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FusionSolar

Smart PV & ESS Generator

White Paper

HUAWEI

Contents

01 Background and Trends

Currently, renewable energy such as PV and wind power are replacing traditional energy, and a clean, low-carbon, secure, and efficient new energy system is gradually built amid a new round of energy transformation. 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, renewable 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.

1/1 Typical Challenges Facing Power Grids in China and Some Countries

A high proportion of grid-connected renewable energy will have a certain impact on the stability of power grids in various countries. Typical problems include wideband oscillation, transient overvoltage, power quality deterioration, and power supply stability of islanded PV & ESS system. In many countries and regions, to improving the grid-related performance of power electronic power supplies such as wind and PV & ESS holds the key to the sustainable development of new energy.

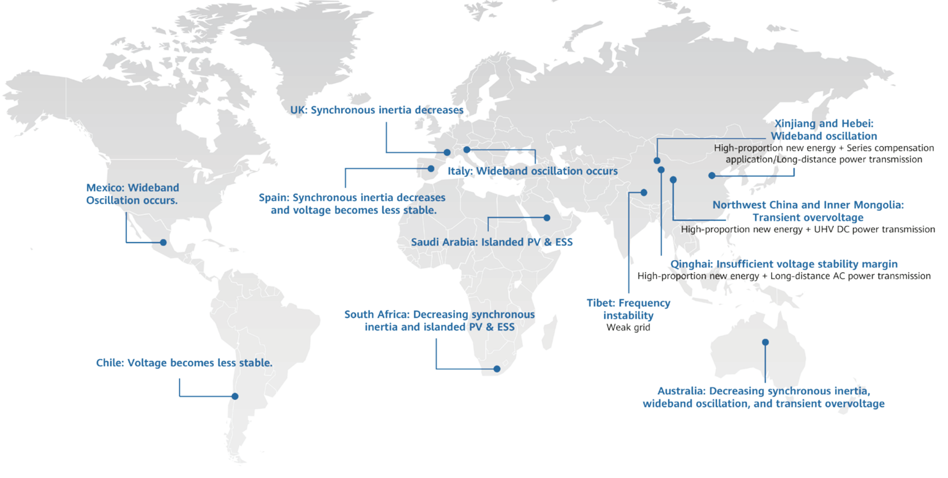


Figure 1 Typical challenges facing power grids in China and some countries

1/2 Huawei's Innovative Practices in the Grid Connection Technology

Huawei has long been committed to improving the safety and stability of new energy connecting to grid.It combines digital technologies with power electronics technologies, and cooperates with global power generation and power grid enterprises, and power user partners based on what it has accumulated in new materials, chip design, and active/passive components. By doing so, Huawei has continuously promoted the development of technologies oriented to grid connection.

Grid following

2014 Huawei completed the first distributed grid-tied harmonic test in the industry and passed the first GBT29319-2012 certification of China Electric Power Research Institute in the 9 MW project for CGN in Jiaxing, Zhejiang.

2014 Huawei cooperated with China Electric Power Research Institute and Qinghai Electric Power Research Institute in carrying out a series of tests, and passed the zero voltage ride-through test, low voltage ride-through test, frequency disturbance test and power quality test in a megawatt-level plant, making it the world's first inverter brand that has passed the zero voltage ride-through certification.

2015 Huawei applied the low short-circuit ratio adaptation algorithm for the first time in the industry in the Fengwei 100 MW PV plant project in Inner Mongolia.

Grid supporting

2018 The AI BOOST active harmonic suppression algorithm is developed to eliminate the risk of harmonic exceeding the threshold in weak power grids.

2019 Australia released a new power grid standard, which was said to be the strictest grid connection-standard in the world. Huawei obtained the admission license this year, making it the world's first and the only PV inverter brand in China.

2020 Huawei was granted the first GBT 37408-2019 certificate by China Electric Power Research Institute, and Huawei inverters became the first product that passed the appraisal of the new national standard in the industry. In the same year, Huawei worked with China Electric Power Research Institute to launch the weak power grid adaptability feature of PV inverters (SCR = 1.5) to ensure the plant stability under transient and steady-state impact in extremely weak power grids, avoiding chain faults and improving new energy consumption margin.

2021 Huawei obtained the first series compensation adaptability algorithm certification by China Electric Power Research Institute (SCCR = 0.7, SCR = 1.2), improving the stability and margin of long-distance AC power transmission.

Grid forming

2021 Huawei participated in the Research on Large-Scale Energy Storage Supporting Safe and Stable Operation of Power System with a High Proportion of Renewable Energy led by Qinghai Electric Power Company, which carried in-depth study on the impact of hardware specifications and control policies of the electrochemical energy storage system on power grid safety and stability, and new energy consumption margin.

2022 Huawei participated in the construction of the world's first GWh-level microgrid project using grid-forming technologies in Red Sea New City, Saudi Arabia.

2023.1 At Gonghe, Qinghai, China, Huawei cooperated with China Electric Power Research Institute, Qinghai Electric Power Research Institute, and China Resources Power to complete the world's first onsite test of the grid-forming PV & ESS, which proved that the grid-forming new-energy power generating system played a key role in strengthening the operation of the power grid and achieving high proportion of renewable energy consumption.

02 Major Challenges

The new power system with new energy as the main source is crucial to achieving the goal of carbon peak and carbon neutrality. Compared with synchronous generators, new energy features low controllability and low rotation inertia. As the penetration rate of new energy increases, the traditional new energy system cannot proactively support the voltage and frequency like synchronous generators when a fault occurs. As a result, it is increasingly difficult for the traditional new energy system to meet the development requirements of the new power system, which brings great challenges to the safe and stable operation of the power system.

2/1 High-proportion new energy is transmitted through UHV DC which worsens transient overvoltage at the transmit end

UHV DC transmission plays an important part in China's West-to-East Power Transmission Project. As clean energy bases develop at scale, there is increasing need for high-proportion new energy transmission through UHV DC. However, due to the commutation failure of the UHV DC system, the transient overvoltage is likely to occur in the power grid at the transmit end.

Under the weak synchronization support environment for the high-proportion new energy, the influence of the reactive power response feature of new energy on the voltage distribution at the grid connection point increases due to insufficient synchronous power supply. Compared with the transient voltage regulation function of the synchronous generator, the traditional PV & ESS system, featuring slow reactive power response and weak voltage regulation during the fault ride-through, cannot effectively suppress the transient overvoltage in case of the DC commutation failure. By contrary, the traditional PV & ESS system leads to reverse power flow caused by control delay and worsens overvoltage at the grid connection point, which restricts the access to and consumption capabilities of new energy power generation.

At present, China has accumulated rich experience in the construction and operation of UHV DC transmission projects, and the power generation capacity of some projects is limited due to transient overvoltage.[1] Taking the Jarud Banner-Qingzhou UHV DC transmission project for example, the simulation results show that when the new energy is generated and the DC commutation fails, the power grid enters the low voltage state first, and the new energy generator enters the low voltage ride-through condition to generate reactive power. After the DC control policy is adjusted, the reactive power surplus at the transmit end causes the power grid to enter the high voltage state. However, the new energy device cannot absorb the reactive power immediately, which further increases the overvoltage level. Finally, the overvoltage may reach 1.3 p.u. or higher, leading to device shutdown for protection.

