and AI technologies to find the optimal operating mode and make forecasts.

## Application

The cloud BMS solution uses a large number of voltage, current, and temperature sensors deployed in the ESS to collect massive data and migrate the data to the cloud. Based on AI algorithms and models, the solution can effectively monitor the battery cell status and forecast the trend. In the battery cell puncture test, a steel needle with a diameter of 1 mm is used to simulate a derivative internal short circuit. The cloud BMS can implement hour-level battery cell thermal runaway warning.

In this way, the risks are controlled in an early stage to avoid greater losses. The cloud BMS technology has been reliably verified in electric vehicles with larger data volume and higher timeliness requirements.

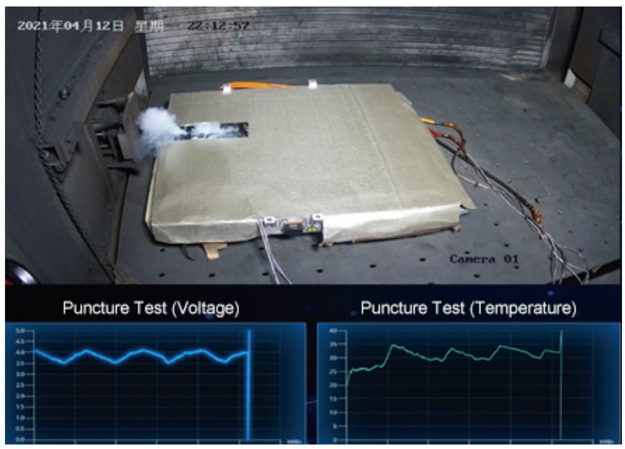



Figure 14 Puncture test of lithium iron phosphate cell

# Trend 6
# PV+ESS+Grid Integration

## Background

In the next three decades, clean energy transformation has become an inevitable trend. Clean energy generation: According to a report released by Ember, an independent climate think tank in the UK in 2022, to achieve the target of 1.5°C global temperature rise, wind and solar energy generation must maintain an annual growth rate of 20% by 2030. In 2021, the proportion of global wind-solar energy yield will exceed 10% of total energy yield for the first time. There is still plenty of room for development in the future. Therefore, many regions around the world have proposed future clean energy development plans.

In June 2022, China issued the 14th Five-Year Plan for Renewable Energy, proposing that the energy yield of renewable energy will increase from 220 million kWh in 2020 to 330 million kWh by 2025, among which the energy yield of wind power and PV will double. On the power generation side, nine clean energy bases are constructed in a centralized manner, and power is transmitted to the load center through UHV power transmission lines. The total installed capacity is

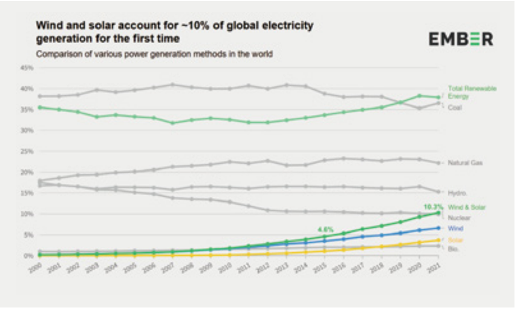



Figure 15: Global Power Review, 2022
(Source: Ember, UK Independent Climate Think Tank)

expected to exceed 500 GW by 2025. On the power consumption side, China is promoting the integrated development of PV buildings in new factories and public buildings and implementing the campaign of solar-powered homes to achieve the preceding objectives.

To ensure energy security in Europe, the EU issued the RepowerEU in May this year, increasing the renewable energy installation target from 1069 GW to 1236 GW (511 GW@2011) in 2030. The PV installation target will reach 600 GW in 2030, offsetting 9 billion cubic meters of natural gas consumption by 2027 to replace natural gas with solar energy. To achieve the preceding objectives, on the power generation side, the UK will build 10.5 GW PV and 5 GW/20 GWh energy storage in Morocco, North Africa. Through 3800 km UHV transmission lines, 26 TWh clean power will be sent to the UK every year, meeting 7.5% of the country's power demands. On the power consumption side, the European Commission also proposed a legally binding European Solar Rooftops Initiative. By 2026, rooftop PV must be installed in all new public buildings and commercial buildings with a rooftop area of more than 250 square meters in the EU. By 2027, PV must be installed on the rooftops of all existing buildings that meet the requirements. By 2029, PV must be installed on the rooftops of all new residential buildings.

## Trend

On the power generation side, a clean energy base of PV+ESS is constructed in areas with rich sunlight resources. The electricity is sent to the load center through UHV power transmission lines. We can build pilot projects around the world to accelerate construction of UHV power grids between regions and achieve more flexible time-space mutual benefit and interconnection. Based on the traditional energy pattern planning, clean energy bases feature multiple energy structures, use high proportion of renewable energy and power electronics equipment, occupy large footprint, and are located in remote areas. Technologies are required to ensure stable grid-connection of PV, collaborative scheduling of multiple energy sources, and intelligent O&M.

