FusionSolarCI C&I On/Off-Grid Solution

Technical Proposal

Issue 01

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Huawei Technologies Co., Ltd.

Huawei Technologies Co., Ltd.

Address: Huawei Industrial Base
Bantian, Longgang
Shenzhen 518129
People's Republic of China

Website: https://www.huawei.com/

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About This Document

This document describes the technical proposal for the on/off-grid solution that uses the commercial and industrial (C&I) liquid-cooled energy storage system (ESS) and the SmartLogger.

Symbol Conventions

The symbols that may be found in this document are defined as follows.

Symbol	Description
DANGER	Indicates a hazard with a high level of risk which, if not avoided, will result in death or serious injury.
WARNING	Indicates a hazard with a medium level of risk which, if not avoided, could result in death or serious injury.
CAUTION	Indicates a hazard with a low level of risk which, if not avoided, could result in minor or moderate injury.
NOTICE	Indicates a potentially hazardous situation which, if not avoided, could result in equipment damage, data loss, performance deterioration, or unanticipated results. NOTICE is used to address practices not related to personal injury.
NOTE	Supplements the important information in the main text. NOTE is used to address information not related to personal injury, equipment damage, and environment deterioration.

Change History

Date	Issue	Description
2024-11-21	V1.0	Completed the draft.
2024-11-26	V1.1	Optimized the description of the power distribution design, common loads, UPS, and the third-party protective relay.

Date	Issue	Description
2024-12-06	V1.1	Optimized the description of the black start feature.
2024-12-25	V1.2	Completed the archiving review and updated the description based on the review comments. Added the description of parameter settings for third-party protective relay in different grid code scenarios.
2024-12-30	V1.2	Released the first official issue.

Contents

1 Application Scenarios

Table 1-1 Application scenarios of the C&I on/off-grid solution

Solution Source	Scenario Type	Scenario Description	Solution Overview	
C&I solution (SmartLogger as the controller and PV+ESS)	Seamed on/off-grid switching	**Application scenario**: disaster recovery. The utility power grid is relatively stable. The PV+ESS system operates in on-grid mode for a long time, which poses high requirements on the on-grid dispatching precision. The on-grid economical operation policy is adopted. When a power outage occurs due to force majeure, the PV+ESS system is able to operate in off-grid mode and provides emergency power supply to critical loads. During on-grid operation, the backup power SOC can be set to reserve power for off-grid emergency power supply. In this scenario, the PV+ESS solution is not coupled with gensets.	PV+ESS (no genset)	SmartLogger+ PV+ESS: The SmartLogger works with the utility power grid detection relay to control the on-grid operation, off-grid operation, and on/off-grid switching of the PV+ESS system.
	Seamless on/off-grid switching (all-time VSG)	**Application scenario**: The utility power grid often experiences power outages. The requirements for on-grid power dispatching and control are not high, and	PV+ESS (no genset)	The SmartLogger works with the whitelisted third-party protective relay to

Solution Source	Scenario Type	Scenario Description	Solution Overview	
		power fluctuations are acceptable. When the system runs in on-grid mode, the economical operation policy is implemented. When the power grid experiences a power outage or major disturbance, the PV+ESS system automatically disconnects the switch at the grid connection point and switches to off-grid mode to ensure continuous power supply to critical loads. When the utility power grid recovers to a stable range, the PV+ESS system seamlessly connects to the power grid and restores the on-grid operation policy. During on-grid operation, the backup power SOC can be set to reserve power for off-grid emergency power supply. If there is a genset, the loads automatically switch to the genset branch by using the ATS and the genset starts to supply power to the loads. The PV+ESS system is decoupled from the genset through the ATS.		implement seamless on/off-grid switching (all-time VSG).
			PV+ESS (loads switching to the genset through the ATS)	The loads automatically switch to the genset branch by using the ATS. The genset serves as the backup power for the PV+ESS system.
	Off-grid	**Application scenarios**: This solution is mainly used to ensure power supply availability, such as remote areas and rural areas where short-term power supply interruption is acceptable. The PV+ESS system forms an independent microgrid to supply power to loads. In the daytime,	Genset replaced by the PV+ESS system	The PV+ESS system runs in off-grid mode without other power supplies. The SmartLogger serves as a controller to automatically control off-grid operation.

Solution Source	Scenario Type	Scenario Description	Solution Overview	
		PV modules supply power to loads and charge the ESS. At night, the ESS supplies power to loads and shuts down after the ESS discharges energy to a low SOC level. In the morning of the next day, the PV+ESS system automatically starts and supplies power to loads. If there is a genset, the loads automatically switch to the genset branch by using the ATS and the genset starts to supply power to the loads. The PV+ESS system is decoupled from the genset through the ATS.	PV+ESS (loads switching to the genset through the ATS)	The SmartLogger serves as a controller to automatically control off-grid operation. The loads automatically switch to the genset branch by using the ATS. The genset serves as the backup power for the PV+ESS system.

Table 1-2 C&I on/off-grid solution features

Feature	Key Performance	Description	Advantages (Compared with Traditional Solutions)
C2C electrical and thermal safety	**C2C** **electrical safety**	**C2C electrical safety: Short circuit prevention and isolation** **1. Dual-level intelligent cell monitoring** The high-precision and automotive-grade battery monitoring integrated circuit (BMIC) collects massive data of cell. The big data self-learning function on the cloud detects 13+ types of faults to provide early warning. 2. Six-side pack insulation Patented reinforced insulation materials are used to provide six-side all-round protection for battery packs and cells to	Traditional solutions: 1. A battery pack is insulated only on both sides, and insulation is unavailable between cells. The insulation layer can withstand electrolyte corrosion for only seven days and 110 V voltage, which may cause shell arcing and cell short circuits. 2. Only three-level or four-level protection is available, and common fuses and contactors have a blind spot between 1200 A and 1600 A. If a high-current cell is short-circuited to the ground, fire may occur within dozens of milliseconds. The fuse reaction time is seconds, the contactor reaction time is hundreds of milliseconds, and the contactor capacity is less

Feature	Key Performance	Description	Advantages (Compared with Traditional Solutions)
		survive 30 days of corrosion by electrolyte and 1500 V voltage, preventing enclosure breakdown by arc and cell short circuits. 3. Five-level system protection Five-level full-range overcurrent protection (pack-level fuse + rack-level enhanced fuse + rack-level enhanced contactor + PCS-level IGBT disconnection + PCS-level instantaneous circuit breaker), covering the AC/DC protection blind spot between 1200 A and 1600 A in conventional systems; unique millisecond-level cell-to-ground short circuit protection, rapid shutdown within 5 ms through the instantaneous circuit breaker 4. Round-the-clock application assurance RCD leakage detection for AC, DC, and auxiliary power + N/PE grounding disconnection detection, round-the-clock real-time online insulation monitoring; rapid shutdown of PCS in case of external leakage or short circuit to prevent personnel injury or damage to ESS components due to high current impact	than 1200 A. Therefore, effective protection cannot be achieved. 3. Only short-circuit leakage between the positive and negative buses can be detected, and short-circuit leakage to the ground and leakage risks on the auxiliary power side cannot be effectively detected, which may cause safety risks such as personal injury.
	C2C thermal safety	C2C thermal safety: Fire mitigation and suppression 1. Cell-level thermal suppression	Traditional solutions: 1. No pack-level directional smoke exhaust: If cell thermal runaway occurs in a pack, combustible gases will be

Feature	Key Performance	Description	Advantages (Compared with Traditional Solutions)
		Inter-cell heat insulation layer prevents thermal diffusion of adjacent cells. The liquid cooling plate at the bottom quickly cools battery cells. 2. Pack-level exhaust Unique pack-level directional gas exhaust design: The IP65 heat-resistant enclosure prevents oxygen from entering the battery packs, eliminating fire risks. The combustible gases are exhausted through an L-shaped duct to prevent combustion and explosion inside the cabinet. 3. System-level fire suppression The battery cabin and power cabin are separated to prevent fires from spreading. The cabin-level independent fire suppression design with pack-level perfluorohexanone fire suppression and cabinet-level aerosol fire suppression enables precise, active, and rapid fire suppression. 4. Consumption-level top-mounted explosion vent The high-strength integrated cabinet with hour-level fire resistance prevents fire from spreading outside the cabinet and affecting surrounding assets. The top explosion vent design prevents explosions and	continuously generated. Combustible gases are discharged in the cabinet. Combustion will occur if the gas concentration inside the cabinet reaches the explosion limit. 2. No explosion vent design is available or an explosion vent is designed at the rear. The cabinet may explode or the pressure is relieved from one side, causing injuries to people around the cabinet.

Feature	Key Performance	Description	Advantages (Compared with Traditional Solutions)
		protects people nearby.	
Lower LCOS	**More dischargeable energy**	1. Accurate powering (1) High system efficiency: The next-generation SiC IGBT module, efficient bidirectional balancing topology of packs, three-phase five-bridge topology of PCS, and efficient regulation and hybrid cooling control algorithm are used to achieve the maximum system round trip efficiency (RTE) of 91.3% (@0.25C, 25°C, including auxiliary power supply). (2) Pack-level optimization 2.0: Each battery pack has a built-in energy optimizer 2.0 with an efficient bidirectional balancing topology to improve system efficiency and achieve real-time active balancing without charge and discharge restrictions. This overcomes the short-board effect and increases the usable energy by 2%in the lifecycle. (3) Phase-level control: Unique asymmetric-phase design of PCS allows for independent power supply of each phase at the maximum capacity, unbalanced three-phase output without a transformer. 2. Smart air and liquid cooling (1) Low energy consumption: The Huawei-developed thermal management	Traditional solutions: 1. The maximum RTE is less than 90%. 2. No battery pack optimizers are used. After long-term operation, the SOH difference between packs will lead to the short-board effect, and the actual available energy within the life cycle will decrease. 3. The traditional PCS does not support phase-level control or three-phase unbalanced output without a transformer. 4. The traditional air cooling mode features low efficiency and high energy consumption. In the traditional liquid cooling mode, the liquid cooling unit runs continuously or frequently starts and stops, resulting in high energy consumption and fault rate. The waste heat of PCS cannot be recycled. 5. Thermal management is not refined, the battery temperature control effect is poor, and the degradation is fast. 6. There is no thermal insulation foam at the liquid cooling pipe connector or at the bottom of the battery pack, causing condensation risks and component failures.

Feature	Key Performance	Description	Advantages (Compared with Traditional Solutions)
		system "Thermal Router" achieves intelligent multi-mode switching, reducing energy consumption by 30%. (2) Slow degradation: Triple heat dissipation optimization slows down the system SOH degradation. (3) High reliability: Automotive-grade liquid cooling system, full-range anti-condensation, failure rate reduced by 60%	
	Lower CAPEX	1. Three-sided cabinet layout saves footprint (the back-to-back distance is only 0.3 m), saving space and improving energy density per unit area by 8%. 2. Transported with prefabricated components in a 20-foot container, reducing the transportation cost by 20%. 3. No trenching or external auxiliary power cable, reducing installation costs 4. Off-grid without isolation transformer/IMD/third-party EMS 5. High PV-to-ESS ratio of 2:1, flexible PV+ESS configuration 6. SmartDesign supports PV+ESS on/off-grid capacity design. Small- and medium-sized projects can be quickly planned and designed, which effectively reduces the system design time and project labor input and supports market	Traditional solutions: 1. Unable to implement three-sided cabinet layout due to front and rear airflow, multi-sided maintenance, or rear explosion vent (back-to-back distance > 0.6 m). 2. The height of an ESS is greater than the standard container height (2.385 m), requiring the use of high containers for transportation, which increases transportation costs. 3. The ports on the AC side are too close to the ground, necessitating the digging of cable trenches or elevating the base, which adds to installation costs. 4. Three-phase three-wire PCS, requiring an external or built-in isolation transformer to carry loads in off-grid mode 5. PV-to-ESS ratio of less than 1:1, inflexible configuration 6. Lack of design tools necessitates manual design, increasing costs and time consumption.

Feature	Key Performance	Description	Advantages (Compared with Traditional Solutions)
		expansion and solution promotion.	
	Lower OPEX	1. Pack-level automatic SOC calibration, free of site visits 2. No need of coolant replacement for 10 years, reducing labor costs and leakage risks	1. Onsite manual SOC calibration by professional engineers, repeated installation and removal for connecting to an external charger, low precision, and high safety risks 2. Traditional coolant has a lifespan of only 3–5 years, necessitating frequent manual replacement. This increases the cost of replacing the coolant and may cause leakage.
High-quality and reliable power supply	**Stable power supply**	1. Fast on/off-grid switching ensures uninterrupted power supply to critical loads. 2. Fast fault ride-through, no fear of inrush current during motor/transformer energization 3. Supports synchronous black start of 20 devices, quick power supply recovery within 10 minutes, and black start with loads, shortening the system outage duration.	Traditional solutions (competitors): 1. Long on/off-grid switching time 2. Fault ride-through not supported 3. Devices are black started one by one, which takes a long time. The load capability of the system is weak during black start.
	Stronger load carrying capability	With the three-phase four-wire five-bridge PCS, no transformer is required to support extremely complex loads such as three-phase unbalanced, single-phase, and half-wave loads. The maximum short-time overcurrent capability is 1.3 times the rated load.	Traditional solutions (competitors): 1. Overcurrent capability: 1.2 times

Feature	Key Performance	Description	Advantages (Compared with Traditional Solutions)
	Better electric energy	1. Intelligent harmonic suppression, on-grid THDi ≤ 1.5%, off-grid THDu ≤ 2% 2. Intelligent circulating current suppression, a maximum of 20 devices connected in parallel in off-grid mode	Traditional solutions (competitors): 1. THDu < 3%, half-wave load capability < 3%, requiring isolation transformers with single-phase and unbalanced load capability in off-grid scenarios 2. No circulating current suppression, a maximum of two to ten devices connected in parallel

NOTICE

This solution is not applicable to scenarios that require high power supply reliability. The system does not have redundancy backup. If a device fails, microgrid breakdown risks still exist.

2 C&I On/Off-Grid Solution Architecture

The C&I microgrid energy storage solution has the following networking architectures: PV+ESS on/off-grid seamed switching system (PQ/VSG), PV+ESS on/off-grid seamless switching system (all-time VSG), and off-grid PV+ESS system.

