SUNGROW

5A Solution for a New Era of PV Industry

SUNGROW Utility-Scale PV Solution White Paper

Clean power for all

FOREWORD

With the continuous advancement of the "carbon peaking and carbon neutrality" campaign and the acceleration of global energy transformation, the photovoltaic (PV) industry has seen leapfrog development in terms of installed capacity and technological innovations. As per forecasts from authoritative sources, the global PV newly installed capacity will exceed 350GW in 2023, which is estimated to rise further to nearly 700GW by 2030. In particular, the installed capacity of utility-scale PV systems will account for more than 50% of the total PV installed capacity worldwide, outranking all other forms of PV facilities.

The deployment of utility-scale PV systems has been gradually expanded on a global scale to cover unconventional geographical settings such as deserts, gobi, hills, mudflats, and offshore areas, thus heightening the safety requirements of PV plants. The capacity of individual utility-scale PV plants has increased on a day-to-day basis, and the on-grid electricity price has decreased consistently; the penetration of new energy is rising rapidly (by more than 50% in some regions), which poses a serious challenge to the stable operation of power grids. New business forms and new market demands are spawning a new round of technological evolution, and the development of utility-scale PV plants will enter a new era!

In order to meet the challenges of the new era of PV development, by leveraging the circuit, semiconductor, heat dissipation, electromagnetics, computing, algorithm, AI, and security technologies, based on the deep integration of devices, solutions, and applications, SUNGROW has unveiled the 5A (All-Scenario Application, All-Day Efficiency, All-Link Safety, All-Life Smart O&M, and All-Grid Support) solution. This pacesetting solution will drive the extensive-scale and high-quality development of the utility-scale PV sector.

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01

Outlook and Challenges

1

Rapid growth of market volume

Thus far, more than 140 countries and regions around the world have set carbon neutrality targets, and favorable policies for PV development have been introduced in many places. These developments, coupled with other factors such as industrial technological advancement, cost reduction, and global energy shortages, have led to the sustained and rapid development of the PV industry. As per BNEF statistics and forecasts: The industry will continue to see high growth in the next five to eight years: PV installed capacity additions will reach 677GW by 2030, a 270% year-on-year increase compared to 2021. In particular, utility-scale PV plants will account for more than 50% of the total added capacity and will remain one of the main driving forces for PV industry development.

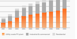


Figure 1: Global PV capacity additions forecasts (source: BNEF)

As the application scenarios become increasingly diversified and sophisticated amid rapid development of the PV industry, the penetration of new energy has further increased, and the levelized cost of electricity (LCOE) has continued to fall, bringing various new challenges to the utility-scale PV sector.

2

Diversification and sophistication of application scenarios brought about safety pressure on power plants

Utility-scale PV plants, typically featuring large capacity and complex systems, are located mostly in areas such as deserts, gobi, hills, mudflats, and offshore areas. System operation and maintenance are very challenging in these areas due to the severe climate and geographical conditions, which brings pressure on the safe operation of plants.

Frequent sandstorms in deserts and gobi mean that sand and dust can easily get into the interior of the PV equipment, which affects reliable equipment operation as a result of poor heat dissipation and part damage. The high salt mist, high temperature, and high humidity in the hills, beaches, and offshore areas exacerbate the aging and damage of the plant equipment. Furthermore, a shift in PV technology applications toward higher power, higher voltage, and higher power density will worsen electrical safety hazards and pose a threat to the safety of assets and personnel in the plants.

3

Rising new energy penetration challenges the stability of power grids

As the number of grid-connected new-energy generation facilities such as solar and wind power plants increase in relation to other forms of grid-connected supplies, the penetration rate of renewable power generation can exceed 60% in some areas. The instability, randomness, and intermittency of PV generation exerts a greater impact on the operation stability of power grids. Compared to the traditional power systems with synchronous generators as the main source of power, the new-type power system is now witnessing an increase in the proportion of power electronic generation equipment and is characterized by low inertia, damping, and voltage support. Furthermore, the adoption of a large number of power electronics, such as converter stations on the power transmission side as well as charging piles and other power consumption equipment, will make the grid more complex, and insufficient active support may easily lead to problems like disconnection from grids. Therefore, it is imperative now to enhance the ability of new-energy power generation to support the new-type power system.