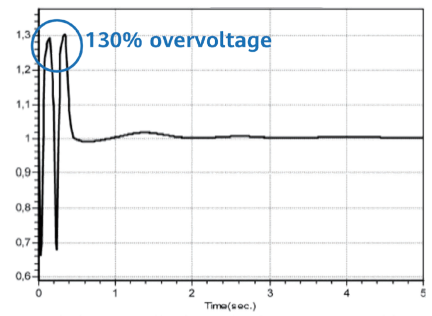


Figure 2 Overvoltage caused by continuous commutation failure in the Jarud Banner 500 kV project

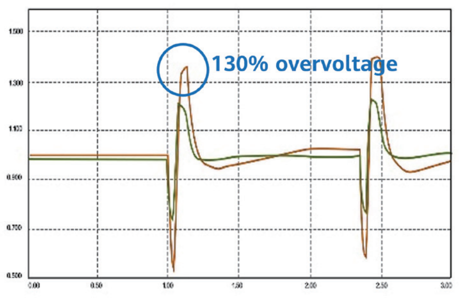


Figure 3 Overvoltage occurred in the local new energy plant near of Jarud Banner

2/2 High-proportion new energy is transmitted over a long distance through the AC power grid, which causes insufficient voltage stability margin

The power flow is transmitted at a large scale and over a long distance through the AC power grid. When the reactive power cannot meet the system requirements, the system voltage will be unstable. Especially when the AC transmission line is faulty, the transmission limit of the transmission line decreases due to the sudden increase of impedance. The synchronous generator can regulate voltage instantaneously and maintain the phase without sudden change. Therefore, when the AC line is faulty, the synchronous generator has strong capabilities to control reactive power and active power, thus ensuring that the PV curve runs within the stable voltage range.

A common PV & ESS system only controls the power instead of phase during the operation, and cannot actively adjust the voltage. As a result, the active power and reactive power cannot be controlled at the moment when the AC line is faulty. When the transmission capacity of the PV plant exceeds a certain threshold, the voltage stability margin of the system is insufficient, which may cause voltage breakdown. In order to maintain voltage stability, the system needs to limit the output power of the PV plant to not exceed the static stability limit, thus limiting the output capability of new energy.

With abundant PV and wind power, Haixi Autonomous Prefecture in Qinghai province serves as a major base for centralized new energy transmission of Qinghai Electric Power Company. It has a long electrical distance for the transmission line and there is no synchronous generator in the near area for voltage support. Qinghai Electric Power Company analyzes the static stability of 750 kV networking lines from Xinjiang to northwest China[2]. The research shows that when an N-2 fault occurs on an external transmission line, voltage instability will occur in Haixi, which limits the output capability of new energy there.

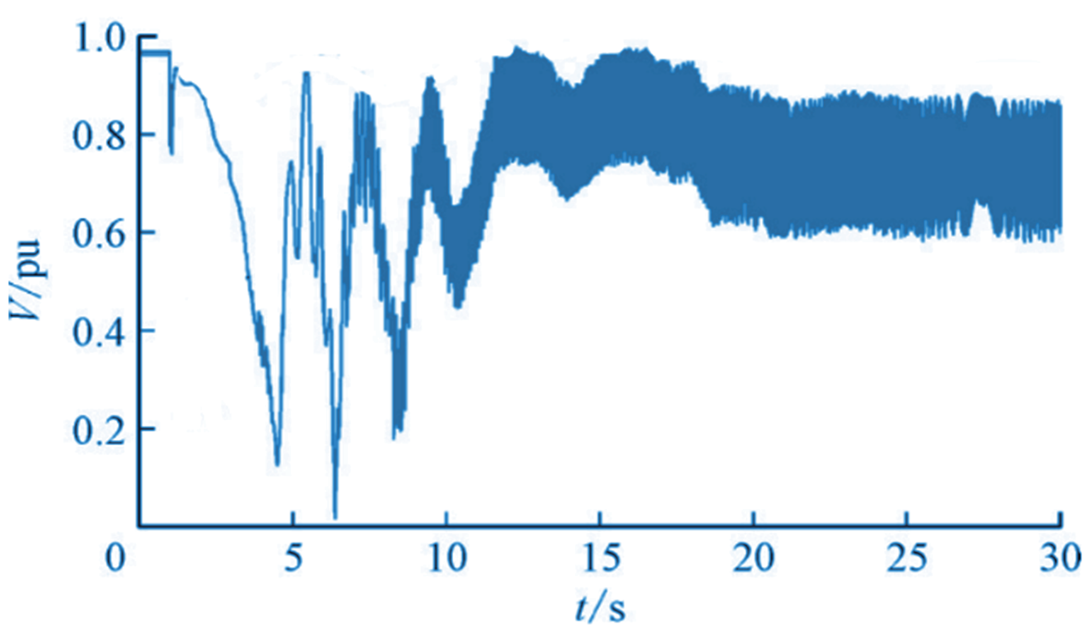


Figure 4 Voltage instability caused by an N-2 fault on a 750 kV transmission line in Haixi

2/3 The low-inertia system at the transmit end of high-proportion new energy makes it more difficult to stabilize frequency

High-proportion new energy is connected in a centralized manner and UHV DC is widely applied. This causes the transmit to shift from a traditional power system that mainly uses mechanical and electromagnetic components to a new power system that contains a high proportion of power electronic components, reducing the system inertia. The frequency stability problem of low-inertia system is increasingly prominent due to the strong uncertainty of output and weak active power support capability. When the system is disturbed by active power, the generator rotor-bearing system can provide powerful inertia to support system without out-of-synchronization, respond to system active imbalance instantaneously, so as to keep the system frequency stable.

Conventional PV & ESS systems use non-synchronization power supply, which cannot provide inertia support and slow down frequency change under active disturbance. In particular, in a "strong DC and weak AC" networking system, when the DC system is faulty, PV power is transferred to the AC transmission line at large scale. The weak inertia support of the transmit end system increases the rotor angle difference between the transmit and the receive ends. In serious cases, the power angle may be unstable.

For example, a large-scale power outage occurred in the UK at about 5 p.m. on August 9, 2019 (local time). The accident stemmed from the line shutdown caused by lightning strikes. As a result, the Hornsea wind farm was disconnected from the power grid and the gas power generators of the Little Barford plant was shut down unexpectedly. This exceeded the frequency adjustment capability of the power grid. Before the accident, the frequency change rate calculated based on the UK power grid inertia (H = 210 GVA/s) was 0.135 Hz/s, which triggered the protection start threshold of some new energy sources. The power grid was further disconnected and the accident scope was expanded. As a result, the frequency decreased to 48.8 Hz, triggering low-frequency load shedding. Power outages occurred in most areas of England and Wales, affecting about 1 million people[3].