On the power consumption side, distributed PV, ESS, and controllable loads are combined to flexibly schedule scattered power generation units and storage units. In this way, resources can be adjusted on the user side to participate in market transactions and respond to loads, achieving peak shaving. This becomes a brand-new business model.

Therefore, building a stable energy system that integrates the PV+ESS+Grid to support PV power supply and consumption will become a key measure to ensure energy security and independence. By integrating digital, power electronics, and energy storage technologies, we can implement intelligent scheduling of multiple energy sources, shifting from balanced generation and consumption to balanced generation, storage, and consumption through combination of multiple energy sources. We can also build an intelligent O&M platform to enable GW-level clean energy bases to be completely or less unattended. 5G, AI, and cloud technologies are used to intelligently manage, operate, and trade massive distributed PV+ESS systems, and build virtual power plants (VPPs). VPPs provide strong technical assurance for users to adjust resources to participate in market transactions and respond to loads for peak shaving.

## Application

In 2022, Yalong River Hydropower joined hands with Huawei to build the 1 GW Kela PV power plant, the world's largest hydro-solar hybrid power plant with the highest installed capacity and altitude. The project officially entered the construction phase and is expected to be connected to the grid in 2023. In the next five years, the planned installed PV capacity will reach 3.2 GW, becoming a shining example in the clean energy base of the Yalong River basin.

Figure 16 Construction effect drawing of Yalong River hydro-solar hybrid base

Multi-energy collaboration of PV and hydropower smoothes PV output fluctuations. In this project, the load of the hydropower plant can be increased or decreased and the reservoir capacity can be adjusted to compensate for the load fluctuation of the PV power plant, delivering stable, balanced, high-quality, and safe power supply, more grid-friendly PV power supply.

Power transmission lines of hydropower improve utilization rate. The power transmission lines of hydropower (Sichuan Jinping-Jiangsu Suzhou and Yazhong-Jiangxi ±800 kV UHV DC transmission lines) are used, so there is no need to build extra UHV AC/DC lines between . At the same time, the utilization rate of the original hydropower transmission lines is improved, achieving more economic benefits. Huawei's full-condition power grid adaptability and excellent power quality effectively support the delivery of the entire renewable energy plant.

In Europe, VPP is relatively mature. Take a well-known VPP operator in Germany as an example. Its main profit model is to directly participate in power transactions such as wind power and PV power generation to obtain profit sharing. Based on the power market price fluctuation once every 15 minutes and 96 times a day, the VPP adjusts the output of distributed energy to achieve power consumption during off-peak hours and power sales during peak hours, maximizing profits. In 2022, the VPP operator has managed more than 10,000 distributed power generation systems, including hydropower plants and solar-wind power plants. The overall management load exceeds 10 GW.

# Trend 7
# Upgraded Safety

07

## Background

PV and ESS safety is the cornerstone of industry development. This requires us to systematically consider all scenarios and processes, fully integrate power electronics, electrochemical, thermal management, and digital technologies to upgrade system safety.

# I. Upgrading the DC Safety of PV Plants

## Trend

With the increasing power of PV modules and inverters to over 500 W and 300 kW, respectively, the DC side safety of PV plants becomes critical. According to the analysis of authoritative organizations, the faults caused by the DC side of PV plants can account for more than 70% of all faults. Moreover, due to the impact of radiation and characteristics of PV modules, traditional circuit breakers and fuses cannot reliably break for protection, which seriously threatens the operation safety of PV plants.

Among the various safety risks that need to be prevented and controlled during PV power generation, electrical safety features multiple risk sources, wide coverage, complicated impacts among risk sources, and highest accident frequency. Grounding faults, arcing, and short circuits are common electrical faults.
In recent years, many serious fire accidents caused by electrical faults have occurred in China. The following are two typical fire accidents caused by multiple factors including grounding faults, short circuits, and arcing.


Figure 17 Fires caused by electrical safety accidents

Currently, blind spots and shortcomings still exist in electrical safety prevention and control on the DC side of PV power generation, such as in standards, electrical safety design, and safety protection device selection. The PV DC overcurrent protection is designed mainly based on IEC 62548 Photovoltaic (PV) arrays - Design requirements, lacking specific standards. In engineering application, issues still exist in the design, configuration of overcurrent protection devices, and quality control of fuses and circuit breakers.