4

On-grid electricity price hits all-time lows, weighing on PV LCOE

Technological advances and large-scale market development have sent the global PV electricity price into a downward trajectory. As per statistics from the China Photovoltaic Industry Association (CPIA): the lowest winning bid price for PV power worldwide has dropped by nearly 90% from USD 8.3 cents/kWh in 2013 to USD 1.04 cents/kWh, with further declines expected in the coming years.

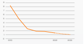


Figure 2 : Global minimum on-grid PV electricity price continues to decrease (2013-2030)

Thus far, competitive bidding has been adopted for grid connection in many countries. However, with intensified market competition, government policy support, and the growing share of renewable electricity generation, it is necessary for the utility-scale PV sector to lower the LCOE by cutting down the amount of initial investment required, improving power generation efficiency, and reducing operation and maintenance costs.

02

SUNGROW 5A Utility-scale PV Plant Solution

In a bid to meet the new challenges facing utility-scale PV power plants, SUNGROW makes the most of its 26-years of experience and expertise in power electronics and its own market insights. By leveraging the circuit, semiconductor, heat dissipation, electromagnetics, computing, algorithm, AI, and security technologies, based on the deep integration of devices, solutions, and applications, SUNGROW has unveiled the 5A (All-Scenario Application, All-Day Efficiency, All-Link Safety, All-Life Smart O&M, and All-Grid Support) solution. This pacesetting solution will drive the extensive-scale and high-quality development of the utility-scale PV sector.

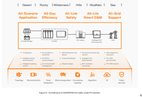


Figure 3 : Architecture of SUNGROW 5A utility-scale PV solution

2.1

All-Scenario Application

While designing utility-scale PV plants, various factors such as the environment, design concept, and grid requirements in different regions should be considered. Based on a string and modular product mix and a series of innovative technical solutions, SUNGROW SA utility-scale PV plant solution adopts a scientific design adaptive to local conditions. With optimized block size design, the system can be applied in deserts, gobi, hills, mudflats, and offshore areas, while ensuring the stable operation of plants.

1 Optimal block size design

Utility-scale PV plants, generally with a large capacity, are mostly located in flat regions. Therefore, large blocks and large-capacity collector lines are preferred, so as to reduce investment and O&M costs. SUNGROW, based on the regional characteristics of PV plants, has launched the 3-9MW block solution, featuring an optimum cost design.

Prefabricated transformers are dominate in the Middle East, Latin America, and Europe, with most blocks measuring more than 6MW in capacity. In particular, the cost of the 8.8MW block system is USD 0.49 cent/W lower than that of the 6.25MW system; while the cost of the 6.25MW block system is USD 0.13 cent/W lower than that of the 3.125MW system.

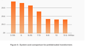


Figure 4 : System cost comparison for prefabricated transformers

The 8.8MW large-block scheme based on the "1+X" modular inverter has been adopted in a 2.1GW plant in the Middle East and a 500MW project in Europe. The adoption of this scheme helps to reduce the cost of initial project investment and improve the efficiency of plant O&M. The 8.8MW block scheme has been adopted in some regions in China, too.

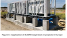


Figure 5 : Application of 8.8MW large block in projects in Europe

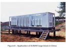


Figure 6 : Application of 8.8MW large block in China

For irregular terrain and scattered plots of land, the SUNGROW-inverter-based 1~4.4MW block solution can be adopted. This solution enables flexible set-ups according to topographical changes, so as to make use of every inch of land and maximize the benefits.