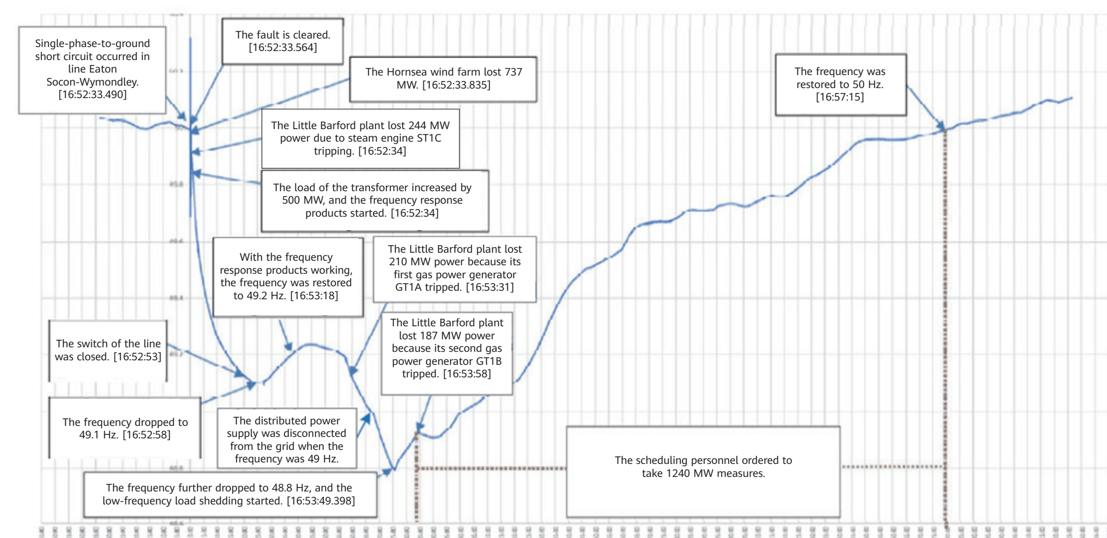


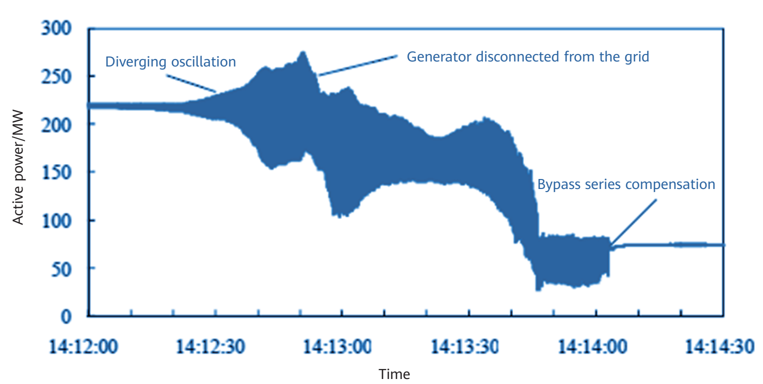
Figure 5 Timing and frequency changes during the power outage on August 9 in the UK

2/4 Multiple power regulation devices add up to wideband oscillation

With the continuous increase of new energy share, multiple power regulation devices between power electronic devices and between power electronic devices and grid, weak or even negative damping may occur on a wider frequency band. This makes the electrical quantity fluctuate with the time period, which leads to the wideband oscillation. The oscillation of synchronous generator is generally caused by oscillation of excitation control, oscillation of speed regulation system, and torsional oscillation of shafting. The oscillation frequency is mainly low frequency oscillation and sub-synchronization oscillation. After large-scale new energy is connected to the power grid, the system oscillation problem becomes more complex because power electronic devices have multiple control modes, such as

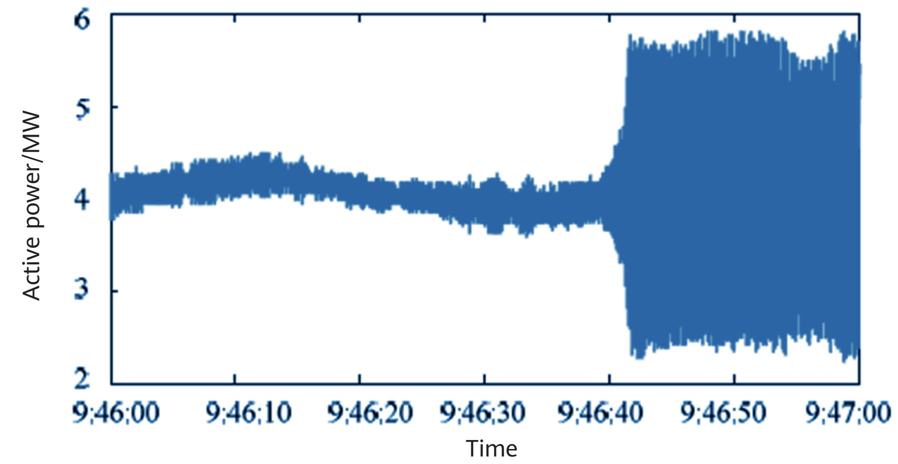
- When the conventional PV & ESS system transmits power through AC over a long distance, low-frequency oscillation occurs due to insufficient damping of the system.
- In order to adapt to the AC long-distance transmission scenario, the series capacitance compensation devices hold the key to improving the transmission capability. The series compensation surge and the interaction between power electronic devices are likely to cause subsynchronous oscillation.
- When the conventional PV & ESS system transmits power through UHV DC, the converter interacts with the DC control system. In this process, the negative damping is introduced, which is likely to cause supersynchronous oscillation.

For example, over 100 sub-synchronous resonances have occurred due to the interaction between wind turbines and series compensation power grids in wind farms in Guyuan, Hebei, China since 2011. The frequency ranges from 3 Hz to 10 Hz, causing abnormal vibration of transformers and disconnection of a large number of fans from the power grid. Since 2015, sub-synchronous oscillations involving wind turbines have frequently occurred in Hami, Xinjiang, China. The frequency ranges from 20 Hz to 40 Hz, and the sub-synchronous oscillation power passes through multi-level power grids, even causing torsional vibration of shaft system of steam turbines and UHV DC power slump[4-5].



(The oscillation gradually stops after a set of bypass series compensation devices exit)

Figure 6 Power oscillation of a wind farm in Guyuan, Hebei



(The generator trips due to protection against torsional vibration)

Figure 7 Power oscillation of a wind farm in Hami, Xinjiang

2/5 Islanded new energy is operated with unreliable and unstable power supply

China's power system has been developing rapidly for many years, making it one of the most advanced countries in power supply reliability. In general, power is generally supplied uninterruptedly in all sectors of society. However, 1 billion people still lack access to reliable power supply in Asia, Africa, and Latin America. In particular, some remote and plateau areas are not covered by power grids (especially salt lake areas in plateaus enriched with more than half of the world's lithium resources). In some developed countries, the generator failure rate increases year by year due to problems such as old facilities, improper maintenance, and personnel shortage. In some areas, the power supply is even less than 60% of the demand, and the power outage lasts for 6 to 10 hours every day. In these areas, people have to rely on the D.G. for a long time to solve the problem of power shortages. Under this background, from the perspective of reliability and cost-effectiveness, the use of PV & ESS of new energy becomes a new choice to improve power supply.

For a long time, the PV & ESS system, as a supplement to synchronous generators, does not actively bear the disturbance in the power system. For islanded new energy power grids, anti-disturbance is where attention should be paid. From the perspective of conventional power systems, the islanded new energy system features low inertia and low short-circuit capacity. Maintaining stable frequency and voltage is the top priority. In addition, the PV & ESS of new energy uses the power electronic converter as the power generation unit, which introduces the complex AC-DC coupling problem to the system. For example, due to the lack of isolation, the abnormal fluctuation of the AC voltage disturbs the DC side, resulting in the conflict of AC and DC power control. As a result, large-scale power grid disconnection occurs. A large number of harmonics are generated when inductive motors and transformers are put into the power grid or when the power grid is short-circuited. This interferes with DC voltage control and may cause large-scale grid disconnection. The capacity of a single unit in the PV & ESS is small, and it is difficult to quickly start the system after an abnormal power failure. The IGBT overcurrent capability is weak, and the transient power angle of the power generation unit is not universally defined. As a result, the power plant in the system is out of synchronization.

03 Smart PV & ESS Generator Solution

To cope with the preceding challenges, Huawei has launched its innovative Smart PV & ESS Generator solution by leveraging its expertise in PV, energy storage, and particularly, grid forming technologies.

3/1 Voltage Stability Technology

Synchronous generators have the subtransient characteristic. When a fault occurs, the internal potential remains unchanged, and a large amount of reactive power can be generated or absorbed transiently. Synchronous generators also have the transient characteristic. When the voltage drops sharply due to a severe fault in the system, the excitation system enters the strong excitation state to provide emergency reactive voltage for the system. The increasing proportion of renewable energy poses severe challenges to voltage stability. The voltage support capability of PV & ESS systems needs to be redefined.

Voltage establishment technology

To imitate the voltage establishment process of synchronous generators, the Smart PV & ESS Generator converts the traditional current control to voltage control by inputting a given voltage and phase. Therefore, for the grid system, the Smart PV & ESS Generator is a voltage source capable of voltage establishment.