2.1 Seamed On/Off-Grid Switching

2.1.1 Scenario Overview

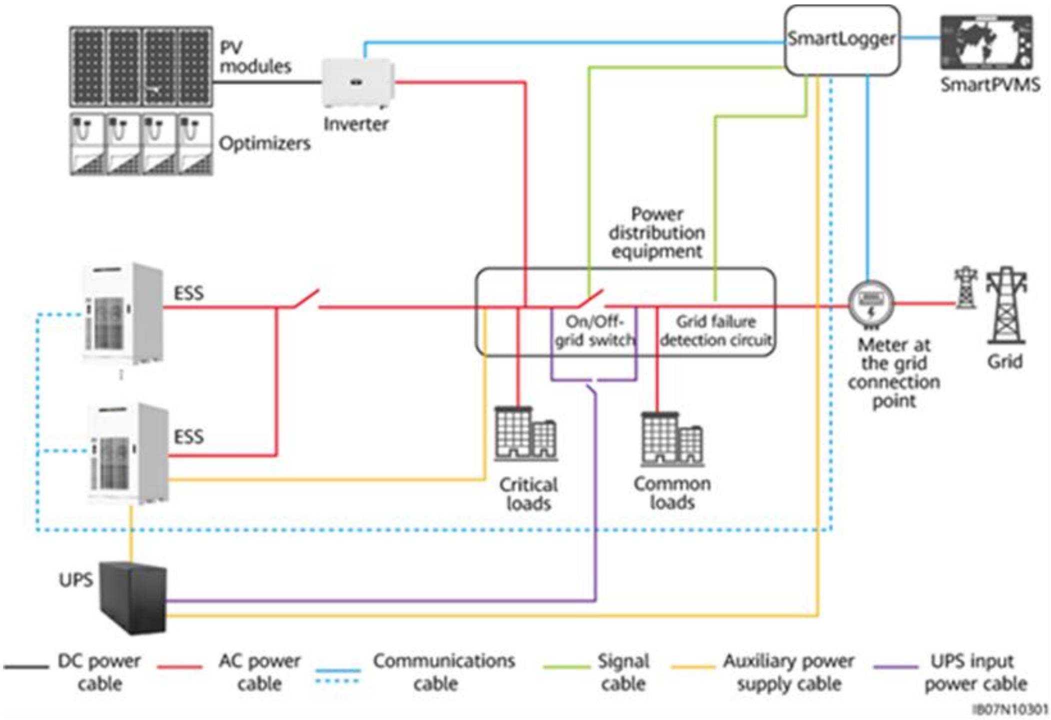
Application scenario: The PV+ESS on/off-grid (PQ/VSG) system is applicable to C&I campuses where the power grid capacity is insufficient, capacity expansion is difficult, and power supply is limited during peak hours. The PV+ESS system can operate in on-grid mode for a long time and has disaster recovery capabilities. When the utility power grid experiences an outage due to force majeure or the system needs to be disconnected from the power grid as required, the PV+ESS system can operate in off-grid mode to provide emergency power to critical loads. During on-grid operation, the backup power SOC can be set to reserve power for off-grid emergency power supply.

In this system, the ESS is AC-coupled, and the microgrid system implements on-grid and off-grid operation through the on/off-grid switch. When the system is off-grid, the ESS functions as the main power supply to support the power grid, and also supplies power together with the PV system to critical loads.

Key feature specifications: 3s for a single ESS and 10s for multiple ESSs (from the time when the switch at the grid connection point is turned off to the time when the AC grid forming is complete)

2.1.2 Solution Structure

Networking architecture of the PV+ESS seamed on/off-grid switching system (PQ/VSG)



2.1.3 System Configurations

Device	Model/Specifications	Quantity	Remarks
Smart String ESS	• LUNA2000-215-2S10	≤ 20	Purchased from the Company. Note: ESSs of different models cannot be used together. The ESS models in the same project must be the same.
Smart PV Inverter (inverter)	M3, V5/V5+, and V6. For details, see the version mapping table.	≤ 30	Purchased from the Company. The maximum capacity ratio of inverter to ESS is 2:1. • Different models cannot be used together. • Inverters from the Company cannot

Device	Model/Specifications	Quantity	Remarks
			be used together with those from other vendors.
Smart PV Optimizer (SUN2000P)	Adapted based on the inverter.	Depending on the actual number of PV modules	Purchased from the Company (optional).
SmartLogger/Controller	SmartLogger3000	1	Purchased from the Company. The SmartLogger functions as a controller.
	SmartModule1000A01	1	Purchased from the Company. The SmartModule is used together with the SmartLogger. Determine whether to configure the SmartModule based on the actual networking.
Meter at the grid connection point	SmartPS-80AI-T0 (DTSU666-HW or YDS60-80)	1	Purchased from the Company. The current on the secondary side of the current transformer (CT) is 1 A or 5 A. The minimum CT sampling precision is 0.5s.
SmartPVMS	SmartPVMS	1	Purchased from the Company.
Power distribution equipment (including the on/off-grid switch and grid failure detection circuit)	• The on/off-grid switch supports remote signal feedback and remote control. • The grid failure detection circuit supports remote I/O signal feedback.	1	Prepared by the customer. Note: The on/off-grid switch must meet the local power distribution requirements, that is, 3P or 4P. If a 4P switch is required and the neutral wire must be disconnected, the neutral point of the PV+ESS system must be reliably

Device	Model/Specifications	Quantity	Remarks
			grounded after the system is switched to the off-grid state (then the grid forming is performed in off-grid mode). During on-grid operation, the ground point needs to be disconnected from the ground, and the status of the on/off-grid switch is linked with the ground point in the grid. That is, the switch at the grid connection point is linked with the internal grounding switch.
UPS	• Power > 1 kVA, online UPS, 220 V • The backup time is greater than or equal to 1 hour. (If the system is off-grid for a long time, the UPS backup time is greater than 48 hours.) • To ensure reliable power supply to the UPS, it is recommended that the UPS power supply be provided from either side of the on/off-grid switch, whichever side is available.	1	Prepared by the customer.

2.2 Seamless On/Off-Grid Switching (All-Time VSG)

2.2.1 Scenario Overview

NOTE

In this version, seamless on/off-grid switching supports only the all-time VSG mode. The solution is used only after restricted review. The go-to-market of the all-time VSG solution must be approved by the business department. Otherwise, the R&D department does not provide technical support for any risks and problems that may arise.

Application scenarios:

The mains supply is unstable, power outages and disturbances often occur, the grid connection point power is not assessed, and the requirements for economic dispatching are not high.

Key function specifications:

- During on-grid operation, the selected economic dispatching policy is executed. (In the all-time VSG on-grid scenario, only the TOU and maximum self-consumption functions are supported, and the zero feed-in control function is not supported.) The backup power SOC can be set (reserve power for off-grid emergency power supply).
- When the power grid experiences a power outage or major disturbance, the PV+ESS system automatically disconnects the switch at the grid connection point and switches to off-grid mode to ensure continuous power supply to critical loads. The time for unplanned on-grid to off-grid switching is less than 150 ms.
- After the mains recovers to a stable range, the PV+ESS system seamlessly connects to the power grid and restores the on-grid operation policy.

If there is a genset, the loads automatically switch to the genset branch by using the ATS and the genset starts to supply power to the loads. The PV+ESS system is decoupled from the genset through the ATS.

Restrictions on the all-time VSG solution (customers need to know and accept the restrictions):

1. Power distribution capacity: Both transformer capacity and power distribution switch capacity shall be greater than 1.2 times the larger value between: Total rated capacity of the PCS + Peak load; Total rated power of the PCS + Total rated capacity of the PV inverter.
2. Confirm that the customer does not have requirements on zero feed-in, feed-in power, or power factor (reactive power).
3. Confirm that the customer has no requirement on the electricity demand, and that the electricity supply from grid and electricity feed-in to grid is within the capacity range of the distribution transformer.
4. If the zero feed-in function is enabled, the PV inverter output power will be limited when the power grid fluctuates.
5. Due to grid fluctuations, the ESS may experience repeated charging and discharging cycles to obtain electricity from the grid or feed in electricity to the grid in a short term. This can cause electricity fee loss.
6. Due to power grid fluctuations, the time for the ESS to charge and discharge to the target range may be prolonged.

Features of the all-time VSG on-grid operation:

- Power grid disturbance/fault ride-through: The PCS can respond to voltage and frequency fluctuations. After the protective relay time arrives, the switch at the grid connection point is turned off.
- On-grid VSG power closed-loop range: ±0.8 Hz, 2% U_n, 1 mHz/s; steady-state active power precision: 2%, dynamic response time: 1s; reactive power control precision: 2%, response time: 10s
- When the frequency fluctuates, the PCS preferentially responds to the voltage and frequency fluctuation and generates power fluctuations. If the controller adjustment cannot keep up with the response speed of the PCS to support the power grid, the power at the grid connection point may not be restricted, and even PV curtailment may occur.

The following table lists the precautions for seamless on/off-grid switching. Before using this solution, check whether it is applicable.

Table 2-1 Table 1 Key precautions for the seamless on/off-grid switching solution

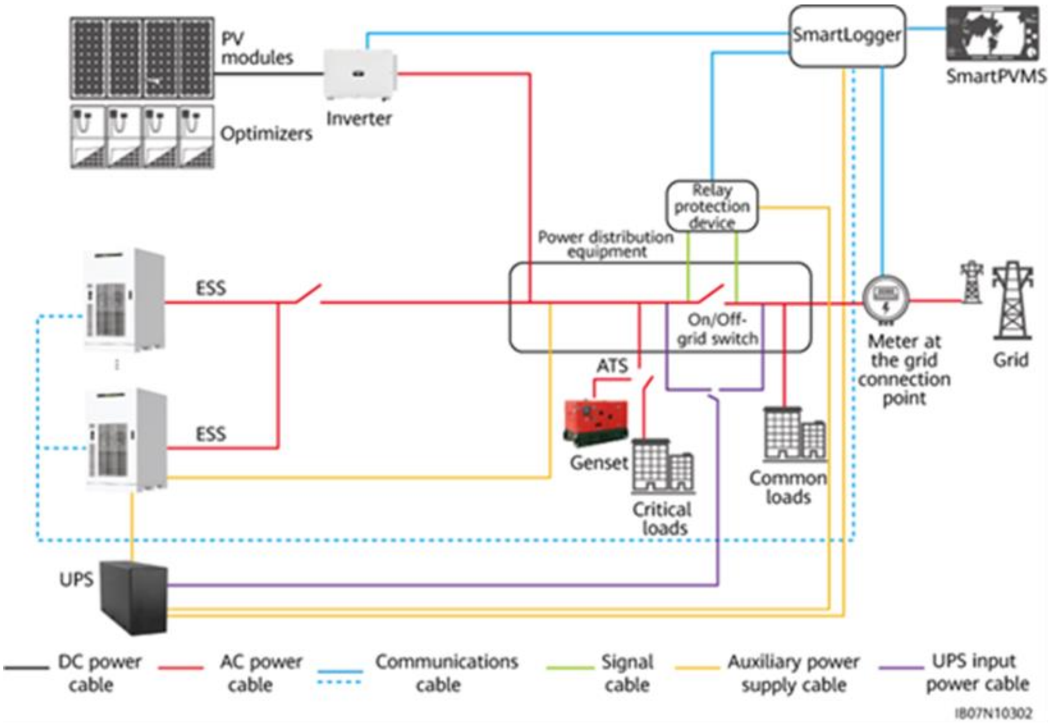
Category	Affected Function	Description
Grid code compliance Note: The seamed on/off-grid switching solution is recommended if the power grid requirements need to be strictly followed.	The solution conflicts with the frequency/voltage fault ride-through requirements of the grid code.	When HVRT/LVRT or fault ride-through occurs, the PV+ESS system quickly disconnects from the power grid and cannot provide reactive power within the time range specified by the grid code. This may violate the requirements of the local power grid company and cause admission risks. To use the seamless on/off-grid switching function, you need to obtain the permission from the local power grid company.
	Impact on anti-islanding requirements of grid codes	1. When the power grid fails, the implementation mode of anti-islanding is changed from device shutdown to off-grid operation. That is, the system disconnects from the grid connection point to isolate the external power grid and provide islanding protection only for the external power grid. 2: Failure to disconnect when an open circuit occurs close to the grid connection point. When a grid outage occurs at an open circuit point near the grid connection point or when there is no load between the grid connection point and the upper-level open circuit point, the grid connection point cannot be identified while in all-time VSG mode. This can lead to

Category	Affected Function	Description
		reverse power flow along the external circuit, posing a risk of anti-islanding protection failure at the grid connection point.
Restrictions on the on-grid operation mode	DOD and SOC operating ranges	It is recommended that the SOC range be 10% to 90%.
Power distribution requirements for the grid connection point	Both transformer capacity and power distribution switch capacity shall be greater than the larger value between: Total rated capacity of the PCS + Peak load; Total rated power of the PCS + Total rated capacity of the PV inverter.	
Impact of VSG on-grid mode	Confirm that the customer does not have requirements on zero feed-in, feed-in power, or power factor (reactive power).	
	Confirm that the customer has no requirement on the electricity demand, and that the electricity supply from grid and electricity feed-in to grid is within the capacity range of the distribution transformer.	
	If the zero feed-in function is enabled, the PV inverter output power will be limited when the power grid fluctuates.	
	Due to grid fluctuations, the ESS may experience repeated charging and discharging cycles to obtain electricity from the grid or feed in electricity to the grid in a short term. This can cause electricity fee loss.	
	Due to power grid fluctuations, the time for the ESS to charge and discharge to the target range	

Category	Affected Function	Description
	may be prolonged.	
	During on-grid operation in VSG mode, the current harmonics of some loads in the power grid are absorbed due to the voltage source feature. The current THDi may exceed the threshold.	

2.2.2 Solution Structure

Network architecture of the PV+ESS on/off-grid (all-time VSG) system (load connected to the genset through the ATS)



2.2.3 System Configurations

Device	Model/Specifications	Quantity	Remarks
Smart String ESS	• LUNA2000-215-2S10	≤ 20	Purchased from the Company. Note: ESSs of different models cannot be used together. The ESS models in the same project must be the same.

Device	Model/Specifications	Quantity	Remarks
			Note: The auxiliary power supply of the liquid-cooled ESS needs to be less than 240 V AC. If necessary, a small transformer needs to be configured to reduce the voltage to less than 240 V AC.
Smart PV Inverter (inverter)	M3, V5/V5+, and V6. For details, see the version mapping in the quick guide.	≤ 30	Purchased from the Company. For the SUN2000-50KTL-M0 and SUN2000-60KTL-M0 inverters, the maximum capacity ratio of inverter to ESS is 1:1. For other models of inverters, the maximum capacity ratio of inverter to ESS is 2:1. • Different models cannot be used together. • Inverters from the Company cannot be used together with those from other vendors.
Smart PV Optimizer (SUN2000P)	Adapted based on the inverter.	Depending on the actual number of PV modules	Purchased from the Company (optional). For details about the mapping, see the inverter description.
SmartLogger/Controller	SmartLogger3000	1	Purchased from the Company.
	SmartModule1000A01	1	Purchased from the Company. The SmartModule is used together with the SmartLogger. Determine whether to configure the SmartModule based on the actual networking.
Meter at the grid connection point	SmartPS-80AI-T0 (DTSU666-HW or YDS60-80)	1	Purchased from the Company. The current on the secondary side of the current transformer (CT) is 1 A or 5 A. The minimum

Device	Model/Specifications	Quantity	Remarks
			CT sampling precision is 0.5s.
SmartPVMS	SmartPVMS	1	Purchased from the Company.
Protective relay	• Schneider: Easergy P3U30-5AAA3BBA • Two groups of potential transformers (PTs) are required.	1	Prepared by the customer.
Power distribution equipment (including the on/off-grid switch)	Power distribution cabinet, including the on/off-grid switch	1	Prepared by the customer. Note: The on/off-grid switch must meet the local power distribution requirements, that is, 3P or 4P. If a 4P switch is required and the neutral wire must be disconnected, the neutral point of the PV+ESS system must be reliably grounded after the system is switched to the off-grid state (then the grid forming is performed in off-grid mode). During on-grid operation, the ground point needs to be disconnected from the ground, and the status of the on/off-grid switch is linked with the ground point in the grid. That is, the switch at the grid connection point is linked with the internal grounding switch.
UPS	• Power > 1 kVA, online UPS, 220 V • The backup time is greater than or equal to 1 hour. (If the system is off-grid for a long time, the UPS backup time is greater than 48 hours.) • To ensure reliable	1	Prepared by the customer.