2 Reliable operation in all scenarios

In the case of large-scale PV plants located in areas with harsh climate such as deserts, gobi, hills, mudflats, and offshore areas, the intrusion of sand and dust into PV equipment may lead to poor heat dissipation, a potential cause for power derating and system suspension. Additionally, water vapor and salt mist can easily corrode PV equipment, resulting in reduced equipment reliability and service life.

SUNGROW products are benchmarked against the highest standards, including the IP66 protection rating and the C5 paint rating, hence suitable for use in various types of complex and harsh environments. The inverter box is made of corrosion-resistant materials like hot-dip galvanized steel and carbon steel. The exterior of the inverter and PCB board both undergo electrostatic spraying treatment with weather-resistant materials, and are thusly highly durable despite severe salt mist corrosion in coastal areas. The fully sealed electronic compartment design prevents air exchange with the outside world. In addition, the door frame is equipped with highly-resilience weather-resistant double-layer sealing strips, protecting the equipment against dust and water and thereby ensuring long-term stable and reliable operation of the power plant.

A 100MW desertification control PV project in China is required to stand the test of strong sandstorms, as frequent dust intrusion affects equipment reliability. In this project, SUNGROW "1+X" modular inverters are deployed, facilitating the reliable operation of the plant with highly efficient heat dissipation and dust-tight design.

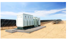


Figure 7 : Application of the "1+X" modular inverter at a PV plant in the desert

A 70MW PV project in China, located in an area of saline-alkali lands and mud flats bordered by the Bohai Sea to the east, is challenged by the risk of equipment corrosion caused by high humidity and high salt mist environments. The project uses SUNGROW SG350HX string inverters to ensure the reliable operation of the plant in offshore areas.

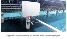


Figure 8 : Application of SG350HX in an offshore project

2.2

All-Day Efficiency

Improving power generation efficiency and reducing loss is an effective way to lower the LCOE. SUNGROW achieves all-day efficiency of power plants by shortening lead time, maximizing power generation, and reducing power consumption: in the early stage of plant construction, with the SUNGROW off-grid commissioning solution, grid connection can be completed as early as possible with an increase in electricity generated; long-string design and intelligent tracking control are adopted to boost system yield; and the automatic night-time MV disconnection solution is employed to ensure zero power loss.

1 Off-grid commissioning solution

During the construction of traditional power plants, grid-connected commissioning can only be started after all the equipment is installed and power transmission has started with the grid approval obtained, which entails additional construction costs and longer lead time before grid connection.

SUNGROW pioneered the off-grid commissioning solution, which involves generating AC power by keeping the inverter working in the voltage-source mode. It can operate in either the low voltage (LV) or high voltage (HV) mode to meet different application requirements. The LV mode is used for construction site power supply, MV withstand test, and the initial grid-connected commissioning of communication and monitoring equipment, etc.; while the HV mode is used for thermal commissioning and joint communication commissioning. With this solution, grid-connected power generation can be started once the construction of booster station is completed, reducing the lead time by more than 30 days, which translates into an increase of 15 million kilowatt-hour in power generation for a 100MW power plant.

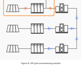


Figure 9 : Off-grid commissioning solution

2 / Long string design

Increasing the number of modules in a single string is an effective way to reduce system cost, but it also poses challenges such as increased DC open-circuit voltage (OCV) and operating voltage. The maximum OCV of the traditional inverter is 1500V. The inverter may not start up normally or may even get damaged with an OCV exceeding 1500V. Also, if the operating voltage rises to about 1400V, a severe power loss may arise due to the inverter's derating behavior.

SUNGROW managed to increase the maximum inverter OCV to 1550V by improving the withstand voltage performance of key components. With the adoption of new temperature uniformity control and ANPC topology, the operating power of inverters at high DC voltage has been increased, enabling up to DC 1500V full-power operation and thus leading to an increase in system yield. Compared to the traditional inverters and systems, with the adoption of the long string scheme, the initial investment cost can be reduced by USD 0.27 cent/W.