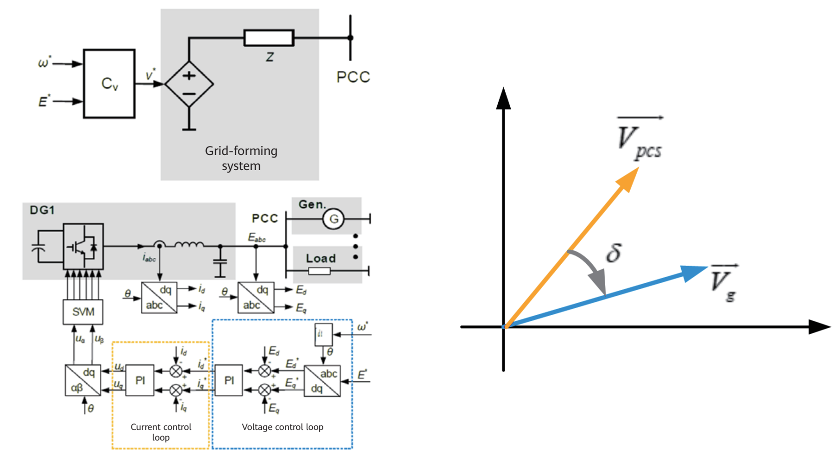


Figure 8 Basic control diagram of grid forming technologies

Fast reactive power response technology

Similar to synchronous generators, the Smart PV & ESS Generator adjusts its internal potential to control the terminal voltage and reactive power of the generator. The internal potential consists of three parts. The first part is the terminal voltage when the converter runs without load. The second part is used to control the reactive droop for terminal voltage during primary voltage regulation. The third part is the output of the terminal voltage regulating unit, which is equivalent to the excitation regulating process of synchronous generators. The reactive power regulation process of the Smart PV & ESS Generator is completely different from the control policy for conventional current sources. Voltage detection and phase sequence decomposition are not required. By controlling and adjusting the internal electric potential, quick reactive power response is possible during fault ride-through. The onsite test results in Qinghai, China in January 2023 show that Huawei's Smart PV & ESS Generator technology can respond to reactive current within 10 ms during the voltage dip of the power grid, supporting quick recovery of terminal voltage.

High-current transient support technology

Synchronous generators can immediately generate reactive power several times the rated capacity to support the power grid during a fault period because the subtransient reactance and transient reactance are small and the stator and rotor have certain overload capabilities. However, power electronic equipment basically does not have overcurrent withstand capability. Therefore, conventional PV & ESS systems can only provide reactive current approximately equal to rated current during fault ride-through. Huawei Smart PV & ESS Generator uses the voltage synchronization technology to enable multiple string PCSs to run stably in parallel without circulating current. In addition, due to the small granularity of string PCSs, the reactive current can be 1 to N times the rated current. The onsite results in Qinghai, China show that Huawei's Smart PV & ESS Generator technology can quickly provide a short-circuit capacity three times the rated capacity during the voltage dip of the power grid, improving the transient current support capability.

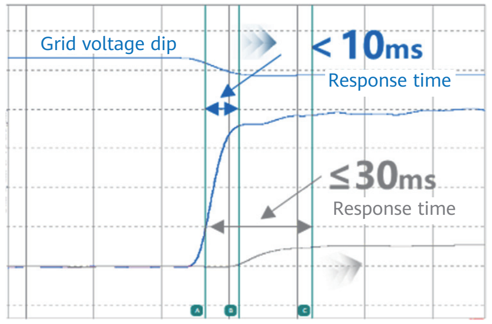


Figure 9 Fast reactive current response of the Smart PV & ESS Generator

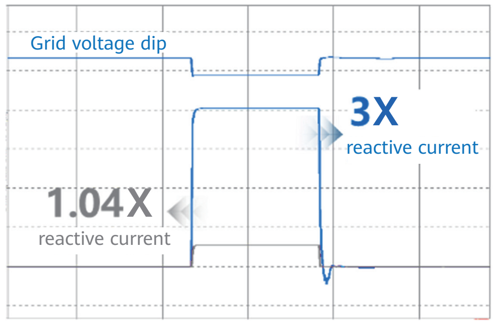


Figure 10 High-current transient support of the Smart PV & ESS Generator

Bipolar conversion architecture

Due to faults such as ultra-high voltage (UHV) DC commutation failure or even locking, transient overvoltage may occur on the power grid at the transmit end. If the PV & ESS system does not have the effective active power control capability during high-voltage ride-through (HVRT), the reactive power of the system may be more excessive and the overvoltage level of the system may be deteriorated. For an ESS, when AC overvoltage occurs on the power grid side, the DC bus voltage of the ESS increases instantaneously. As a result, the ESS output power will be reduced or even reversed. Huawei Smart PV & ESS Generator adopts the DC/DC and DC/AC bipolar conversion architecture. When the power grid voltage increases, the overvoltage is conducted to the DC bus side of the converter. The boost voltage does not affect the battery voltage. Therefore, the active power can be more stable during HVRT, lest the performance deterioration of the controller causes more excessive reactive power.

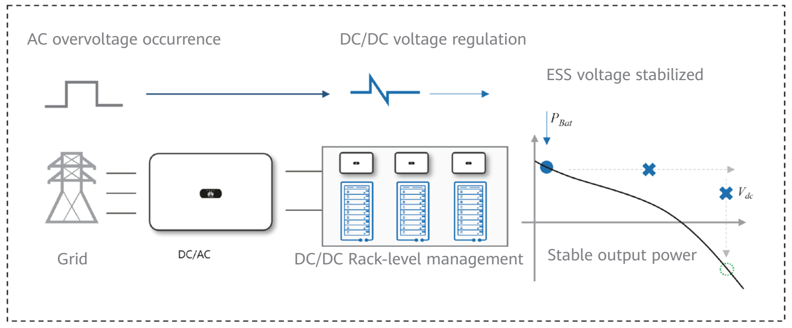


Figure 11 Bipolar architecture improves active power control capability

3/2 Frequency Stability Technology

Synchronous generators have a large inertia. By adjusting the mechanical torque, synchronous generators can generate or absorb a large amount of active power instantaneously, and provide short-time active power support in response to the frequency change rate of the system. Synchronous generators also have a speed adjustment system, which uses a frequency regulator to respond to the frequency deviation of the power grid. When the frequency drops sharply due to a severe fault in the system, synchronous generators perform primary frequency response (PFR) to provide continuous active power support in response to the frequency deviation of the system. With the high penetration rate of renewable energy, the inertia and PFR capability of the power grids are decreasing, severely compromising frequency stability. Therefore, the frequency support capability of the PV & ESS system needs to be redefined.

Virtual inertia support technology

The mechanical motion equation of synchronous generators is imitated using control policies based on the virtual inertia J and damping coefficient D of the Smart PV & ESS Generator. In this case, the PV and energy storage batteries can be compared to a prime mover, and the converter is equivalent to a generator. In this way, the two-stage model of synchronous generators can be imitated. The frequency change of the system is usually caused by the impact of unbalanced power. In this process, the Smart PV & ESS Generator also senses the effect of unbalanced power. Under the effect of unbalanced torque, the Smart PV & ESS Generator actively and quickly injects electromagnetic power into the power grid to imitate the changes in the kinetic energy of the rotor and implement inertia support for the system. Different from those of synchronous generators, the parameters of the power electronic equipment are less prone to hardware limitation. Therefore, the virtual inertia J and damping coefficient D of the Smart PV & ESS Generator can be set flexibly to adapt to different operation scenarios and improve the frequency control of the system. The field test results in Qinghai, China show that Huawei's Smart PV & ESS Generator technology can achieve inertia power output when the power grid frequency drops at 0.5 Hz/s.