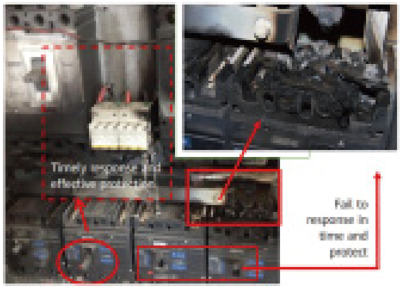



Figure 18 Case 1: DC circuit breaker failure

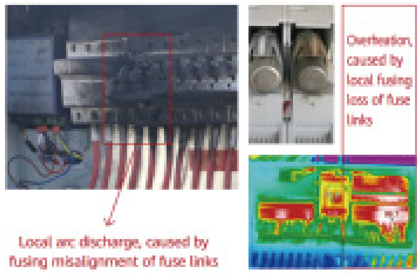



Figure 19 Case 2: DC fuse arcing

Figure 20 Case 3: Burnt DC terminals due to overtemperature

Therefore, the intelligent DC protection technology is required to effectively protect against faults such as reverse string connection, current backfeed, and bus short circuit. If an exception occurs, the PV inverter needs to disconnect the DC fault in milliseconds. In addition, abnormal inverter terminal temperature is usually an early warning of a fault. When a certain threshold temperature is exceeded, an automatic shut-down mechanism with the smart connector temperature detection function is required.

## Application

### Smart String-Level Disconnect (SSLD) Technology:

In 2021, Huawei invented the SSLD technology to reliably disconnect DC system faults occurring on the DC side. The technology obtained the Level-I certification by China General Certification Center (CGC).

In the same year, CGC and Huawei completed an onsite test in a 400 MW power plant project in Hebei Province. The test strictly complied with the CGC/GF 192:2021A Technical Specification for Evaluation of Smart String-Level Disconnect and CGC-R 49064:2021 Evaluation and Certification Rules for Smart String-Level Disconnect (PV Inverter). The results showed that the SSLD function can reliably disconnect the DC side of the modules and the inverter if an internal short circuit occurs in it, and ensure the safety of the DC system of the power plant.


Figure 21 SSLD function certificate

Figure 22 SSLD function certificate

### Smart Connector-Level Detection (SCLD) Technology:

In a traditional solution, DC terminals of the inverter are fixed on the external mechanical part, and the terminal ends are routed through the cable bundles, and then to the printed circuit board (PCB) through the DC switches. Although this solution is relatively simple in design, DC terminals need to be pierced, positioned, and fastened one by one, and pins need to be manually inserted after the insulation parts are fixed. Therefore, the production efficiency is low and the insertion may not be in place. Moreover, if external factors such as poor connection and damage cause the overtemperature of the terminals, the inverter will detect the abnormal electrical signal only when the temperature rises to the point that the cable has already been burned. In addition, because of the large quantity of connected cables, the accident is more likely to spread out.

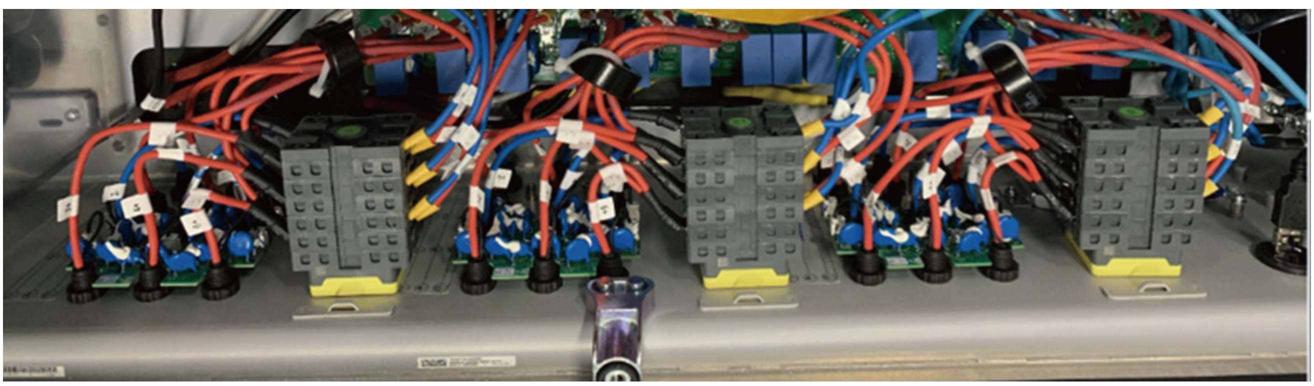


Figure 23 Traditional DC terminal connection mode of the inverter

To avoid such type of faults, Huawei innovatively adopts the on-board terminal design. The customized on-board terminals can be directly soldered on the PCB, eliminating the need for manual pin insertion and cabling. This reduces the risk of poor DC terminal insertion caused by improper cabling and ensures high reliability in production. Meanwhile, after the terminal is soldered on the PCB, the NTC sensor can be added near the terminal through-current point, enabling data collection, a basis of digital and intelligent terminal detection. Then data transmission is carried out through the signal link on the PCB, and finally signal detection and data calculation are carried out through the chip. As such, the SCLD is complete. In particular, when a terminal is not properly connected, the metal core is not properly crimped, and the terminal is not in good contact or polluted by chemicals due to external forces, abnormality is rapidly reported in real time and protection is enabled to avoid further deterioration and spread of faults and ensure the safety and reliability of the DC side of the system.