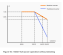


Figure 10 : 1500V full-power operation without derating

In China, the traditional 2P fixed bracket solution is adopted in most cases. Taking the P-type 182mm module widely adopted in North China for example, in the traditional scheme, 26 modules are connected in one string; however, in the long string scheme, 28 modules are connected, saving bracket and cable costs by USD 0.29 cent / W.

The optimal number of modules connected in series for different regions, temperature ranges, and module types are as follows:

Number of modules in series under different temperatures

Module type	Minimum daytime temperature(°C)	Traditional solution (modules/string)	Long string solution (modules/string)
P-type 182mm module 550W	-30≤T<-20	26	27
	-20≤T<-5	26	28
	-5≤T<8	26	29
	8≤T	26	30
P-type 210mm module 660W	-30≤T<-28	28	29
	-28≤T<-13	28	30
	-13≤T<1	30	31
	1≤T	30	32

In an 800MW PV plant in the Middle East, where 182mm bifacial modules are used, SUNGROW string inverters are deployed. In this project, 30 modules are connected in one string, two modules more than the traditional design, thus significantly reducing system cost.

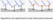
Figure 11 : An 800MW PV power plant in the Middle East

3 ✓ Intelligent tracking-control

In practice, the traditional tracking solution relies mainly on the automatic adjustment of the bracket, without data exchange with the inverter, thus making it difficult to ensure optimal power generation performance. Furthermore, where the inverter directly controls how the bracket works, the responsibility cannot be clearly ascribed if any failure occurs.

SUNGROW has developed intelligent tracking control technologies for unifacial and bifacial module systems respectively. The optimal rotation angle of the bracket under different weather conditions is determined based on inverter data and AI model analysis. The findings are then fed into the bracket controller, and closed-loop control is conducted based on real-time power generation data. As a result, overall system yield is increased by more than 1% compared to traditional tracking schemes. Furthermore, SUNGROW' s data platform is open to all bracket manufacturers, so that the roles and responsibilities can be clearly defined.

Algorithms are optimized to avoid obstruction between modules in front and rear rows in highly complex terrains



Algorithms are optimized to avoid obstruction between modules in front and rear rows caused by low solar elevation in the morning and evening

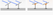


Figure 12 : Real-world adjustment operations in various scenarios

Taking a 100MW power plant in China as an example, according to the comprehensive assessment and verification by China General Certification Center (CGC), compared to traditional algorithms, the adoption of this intelligent tracking control technology enables the array yield to climb by 3.62% overall, with an increase of 11.42%, 5.81%, and 1.72% respectively in rainy, cloudy, and sunny days.

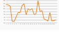


Figure 13 : Daily increase in power output achieved through SUNGROW solutions over conventional approaches

4 / Intelligent MV disconnection

Once a PV system is connected to the grid, standby loss will be incurred by the MV station at night. The first-ever smart MV disconnection solution developed by SUNGROW enables intelligent joint control between the inverter and the MV disconnection device to automate switching control of the MV collector line. That is, when all inverters are switched to standby mode at night, the MV disconnection device will then control the PV system and disconnect automatically from the collector line. Once startup is triggered for any inverter in the morning, the system will soft start the inverter in voltage source mode, thus enabling zero-current connection.
For instance, the no-load loss of a EU548-tier2 3.125MVA oil-immersed transformer is 2.26kW. For a 1GW plant, where the intelligent MV disconnection solution is applied, a total of approximately 79 million kWh of energy can be saved in 25 years.

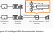


Figure 14 : Intelligent MV disconnection solution

In a 200MW PV project in the US., the SUNGROW SG3600UD-MV system is deployed, along with the smart MV disconnection solution, thus enabling "zero load loss" at night.