Active fast PFR technology

The PFR of the Smart PV & ESS Generator can imitate the speed regulator of synchronous generators and calculate the deviation instruction of the mechanical power by detecting the frequency difference to control the droop of the active power and system frequency. The active power regulation of the Smart PV & ESS Generator is different from the PQ control policy of conventional current sources. Based on the tracking of feed-in power, the Smart PV & ESS Generator can adjust the active power based on the frequency deviation at the grid connection point, effectively improving the capability of the PV & ESS system to cope with frequency exceptions. The field test results in Qinghai, China also show that Huawei's Smart PV & ESS Generator technology can achieve faster and stronger active power response and support system frequency recovery through virtual inertia response and fast PFR during power grid frequency drop.

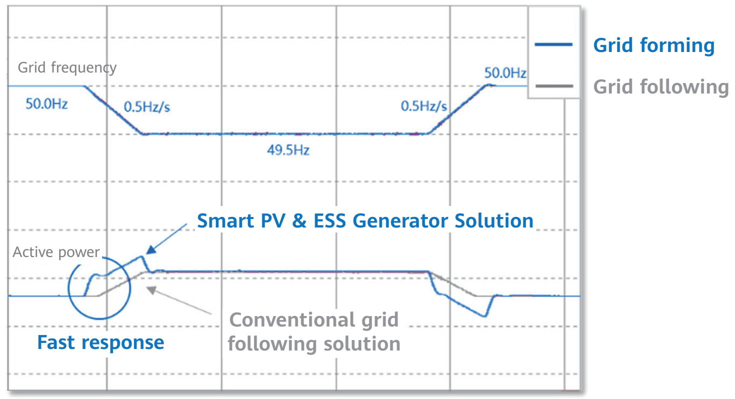


Figure 12 Frequency response capability comparison between the Smart PV & ESS Generator and the conventional PV+ESS system

3/3 Wideband Oscillation Suppression Technology

Currently, some countries and regions have released power oscillation suppression requirements on grid forming technologies. For example, some PV & ESS system in Europe need to provide 0.3–2 Hz active power oscillation damping (POD) and reactive POD capabilities. Regardless of low-frequency oscillation, subsynchronous oscillation, or supersynchronous oscillation, the core is to provide a function of suppressing power oscillation through controllable damping, so as to cope with the wideband frequency oscillation risk caused by the connection of a high proportion of power electronic devices.

Low-frequency POD technology

Generally, a power system stabilizer (PSS) is added to the excitation system of synchronous generators to form an additional damping control to improve the system damping and suppress low-frequency oscillation. Based on this principle, the low-frequency POD technology is introduced to the power plant controller (PPC) to enable the PV & ESS system to have the PSS function of synchronous generators and output additional damping control power. In this way, the low-frequency oscillation from 0.1 Hz to 2.5 Hz is suppressed. The following figure shows the simulation effect of low-frequency POD in PPC.

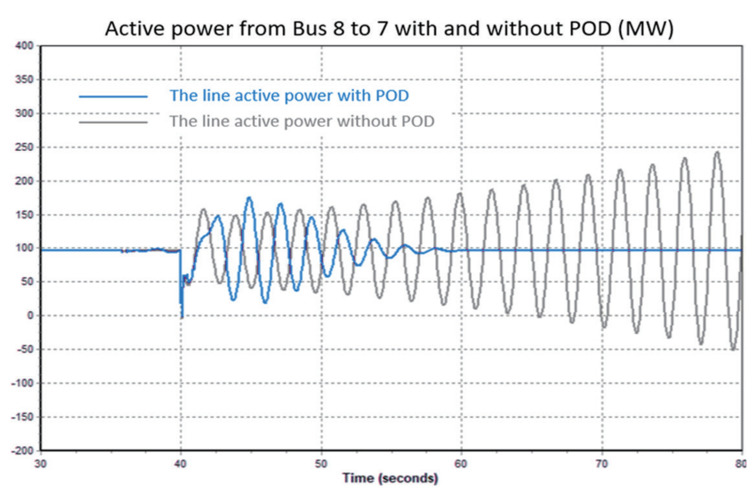


Figure 13 Power suppression effect of low-frequency POD

Adaptive virtual impedance technology

To solve the subsynchronous/supersynchronous oscillation, Huawei Smart PV solution uses the adaptive virtual impedance technology to dynamically adjust the electrical characteristics of the plant through AI self-learning to match the power grid characteristics. In this way, the inverter and PCS can actively adjust their impedance and change the amplitude-frequency and phase-frequency characteristics of the output impedance to improve stability. This prevents power oscillation caused by insufficient damping in the subsynchronous/supersynchronous frequency bands.

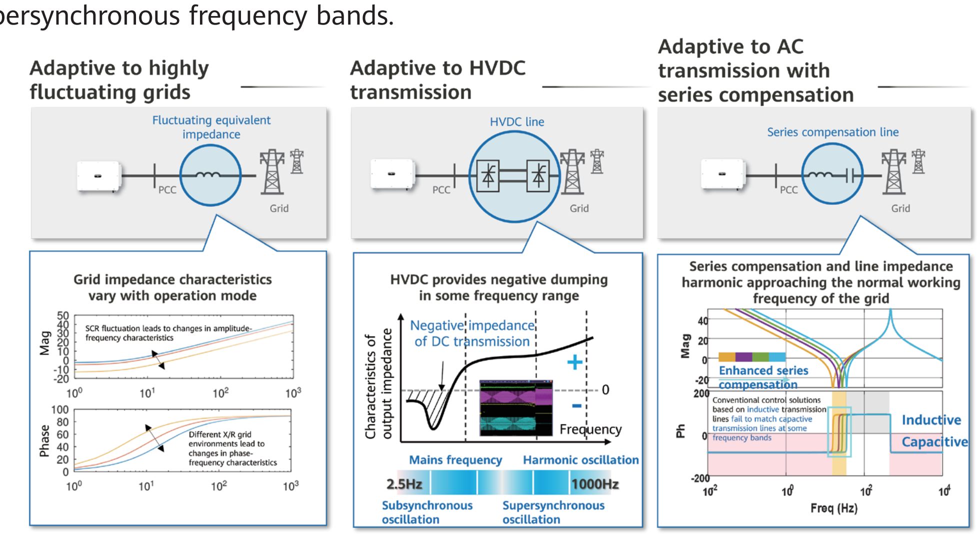


Figure 14 Adaptive virtual impedance technology

3/4 Fault Ride-through Technology in 100% Power Electronics System

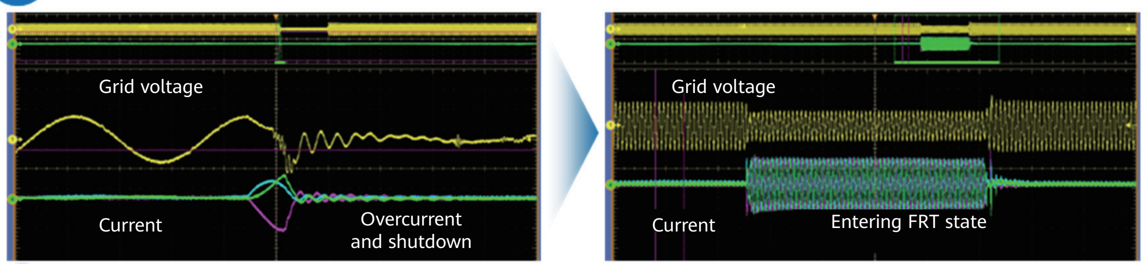
In common grid-tied renewable energy systems, fault ride-through is the most complex technology and has the greatest impact on the operation margin of the power system. This is also true for 100% renewable energy islanded power grids. However, the challenges of fault ride-through in 100% power electronics systems are much more severe than those in grid-tied systems.

