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Redefine Arc Safety of Inverter System

Utility PV Pressure Relief and Explosion-proof Safety Design White Paper

Preface

With the continued approach to the carbon peaking and carbon neutrality goals and the accelerating global energy transition, coupled with the introduction of favorable policies for the PV industry and advancements in technology, cost reductions, global energy shortage and other factors, the PV industry continues to develop rapidly, hastening its transition to a primary energy source.

As the backbone of PV power generation, utility-scale PV power stations are gradually spreading to various scenarios such as deserts, wilderness, hills and offshore sites. However, the system is also increasingly complex, bringing new challenges to the safe operation of power stations. Of particular concern is the increasing risk of arcing failures. According to relevant statistics, arcing faults account for 10-20% of all PV safety incidents, varying based on geographical location, system design, and maintenance quality. These faults may not only lead to significant economic losses, but also pose serious safety risks such as fire or casualties.

In order to ensure the safety of PV inverter systems in diverse and dynamic environments, and to comprehensively evaluate the forward-looking application of arcing safety technology, internationally recognized organizations such as TÜV Rheinland and Intertek of Germany, commissioned by Sungrow Power Supply Co., Ltd., have jointly carried out a comprehensive evaluation and performance validation of its inverter system's pressure relief and explosion-proof safety technologies.

This white paper aims to provide comprehensive and in-depth technical insights for PV power station developers and technology innovators, facilitating a more accurate understanding and acknowledgment of the arcing safety of inverter systems within the industry. Through this, it seeks to drive continuous improvement in PV safety performance.

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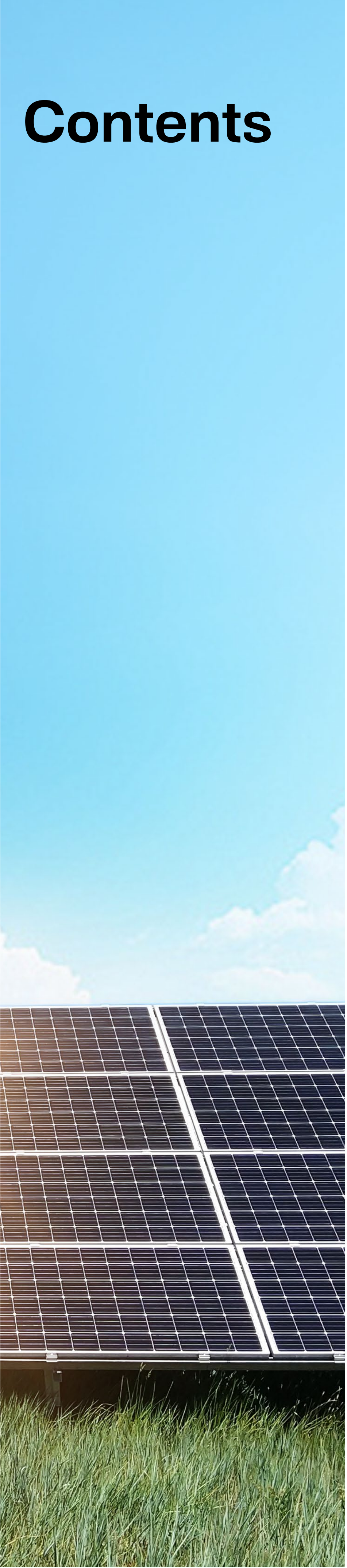

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Technology Development Background

1.1 Rapid development of utility-scale PV

As more than 140 countries and regions around the world have established their carbon neutrality goals and attach importance to energy security and independence, the PV industry is experiencing a transformative period marked by significant increases in installed capacity and technological innovation. According to BloombergNEF, the global PV installed capacity will exceed 444 GW in 2023 and 700 GW in 2030. As shown in the figure below depicting the trend of global PV installations from 2021 to 2030, utility-scale PV installations account for more than 50% of the total global PV capacity, firmly establishing itself as the mainstay of the industry with tremendous development potential.