Figure 24 On-board design of Huawei inverter terminals

## II. Upgrading the Safety of Distributed Rooftop PV Panels

### ▶ Trend

Arc Fault Circuit Breaker (AFCI):
In distributed PV scenarios, power plants have small capacity, scattered locations, and complex application scenarios, mostly in industrial or residential areas. Therefore, the building and personal safety becomes a common concern and active safety

| Requirements Items / Level | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| Arc Fault Point Locating | Unable to Locate | Unable to Locate | Unable to Locate | Locate |
| Detectable Cable Length | 61m | 80m | 80m (single-phase)<br>200m (three-phase) | 80m (single-phase)<br>200m (three-phase) |
| Max. Current | 0.9 Imax | 0.9 Imax | 0.9 Imax | Imax |
| Arc Energy | 750J | 600J | 600J | 500J |
| Shutdown Time | 2.5s | 1.5s | 1.5s | 0.5s |
| Detection Precision | 100% | 100% | 100% | 100% |
| Technical Requirements | PV String Detection | Optimizer system +1% high-precision independent CT | > 200DMIPS high-performance CPU+0.5% independent CT | > 200DMIPS high-performance CPU+0.5% independent CT |

Figure 25 CGC AFCI Level 1 to Level 4 standards

protection are increasingly important. At present, more than 80% of fires in PV modules are caused by DC arcing. Once the contact points of PV modules are in poor connection, the wire is damp, or the insulation material is damaged, high voltage arcs will occur. Because the arc signal is related to many factors such as line length and current, and the equipment operating environment is complex and changing, the precise arc detection faces great

challenges. Currently, according to China General Certification Center (CGC)/GF 175:2020 Technical Specifications for Arc Detection and Rapid Shutdown Performance Evaluation, AFCI is usually divided into four levels by performance.

### Module-Level Rapid Shutdown

The PV modules on the DC side are connected in series. When the PV modules are exposed to sunlight, the PV strings generate a high voltage of 600 V to 1000 V, which poses a threat to the personal safety of rooftop O&M personnel. In the event of a fire in PV modules, the high voltage of the PV string will affect the fire extinguishing and rescue efforts of firefighters. Therefore, it is necessary to implement the rapid shutdown function at the module level using power electronics technology.

## Application

More and more countries around the world have issued stricter regulations on the PV DC side safety. For example, the US NEC 2017 Section 690.11 and the Canadian Electrical Code 2021 stipulate that any PV system above 80 V must support AFCI. According to the German standard VDE-AR-E 2100-712, if the inverter in the PV system is shut down or the power grid is faulty, the DC voltage must be less than 120 V. According to Section 4.3.13 of the Thai Electrical Code: Solar Rooftop Power Supply Installations 2022, rooftop PV plants must have the capability of rapid shutdown for PV modules.

In actual applications, China National Petroleum Corporation (CNPC) and Sinopec have used Huawei FusionSolar solution in some gas stations in Wuhan and Inner Mongolia. The solution provides AFCI and rapid shutdown for PV modules, meeting strict safety standards. A Dutch painting factory with many chemical materials also applies these two technologies in its 2.54 MW PV power plant, greatly raising the safety protection standard.

Figure 26 Cases of CNPC, Sinopec, and Dutch painting factory

## III. Upgrading Energy Storage System (ESS) Safety

### ▶ Trend

As an important part of the new power system, lithium battery energy storage has ushered in explosive growth and wide application. However, the frequent safety accidents of ESSs draw public attention, which have become a concern in the industry that cannot be ignored. In 2022, nearly 20 fires and explosions of ESS power plants occurred worldwide, causing serious personal safety and economic losses and sounding alarms

for the whole industry. In order to realize the sound and sustainable development of the industry, the safety problem needs to be solved urgently. At the same time, the industry's relevant regulations and standards are also constantly improving. In April 2022, China National Energy Administration issued the Notice on Strengthening the Safety Management of Electrochemical Energy Storage Plants, which proposed 14 measures in five areas, requiring all electric power enterprises to strengthen the safety management of electrochemical energy storage plants with a high sense of responsibility and mission, highlighting the safety design of energy storage plants, and raising the entry bar for energy storage.

The ESS safety design focuses on protecting the DC side of batteries. Many batteries are connected in series or parallel, bringing great difficulties to the monitoring, control, and fire protection of the system. Energy storage safety relies on the overall safety design of the system. By integrating advanced power electronics technologies with digital technologies such as cloud and AI, the key is accurate and reliable monitoring and management of energy storage products from the battery cell level to the system level. The traditional protection mode based on passive response and physical isolation is upgraded to active automatic protection and even alarm prediction in advance, implementing multi-dimensional safety design from hardware to software, and from structure to algorithm.