Device	Model/Specifications	Quantity	Remarks
	power supply to the UPS, it is recommended that the UPS power supply be provided from either side of the on/off-grid switch, whichever side is available.		
Genset	Three-phase	1	Prepared by the customer (optional).
ATS	Dual power supply switching device	1	Prepared by the customer (optional).

2.3 Off-grid

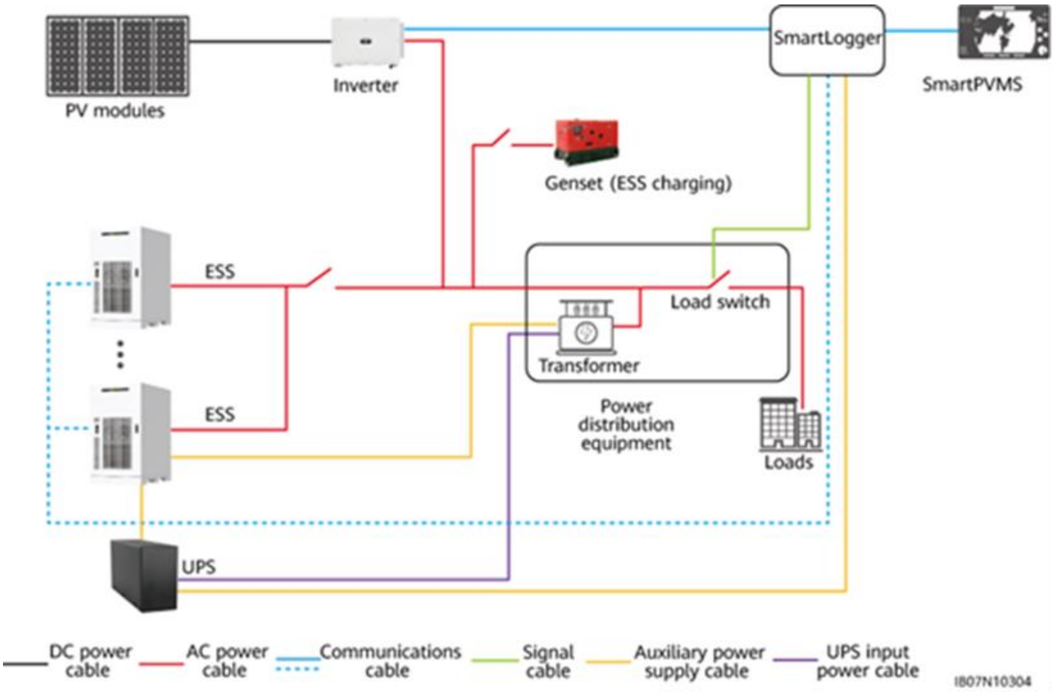
2.3.1 Scenario Overview

Application scenarios: This solution is mainly used to ensure power supply availability, such as remote areas and rural areas where short-term power supply interruption is acceptable.

The PV+ESS system forms an independent microgrid to supply power to loads. In the daytime, PV modules supply power to loads and charge the ESS. At night, the ESS supplies power to loads and shuts down after the ESS discharges energy to a low SOC level. In the morning of the next day, the PV+ESS system automatically starts and supplies power to loads.

If there is a genset, the loads automatically switch to the genset branch by using the ATS and the genset starts to supply power to the loads. The PV+ESS system is decoupled from the genset through the ATS.

2.3.2 Solution Structure



2.3.3 System Configurations

Device	Model/Specifications	Quantity	Remarks
Smart String ESS	• LUNA2000-215-2S10	≤ 20	Purchased from the Company. Note: ESSs of different models cannot be used together. The ESS models in the same project must be the same.
Smart PV Inverter (Inverter)	M3, V5/V5+, and V6. For details, see the version mapping in the quick guide.	≤ 30	Purchased from the Company. The maximum capacity ratio of inverter to ESS is 2:1. • Different models cannot be used together. • Inverters from the Company cannot be used together with those from other vendors. • Do not configure optimizers to avoid

Device	Model/Specifications	Quantity	Remarks
			function conflicts in off-grid scenarios. • Only the SUN2000-29.9KTL-M3, SUN2000-30KTL-M3, SUN2000-36KTL-M3, SUN2000-40KTL-M3, SUN2000-50KTL-M3, and SUN2000-50KTL-ZHM3 support PV grid forming.
SmartLogger/ Controller	SmartLogger3000	1	Purchased from the Company.
	SmartModule1000A01	1	Purchased from the Company. The SmartModule is used with the SmartLogger.
SmartPVMS	SmartPVMS	1	Purchased from the Company.
Power distribution equipment (including the load switch)	Power distribution cabinet (PDC)		Prepared by the customer. Note: For the PV+ESS low-voltage coupling power supply system, the neutral point must be reliably grounded.
	Load switch: Supports I/O status feedback and control.	1	
UPS	• Power ≥ 1 kVA, 220 V AC • It is recommended that the power backup duration be greater than 48 hours.	1	Prepared by the customer.
Genset	/	-	Optional. Prepared by the customer. (Ensure that the emergency power supply is available and can be maintained.)

2.4 Communication Networking

In this scenario, the SmartLogger3000 is configured. One SmartLogger manages multiple ESSs and inverters, and one meter to form an array.

Intra-array communication:

- The inverters communicate with the SmartLogger, and the meter communicates with the SmartLogger over RS485.
- The ESSs communicate with the SmartLogger over FE in star or ring topology.

Maximum communication distance of the SmartLogger:

- RS485: 1000 m
- FE: 100 m

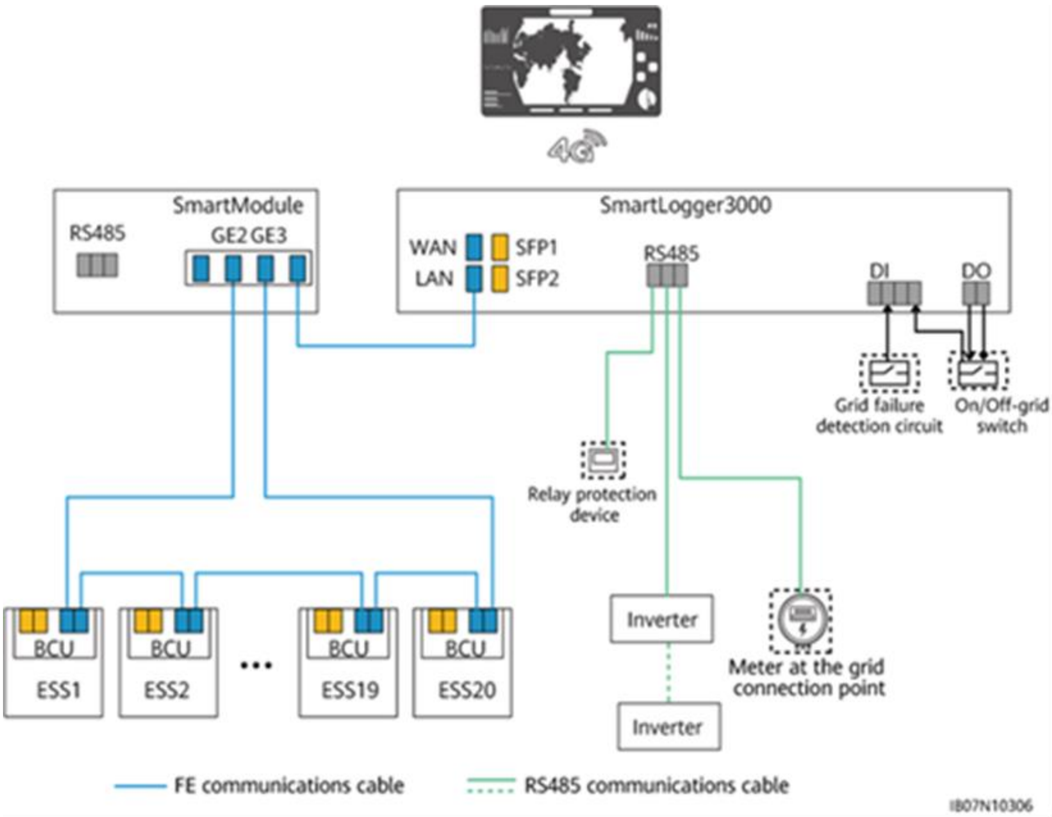
Select any of the following topologies based on the quantities of ESSs in the array and the deployment of optical fibers.

Typical Scenario 1: SmartLogger+ESS FE Ring Networking

In this scenario, the SmartLogger3000 and SmartModule are configured.

- A single FE ring network supports a maximum of 20 ESSs, and the distance between any two nodes is less than 100 m.
- One SmartLogger can connect to a maximum of 20 ESSs.

Figure 2-1 SmartLogger+ESS FE ring network (The devices in the dotted boxes are optional.)



NOTICE

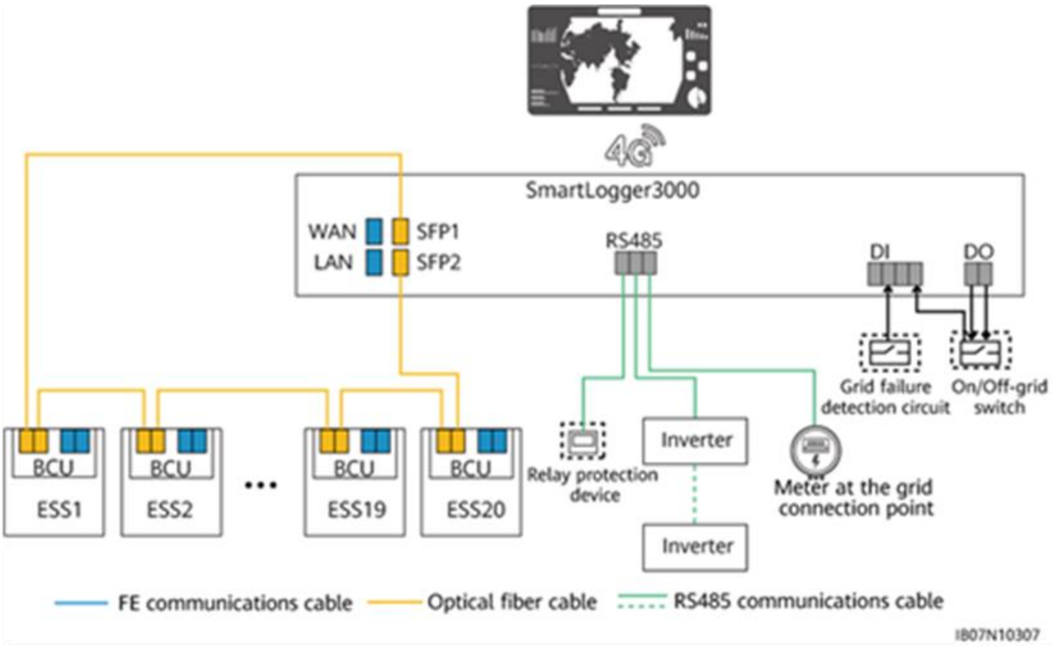
1. If the ESS FE ring topology is implemented through the SmartModule, the ESS must be connected to the GE2 and GE3 ports of the SmartModule. Otherwise, the SmartLogger cannot communicate with the ESS properly.
2. Network cables with a shield layer are recommended.

Typical Scenario 2: SmartLogger+ESS Fiber Ring Networking

In this scenario, the SmartLogger3000 is configured.

- One fiber ring network supports a maximum of 20 ESSs.
- One SmartLogger can connect to a maximum of 20 ESSs.

Figure 2-2 SmartLogger+ESS fiber ring+PCS FE ring topology (The devices in the dotted boxes are optional.)



NOTICE

Check whether the SmartLogger supports optical fiber networking based on its model and specifications.

2.5 Power Distribution Design

NOTICE

The power distribution and electrical connections of the PV+ESS system must comply with the installation regulations of the device and the country or region where the device is located.

The cables from the inverter and ESS to the PDC shall be at least 5 m long.

Leakage protection: Configured based on local power distribution regulations. The device enclosure must be reliably grounded to ensure reliable PE connection.

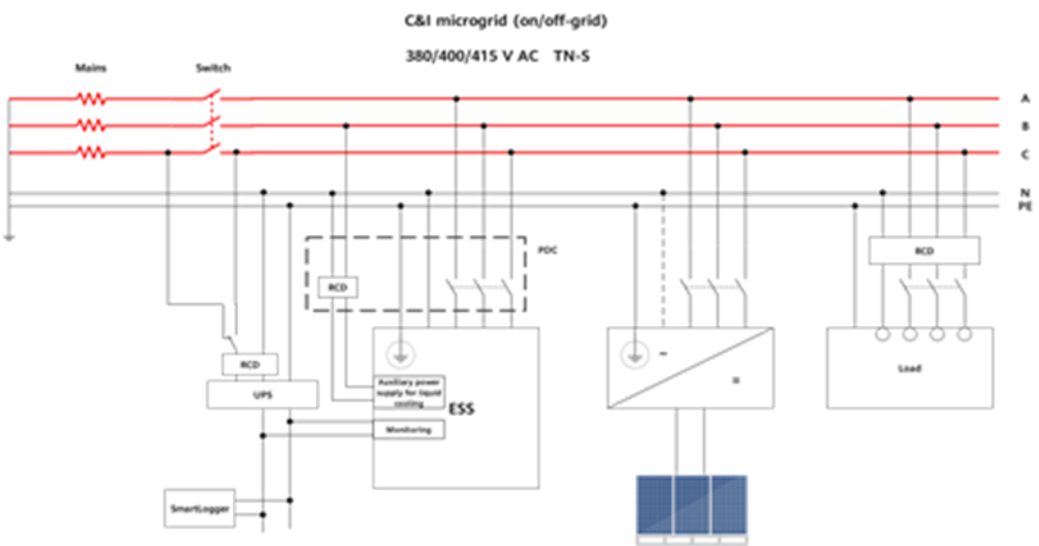
Cable connection: For details about the cables and terminals of the PV and ESS devices, including the main power cable and auxiliary power cable, see the product manual. Ensure that the neutral wire of the ESS is securely connected. Otherwise, the AC electrical devices in the system will be damaged. The cables from the inverter and ESS to the PDC must be at least 5 m long.

Phase sequence: The phase sequences of all PCSs, inverters, PDCs, and transformers in the array must be the same. The default phase sequence of the PCSs is ABC. (The phase sequence cannot be adjusted using software. If you need to adjust the phase sequence, adjust the physical cable connections.)

(1) On-grid/Off-grid—Scenario where the neutral wire of the power distribution system cannot be disconnected

In off-grid mode, if it is required that the neutral wire should not be disconnected from the power grid (for example, in Australia and South Africa), refer to the local power grid requirements, and select a 3P switch (or a 4P switch with the neutral wire not connected) as the on/off-grid switch.