Figure 15 : Application of night-time MV disconnection solution

2.3

All-Life Smart O&M

Utility-scale PV plants tend to be large in capacity and footprint. O&M in these plants involves working in highly complex scenarios, so both the operation and maintenance of such PV power plants can be very challenging. While conventional O&M methods are rather inefficient due to heavy reliance on manual work, SUNGROW applies innovative technologies such as modular design, global IV diagnosis, DC MPLC communication, and auto air duct cleaning, to minimize, and even eliminate, manual intervention in PV system operation and maintenance, substantially enhancing O&M efficiency while reducing O&M costs.

1 Modular design

Traditional central inverters typically have high output power but are prone to significant power generation losses in the event of a malfunction. Additionally, they generally require dedicated personnel for maintenance.

Core components of the "1+X" modular inverter, such as IGBT, capacitor, and fan, all adopt modular design, which enables "plug and play" and hence shortens the maintenance time by nearly 70% from 6h to 2h.

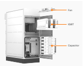


Figure 16 : Modular component design

Each inverter unit of the "1+X" modular inverter is electrically independent, so the failure of one single unit does not affect the power output of the others. In the event of a serious failure where the entire inverter needs to be replaced, the standby equipment can be put into place within 0.5 day, thus reducing the failure loss by 95% while increasing uptime.

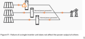


Figure 17 : Failure of a single inverter unit does not affect the power output of others

2 ✓ Smart IV diagnosis

IV scanning for string inverters has become a time-tested technology today. However, for high-power inverters, due to the large number of strings connected, it is difficult to retrieve and analyze string IV curve data, and no feasible solution is currently available in the industry.

SUNGROW has launched the pioneering smart string IV diagnosis technology for modular inverters. Integrating high-precision Shunt current sampling and intelligent voltage recognition technologies, through joint control with the intelligent combiner box, this technology helps to tackle the difficulty of IV curve diagnosis in string outputs combination. The string diagnosis model is trained and optimized using operation data retrieved from PV plants with a combined installed capacity of more than 50GW, seeking to accurately identify various string faults and carry out global smart diagnosis.

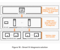

Issuance of diagnostic command
Display of diagnostic results
Diagnostic process control
Data collection & diagnosis
Modular inverter
Retrieve data and transfer

Figure 18 - Smart IV diagnosis solution

The smart IV diagnosis technology for modular inverters enables the accurate identification of 16 common faults such as string shaded, PID, cracks, and hot spots, with an accuracy of over 95%. This technology has been accredited by the TÜV Rheinland Field Evaluation Services.

Figure 19 - TÜV Rheinland Certificate

Correlation between the electrical parameters of strings and exception types

Electrical parameters	Type of exception
Low string open circuit voltage (OCV)	Diode short circuit, interrupted grid lines, PID, hotspot
High string series resistance	Cable aging, cable too long/too thin, PID
Minor current mismatch in the string	Shaded, hot spot, pollutant occlusion
Major current mismatch in the string	Broken glass, severe cracking, and severe occlusion of a small number of components
Low string maximum power point	Aging and attenuation, big difference in installation angle, dust occlusion
Positive string voltage with 0 current	String open circuit

3 ✓ DC MPLC communication

Traditional central inverters and combiner boxes mostly feature 485 wire communication, which requires separate communication cables and therefore entails intensive construction workload and high costs. Furthermore, after the inverters and combiner boxes are put into operation, communication interruptions can be easily caused by broken cables or lightning strikes, making O&M exceedingly difficult. In addition, as daisy chain design is usually adopted in 485 wire communication, the damage to one single piece of equipment may cause communication in the whole subarray to be interrupted.

Featuring customized chipsets, SUNGROW's DC MPLC communication solution applies advanced digital signal processing and channel coding technology and adaptive selection strategy to communication band modulation and demodulation, thus allowing two-way communication between the combiner box and the inverter, which is an industry-first application.