## ▶ Application

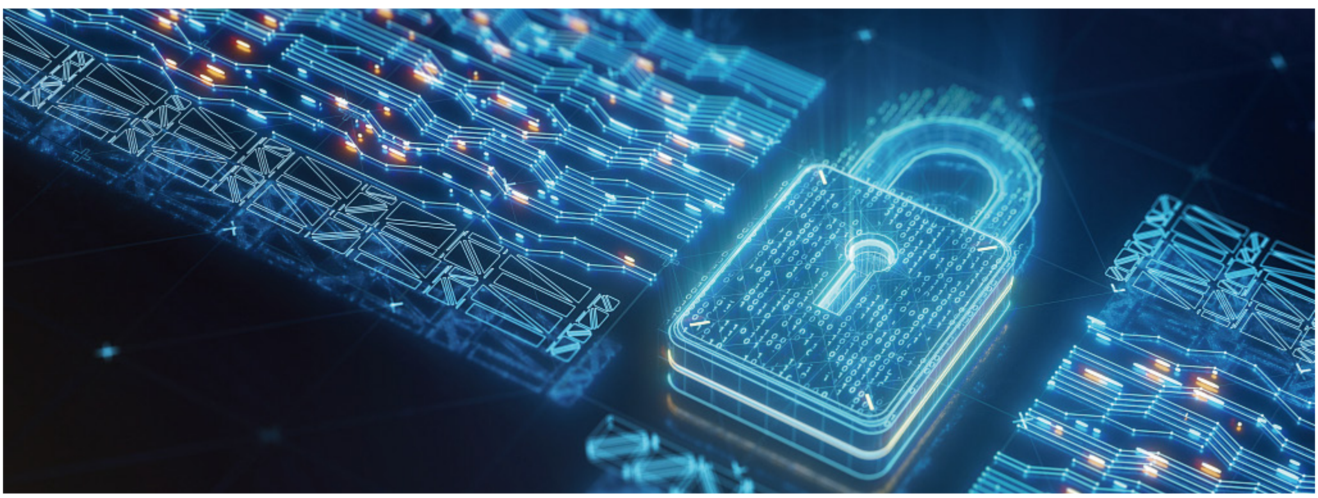
Singapore's first megawatt-level energy storage project launched in 2022 adopts a Smart String ESS with the four-level active shutdown function to implement end-to-end comprehensive protection and ensure safe and reliable operation of the system. In addition, the conventional energy storage interface is charged during installation, which poses certain risks to installation personnel and is prone to short circuit and battery damage. The battery pack optimizer of the Smart String ESS can shut down the voltage of the battery pack port to 0 V to prevent injury caused by electric shock during installation. To ensure structural and fire safety, the Smart String ESS complies with the strict Certificate of Conformity (CoC) for fire resistance, EN ISO 1182, and EN ISO 1716, and relevant materials meet the flame retardance and fire wall tests.

# Trend 8
# Security and Trustworthiness

08

## Background

Although PV systems create benefits for owners, they need to be protected from equipment safety and information security risks. In terms of equipment safety, the external environment of PV system is often complex and changing, and the decreasing environmental tolerance of system equipment may lead to equipment failure, affecting system operation and causing economic loss. In terms of information security, the plant management system manages the plant in a unified manner, but also faces the risk of external network attacks. In extreme cases, the plant may break down, and the plant information or personal privacy data may be breached or tampered with. Both equipment faults and external attacks bring great challenges to the safety and security of PV systems.



## Trend

Equipment security (from reliability to availability):

o avoid economic losses caused by equipment failure, high-reliability power plant equipment is required to ensure system safety. Through component selection, rigorous testing, and reliable production, the environmental tolerance of PV devices is improved, the failure rate is reduced, and the service life of PV equipment is ensured. For example, the designed service life of Huawei inverters is 25 years. However, these measures rely only on the reliability of the equipment, and cannot implement proactive fault warning and prevention. Therefore, the availability of plant equipment still needs to be further improved. For example, fault diagnosis and module-level monitoring are developing rapidly in the industry. When a fault occurs, the equipment can be warned in advance, the fault can be quickly located and have the type determined. Faults are isolated to reduce the impact scope and maintain faulty equipment to ensure quick recovery. In addition, the self-controllability of key components ensures the continuous supply of equipment and further improves the availability of the power plant system.

Information security (from security to resilience):

To prevent malicious external attacks, the plant system must ban any unauthorized access to system information, prevent disclosure of personal privacy or sensitive data, and ensure that information is not modified or damaged by unauthorized access. Typical measures include secure boot, digital signatures, and centralized certificate management. However, these passive information security measures cannot cope with the complex and changeable network environment. It is necessary to change from passive to active security protection. For example, real-time adjustment of system intrusion detection policies enables the power plant system to have independent intrusion detection capabilities. After detecting a network security incident or potential risk, the system responds to the incident in a timely manner and takes corresponding measures to quickly restore the damaged functions or services and ensure service continuity. In addition, the networking protocols of the management system are based on the module level to minimize the impact of external network attacks on the power plant system as well as economic losses.