Figure 2-3 Power distribution diagram when the 3P switch at the grid connection point is disconnected (the neutral wire cannot be disconnected)



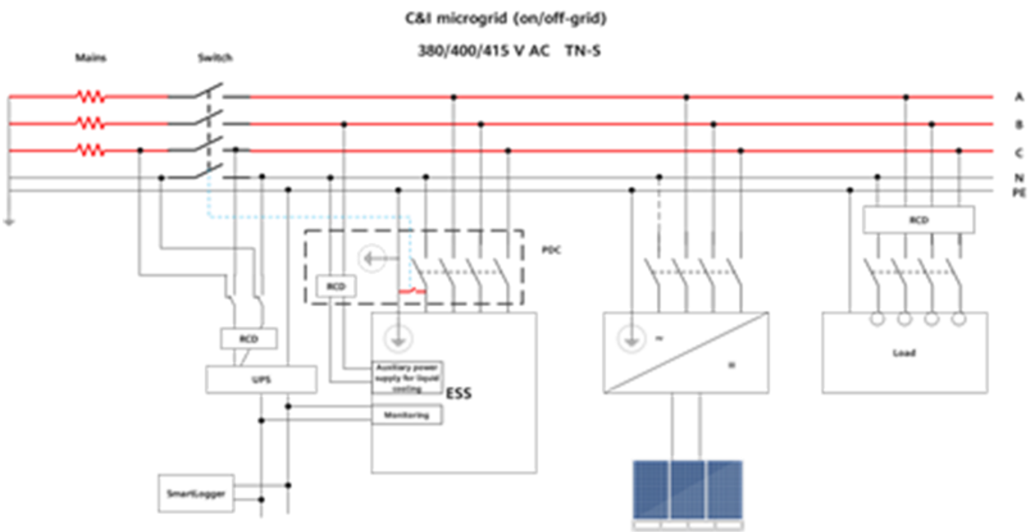
(2) On-grid/Off-grid—Scenario where the neutral wire of the power distribution system is disconnected

In off-grid mode, if the neutral wire needs to be disconnected from the power grid (for example, in Germany), refer to the local power grid requirements and select a 4P switch as the on/off-grid switch. After the switch is turned off, the neutral wire grounding switch inside the microgrid is turned on. After grid connection, the neutral wire grounding switch inside the microgrid is turned off.

CAUTION

During on-grid operation, the neutral wire grounding switch inside the microgrid cannot be on all the time. Otherwise, the on-grid system may be grounded at multiple points, which violates the power distribution regulations.

Figure 2-4 Power distribution diagram when the 4P switch at the grid connection point is disconnected (the neutral wire is disconnected)



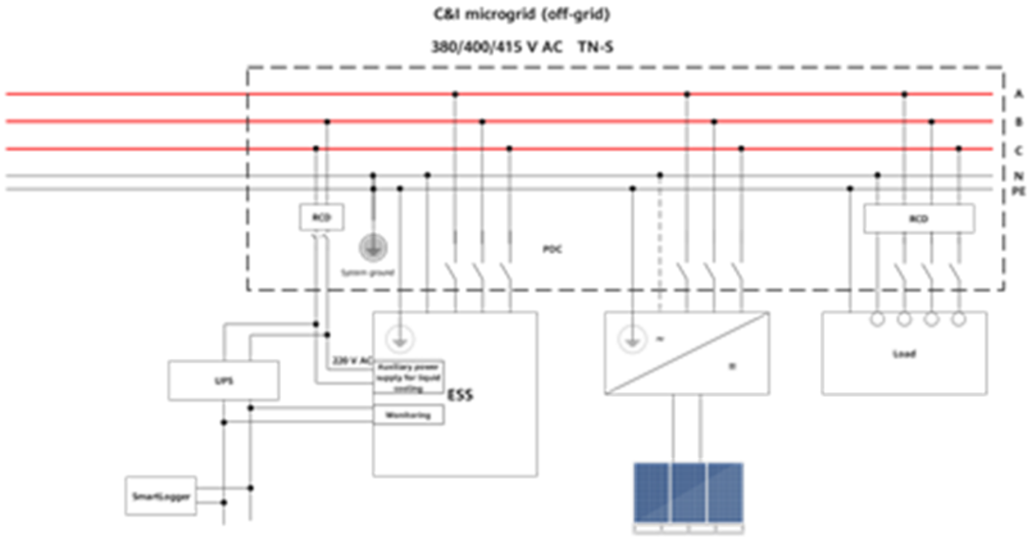
Note: The preceding figure is only a brief diagram. For details, see the PDC electrical diagram.

If a 4P switch is required and the neutral wire must be disconnected, the neutral point of the PV+ESS system must be reliably grounded after the system is switched to the off-grid state (then the grid forming is performed in off-grid mode). During on-grid operation, the ground point needs to be disconnected from the ground, and the status of the on/off-grid switch is linked with the ground point in the grid. That is, the switch at the grid connection point is linked with the internal grounding switch.

(3) Off-grid only—Power distribution

In off-grid operation, the neutral wire for power distribution must be reliably grounded at the power supply side. It is recommended that the system grounding be configured in the PDC to form a TN system for external power supply.

Figure 2-5 Off-grid power distribution diagram

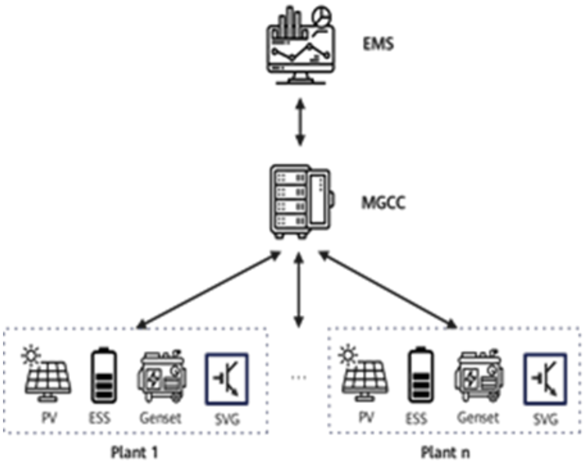


2.6 Dispatching Control Structure

The microgrid is controlled in a hierarchical structure. Different energy scheduling modes are used to achieve economical and reliable operation of the microgrid. A typical control hierarchy of the microgrid is shown in the following figure, and includes three layers.

1. **Primary control: Distributed local control**, which is usually referred to as primary regulation. During on-grid operation, the microgrid ESS usually works in PQ mode, and primary frequency and voltage regulation is disabled. During off-grid operation, the microgrid ESS works in VSG mode and implements primary regulation based on the frequency and voltage droop characteristics. The primary regulation responds to transient active power and reactive power disturbances, such as power generation and/or load loss, connection/disconnection of shunt reactors and cables, energization/deenergization of transformers, and startup/shutdown of induction motors. On the premise that the microgrid has sufficient active power and reactive power reserve, the primary regulation feature ensures automatic frequency and voltage recovery by automatically balancing active power and reactive power in steady and transient states.
2. **Secondary control: Centralized coordination and control**, which is usually referred to as secondary regulation. During on-grid operation, the PV system, ESS, genset, and other power supplies in the microgrid respond to the dispatch command of the MGCC and implement secondary regulation through active and reactive power control at the grid connection point. During off-grid operation, when load disturbance occurs, the frequency and/or voltage of the microgrid may deviate from the rated value after the autonomous primary regulation of the microgrid. In this case, the MGCC can be used to control the active and reactive power of the microgrid to restore the microgrid frequency and voltage to the rated values.
3. **Tertiary control: Optimized dispatch control**, which is sometimes referred to as tertiary regulation. It is mainly implemented by the EMS. The EMS performs

intra-day energy balancing and scheduling based on the PV power forecasting system and load power forecasting system, including the SOC control for the ESS and the startup/shutdown control for the genset to ensure the economical and optimal operation of the microgrid.



Tertiary control Optimized dispatch control	Economic dispatch and safety operation margin management
Secondary control Centralized coordination and control	On-grid/Off-grid switching Secondary voltage and frequency regulation Planned/Unplanned islanding Black start Emergency control
Primary control Distributed local control	Primary frequency and voltage regulation based on the grid-forming ESS

2.7 Solution Competitiveness Building and Valuable Features

Main evolution and competitive points of the solution: Build competitiveness by focusing on lower LCOS, safe, reliable, and high-quality stable power supply.

Table 2-2 Main evolution points

Level-1 Feature	Level-2 Feature	Feature Description (Compared with the Previous Generation)	Feature Description (Compared with Conventional Solutions)	Competitiveness
Better CAPEX	No isolation transformer	The three-phase four-wire PCS used in the on/off-grid scenario can supply power to loads without isolation transformers, reducing the system investment by more than 5%, saving the footprint, and greatly reducing the delivery difficulty. vs. the previous generation: The	vs. all competitors: Their three-phase PCSs can supply power to loads in off-grid mode only with isolation transformers.	+

Level-1 Feature	Level-2 Feature	Feature Description (Compared with the Previous Generation)	Feature Description (Compared with Conventional Solutions)	Competitiveness
		three-phase four-wire PCS can supply power to loads only with an isolation transformer.		
	No third-party IMD	The neutral wire of the three-phase four-wire PCS is directly connected to the ground. A built-in RCD at the ESS DC side detects current leakage. Therefore, no third-party IMD is required, reducing the system cost and delivery difficulty. vs. the previous generation: An IMD shall be configured in the off-grid scenario.	vs. all competitors: Their three-phase three-wire PCSs have the same architecture as the previous generation.	=
	High PV-to-ESS ratio: 2:1	The PV+ESS on/off-grid solution supports a maximum PV-to-ESS ratio of 2:1, effectively reducing the system configuration cost. vs. the previous generation: The maximum PV-to-ESS ratio is 2:1 in the off-grid scenario and seamed on/off-grid switching scenario. The maximum PV-to-ESS ratio is 1:1 in the seamless on/off-grid switching scenario.	vs. all competitors: The PV-to-ESS ratio is less than 1:1. PV module oversizing reduces stability.	+
	Capacity design tool	SmartDesign supports PV+ESS on/off-grid capacity design. Small- and medium-sized projects can be	vs. all competitors: They use the commercial design tools provided by third-party vendors.	+

Level-1 Feature	Level-2 Feature	Feature Description (Compared with the Previous Generation)	Feature Description (Compared with Conventional Solutions)	Competitiveness
		quickly planned and designed, which effectively reduces the system design time and project labor input and supports market expansion and solution promotion.		
Lower OPEX	PV system for grid forming and emergency power supply	The inverter provides the grid forming function and serves as the emergency power supply in off-grid scenarios. When the ESS is shut down and overdischarged, set the inverter to VSG mode to establish an AC emergency power supply to charge the ESS. In this way, gensets are not required for commissioning in emergencies, reducing O&M costs.	vs. all competitors: Other vendors do not provide this feature. Gensets are required to provide emergency power supply.	++
Safety and reliability	Rapid on/off-grid switching	The SmartLogger, third-party auxiliary devices, and next-generation PCS are developed to adapt to the rapid on/off-grid switching function. Currently, in scenarios with a single ESS, the seamed on/off-grid switching time is 3s. In scenarios with multiple ESSs, the seamed on/off-grid switching time is 10s. The on/off-grid switching in all-time VSG mode is within 150 ms. The power	vs. all competitors: on a par in terms of seamed switching; seamless switching taking 20 ms to 50 ms	-

Level-1 Feature	Level-2 Feature	Feature Description (Compared with the Previous Generation)	Feature Description (Compared with Conventional Solutions)	Competitiveness
		supply continuity and reliability of the system are ensured. vs. the previous generation: seamed switching in 2 minutes; 150 ms on/off-grid switching in all-time VSG mode		
	Grid forming Grid forming load capacity	The PCS provides the balancing bridge, which greatly improves the loading capability. The PCS can directly supply power to single-phase loads (R/RL/RC loads) without a transformer. It supports 5% half-wave loads and a maximum of 10% motor loads. The THDu is less than or equal to 2%, and the maximum short-time overcurrent capability is 1.3 times the rated current. vs. the previous generation: The PCS without an isolation transformer cannot supply power to single-phase loads. After an isolation transformer is connected, the PCS supports unbalanced loads. The half-wave load capability is weak.	vs. all competitors: THDu < 3%. An isolation transformer is required for off-grid scenarios to support single-phase loads and unbalanced loads. The overcurrent capability is less than 1.2 times.	+
	Array-level one-click black	The synchronous black start control of multiple devices simplifies the internal	vs. all competitors: Devices are black started one by one, which takes a	+

Level-1 Feature	Level-2 Feature	Feature Description (Compared with the Previous Generation)	Feature Description (Compared with Conventional Solutions)	Competitiveness
	start	control process, shortens the array-level black start time to less than 10 minutes, and supports black start with loads to shorten the system power failure duration. vs. the previous generation: array-level black time of 15 minutes	long time. The load capacity of the system is weak during black start.	

3 System Features and Basic Concepts

3.1 Main System Functions

Table 3-1 System features and functions

Feature	Description
ESS black start	Black start mode: remote black start 1. The system provides the UPS, microgrid control system (including the MGCC, SmartLogger, and switches), and auxiliary power supply for the ESS. 2. The excitation voltage of the transformer in the system is established by the PCS, and the stable microgrid voltage is established gradually. 3. The ESS has the synchronous black start capability to reduce the dependency of the plant on gensets for black start. The array black start time is within 10 minutes.
Off-grid	1. The ESS works in grid-forming mode as the main power source and provides reference voltage and frequency for the power grid. 2. The PV inverter works in grid-following mode and provides active power for the power grid to assist in power grid voltage control. 3. The PV-to-ESS ratio can be as high as 2:1. 4. Under the control of the MGCC, the power supply meets the active power and reactive power requirements of internal loads. If necessary, standby distributed power systems can be started

Feature	Description
	or loads can be reduced to ensure the reliability of the power supply to the critical loads. 5. The ESS and PV inverters actively control the voltage and frequency to maintain the stability of the microgrid voltage and frequency. 6. The PCS in VSG mode can respond to the secondary voltage or frequency regulation command from the upper-level MGCC. 7. The PCS supports VSG networking. The virtual inertia time constant and virtual armature impedance are configurable. 8. The system supports fault ride-through in the case of three-phase-to-ground, single-phase-to-ground, or inter-phase short circuit. 9. The three-phase four-wire PCS, without the need for an isolation transformer, supports long-term operation with unbalanced loads within the load constraint range. 10. Off-grid THDu ≤ 2% (rated linear balanced load R, RL, or RC, PF = [–0.8 to +0.8])
Seamed on/off-grid switching	Supports planned and unplanned on/off-grid switching, and automatic and manual (semi-automatic) on/off-grid switching; provides an interface for controlling on/off-grid switching. The PV-to-ESS ratio cannot exceed 2:1.
Seamless on/off-grid switching (all-time VSG)	Supports planned and unplanned on/off-grid switching. The seamless switching time is less than 150 ms.
Off-grid auto-start	After the off-grid PV+ESS system shuts down due to low SOC at night and the sunlight recovers in the morning of the next day, the system automatically detects the sunlight recovery, detects the power generation capability (static MPPT estimation), and starts the ESS to resume the power supply. Note: The UPS backup duration must be configured to ensure the continuous running of the monitoring system.
High PV-to-ESS ratio (inverter microgrid compatibility)	After the PV inverter is seamlessly connected to or disconnected from the grid, the microgrid compatibility function needs to be enabled. 1. In the off-grid scenario or seamless on/off-grid switching scenario, the microgrid compatibility function of the inverter must be always enabled. In the seamed PV+ESS on/off-grid switching scenario, the microgrid compatibility of the inverter is disabled during on-grid operation and is enabled during off-grid operation. The microgrid compatibility can be automatically set through the controller. 2. The inverter can support a high PV-to-ESS ratio of 2:1 only after the microgrid compatibility function is configured. For details about the inverter model, see the mapping description.
PV+ESS	The PCS supports the three-phase four-wire architecture and can

Feature	Description
low-voltage coupling without isolation transformers	be directly coupled with the PV inverter on the low-voltage side (the cable distance constraint must be met). The PCS is equipped with an N bridge arm and does not require an isolation transformer. It can supply power to single-phase loads, three-phase unbalanced loads, and half-wave loads.
PV+ESS system control	The SmartLogger can be used as a controller, eliminating the need for a third-party controller or MGCC.
On-grid dispatching control policy	Seamed on/off-grid switching: The off-grid power backup policy is supported based on the dispatching policy in the on-grid scenario. Seamless on/off-grid switching (all-time VSG): Only the maximum self-consumption and TOU are supported. Note: The on-grid dispatched power fluctuates due to the impact of the power grid frequency or voltage disturbance. Carefully evaluate the applicability of this feature to customer requirements. Off-grid only: N/A.