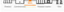


Figure 20 : DC MPLC solution

Unlike the 485 wire communication solution, the DC MPLC communication does not require laying of communication cables. This innovative solution ensures a communication delay of 20ms, a packet loss rate of <0.5%, a communication distance of > 1000m, and great interference resistance performance. Besides, O&M costs are significantly reduced, as it does not require maintenance during the first 25 years of operation. The solution has passed the field test and obtained the L4 certificate issued by the CQC, making SUNGROW the pacesetter in the whole industry.

4 ✓ Air-duct health AI management

PV inverters typically adopt air cooling. The downside of this design is that small particles such as dust and willow catkins/pollen can easily block the air inlet and radiator, affecting heat dissipation in the inverter. If such particles are not promptly removed, the inverter may derate or even shut down due to overheating.

The SUNGROW Air-duct health AI management is able to conduct cluster analysis of core component data, such as temperature, output power/voltage, and fan speed, applying a combination of algorithms such as surface fitting, neural network, and environmental diagnosis. It enables auto-identification of the severity of blockage in the heat exchanger, the main air duct inlet, and the radiator, and is able to send alerts automatically and trigger reverse dust removal, so as to clean the blockage and keep the air duct in a good state.

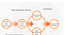


Figure 21 : AI duct health management

2.4

All-Link Safety

Due to the complexity of utility-scale PV system operations, faults such as insulation damage, DC arcing, and short circuit occur from time to time, which poses serious threats to the system and personnel safety. Furthermore, security issues are further compounded by the growing complexity of power system structure and continuous network expansion. Relying on highly innovative technologies such as intelligent string disconnection, 24/7 insulation monitoring, DC parallel arc detection and disconnection, post-fault pressure relief, and triple data protection, SUNGROW ensures "All-Link Safety" for components, lines, equipment, personnel, and data involved, thereby delivering effective protection for plant assets and personnel safety.

1 / 24H insulation monitoring

Abrasion, corrosion, aging, and other factors may cause safety issues resulting from cable insulation failure. Some countries and regions have set explicit requirements on AC insulation monitoring in their national standards. For example, in the German "VDE 0100-410" standard, insulation monitoring is a mandatory requirement; while as per the IEC62109 standard, insulation monitoring shall be available for non-insulated transformers.

SUNGROW's 24/7 AC and DC insulation monitoring solution is able to work in tandem with the anti-PID device, as well as to track impedance in real time and trigger early warnings to reduce the risk of electric shock and fire. Conventional solutions generally adopt third-party AC insulation monitoring devices, hence, compatibility between the AC and DC monitoring devices is rather poor, which leads to high risks of false alarms and miss operation. The SUNGROW solution, which is compatible with third-party AC and DC insulation monitoring devices, represents an answer to this problem.

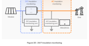


Figure 22 : 24/7 insulation monitoring

2 ⁄ DC parallel arc protection

DC arcing is one of the common causes of fault spreading in PV power plants. DC arcing faults can be divided into series arcing, parallel arcing, and ground arcing. Parallel arcing usually generates a substantial amount of energy and causes greater damage, and it is quite difficult to disconnect the system in such cases. Yet, no effective solution was established.

SUNGROW invented the first DC parallel arcing detection and disconnection technology. Applying the intelligent arcing diagnosis algorithm, it is able to analyze and compare the amplitude, slope, oscillation counts, and frequency of DC voltage and current before and after arcing, as well as adaptively adjust the protection threshold according to the application scenarios. This technology enables accurate identification of arcing signals and automatic disconnection of all loops through coordinated control, thus guaranteeing subarray safety.

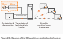

20ms
20ms
Detection
Electrical arc
Arc detection & disconnection
Transmission of fault signals to inverter
Linked to combiner boxes in subarrays

Figure 23 : Diagram of the DC parallel arc protection technology

This solution involves training the model with massive databases and thus improving the system's self-learning capacity. It then empowers the system with the ability to accurately recognize signals of parallel arcing in all scenarios under all working conditions and to promptly shut down the system within 40ms, so as to prevent risks caused by the arcing spreading further and protect the safety of the power plant. Through field testing, the CGC certifies that the SUNGROW DC parallel arc protection technology meets the L4 requirements.