Safety and privacy:

The PV plant system should also do no harm to human and environment and protect data privacy. Personal and environmental safety can be ensured by AFCI, module-level rapid shutdown (RSD), SSLD, and good electromagnetic compatibility. In terms of privacy, the use of private data should be legal, proper, and transparent to data subjects. For example, Huawei ensures the security of personal privacy data through end users' authorization and permission. In addition, data should be collected for specific, clear, and legitimate purposes. Personal data should be anonymized or pseudonymized to protect personal privacy from illegal disclosure.

## Application

Common Criteria (CC):

Huawei's commercial inverters have passed the industry's first CC EAL3+ certification, leading the security certification in the PV industry.

IEC 62443:

Huawei's network management system, SmartLogger3000, LUNA2000B (C&I ESS), and LUNA2000C (utility-scale ESS) have obtained the IEC 62443-4-2 SL2 certification. The product development process has obtained the highest level of IEC 62443-4-1 ML3 certification in the PV industry.

ISO 27001:

Huawei has obtained the ISO 27001 certification for information security management.
The collaboration of technological enterprises, industry, and society will help the PV industry build digital trust and carry on a path of sustainable and sound development.

# Trend 9
# Digitalization

09

## ▶ Background

Digitalization helps drive productivity and economy development. To embrace an intelligent future, more than 170 countries and regions around the world have developed digital strategies based on their own conditions. Industries are also facing digital transformation. Throughout history, every progress of human society is accompanied by an energy revolution. In recent years, carbon neutrality has attracted wide attention worldwide, and the construction of a new power system centered on renewable energy is an absolute trend. Renewable energy, such as solar power and wind power generated by PV panels and fans respectively, is gradually replacing fossil energy. From the perspective of loads, many new energy consumption forms represented by electric vehicles, electric pumps, and electric heating devices keep emerging on a large scale. The changes on energy generation and consumption lead to high uncertainty in the system and the stability of power grids is threatened. Moreover, a large number of widely distributed sensors are connected to the system, which requires higher dynamic monitoring and balancing capabilities of the power system.

To address these challenges, it is urgent for the energy industry to go digital. Only by visualizing, managing, and controlling the full process of energy generation, transmission, storage, distribution, and consumption, can we promote the rapid development of a green, sustainable, and mutually beneficial energy system and eventually realize autonomous driving of the entire power system.

## Trend

Power electronics technologies are used together with advanced digital technologies. Power electronics technologies are a key to efficient production, conversion, storage, and consumption of electricity. The integration of power electronics technologies and digital technologies such as 5G, AI, cloud computing, big data, and the IoT, achieves managing "watts" with "bits". With the rapid evolution of digital technologies, it is estimated that more than 95% of the world's power plants will be fully digitalized by 2027.

Previous renewable energy equipment, such as centralized inverters and centralized ESSs, lacks information collection and reporting channels. Therefore, the overall operating status is difficult to track and monitor, and refined management is even more difficult. Digital technologies, however, can make the vague, unmeasurable information in the equipment visible and measurable, making the "black box" transparent. The equipment often integrates functions of power conversion, data collection, remote control, online analysis, and auto-adaptation, and extends management to levels such as modules and battery cells. In addition, the use of power line communication (PLC) instead of RS485 for equipment data transmission can reduce the network deployment and improve the transmission speed, so that "dumb" equipment can"talk" and even "speak".

Connecting siloed power plants for energy collaboration is also a vital task in power plant digitalization. As the focus of China's "14th Five-Year" Development Plan for Renewable Energy, planning and construction of nine major energy bases that integrate wind, solar, hydro, and thermal power and ESSs, are being accelerated. A large-scale base usually has a large footprint and contains multiple energy sources. These two features pose challenges of large amount of equipment data, difficult site visits, and high security and collaboration requirements. Therefore, it is a necessity to build a digital platform that integrates big data, AI, IoT, GIS, and video surveillance technologies to support asset management, operations management, O&M management, multi-energy support, and intelligent security and achieve intelligent O&M, system integration, multi-energy collaboration, efficient power generation, and interconnection between power plants.

For the power grid, in order to ensure stable power supply, traditional manual inspection has high work intensity and may pose risks for workers during climbing and field operation. In contrast, advanced digital technologies, especially the 5G technology with a high bandwidth and low latency, and infrared detection technology are used to remotely command UAV patrol inspection, which can greatly improve power supply reliability.