3.2 VSG

The VSG simulates the electromechanical transient characteristics of the synchronous generator so that the power supply using the converter has the characteristics of the synchronous generator, such as inertia, damping, primary frequency control, and reactive voltage control. The VSG follows the mechanical equation and electromagnetic equation. The PCS is controlled to have similar functions as the traditional generator in terms of mechanism and external characteristics, especially inertia. For example, the load fluctuation within a certain range will not immediately cause large grid disturbance because the synchronous generator has inertia. The moment of inertia of the traditional synchronous generator is a physical quantity related to its size, which usually increases with the increase of power. However, the virtual inertia of the VSG technology is flexible because it is closely related to the configuration of the energy storage unit. Damping in the traditional synchronous generator is a coefficient of damping torque varying with rotational speed, which mainly depends on the type and operation condition of the generator. When the synchronous generator is connected to the grid, electromagnetic damping is generated due to damper windings. Similarly, due to the introduction of virtual damping, the VSG technology has the capability of power oscillation damping.

When the PCS runs in VSG mode, the following parameters can be adjusted. (The parameters are set by default. If you need to adjust the parameters, contact Huawei engineers.)

No.	Configurable Parameters	Variable	Unit	Default	Magnification	Scope
1	Virtual resistance	R_{vir}	%	2	10%	0–5

No.	Configurable Parameters	Variable	Unit	Default	Magnification	Scope
2	Virtual inductive reactance	X_{vir}	%	1.2	10%	0–5
3	Inertia time constant of VSM	T_J	s	0.9	10%	0–20
4	Excitation time constant of VSM	T_Φ	s	0	10%	0–100
5%	P-f adjustment coefficient	k_δ	%	1	10%	0.5–5
6	Q-V adjustment coefficient	k_v	%	3	10%	0.3–10
7	Base frequency coefficient	k_{fB}	%	100%	10%	90–110
8	Base voltage coefficient	k_{vB}	%	100%	10%	90–110
9	Delta frequency of synchronous control	δ_f	%	0	100%	–10 to +10
10%	Delta voltage of synchronous	δ_v	%	0	100%	–10 to +10
11	VSG Subsynchronous oscillation suppression gain	Asso	/	0	0	0–2
12	VSG filter band selection for suppressing subsynchronous oscillation	FilterType	/	0	1	0, 1, 2, 3

3.3 Black start

3.3.1 Introduction

With the development of distributed power generation technologies, multiple distributed power supplies, energy storage devices, loads, and control devices are combined into an independent power supply system, and are connected to a larger power grid or an isolated power grid as a microgrid. When the main power grid is faulty or under maintenance, the microgrid can run in an islanded state to supply stable power. When the microgrid system runs in islanded mode, the system may lose power due to some faults. To further improve the power supply reliability, the microgrid system should support black start in islanded mode. With the black start function, after the entire microgrid is shut down due to external or internal faults, the power sources with the black start capability in the microgrid start first and help start those without the black start capability. In this way, the microgrid gradually recovers without the help of the utility power grid or other microgrids.

The C&I on/off-grid solution uses the ESS as the black start power source.

3.3.2 ESS Black Start Feature Description

Table 3-2 C&I on/off-grid black start feature panorama

Black Start Feature Category		Prerequisites	Scenario	Usage	Function Specifications
Commanded black start for arrays	One-click black start	(1) The SmartLogger and ESS monitoring unit are powered by the UPS. (2) Before the initial deployment, ensure that the grid code of the array is the same as the local grid code. You are advised to perform deployment before executing the array black start command. (3) SOC > 0%. **If the SOC is 0% or a battery undervoltage alarm is generated, charge the ESS first.**	Off-grid local O&M	Log in to the SmartLogger WebUI or app and deliver the command. (*Note: The feature is available on the app only after the MGCC function is enabled on the SmartLogger.*)	(1) For details about the black start loading capability, see the ESS loading capability (chapter 4). (2) Black start time ≤ 10 minutes
			Black start of a single array controlled by a third-party MGCC	The third-party MGCC sends the black start command to the SmartLogger through Modbus TCP.	
	Step-by-step black start		The third-party MGCC controls the synchronous black start of multiple arrays.	The third-party MGCC sends the black start command to the SmartLogger through Modbus TCP.	
Single system black start by pressing the button	Single system black start by pressing the button	(1) If multiple cabinets are connected in parallel, disconnect loads first. (2) Before the initial deployment, turn off the AC	Used for local O&M when the SmartLogger and ESS monitoring unit are not powered by the UPS.	Press the black start button on the ESS. (*Constraints: 1. Press and hold the black start button for more than 10s. 2. Wait for 1 minute*	

Black Start Feature Category		Prerequisites	Scenario	Usage	Function Specifications
		switch of the cabinet. This prevents device damage caused by voltage and frequency non-compliance due to the inconsistency between the default grid code and the local grid code. (3) SOC > 0%. **If the SOC is 0% or a battery undervoltage alarm is generated, charge the ESS first.**		*before pressing the black start button again after the first press.*)	

3.3.3 Capability Specifications of Black Start

1. Black start with loads: For details, see chapter 4.
2. Multi-stage transformer energization and de-energization are not supported.
3. Black start time: 10 minutes
4. Black start SOC requirements: Black start can be performed when the SOC is greater than 0. *Note: If the SOC is less than the array end-of-discharge SOC, charge the ESS after startup.*

   If the MGCC is used during microgrid operation, the SOC is greater than the array end-of-discharge SOC. (To ensure stable operation of the microgrid, a 5% hysteresis is reserved between the lower limit of the microgrid operation SOC controlled by the MGCC and the array end-of-discharge SOC.)
5. To prevent black start failure caused by system power imbalance due to PV output power recovery during ESS voltage establishment, it is advised to limit the PV power to zero before the black start (setting active PV power adjustment in fixed value to 0 through register 40378).

3.3.4 Other Precautions

3.3.4.1 Low Temperature Scenario

Background:

In extremely cold areas, the ESS needs to support black start at –30°C to cope with microgrid blackouts that may occur during onsite deployment or operation.

Specifications:

Temperature > –30°C

Constraints:

Affected by the cell feature, the ESS can discharge energy at –30°C but can be charged only at above 10°C (charging at full power is supported at above 20°C). Therefore, the prerequisite for black start at a low temperature is that the ESS has sufficient SOC or an external power supply is provided for heating the ESS to above 10°C. Then the ESS is charged by the PV system or another power supply, supporting stable operation of the entire microgrid.

If the ESS has been shut down for a long time and placed in a low-temperature environment, reserve 15 hours for the cell temperature to increase from –30°C to a temperature that allows the ESS to run properly.

If the ESS is heated through self-discharge, disconnect the loads and reserve 30% SOC for the ESS.

Table 3-3 Reserved heating time and recommended SOC after long-term placement in a low-temperature environment

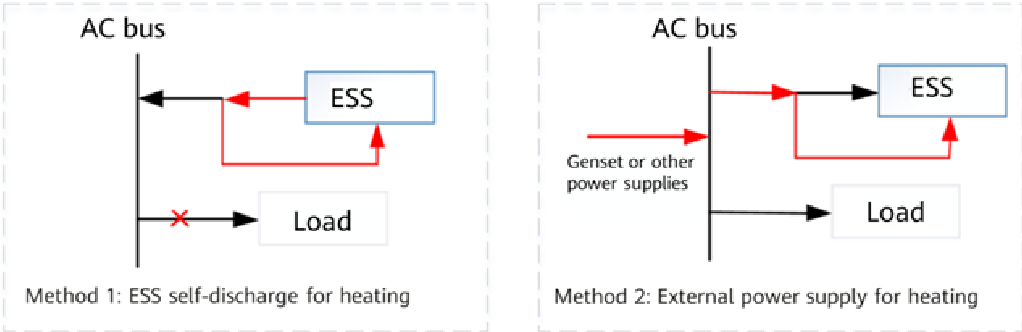
Model	Initial Temperature	Reserved Heating Time (Example Target Temperature: 21°C)	Reserved Heating Power	Recommended Reserved SOC for Heating Through Self-discharge
LUNA2000-215-2S10	–30°C	15 hours	3.5 kW	30%

Low-temperature black start principle:

Black start after supplying power to the auxiliary PTC heater in the ESS

(1) Method 1: ESS self-discharge. If the reserved ESS SOC is sufficient to support the ESS to be heated from a low temperature to above 10°C and another power supply (usually the PV system) charges the ESS when the temperature reaches 10°C, the black start can be directly performed.

(2) Method 2: External power supply. If the reserved ESS SOC is insufficient to support the ESS to be heated from a low temperature to above 10°C, the ESS will run out of its energy before the temperature rises to the target value. In this case, use the external power supply to heat the ESS. After the temperature rises to above 10°C, perform the black start.



3.3.4.2 Deployment Scenario Where the Monitoring Unit Is Not Powered by a UPS

It is recommended that the microgrid be configured with a UPS to supply power to the SmartLogger and ESS monitoring unit. In this case, you can log in to the SmartLogger WebUI or local SmartLogger app to perform startup authorization and array deployment.

If there is no UPS or the UPS has no power, you can perform deployment by pressing the local black start button to establish the voltage. In this case, you need to obtain startup authorization and set the grid code first.

Considering that the preset grid code of the ESS may not match the local grid code, especially when there are differences in rated voltage and frequency, directly supplying power to loads can cause device damage. Therefore, before pressing the local black start button for the first time, turn off the AC switch of the ESS to prevent exceptions on other devices on the AC bus. The recommended procedure is as follows:

Step 1 Turn off the AC switch of the ESS for black start.

Step 2 Open the cabinet door and press the black start button for at least 10s.

Step 3 Close the cabinet door. After the monitoring unit is powered on, use the local app to connect to the ESS, perform startup authorization, and set the grid code.

Note: 1. If the startup authorization is not obtained, ESS power-on is not allowed and black start fails. 2. Modifying the grid code will reset the device and stop the ESS. In this case, you need to trigger the black start again.

Step 4 Turn on the AC switch of the ESS for black start.

Step 5 Repeat step 2 to press the local black start button again after an interval of at least 1 minute.

Step 6 Close the cabinet door. After the black start is complete, log in to the SmartLogger WebUI or local SmartLogger app and perform deployment according to the wizard.

----End

3.4 On/Off-Grid Switching

3.4.1 Concepts

The on/off-grid switching of the microgrid system involves three transition processes:

(1) Intentional off-grid

The microgrid switches from the on-grid mode to the off-grid (islanding) mode as planned.

(2) Unintentional off-grid

When the microgrid detects that the utility power grid is abnormal, the microgrid switches from the on-grid mode to the off-grid (islanding) mode.

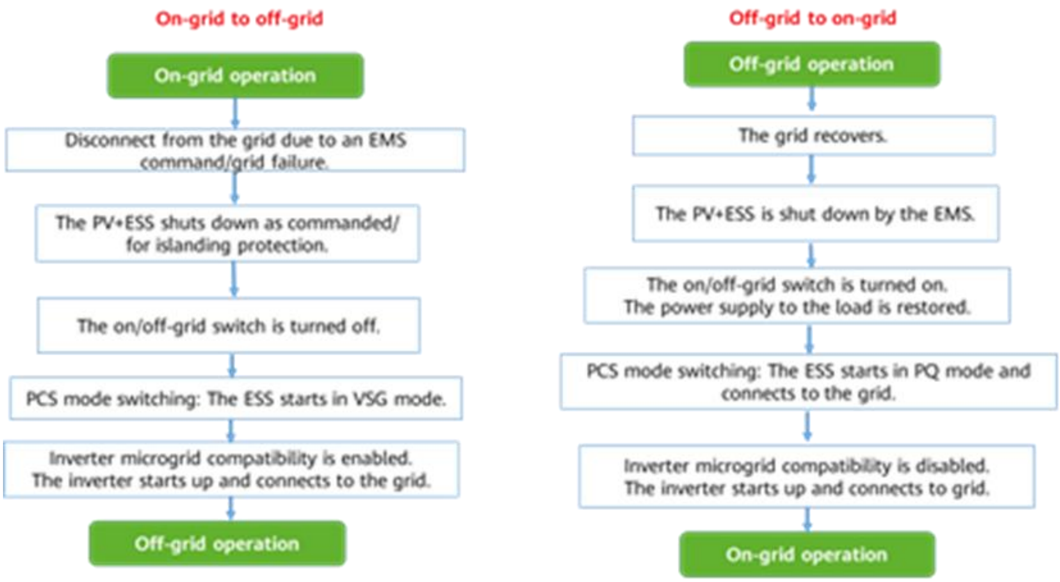
(3) Off-grid to on-grid

After the power grid recovers, the microgrid switches from off-grid to on-grid according to the preset procedure.

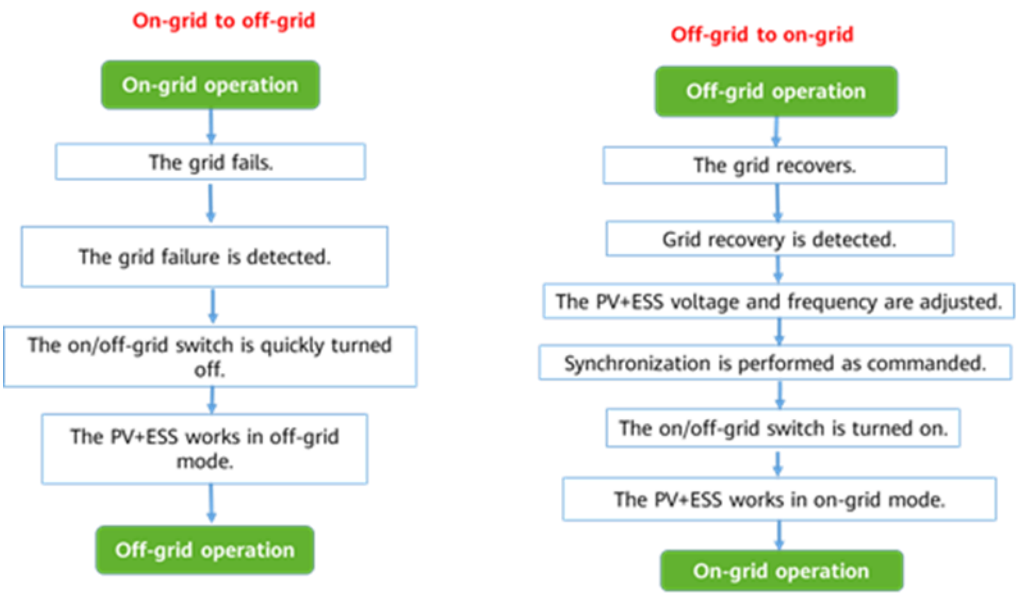
The switching can be classified into **seamed on/off-grid switching** and **seamless on/off-grid switching** (switching without powering off the ESS), based on whether the AC side of the device is shut down and restarted during the switching.