3 ⁄ Pressure relief design

The sealing integrity of inverters has improved consistently in line with advances in the level of protection provided by PV inverters. When a fault occurs, the defect generates high-pressure gas, and air expands as a result of high-temperature arcing. Unless the additional pressure is released, structural safeguards will fail, and arc spray may cause equipment damage or injury to personnel.

SUNGROW's pressure relief design adopts patented dual safeguards combining explosion-proof lock and pressure relief damper. Once the internal pressure of the inverter exceeds the upper limit, the explosion-proof lock immediately locks the compartment to prevent the high-temperature arc from blowing out. At the same time, the pressure relief damper automatically opens to release the pressure from the compartment, avoiding personnel injuries caused by the ejection of structural parts such as the compartment door.

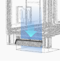


Figure 24 : Pressure relief design

4 ✓ Triple data protection

Tightening cybersecurity control has become a consensus in the new energy industry, and certain countries have set clear requirements in relevant national standards. The International Electrotechnical Commission has successively issued the IEC 62443 series standards, calling on manufacturers to comply with IEC 62443 series industrial control standards and obtain related certificates, in a bid to reduce information security risks associated with industrial control networks.

Following the IEC 62443 Security Development Lifecycle (SDL) procedure, SUNGROW adopts the hardware OTP (one-time password) technology to ensure secure system start-up, applies role-based access control (RBAC) to manage user access, and encrypts data for transmission in the hypertext transfer protocol secure (HTTPS) format. These technologies comprehensively guarantee the network security of the plants, all the way from equipment to the system level, and have obtained the IEC 62443-1 and IEC 62443-2 certificates.

ATTESTATION OF CONFORMITY

Figure 25 : IEC 62443 Network Security Certificate

2.5

All-Grid Support

As the penetration of new energy continues to rise, the power grid becomes increasingly complex due to dynamic impedance changes, high-voltage DC lockout, switching of reactive power compensation equipment, and multi-energy integration, bringing multiple challenges to the new-type power systems. Leveraging new technologies such as strong-weak grid adaptation, fast power control, wideband oscillation suppression, transient overvoltage suppression, and PV-VSG, SUNGROW further improves the grid support capacity, and contributes positively to the stable operation of new-type power systems.

1 Self-adaptation to weak grid

In the process of grid-connected commissioning, inverter parameters need to be adjusted according to grid strength. Traditional manual calculation and adjustment methods are time and energy consuming and cannot guarantee that the parameters are set in a timely manner. Additionally, during the operation of the power plant, the strength of the grid decreases as the number of new power generation facilities connected to the grid increases (relative to the total number of on-grid generation facilities). If the inverter cannot automatically adapt to changes in grid impedance, the problem of disconnection from the grid may arise due to oscillation, which would, in turn, entail efforts to locate the fault and manual diagnosis and debugging result in a severe loss in the electricity generated.

On the other hand, SUNGROW inverters can identify grid strength within 40ms, automatically adjust the control strategy and parameters accordingly, and adapt themselves to the working conditions of the power grid to ensure one-time successful grid connection as well as to avoid power generation loss caused by oscillation during operation.

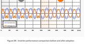


Figure 26 - Inverter performance comparison before and after adoption

2 ⁄ Fast power response

Power systems now have higher requirements for PV plants regarding the response time and precision of active/reactive power control, in order to ensure the stability of grid voltage and frequency. For example, as per the UK G99 standard, the reactive power output response of the power park module shall commence within 200ms of the application of the step. While the US IEEE 2800 standard requires the reaction time to be less than 200ms.