	Grid-tied System Voltage, Frequency, and Phase Are Mainly Maintained by Synchronous Generators	Islanded System Voltage, Frequency, and Phase Are Maintained by Renewable Energy Systems
Short circuit fault occurrence	The main challenge is to accurately identify phase jumps and ensure accurate subsequent phase tracking.	When voltage source control is used, the overcurrent risk of power electronics equipment is higher, and the current level of semiconductor devices needs to be suppressed quickly.
Short circuit fault period	Reactive and active currents need to be injected according to the grid connection standard. Fault ride-through occurs repeatedly.	The short-circuit current is very low, the residual voltage of the faulty system is low, and the power supplies are more likely to lose synchronization. An islanded system may not be characterized by inductiveness. Injection of reactive power may not effectively increase the voltage, and even cause control saturation. As a result, the islanded system loses the control margin and breaks down. For the ESS, the AC and DC voltages may be coupled due to abnormal voltage fluctuations. Improper handling may cause conflicts between the battery and PCS control directions, resulting in unstable control.
Short circuit fault clearance	Overvoltage needs to be suppressed to restore active output.	After the fault is rectified, the voltage recovers. High-volume transformer magnetization and simultaneous connection of a large number of loads cause secondary transient impact. The phase of each power supply changes significantly, easily resulting in the loss of synchronization. Because part of the grid was cut off after the fault occurred, the original matching relationship between the power supplies and the loads no longer exists. As a result, the frequency and voltage are distorted again, causing other chain reactions.

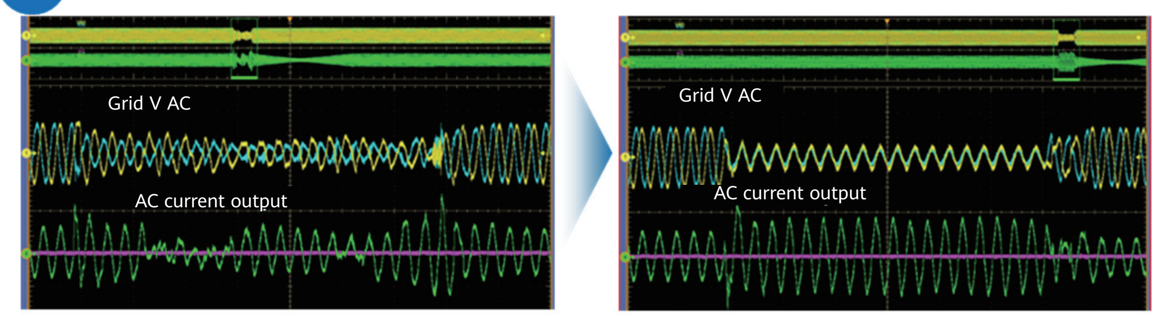
Figure 15 Comparison between grid-tied systems and islanded systems during fault ride-through

Off-grid fault ride-through is the biggest challenge in large-scale islanded power grids. Currently, there is no mature mechanism or standard to refer to around the world. By applying multi-disciplinary technologies, Huawei fully covers the microsecond to second-level dynamic process during fault ride-through. Currently, fault ride-through is feasible in a multi-source high-voltage power generation and transmission system composed of 100% power electronics devices. These technologies include high-overload IGBT packaging, IGBT dynamic current limiting, AC/DC voltage isolation, short-circuit energy matching, dynamic pulse-width modulation (PWM) mechanism, resynchronization after loss of synchronization, and microgrid adaptive dynamic derating.

1 IGBT-level: Transient current limiting for device-level safety



2 Device-level: Avoiding control saturation to maintain grid forming capability



3 System-level: Post-fault synchronization algorithm

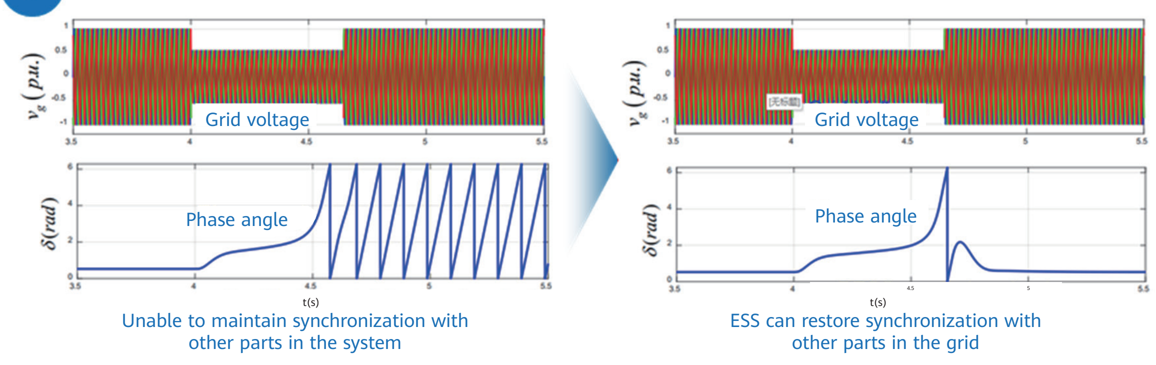


Figure 16 Multiple off-grid fault ride-through technologies

3/5 Batch Black Start Technology

After the entire power system fails due to external or internal faults, only the power supply with the black start capability in the system is used to drive the power supplies without the black startup capability in the power system, gradually expanding the system recovery scope until the entire power supply is restored. This process is called black start.

In a conventional power plant, a single generator set has a large capacity. After the black start of a single generator set, the generator set alone can drive the transformers, lines, and power loads in a large area. Therefore, the operation is relatively simple in terms of the electrical process during the black start. However, the minimum capacity of an ESS array (battery containers and PCSs connected to the same medium-voltage transformer) is only 2.5–6 MW, which is too low. The connection of any load or transformer can easily cause overload and system breakdown again. Therefore, for an islanded power grid with a capacity larger than 10 MW, multiple ESS arrays must perform black start synchronously to provide adequate capacity for the subsequent connection of loads and generators.

To implement batch black start of multiple ESS arrays, two major challenges need to be overcome: synchronous voltage establishment and impact caused by the connection of transformers and loads. In a black start process, each ESS PCS aims to control the voltage. However, due to instruction synchronization and voltage control precision problems, the voltage establishment process of different PCSs may not be synchronous, causing voltage differences. Because the electrical distances in each ESS array and between ESS arrays are short, a slight voltage difference easily generates noticeable circulating current. As a result, the PCSs shut down due to overcurrent (Figure 17). Electrical distances are determined by the physical wiring and cannot be changed. Therefore, the key to batch black start is to improve the consistency of voltage output.

Huawei has developed a voltage synchronization technology that does not rely on the synchronous parallel cables. This technology enables multiple PCSs to perform automatic and synchronous voltage control and voltage sampling calibration during the black start process without increasing the project cost. Meanwhile, based on the hardware communication protocol, the black start instruction from the upper-level EMS can be transmitted to all ESSs with approximately the same delay. Based on these two mechanisms, the consistency of voltage control is greatly improved, and circulating current is minimized (Figure 18). In the Red Sea project in Saudi Arabia, Huawei has implemented synchronous startup of more than 1000 PCSs. The black start of the entire 100 MW system takes only 10 minutes.