1. **Seamed on/off-grid switching**: After a mains outage occurs, the AC side of the PV+ESS system shuts down, the switch between the system and the power grid is turned off, and the loads are disconnected. Then, the PCS switches from the PQ mode to the VSG mode for grid forming. After the startup is complete, the loads are connected.
2. **Seamless on/off-grid switching (all-time VSG)**: The C&I seamless on/off-grid switching solution means that the PV+ESS system does not shut down during the on/off-grid switching. In unintentional off-grid scenarios, the PCS works in VSG mode all the time to implement on/off-grid switching with the cooperation of the system controller and on/off-grid switch.

Seamed on/off-grid switching



Seamless on/off-grid switching



Synchronization

In the seamless on/off-grid switching scenario, after the mains recovers, the SmartLogger adjusts the PV+ESS microgrid voltage and frequency after detecting that the mains recovers and is stable (power grid frequency: f_n±1 Hz; power grid voltage: U_n±10%). When the frequency difference is less than 0.1 Hz and the voltage difference is less than 5% U_n, the protective relay performs a synchronization check and the switch is closed for grid reconnection. Then the on-grid operation control is restored. During the switching, the loads remain energized.

Note: If a synchronization process is abnormal or fails, the SmartLogger will initiate another synchronization process after a short delay.

3.4.2 Seamed On/Off-Grid Switching

In the seamed on/off-grid switching scenario, the ESS works in PQ mode during on-grid operation and in VSG mode during off-grid operation. At the system control layer, the switching mode can be automatic, manual (semi-automatic), or no control.

1. In PQ/VSG mode, the seamed on/off-grid switching mode can be set to no control, automatic, or manual.

   a. By default, the no control mode is used.

   b. When the automatic mode is to be selected, check whether the on/off-grid switch DI/DO and power failure detection DI are configured. If either of them is not configured, a message is displayed, indicating that xxx is not configured and the mode cannot be set to the automatic mode.

   c. When the manual mode is to be selected, check whether the on/off-grid switch DI is configured. If not, a message is displayed, indicating that the manual mode cannot be selected because the on/off-grid switch status feedback port is not configured.
2. The change of the on/off-grid switching mode requires secondary authentication.
3. The following help information is added next to the on/off-grid switching mode:

- Automatic: The on/off-grid switching is performed automatically based on the status of the mains power. When you set on/off-grid switching mode to this mode, an immediate on/off-grid switching may be triggered, depending on the status of the mains power.
- Manual: The on/off-grid switching will be triggered by manually turning on or off the switch at the grid connection point.
- No control: All the operations involved in the on/off-grid switching are manually performed.

Based on the operation status and conversion relationship of the on/off-grid system, the system can be classified into on-grid operation, on-grid to off-grid switching, off-grid operation, off-grid to on-grid switching, and black start. The details are as follows:

Table 3-4 Operation modes in the seamed on/off-grid switching scenario

No.	Operation Mode	Description	
1	On-grid	1. The PV+ESS system is connected to the power grid in PQ mode. The new backup power mode is compatible with the existing dispatching control policies (such as the maximum self-consumption and TOU) for on-grid operation. 2. When the backup power mode is enabled and the SOC is lower than the off-grid backup power SOC, the ESS does not discharge and does not work in on-grid mode. 3. If the SOC is higher than the off-grid power backup SOC, the ESS works in the preset on-grid mode.	
2	On-grid to off-grid	1. Unintentional off-grid: After receiving the power failure detection signal or the on/off-grid switch disconnection signal, the SmartLogger switches the PQ mode to the VSG mode, and then transfers the ESS and PV system to off-grid mode. 2. After the power grid fails, the AC side fails, and the DC side of the ESS remains energized for at least 5 minutes. 3. After confirming the status of the power grid, PV+ESS system, on/off-grid switch, and other devices, the controller performs off-grid mode/configuration settings. 4. The controller starts the ESS and PV system, restores the power supply to loads, and performs off-grid	

No.	Operation Mode	Description	
		operation control.	
3	Off-grid	1. When the system is off-grid, the SmartLogger supports PV+ESS coordinated control to ensure that the ESS SOC/power is within the preset range. 2. Secondary voltage and frequency regulation is supported during off-grid operation.	
4	Off-grid to on-grid	1. The power grid is recovered, and the SmartLogger receives the power supply recovery signal. 2. Shut down the PV+ESS system, turn on the switch at the grid connection point, and set the PV+ESS mode, features, and parameters. 3. Power on the system, connect it to the power grid, and perform on-grid dispatching control.	
5%	Black start	The black start operation is performed after the on/off-grid switching is abnormal or the system is shut down due to timeout, or the fault is rectified during O&M. For details, see the black start feature design description.	

NOTE

If an ATS is available for connecting customer's loads to the genset, the ATS may automatically perform transfer during the PV+ESS switching because the SmartLogger does not detect the ATS and genset status. You can increase the ATS transfer delay to avoid overlapping with the seamed PV+ESS switching time. Otherwise, the ATS may be triggered or the genset may be started or stopped.

3.4.3 Seamless On/Off-Grid Switching (All-Time VSG)

(1) Overview

In this solution, the PCS supports PV+ESS on/off-grid switching in all-time VSG mode. The ESS runs in VSG mode during on-grid and off-grid operation.

On-grid operation control mode: During on-grid operation in all-time VSG mode, only the maximum self-consumption and TOU are supported.

The PV inverter works in PQ mode and microgrid compatibility is enabled.

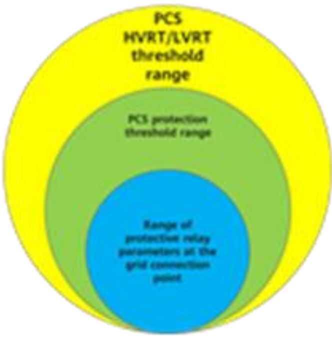
(2) Power characteristics during on-grid operation in VSG mode

- Power grid disturbance/fault ride-through: The PCS can respond to voltage and frequency fluctuations. After the protective relay time arrives, the switch at the grid connection point is turned off.
- On-grid VSG power closed-loop range: ±0.8 Hz, 2% U_n, 1 mHz/s; steady-state active power precision: 2%, dynamic response time: 1s; reactive power control precision: 2%, response time: 10s
- When the frequency fluctuates, the PCS preferentially responds to the voltage and frequency fluctuation and generates power fluctuations. If the controller adjustment cannot keep up with the response speed of the PCS to support the power grid, the power at the grid connection point may not be restricted, and even PV curtailment may occur.

(3) Seamless on/off-grid switching protection

The seamless on/off-grid switching solution involves the coordination of multiple devices, including the grid connection point detection device (third-party protective relay) and PCS (frequency and voltage protection and LVRT/HVRT). The target functions can be implemented only when each component correctly acts according to the preset logic. The overall logic requirements for C&I seamless switching are as follows: Before the switch at the grid connection point is turned off, the PCS must be able to run properly without triggering shutdown due to protection. After the switch is turned off, the system switches to the off-grid mode and can run properly. The following figure shows the relationship of system protection parameters.

Figure 3-1 Protection parameter settings for the seamless on/off-grid switching system



Working Condition	Grid Connection Point—Protective Relay (Values of the Protective Relay Parameters Cannot Exceed These Ranges)	PCS (Protection Parameters) (Manually Set After Deployment)	PCS (HVRT/LVRT) (Automatically Implemented by Software)
Overvoltage (two segments)	1.1 U_n or above: protection after 10s (maximum delay) 1.3 U_n or above: 100 ms	PCS level-1 protection (1.2 U_n): 10.5s PCS level-2 protection (1.3 U_n): 300 ms	The HVRT and LVRT thresholds must be greater than the PCS protection ranges. (HVRT: above 1.1 U_n, 20s HVRT: above 1.2 U_n,

Working Condition	Grid Connection Point—Protective Relay (Values of the Protective Relay Parameters Cannot Exceed These Ranges)	PCS (Protection Parameters) (Manually Set After Deployment)	PCS (HVRT/LVRT) (Automatically Implemented by Software)
			10.5s HVRT: above 1.3 U_n, above 0.5s)
Undervoltage (two segments)	Below 0.9 U_n: protection after 10s (maximum delay) Below 0.8 U_n: instantaneous protection	PCS level-1 undervoltage (0.9 U_n): 10s PCS level-1 undervoltage (0.8 U_n): 1s	The HVRT/LVRT thresholds must be greater than the PCS protection ranges. (Undervoltage 0.8 U_n: above 1s)
Frequency protection	Frequency protection: f_n±2 Hz@500 ms (maximum delay)	The PCS overfrequency/underfrequency range shall be greater than the protective relay range (inherited from 23B-bugfix, PCS overfrequency/underfrequency range: f_n±10% Hz@1s).	The HVRT/LVRT thresholds must be greater than the PCS protection ranges.
	Frequency change rate: 5 Hz/s, no delay (the delay is set to the minimum value)	/	Optional, backup protection

Note: In extreme working conditions beyond the preceding protective relay range, the PCS can be shut down for protection.

For a grid code with only one level of protection:

- If PCS overvoltage occurs, set the parameters according to the preceding table (PCS level-1 overvoltage protection threshold).
- If PCS undervoltage occurs, set the parameters according to the preceding table (PCS level-1 undervoltage protection threshold).

For a grid code with three or more levels of protection:

- Level 3 or higher: overvoltage/undervoltage protection. The setting is the same as that of level 2.
- If the frequency protection is level 2 or higher, the setting is the same as level 1.

- If frequency change rate protection is required, disable it.

Table 3-5 Grid connection parameter setting for synchronization

Function	Solution Configuration
Determination of power grid recovery before synchronization	Determination before synchronization: 1. Power grid frequency: Check whether the power grid frequency is not higher than f_n±1 Hz. 2. Power grid voltage: Check whether the power grid voltage is not higher than U_n+10%. (Currently, the undervoltage recovery threshold is 0.9 U_n@10s by default, which is reserved.)
Synchronization detection precision	• The on/off-grid controller can adjust the voltage and frequency so that both sides of the switch at the grid connection point meet the synchronization conditions. The precision requirements are as follows: The frequency difference is less than or equal to 0.1 Hz, and the amplitude difference is less than or equal to 5% U_n (U_n is the rated voltage of the utility power grid). • The protective relay detection precision requirement is as follows: The voltage phase difference is less than or equal to 3°. • Time of turning on the switch at the grid connection point ≤ 100 ms

3.5 ESS SOC Configuration Description

SOC configuration in the off-grid scenario

SOC Settings	SOC Settings on C&I SmartLogger (MGCC)	Value Range	Recommended Default Value		
			Recommended Value	**Recommended Application Scope in the Quick Guide**	**Setting Constraints**
Rack end-of-charge SOC	Rack end-of-charge SOC (configurable at the array level)	90%–100%	100%	95%–100%	Reserve a hysteresis of 5% or more between the upper limit of off-grid operation and the rack end-of-charge SOC. Otherwise, microgrid
Use of the microgrid central controller (MGCC)	Off-grid (Array) end-of-charge SOC	85%–98%	90%	85%–95%	

SOC Settings	SOC Settings on C&I SmartLogger (MGCC)	Value Range	Recommended Default Value		
			Recommended Value	**Recommended Application Scope in the Quick Guide**	**Setting Constraints**
					blackouts may occur.
	SOC threshold for stopping load shedding	26%–40%	30%	26%–40%	/
	SOC threshold for starting load shedding	10%–25%	20%	10%–25%	/
	Off-grid (Array) end-of-discharge SOC	10%–20%	10%	10%–15%	Reserve a hysteresis of 5% or more between the lower limit of off-grid operation and the rack end-of-discharge SOC. Otherwise, microgrid blackouts may occur.
	Reserved SOC required for automatic startup after irradiance restoration				
Rack end-of-discharge SOC	Rack end-of-discharge SOC (configurable at the array level)	0%–15%	5%	0%–5%	
Black start logic	Minimum SOC for black start	The default value is 0 (when the current limit is not 0) and cannot be changed.	Not perceived externally		

SOC setting in the on/off-grid switching (seamed/seamless) scenario

SOC Settings	SOC Settings on C&I SmartLogger (MGCC)	Value Range	Recommended Default Value		
			Recommended Value	Recommended Application Scope in the Quick Guide	Function Description
Rack end-of-charge SOC	Rack end-of-charge SOC (configurable at the array level)	90%–100%	100%	95%–100%	Reserve a hysteresis of 5% or more between the upper limit of off-grid operation and the rack end-of-charge SOC. Otherwise, microgrid blackouts may occur.
Use of the MGCC	On-grid (Array) end-of-charge SOC	85%–98%	90%	85%–95%	
	Off-grid (Array) end-of-charge SOC	85%–98%	90%	85%–95%	
	Off-grid power backup SOC	20%–90%	40%	20%–90%	The upper limit does not exceed the end-of-charge SOC.
	Off-grid (Array) end-of-discharge SOC	10%–20%	10%	10%–15%	Reserve a hysteresis of 5% or more between the lower limit of off-grid operation and the rack end-of-discharge SOC. Otherwise, microgrid blackouts may occur.
	Reserved SOC required for automatic startup after irradiance restoration				
Rack end-of-discharge SOC	Rack end-of-discharge SOC (configurable at the array level)	0%–15%	5%	0%–5%	
Black start logic	Minimum SOC for black start	The default value is 0 (when	Not perceived externally		

SOC Settings	SOC Settings on C&I SmartLogger (MGCC)	Value Range	Recommended Default Value		
			Recommended Value	Recommended Application Scope in the Quick Guide	Function Description
		the current limit is not 0) and cannot be changed.			

4 Loading Capability

When planning the installed ESS capacity, ensure that the total rated capacity of all loads does not exceed 2/3 of the PCS rated capacity (the load of each phase cannot exceed 2/3 of the single-phase rated capacity) when the on/off-grid system is running. That is, when the grid-forming PCS is running with loads, a certain capacity is reserved to withstand load power fluctuation, ensuring stable running of the microgrid.

4.1 Loading Capability Constraints

The load status determines the requirements for the power supply configured in the system and is the primary factor that affects the stability of the microgrid system. The microgrid requires the PCS to run in VSG mode to form a power grid. When the system has the following loads, pay special attention to the capacity design and ensure that the configuration does not exceed the range.