## ▶ Application

Huaneng Dongfang Smart PV Power Plant utilizes the ash land resources and a 12 MW PV power generation system is built on a 0.16 million m2 ash land, with an average annual power generation of more than 12 million kWh. The plant has achieved a number of innovations in the industry. Traditional plants use RS485 and optical fiber ring network communications but this project uses PLC and broadband wireless communication. This solution simplifies construction and installation, and provides customers with an easy-to-deploy, high-bandwidth, and high-security network environment. It can be applied to multiple services, including production, security protection, and mobile inspection, to support end-to-end production and O&M of smart PV plants. In terms of asset management, to solve difficulties in power plant asset allocation and redundant purchase, the project has established a PV power plant asset information database, which can automatically scan asset location information and code information into the database. In addition, the plant adopts the intelligent cloud management system, which uses the mobile app to monitor the plant production and operation anytime and anywhere.

Fujian Pinghe has launched the whole-county rollout of the rooftop distributed PV project since 2022, with a total rooftop area of 460,000 m2. It is estimated that the first phase of the PV project will produce 89.18 million kWh of green power every year after it is connected to the grid and put into operation, and that more than 2.2 billion kWh of green power will be produced in 2025. The project networks PV resources, standardizes construction, conducts intelligent O&M, and centralizes management by integrating advantages and digital technologies. The SmartPVMS (Cloud) is used to manage the system of the whole county on cloud, integrate energy flow and information flow, implement intelligent connection in all scenarios, and ensure that PV plants are could-ready upon power-on. In this way, intelligent, high-quality, maintenance-free, and cost-effective PV plant status monitoring and intelligent O&M services are implemented. Through the construction of a new power system centered on renewable energy, Pinghe embraces a bright future.

Figure 27 Huaneng Dongfang Power Plant in Hainan

Figure 28 Xikeng Village Committee, Pinghe County, Fujian

# Trend 10
# AI Application

10

## Background

In recent years, the rapid progress of AI technologies has greatly influenced the economic development of human society and the transformation of production and life style. AI technologies have been implemented in finance, healthcare, manufacturing, education, security, and energy and can adapt to increasingly abundant application scenarios in the process of commercialization in all directions. The wide application and commercialization of AI have accelerated the digitalization of enterprises, the optimization of industry chain structure, and the improvement of information utilization efficiency. Countries and regions around the world, such as the US, EU, UK, Japan, and China, support the development of the AI industry and continuously implement new applications. With the deepening of digitalization of power plants, the amount of data generated by equipment increases explosively, which provides a good foundation for the wide application of AI. AI is rapidly becoming the cornerstone of innovation. At the same time, the integration of AI with cloud

computing and big data technologies keeps going further, and the tool chain around data processing, model training, deployment and operation, and security monitoring is being enriched. In the field of renewable energy, AI, like power electronics and Internet technologies, will drive profound changes in the whole industry.

## Trend

AI technologies will be widely used in renewable energy with strong fluctuations and high uncertainty, and play an irreplaceable role in the whole life cycle of PV plants including manufacturing, construction, O&M, optimization, and operations.

In production and manufacturing, AI image recognition can be used to intelligently analyze and judge over 100 quality inspection data items during the production process, improving quality inspection efficiency. The production efficiency of a PV module production line is increased by over 10%, and the daily output of a single production line is increased from 900+ to 1000+ modules. During power plant design and construction, AI can be used in onsite exploration, including satellite site survey, rooftop modeling, automatic module layout, and automatic electrical connection, to continuously improve design efficiency and precision.

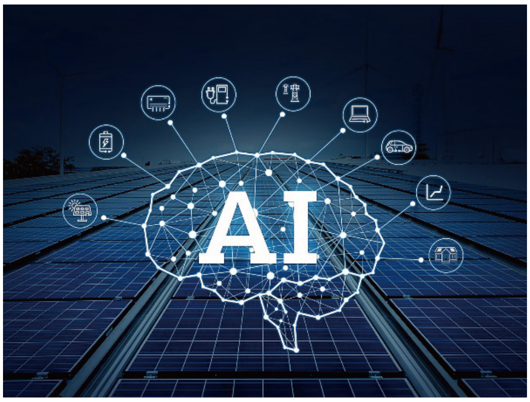



Figure 29 Wide application of AI technologies in renewable energy

In terms of system optimization, the massive data generated by the power plant can be used to reconstruct the tracking support algorithm to make up for the defects of the traditional astronomical algorithm in shading and raining scenarios, find the optimal angle, and significantly improve the PV power generation efficiency. In addition, AI can be used to optimize the MPPT tracking algorithm, which can also improve energy yield.