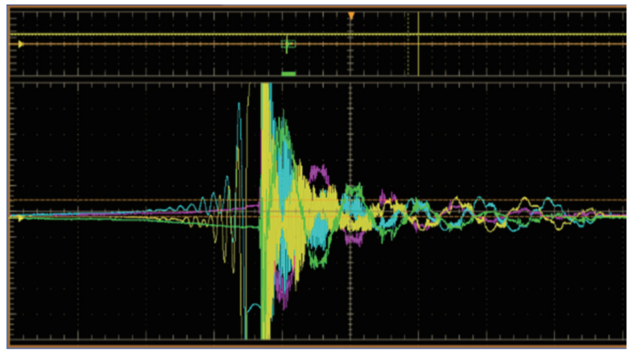


Figure 17 In the conventional solution
a slight voltage difference may cause noticeable circulating current

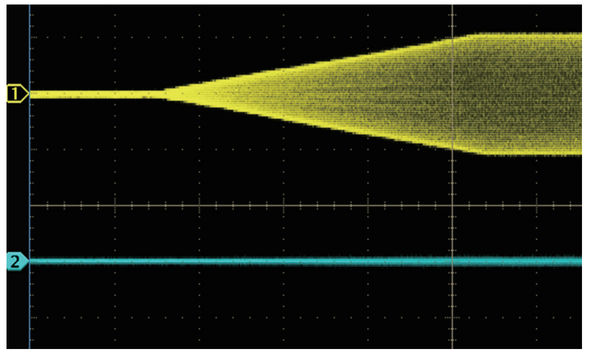


Figure 18 Huawei solution minimizes circulating current

3/6 Active Harmonic Suppression Technology

Conventional PV & ESS systems mainly reduce the harmonic current injected into the power grid through harmonic current control. However, in a weak grid environment, connecting multiple renewable energy power plants to the same point of common coupling (PCC) increases the harmonic current at the PCC. In addition, the harmonic impedance of the system increases, causing continuous increase of harmonic voltage. Therefore, the existing harmonic current control method can only avoid deteriorating the harmonic voltage of the power grid as much as possible, but cannot improve the background harmonic voltage of the power grid.

Huawei's Smart PV & ESS Generator leverages years of Huawei's expertise in software algorithms and weak grid operation experience in the communications industry, precise mathematical models for different types of grid connection scenarios, plant design, and grid operation. Huawei also trains the optimal grid connection control algorithm using big data, provides active harmonic damping effect using the advanced active harmonic suppression technology, and improves the voltage quality of the power grid by controlling the current harmonic path and absorbing harmonic current. In this way, the Smart PV & ESS Generator has the function of absorbing harmonics similar to that of synchronous generators. The grid connection harmonic voltage THDu < 1.5%.

The power plant generates only active power.

There are non-linear loads near the PV plant.

Conventional control algorithm

Active harmonic suppression

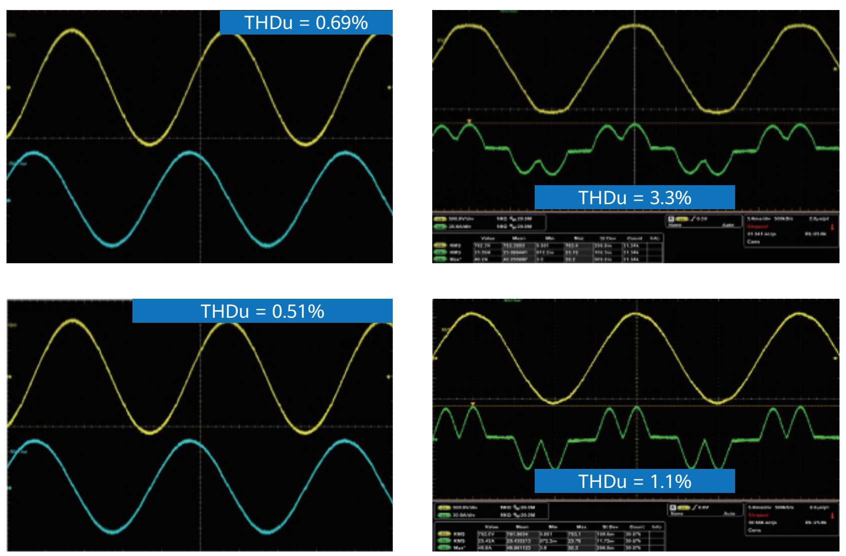
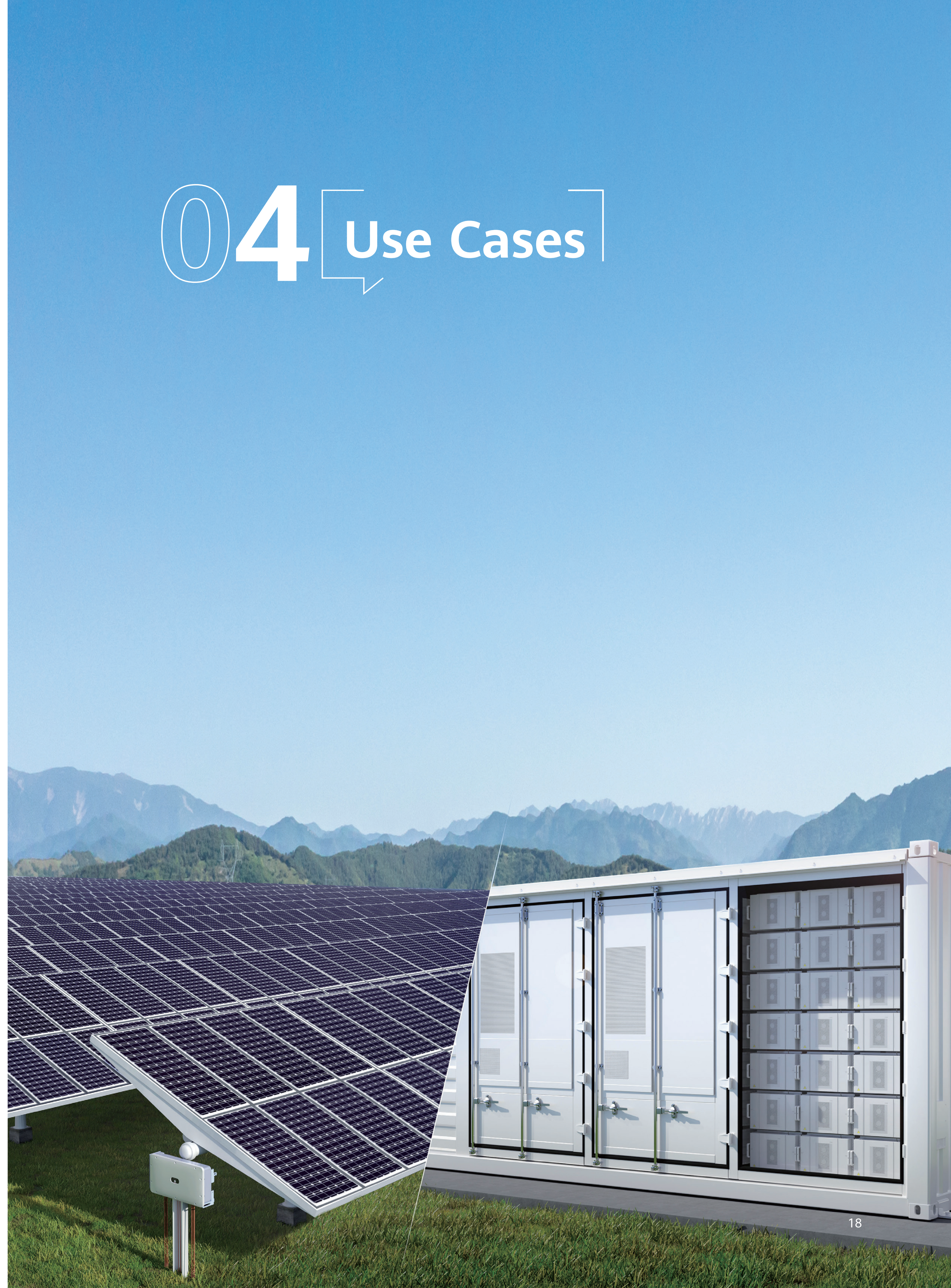


Figure 19 Comparison between the active harmonic suppression technology and the conventional solution



04 Use Cases

4/1 Qinghai, China

Qinghai has rich renewable energy resources and two ten-million kW-level PV bases. There is a strong demand for renewable energy transmission. As early as 2014, Huawei's 200 MW PV plant in Gonghe, Qinghai successfully passed tests such as zero voltage ride-through (ZVRT) and LVRT. Huawei inverters demonstrated excellent performance in weak grid connection and were highly recognized by the owner.