Table 4-1 Loading capability constraints of the PV+ESS on/off-grid or off-grid solution

Category	Constraint	Remarks
Linear load	The PCS supports rated linear loads (R, RL, and RC loads, PF = [–0.8 to +0.8]). Considering transient stability issues such as load fluctuation and fault ride-through, the steady-state peak value of the load capacity shall not exceed 2/3 of the rated capacity of the PCS. (Note: The load of each phase cannot exceed 2/3 of the rated capacity of a single phase and the single-phase rated capacity is 1/3 of the PCS rated capacity, that is, the load of each phase $< 2/3 \times P_n \times 1/3$.)	The PCS is an electronic device. Generally, the overcurrent capability of the PCS is very weak. The nominal rated capability is almost the same as the maximum capability. During load configuration, capacity redundancy of the PCS shall be reserved for transient HVRT/LVRT faults, inrush current due to load connection, and

Category	Constraint	Remarks
	For off-grid scenarios involving remote power supply, the capacitive/inductive loads of the transmission cables shall be considered as part of the loads, which adhere to the 2/3 constraint.	inrush current due to transformer energization. Otherwise, the PCS may lack sufficient current capability to stabilize the AC side when the microgrid fluctuates transiently. In this case, the risk of triggering PCS overcurrent protection is high, and it is difficult to restore the PCS in the future.
Non-linear load	1. Crest factor (CF): The PCS with a transformer can supply power to non-linear loads. The CF of non-linear loads is less than or equal to 2. (If the CF exceeds 2, load harmonic control is required.) 2. Harmonic: The total current harmonics of loads comply with specifications or standards. 3. Half-wave loads: For half-wave loads, the total even harmonic distortion shall be less than 5%.	Common load devices include the variable-frequency drive, rectifier, switch-mode power supply, and UPS. For details about the load harmonic requirements, see IEEE Std 519-2014 *IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems* and GB/T 14549-93 *Quality of electric energy supply—Harmonics in public supply network*.
Unbalanced load	Under the constraint of the system load rate, the PCS can run for a long time with unbalanced resistive loads in a stable state, including: (1) One phase at 2/3 capacity, with the other two phases unloaded. (2) Two phases at 2/3 capacity, with one phase unloaded. Note: The single-phase rated capacity is 1/3 of the PCS rated capacity.	Three-phase imbalance: The load currents of the three phases are different. If the difference is large, the power distribution device may be overheated and the cable loss may increase. In the low-voltage power distribution network, there are a large number of single-phase loads. Therefore, the loads shall be evenly distributed to the three phases during power distribution. Common formula for calculating the imbalance: (Maximum phase current –

Category	Constraint	Remarks
		Minimum phase current)/Maximum phase current
Motor load	If there is a motor load, check whether the motor load meets the loading capability requirements. (1) The load of motors that use DOL starters or star-delta starters (the maximum inrush current is 10 times the rated current) shall not exceed 10% of the PCS rated power (if this value is exceeded, you are advised to add variable-frequency drives). If the PCS supplies power to load, the load of motors shall be decreased accordingly in the same proportion. If the motor load is 10 kW and other loads are 40 kW, the capacity of the PCS shall be greater than 159.7 kW (10 kW x 10 + 40 kW/0.67 = 159.7 kW). (2) For variable-frequency or soft-start motor loads, the load power cannot exceed 2/3 of the rated power of the PCS. (3) When asynchronous loads are connected in off-grid mode, oscillation issues may arise. These can typically be resolved by enabling default parameter settings through the interface. However, in rare cases where the default control parameters are insufficient to suppress oscillation, professional maintenance personnel may be required to locate the fault and adjust the parameters for suppression.	Oscillations are likely to occur in factory, mine, and farm scenarios. Common symptoms of motor load oscillation during off-grid operation are as follows: 1. Asynchronous loads within the specifications fail to be started. 2. When the asynchronous loads are running, they produce abnormal sounds and the enclosures may exhibit noticeable shaking. 3. The lights flicker.
Transformer energization	The instantaneous peak current (basic current plus inrush current) upon all load energization shall not exceed 1.1 times of the PCS rated current. Transformers: Constraints on load transformer energization: Supports the energization of a transformer whose capacity does not exceed 50% of the total operating capacity of the PCS. Transformer on the load side: When the power of the transformer on the load side is greater than or equal to 50% of the rated power of the PCS, the switch on the PCS side of the transformer shall	When a transformer is energized, there is a possibility that the PCS shuts down for protection. In this case, check whether the PCS is normal. If the PCS is normal, restart the PCS. Suggestion: The transformer starts with the PCS black start to prevent overcurrent protection caused by direct transformer energization.

Category	Constraint	Remarks
	be always turned on.	

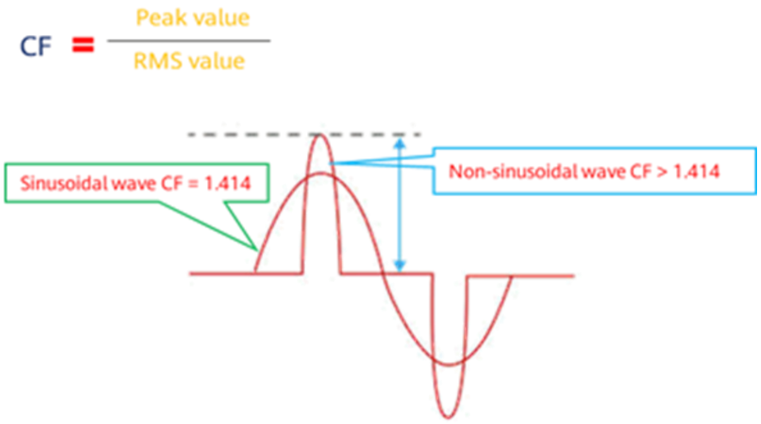
4.2 Common Load Classification

(1) Non-linear load

CF of the non-linear load: ratio of the peak amplitude of a waveform to its RMS value. This is a value without a unit. The CF value of the sinusoidal wave is 1.414.

Calculation formula:

Figure 4-1 Diagram of different CFs



The current protection of various loads of the PCS is calculated based on the RMS of the sinusoidal fundamental wave. The CF value represents the instantaneous peak value of the waveform. Based on the RMS current protection threshold of the fundamental wave, if the CF value is too large, the peak current will far exceed the peak value of the sinusoidal fundamental wave current. As a result, the loading capability of the PCS decreases, or hardware shutdown is triggered for protection.

C&I microgrid constraint: The load CF is less than 2. If the CF is greater than 2, load harmonic control is required.

(2) Motor load start impact

When a motor is started directly, the rotor remains stationary at the moment of energization. The rotating magnetic field generated by the stator winding cuts through the rotor at maximum speed. According to Faraday's electromagnetic induction law, this process generates a significant induced electromotive force in the rotor winding. As a result, the startup current that is 5 to 12 times the rated current of the motor is generated. The sharp increase of the current poses a serious challenge to the capabilities of the motor and the power supply.

Figure 4-2 DOL starting of an asynchronous motor

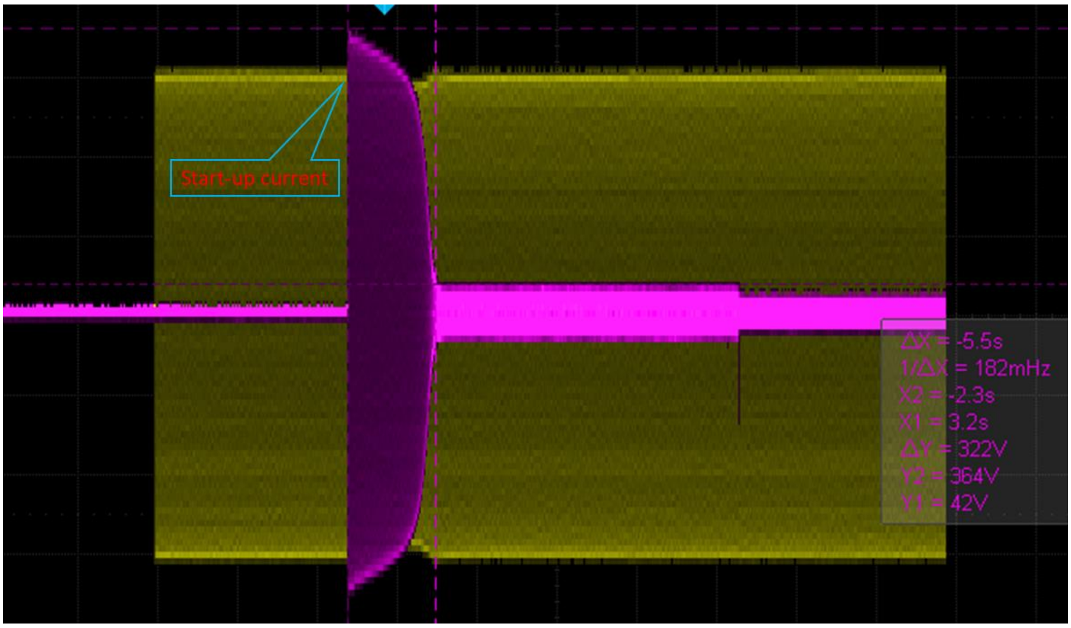
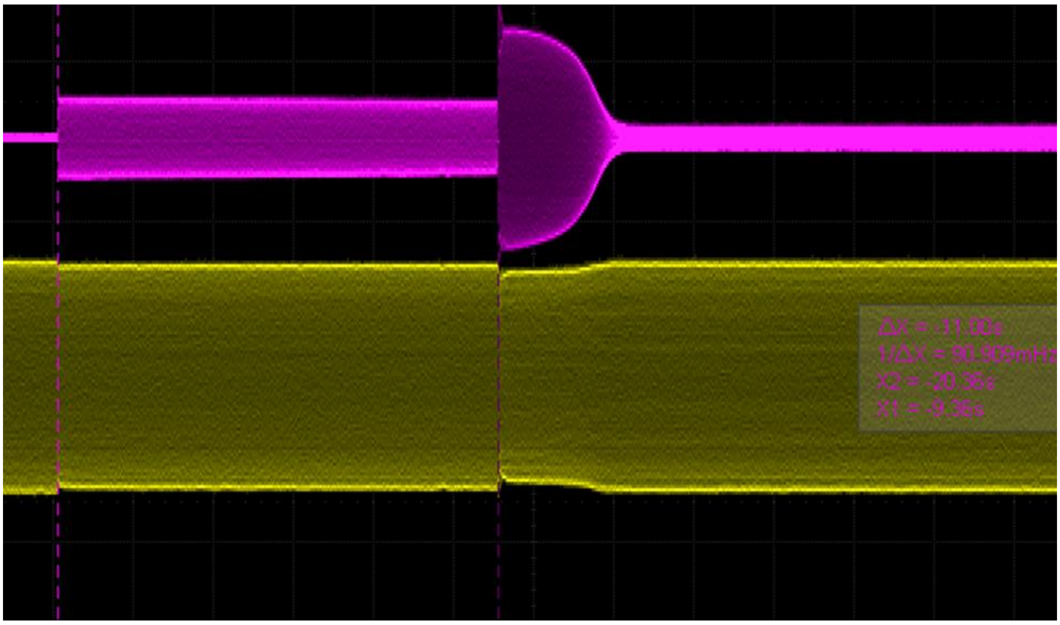
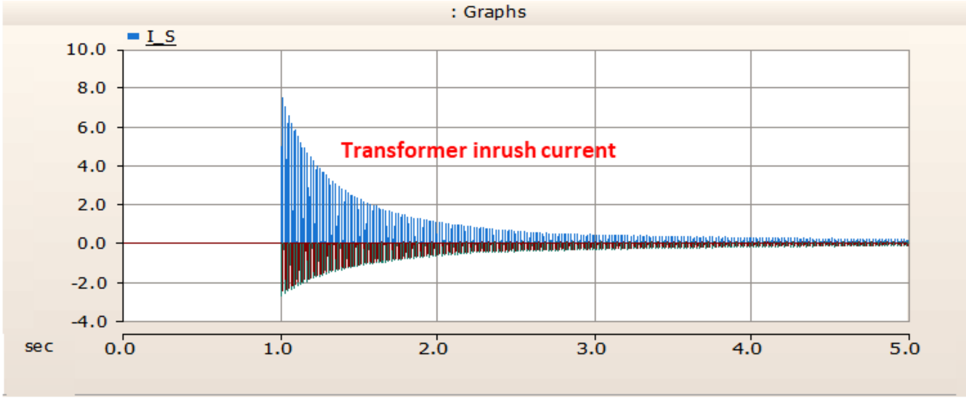


Figure 4-3 Star delta starting of an asynchronous motor



(3) Impact caused by transformer energization

When the transformer is energized, inrush current will occur. The inrush current is the transient current generated in the winding when the transformer connected to the grid is energized without load. Before the transformer is energized, when the residual magnetic flux in the iron core is in the same direction as the magnetic flux generated by the operating voltage of the transformer, the total magnetic flux far exceeds the saturation magnetic flux of the iron core, causing instant saturation of the iron core and generating a large current. The peak current can reach 8–10 times the rated current of the transformer, which can easily trigger protection in the transformer and lines, and even cause power overcurrent protection.



Appendix: Common load classification and constraints

No.	Term		Definition	Common Devices and Requirements
1 2	General classification	Resistive load	There is no phase difference in load current and voltage, and a resistive load is mainly composed of resistance heating equipment.	Household appliances: incandescent lamps, electric irons, oil heaters, electric blankets, electric ovens, electric water heaters, electric kettles, electric cookers, etc C&I equipment: resistance furnaces, drying boxes, electric heaters, etc.
3		Inductive load	The phase difference between the current and voltage consumed by an inductive load is 90 degrees lagging, and an inductive load is mainly composed of motors.	Household appliances: motors, transformers, refrigerators, air conditioners, electric fans, washing machines, vacuum cleaners, hair dryers, microwave ovens, etc. C&I equipment: machine tools, hydraulic machines, ventilators, elevators, lifting equipment, freezers, conveyor belts, water pumps, wrapping machines, etc.
		Capacitive load	The phase difference between the current and voltage consumed by a capacitive load is 90 degrees leading.	Capacitors, TV sets, and IT devices such as computers
4	Linear and non-linear loads	Linear load	A load whose load impedance is constant when a variable sinusoidal voltage is applied. Linear loads include pure resistive loads (power factor = 1), inductive loads (power factor < 1), capacitive loads (power factor < 1), pure inductive loads, and pure capacitive loads (power factor = 0).	Pure resistive loads (power factor = 1), inductive loads (power factor < 1), capacitive loads (power factor < 1), pure inductive loads, and pure capacitive loads (power factor = 0)
5		Non-linear load	A load whose impedance is not always a constant and varies with other parameters such as voltage or time. An important feature of a non-linear load is that the current is not sinusoidal when a sinusoidal voltage is applied to the load.	Frequency converters, switch-mode power supplies, UPSs, rectifiers, fluorescent lamps (ballasts)
6	Special definition	RCD load	To simulate a single-phase or three-phase steady-state rectifier/capacitor load, the RCD load is a diode rectifier bridge with a capacitor and a resistor parallel circuit on the output side.	Benchmark non-linear loads
7	Special definition	Half-wave load	A load that is a half-wave rectification circuit	Single-phase half-wave rectification circuits, three-phase half-wave rectification circuits, and half-wave rectification circuits are mainly used in electrical devices with adjustable power, such as rice cookers, hair dryers, electric vehicle chargers, and soldering irons.
8	Special definition	Surge load	A power consumption device that has a high rated capacity (30% higher than the transformer capacity) and is frequently and intermittently consumes a large amount of power	Surge harmonic loads (such as electric welding machines), frequently started motors (such as punching machines and paper cutting machines), and electric arc furnaces (electric furnaces that melt ores and metals using high temperatures generated by electrode arcs)
9	Unbalanced load	Balanced load	There is no negative sequence or zero sequence component during the normal operation of the power system.	Allowed voltage unbalance factor (VUF) (according to GB T15543): The allowed VUF of the common connection point in the power system is 2% and the transient VUF cannot exceed 4%. The reasons of voltage unbalance include load unbalance, system three-phase impedance asymmetry, and incorrect tuning of arc suppression coil.
10		Unbalanced load	Voltage unbalance of the common connection point caused by the negative sequence component during the normal operation of the power system	