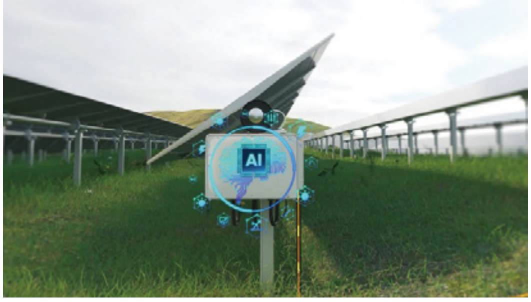



Figure 30 AI-enabled tracking support facilitating power generation

In terms of detection and diagnosis, the Smart I-V Curve Diagnosis function is combined with the UAV CV inspection function. Based on the analysis of the current and voltage curves of the PV strings, the infrared and visible light detection results are used to improve the efficiency of locating PV module faults and evaluating efficiency. For batteries, the AI-based BMS system can predict the risk and life of thermal runaways by analyzing the battery cell data, and optimize the charging and discharging strategies to prolong the service life of the batteries.

Figure 31 Combination of Smart I-V-Curve Diagnosis and UAV inspection

Power prediction mainly depends on radiation and temperature. Because solar radiation and temperature are affected by many meteorological characteristics, there are many uncertain factors. Prediction technologies that use AI technologies such as deep learning have obvious advantages over traditional methods in accuracy, usability, and flexibility.

In energy scheduling, the integration of PV, ESS, and charger gradually becomes a trend. In residential and C&I energy management, AI technologies enable power production and storage to better match the load curves, helping users increase the self-consumption rate and reduce the overall operating cost and carbon emissions. For power grids, thanks to the rapid development of renewable energy, especially distributed PV+ESS, massive heterogeneous data has been accumulated. Further processing of data through AI technologies helps realize intelligent distribution grids and provides support for power system control and decision-making.

The energy industry has gradually moved into a data-driven era. A consensus has been reached in the industry to better collect, utilize, and maximize the value behind data. AI, as one of the most typical technologies of intelligence, will play an important role in it.

## ▶ Application

Mengxu 200 MW PV power plant is located in Yuchai, Guangxi. The project adopts flat single-axis tracking supports. Due to the humid climate in Yuchai, the power generation capacity is affected by rainy days for a long time, while the traditional tracking supports cannot effectively improve power yields in rainy days. The Smart DC System (SDS) uses AI technologies to optimize the angle of the tracking support to effectively avoid the loss of energy yield in rainy days. After one year of usage, the energy yield is increased by 1.66% on average.

Figure 32 Mengxu 200 MW PV power plant in Yuchai, Guangxi,China

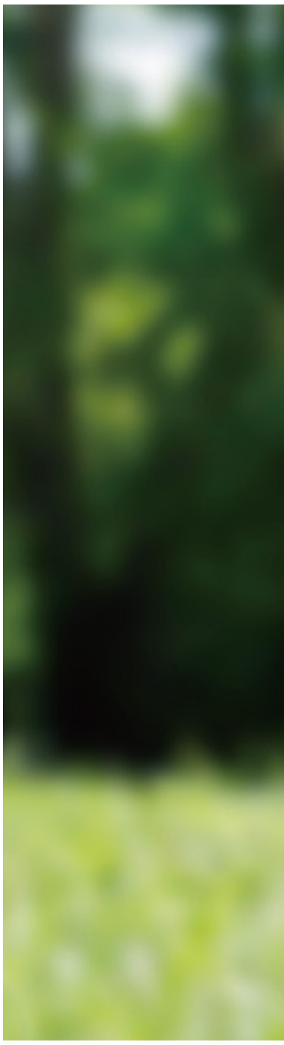
The 30 MW PV project of Asia Meranti Sdn Bhd, which is located in Perak, Malaysia, is scattered in three counties. Due to the large span of the site and insufficient staff, the O&M work of the site mainly focuses on broken modules found by manual site visits and disconnected strings found by the SCADA system. To effectively perform O&M, identify faulty PV strings, and improve power generation efficiency, the plant started to use the Smart I-V Curve Diagnosis technology at the end of 2019. Manual site inspection is replaced by remote scanning tasks, and the AI algorithm is used to analyze I-V characteristic curves to quickly locate and characterize faulty PV strings. This saves more than 2000 hours of manual labor hours for the plant per year.

Figure 33 The 30 MW PV plant in Malaysia

For distributed power generation, AI-based energy scheduling and collaboration of PV, ESS, and charger are drawing public attention and have been applied in some European countries. The AI algorithm is used to predict the optimal charging and discharging curves of the ESS based on the power generation forecast and load power consumption forecast data of the power plant, realizing the optimal power control of the PV & ESS system, maximizing the economic benefits of users, and expected to increase the comprehensive payback of owners by more than 8%.

# Conclusion

We should seize the moment and look to the future. The convergence of 5G, cloud, and AI technologies is shaping a world where everything is sensed, connected, and intelligent at a speed faster than we think. By taking insights into the top 10 trends for the PV industry, Huawei envisions a green and intelligent world within reach where every individual, organization, and enterprise concerned about green and sustainable development will gain some inspirations. Let's work together to achieve the carbon neutrality targets and build a green and bright future!





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