In recent years, Qinghai Province has built strengths in the entire chain of renewable energy industry with an increasing proportion of renewable energy. By the end of 2022, Qinghai Province has installed 28.14 million kW of renewable energy plants, accounting for 63%. However, due to concerns on the safe and stable operation of the power system, the pressure of renewable energy is increasing every day. On the one hand, the synchronous generators with strong support function planned in the early stage of Qingyu DC transmission line in Hainan Tibetan Autonomous Prefecture, Qinghai, were not put into production as scheduled. Moreover, the power supplies in the nearby areas were all renewable energy. As a result, the commutation failure of the Qingyu DC transmission system causes fast changes in the fault voltage, during which reactive power inversion occurs, further deteriorating overvoltage and causing grid disconnection or even device damages. On the other hand, there is no conventional synchronous power supply in Haixi region of Qinghai. After the DC commutation in Jiquan, Xinjiang fails or the N-2 channel between Xinjiang and Northwest grid is faulty, the power flow is transferred to Haixi, Qinghai, causing low voltage problems.

Based on the actual operation status of Qinghai, the power grid company released technical requirements for renewable energy power plants in 2020 according to the Code on Security and Stability for Power System (GB 38755-2019). Renewable energy power plants in Qinghai must meet the frequency and voltage withstand requirements as well as high and low voltage ride-through and continuous ride-through requirements to ensure the safe and stable operation of the power system. Huawei optimized the inverter performance from multiple aspects for the full-grid operation scenario and performed performance tests for the generators in Hongqi Plant I. It took only two hours to complete all the tests, and Huawei inverters passed all the tests in one attempt.

Figure 20 Huawei participated in the grid connection test of the Qingyu DC generators

To further improve the renewable energy consumption capability of Qinghai Province, China's National Energy Administration commissioned Qinghai Electric Power Company to carry out the research on large-scale energy storage supporting safe and stable operation of power systems with high-proportion renewable energy in 2021. As a team member, Huawei actively participated in research, evaluated the feasibility of technical specifications, and helped complete electromagnetic simulation verification and key technology verification for voltage-supporting energy storage. The research results show that the voltage-supporting energy storage has effectively improved renewable energy consumption and DC transmission capability of Qinghai Power Grid, filling the gap in China's DC transmission.

Based on the Smart PV & ESS Generator solution developed by Huawei, Huawei worked with China Resources Power on the continuous verification and demonstration of the research topics under the guidance of China Electric Power Research Institute and Qinghai Electric Power Research Institute in 2022, and completed the world's first grid forming PV & ESS system test at Gonghe PV plant in Qinghai in January 2023. The tests include parallel stability of the grid forming system, one-time and multi-time high/low voltage fault ride-through, PFR, and inertia response tests. The tests fully verify that the grid forming renewable power generation systems are critical to support grids with a high proportion of renewable energy, marking a milestone in the development of renewable energy.

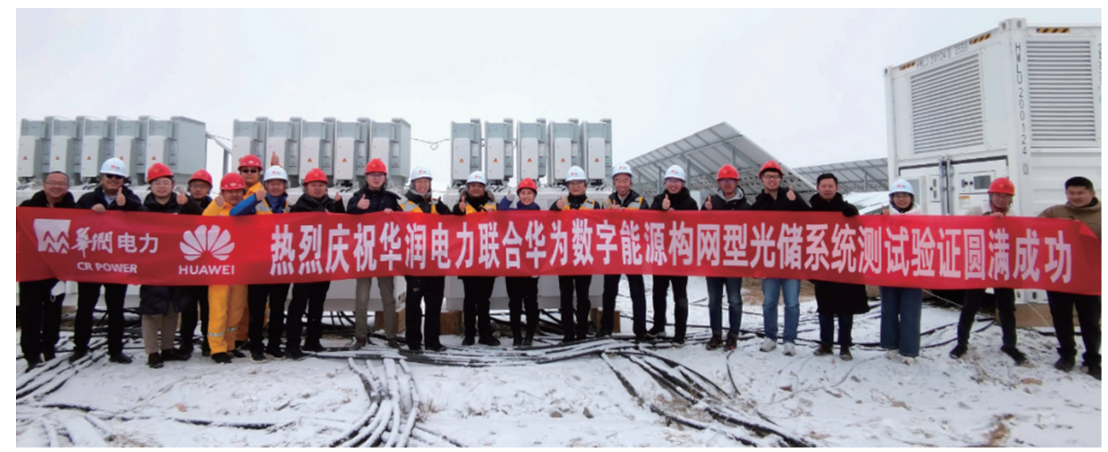


Figure 21 Completion of grid forming PV & ESS system tests in Gonghe, Qinghai

4/2 Saudi Arabia

The Red Sea project is a key infrastructure project planned in the Saudi Vision 2030. Red Sea utility is the first to adopt the public-private partnership (PPP) model in Saudi Arabia's infrastructure construction. It is expected to provide 100% renewable energy for 1 million people. As the world's first GWh-level microgrid project, it consists of 400 MW PV modules and 1.3 GWh energy storage. A small number of gas generators are deployed as backup. This system has high requirements on grid forming and grid stability. Huawei provides an overall smart microgrid solution. Parts of the project have been delivered by the end of 2022. Currently, parts of the grid have been constructed and started to supply power, and the rest is expected to be completed in the middle of 2023.

The Red Sea project is essentially a 110 kV power grid composed of PV and ESS systems. The challenges of the project include project delivery, grid forming, and stable power supply for end users.

Huawei provides a modular and pre-integrated microgrid energy storage solution, and helps the customer complete the preparation, plan implementation, and field experiment design for microgrid delivery, achieving the customer's goal of quick delivery.

As a power grid featuring PV-ESS synergy, the overall operation logic and power grid performance indicators need to be designed and simulated in detail. With its capabilities in design, simulation, and microgrid test platforms, Huawei has helped customers complete microgrid logic design and simulation in the past two years, including PV+ESS grid forming, power grid SCR design, energy distribution logic design, and power grid control stability design, transient state design, primary and secondary voltage and frequency regulation, PV/BESS/SVG dynamic voltage regulation, power grid frequency and voltage control after load shedding, synchronous black start of 1000+ PCSs, multi-switch collaboration in the power grid, and synchronous and asynchronous design, which are verified in real-world environments and can achieve the goal of stable operation.

The Red Sea Microgrid will supply clean electricity to hotels, desalination plants, sewage treatment plants, airports, hospitals, and more. Various power supply devices and operation types of different users pose challenges to the stable operation of the power grid. In the actual environment, multiple types of devices and operations have been verified to ensure stable running.

Figure 22 1.3 GWh microgrid energy storage project in Red Sea, Saudi Arabia

05 Conclusion

It takes the efforts of the whole industry to address the grid connection of plants with high proportion of renewable energy. Huawei adheres to the concept of "triple convergence": the convergence of power electronics and digital technologies, the convergence of PV and energy storage, and the convergence of energy flow and information flow. Huawei builds a Smart PV & ESS Generator solution to redefine voltage and frequency stability. In addition, Huawei continuously innovates technologies such as wideband oscillation suppression, fault ride-through, and batch black start to achieve stable grid connection and consumption of renewable power plants, and work with partners along the industry chain to accelerate PV evolution to a main energy source.

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