4.3 Capacity Design Constraints

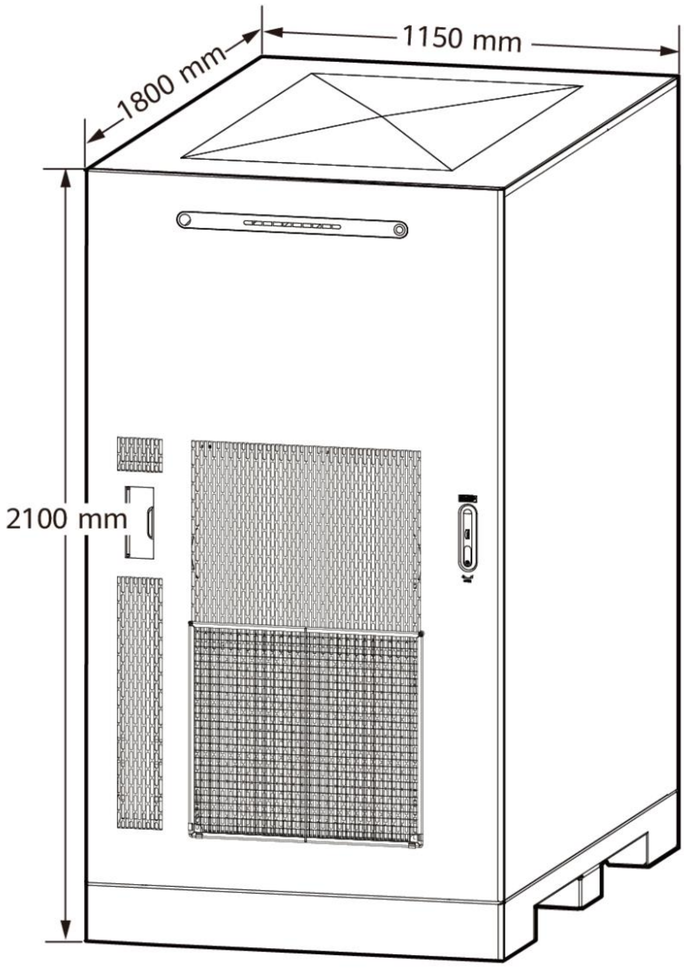
When planning the installed ESS capacity, ensure that the total rated capacity of all loads does not exceed 2/3 of the PCS rated capacity (the load of each phase cannot exceed 2/3 of the rated capacity of a single phase, that is, the load of each phase < 2/3 x P_n x 1/3) when the on/off-grid system is running. That is, when the grid-forming PCS is running with loads, a certain capacity is reserved to withstand load power fluctuation, ensuring stable running of the microgrid. In addition, the configuration constraints of non-linear loads and impact loads shall be met. For details about the capacity design with load constraints, see this section.

Note: When designing the capacity, consider the capacity constraints and protection settings of the customer's distribution transformer.

5 Device Description

5.1 ESS

LUNA2000-215-2S10 is the Smart String ESS (ESS for short). The ESS is a prefabricated all-in-one energy storage system that integrates the prefabricated modular structure system, power supply and distribution system, monitoring system, environment control system, fire suppression system, and integrated cabling system. It features high safety and reliability, fast deployment, low cost, high efficiency, and intelligent management.


1800 mm
1150 mm
2100 mm

The configurations of the Smart String ESS (ESS for short) vary with the power grid voltage level and fire suppression requirements. The following model is available: LUNA2000-215-2S10. For details, see the manual.

For details about Smart String ESS, see ***LUNA2000-(215-2S10) Series Smart String ESS User Manual*** (https://support.huawei.com/enterprise/en/doc/EDOC1100394281).

5.1.1 Key Design Points for ESS Applications

NOTICE

This section describes the key points of design and boundary conditions that customers must comply with before using Huawei C&I Smart String ESS Solution. In case of nonconforming items, the system design may be incorrect, the solution may fail to work, or the project operation may be affected. For details, see the ESS product manual.

5.1.2 Array Layout

For details, see the site selection and space requirements in the user manual of the ESS.

5.1.3 ESS Safety Requirements

NOTICE

The ESS site selection and fire safety must comply with local laws and regulations. Reference standards include but are not limited to GB 51048 *Design code for electrochemical energy storage station*, GB 50016 *Code for fire protection design of buildings*, and NFPA 855 *Standard for the Installation of Stationary Energy Storage Systems*.

The site of the ESS must meet the site selection requirements in the user manual.

5.1.4 Introduction to the PCS

1. Specifications

For details, see the user manual.

NOTICE

The off-grid configuration specifications of the PCS must meet the loading capability requirements described in this document.

2. Resonance constraints of PV+ESS coupling

The cables from the inverter and ESS to the PDC must be at least 5 m long to prevent device resonance. (There is no requirement on the cable connection distance for the V3 inverter. If resonance occurs in a project, add a magnetic ring to solve the problem.)

NOTICE

The power distribution and electrical connections of the PV+ESS system must comply with the installation regulations of the device and the country or region where the device is located.

Leakage protection: Configured based on local power distribution regulations. The device enclosure must be reliably grounded to ensure reliable PE connection.

Cable connection: For details about the cables and terminals of the PV and ESS devices, including the main power cable and auxiliary power cable, see the product manual. Ensure that the neutral wire of the ESS is securely connected. Otherwise, the AC electrical devices in the system will be damaged.

Phase sequence: The phase sequences of all PCSs, inverters, PDCs, and transformers in the array must be the same. The default phase sequence of the PCSs is ABC. (The phase sequence cannot be adjusted using software. If you need to adjust the phase sequence, adjust the physical cable connections.)

5.2 PV Inverter

See the user manual of the corresponding inverter model.

The PV inverter must support the microgrid compatibility function.

5.3 SmartLogger (Controller)

The SmartLogger3000 is recommended for the C&I PV+ESS system networking. The SmartLogger3000A/B/C comes standard with two optical ports, one WAN port, one LAN port, and three RS485 ports. The SmartModule provides four LAN ports and three RS485 ports.

For PV+ESS scenarios outside China, the PV side supports RS485/MBUS networking, and FE ring networking is recommended for the ESS. The ESS also supports fiber ring networking.

The SmartLogger3000 supports FE or optical fiber networking in the northbound direction.

The power meter at the grid connection point is connected to the RS485 port on the SmartLogger3000 through an RS485 communications cable.

The SmartLogger monitors and manages PV+ESS system. It converges ports, converts protocols, collects and stores data, and centrally monitors and maintains the equipment in PV+ESS system. The SmartLogger has the following features:

- Intelligent and flexible: Connects to the inverter, ESS, and optimizer, and supports one-click commissioning.
- Easy to use: Supports wizard-based settings, and facilitates parameter settings and device connection.

SmartLogger picture

NOTE

For details about how to use the SmartLogger as a controller, see the C&I microgrid solution quick guide.

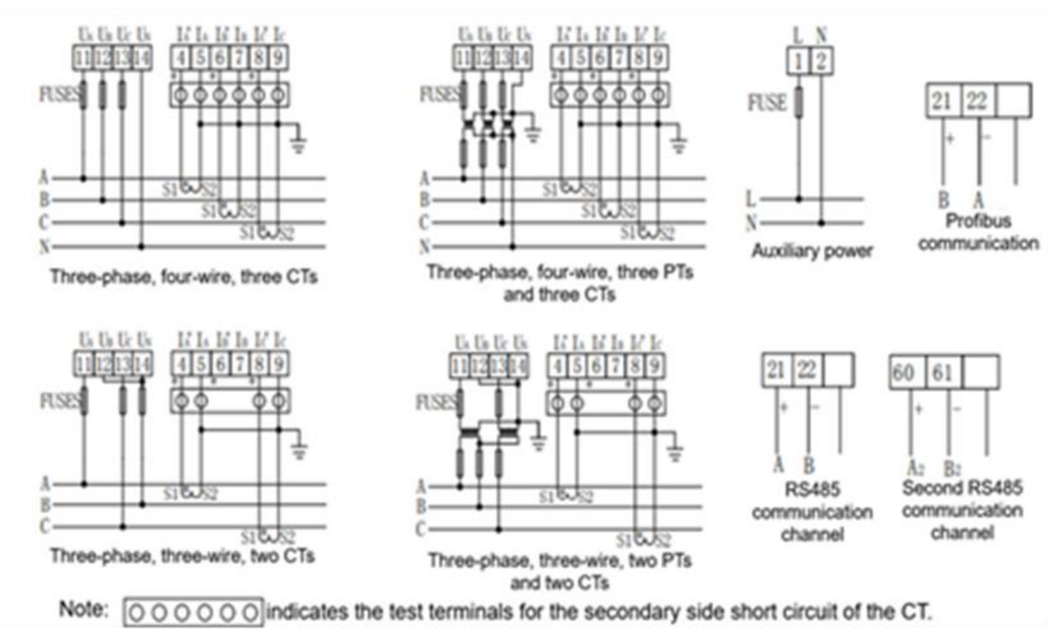
5.4 Smart Power Sensor (Power Meter)

For coordinated control of the PV+ESS system, a Smart Power Sensor (power meter at the grid connection point) is required. Currently, the SmartPS-80AI-T0 (DTSU666-HW and YDS60-80) has been verified. For other meter models, submit a verification application to the RAT.

In the 10 kV on-grid scenario, a 10 kV/100 V PT with a minimum sampling precision of 0.5s is required.

The current on the secondary side of the current transformer (CT) is 1 A or 5 A. The minimum CT sampling precision is 0.5s.

Smart Power Sensor wiring diagram (For details, see the *Commercial and Industrial On-Grid Energy Storage Solution Quick Guide*.)



5.5 On/Off-Grid Switch

In the C&I on/off-grid switching scenario, you need to use the on/off-grid switch to ensure that there is a clear electrical isolation breakpoint between the microgrid system and the utility power grid. ACBs and MCCBs are recommended for low-voltage grid-connected projects. The specific requirements are as follows.

Table 5-1 Requirements for the switch at the grid connection point in the on/off-grid switching scenario

Scenario	Requirements for the On/Off-Grid Switch
Seamed on/off-grid switching	Automatic seamed on/off-grid switching: The switch supports remote switch-on and switch-off (I/O control). A UPS is configured for the switch control loop to remotely control the switch when mains supply is lost. The switch status auxiliary contact is connected to the EMS.
	Manual on/off-grid switching: The switch status auxiliary contact is connected to the EMS.
Seamless on/off-grid switching	The switch supports remote switch-on and switch-off (I/O control). A UPS is configured for the switch control loop to remotely control the switch when mains supply is lost. The switch status auxiliary contact is connected to the EMS.

5.6 Protective Relay

Whitelist: Schneider P3U30 Hardware model: P3U30-5AAA3BBA (P3U30-5AAA3BBAC in China) (f_n: 50/60 Hz, In: 1/5 A, U_{aux}: 45–230 V AC/DC)

For details about how to use the protective relay, see the quick guide of the solution and the Schneider P3U30 configuration materials provided with the solution.

5.7 UPS

The UPS provides stable power supply for the monitoring system (SmartLogger, battery monitoring device, protective relay, and on/off-grid switch). UPS functions: When the AC system experiences an HVRT/LVRT, the voltage is low during on/off-grid switching, or an AC power failure occurs due to low SOC at night, the UPS supplies stable power to the monitoring system to support reliable operations of devices under various working conditions and ensure normal remote monitoring.

Specifications: UPS power ≥ 1 kVA, online UPS, 220 V. The backup time is selected based on the scenario configuration requirements.

In the off-grid scenario, to cope with possible PV+ESS shutdown (especially shutdown due to low SOC at night), the UPS needs to supply power to monitoring devices for a long time, so that self-recovery control and ESS charging control are performed when the irradiance recovers to a sufficient degree on the next day. In off-grid scenarios, it is recommended that the UPS backup time be greater than 48 hours (or other UPSs with the PV deployment function be used).

Note: The recommended formula for selecting the battery capacity is as follows:

Total electricity of UPS batteries (kWh) = (15 W + 15 W x *N* battery cabinets) x 48 x 2/1000 (Coefficient 2 is used to cover factors such as the depth of charge/discharge, efficiency, and self-discharge.)

Total Ah of UPS batteries = 1000 x kWh/Battery voltage (12 V, 24 V, or 48 V)

For details about the recommended UPS battery capacity for the PV+ESS system, see the following table.

Table 5-2 Recommended UPS capacity in off-grid scenarios

Number of Battery Cabinets	UPS Battery Capacity (kWh)	Battery Ah (12 V)	Battery Ah (24 V)	Battery Ah (48 V)
1	2.88	240	120	60
2	4.32	360	180	90%
3	5.76	480	240	120
4	7.2	600	300	150
5%	8.64	720	360	180
6	10.08	840	420	210
7	11.52	960	480	240
8	12.96	1080	540	270
9	14.4	1200	600	300
10%	15.84	1320	660	330
11	17.28	1440	720	360
12	18.72	1560	780	390
13	20.16	1680	840	420
14	21.6	1800	900	450
15	23.04	1920	960	480
16	24.48	2040	1020	510
17	25.92	2160	1080	540
18	27.36	2280	1140	570
19	28.8	2400	1200	600
20%	30.24	2520	1260	630

5.8 Management System

For details, see the Smart PV Management System (Plant) documents.

6 Appendix: System Commissioning

For details about system commissioning, see the C&I solution quick guide.

6.1 O&M Methods

Table 6-1 O&M methods

O&M Method	Description	Main Application Scenario	Reference Document
SmartLogger WebUI	A PC is connected to the SmartLogger to manage the ESSs, inverters, and the meter in the array.	Deployment and commissioning	SmartLogger3000 User Manual
SmartPVMS	The SmartPVMS is deployed on a public network. It displays the current and historical running status of power plants and supports intelligent alarm reporting, analysis, diagnosis, and O&M.	Viewing plant information and managing devices at a site after deployment and commissioning	• SmartPVMS 24.6.0 FusionSolar SmartPVMS User Manual (Owner) • SmartPVMS 24.6.0 FusionSolar SmartPVMS User Manual (Installer)
Local app	The app is locally connected to an	• Modifying the parameters of a	FusionSolar App

O&M Method	Description	Main Application Scenario	Reference Document
	ESS or an inverter to locally manage the ESS or the inverter.	single device locally • Upgrading the software version of a single device locally	User Manual

6.2 Deployment and Commissioning

This section describes installation, cable connection, device power-on, and deployment and commissioning.

For details about how to install and connect cables, see the corresponding user manual or quick guide.

6.3 Software Upgrade

(1) Seamed/Seamless on/off-grid switching

Upgrade the device when the mains supply is normal to prevent power failure on the customer side caused by software upgrade.

(2) Off-grid only

Pay attention to the following points when upgrading the software in off-grid scenarios:

1. During the software upgrade of the ESS, the AC output stops.
2. When upgrading the ESSs in an array, you are advised to select a period when the load rate is low.
3. For simultaneous upgrades in an array, you are advised to turn off the load switch first. After the upgrade is complete, restore the operation of the array.
4. If the upgrade is performed one by one, ensure that no overcurrent occurs.

6.4 Off-Grid Maintenance Emergency Power Supply

For off-grid projects, emergency power supplies (such as mobile gensets and mobile backup power devices) need to be carried for onsite maintenance in some working conditions.

1. The UPS has no power during off-grid deployment and commissioning.
2. The ESS is charged after the SOC decreases to 0%.
3. The coolant of the LTMS needs to be replaced, or an internal module needs to be replaced due to a fault.

If the off-grid PV+ESS system breaks down, the SOC is almost 0%, the system cannot automatically recover, and charging is required, you can use the emergency genset or other emergency mobile power supplies to charge the ESS. For details, see the related maintenance materials.