Based on the MPLC communication and real-time Goose protocol, the entire family of SUNGROW inverters is capable of performing fast power response through fast current loop (FCL) control while reducing the reactive power response time to 20ms, providing stronger reactive power support.

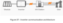


Figure 27 : Inverter communication architecture

3 ⁄ Power oscillation damping

Wideband oscillation may arise from the interactions between power electronic equipment and between such equipment and weak grids, series compensation grids, and reactive power compensation devices. As the weight of power electronic equipment such as wind farms, PV, energy storage, electrified railway, and charging piles in the new-type power systems continues to increase, such oscillation must be effectively controlled. Otherwise, it may cause equipment damage, disconnection of new power generation equipment from the grid, and system outage, and the risk can be easily spilled over to the user side through cascading failure, resulting in extensive blackouts. Based on smart fast frequency-domain/time-domain power resonance analysis, power control commands are produced through impedance reshaping and multi-circuit collaborative control, and the inverter then quickly executes the commands to avoid negative damping, thus suppressing wideband oscillation.

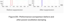
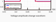


Figure 28 : Performance comparison before and after power oscillation damping

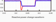
4 ✓ Transient overvoltage suppression

When HVDC commutation fails or the reactive power compensation device is switched on, the system is prone to transient overvoltage, and the equipment may be damaged in some cases. With traditional current source inverters, transient overvoltage cannot be suppressed quickly enough.

When transient overvoltage occurs, SUNGROW inverters automatically generate instantaneous reactive power support and suppress transient overvoltage by quickly switching to the voltage source mode.



Voltage amplitude change waveform



Reactive power change waveform

Figure 29 : Performance comparison before and after transient overvoltage suppression

5 ✓ PV-VSG grid forming

With the extensive integration of renewable energy power plants, the adoption of power electronic equipment has increased in relation to other types of power generators. With the decline in synchronous generators capacity, system inertia also declines, giving rise to fluctuations in grid voltage and frequency, and even resulting in disconnection from the grid. Conventional current source inverters cannot automatically support the stability of the power grid, and the voltage-source virtual synchronous generator (VSG) technology is unable to track the maximum power point.

The PV-VSG grid-forming technology developed by SUNGROW can not only perform real-time tracking of the PV maximum power point, but also enables PV inverters to demonstrate the characteristics of synchronous generators. The inverter can perform inertia response within several milliseconds by rapidly controlling voltage amplitude and phase angle, and promptly suppress fluctuations in grid voltage and frequency to further improve the stability of PV plant /PV&ES plant. This will facilitate higher penetration of new energy.

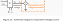


Figure 30 : Schematic diagram of equivalent voltage source

Electricity produced in a PV plant in China could not be transmitted due to checkpoint restrictions, and mismatches between PV facilities and the local loads could easily cause grid fluctuations. With SUNGROW inverters featuring the PV-VSG grid-forming technology, in grid-connected mode, virtual inertia is provided to support the grid in real time and the amplitude of fluctuations in the 10kV bus voltage will be lowered from 15% to 10%; and while in off-grid mode, a regional micro-grid will be built to meet the demand for power supply.

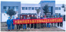
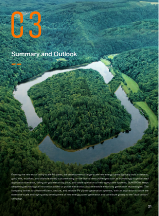


Figure 21 : A Wind, Solar, and Storage Project in China



03

Summary and Outlook

Entering the new era of utility-scale PV plants, the development of large-scale new energy bases (typically built in deserts, gobi, hills, mudflats, and offshore areas) is accelerating. In the face of new challenges such as increasingly sophisticated application scenarios, falling on-grid electricity price, and stable operation of new-type power systems, SUNGROW keeps deepening technological innovation based on power electronics and renewable electricity generation technologies. The company strives to create efficient, secure, and reliable PV power generation systems, with an aspiration to drive the extensive-scale and high-quality development of new energy power generation and contribute greatly to the "dual carbon" campaign.

SUNGROW

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