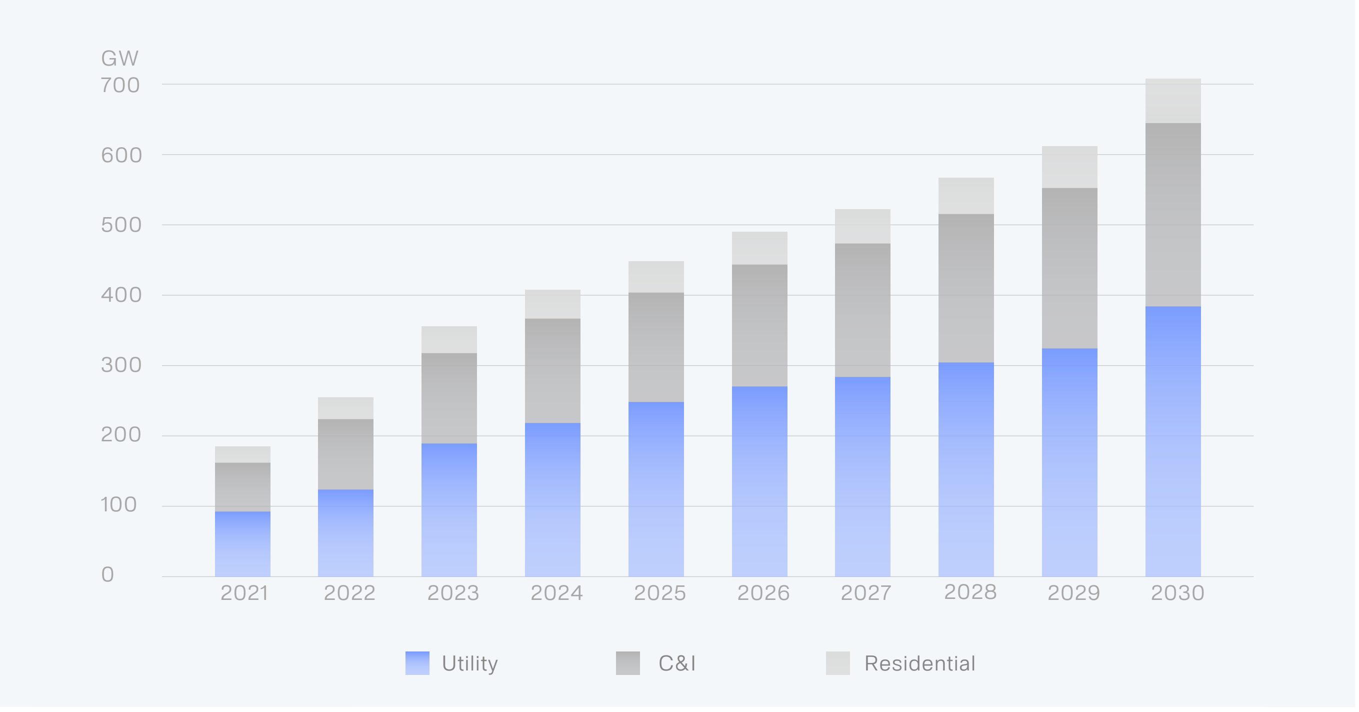

Figure 1 Forecast of global new installed PV capacity (source: BNEF)

1.2 Risk of arcing cannot be underestimated

As the industry grows rapidly, the voltage of utility-scale PV modules continues to rise, and the capacity of a single power station has gradually grown from hundred-megawatt level to gigawatt scale, especially in the Middle East, where the capacity of multiple power stations has exceeded 2 GW. The PV system also evolves towards long string access, large sub-arrays, and high DC/AC ratio. The application scenarios are becoming more complex, such as deserts, plateaus, offshore sites, pastureland, agriculture zones, and other places with harsh climate and geographical conditions, making operation and maintenance increasingly difficult. These factors have increased potential safety hazards within the system, posing threats to both asset security and personnel safety at power stations.

According to the statistics from Mannheimer Versicherung, a German insurance company, although fires account only 2% of all the safety accidents at PV power stations, they have the greatest impact, with the largest proportion of compensation (32%). In addition, the National Solar Center of BRE found that 13 of the 80 fire accidents reported in the past resulted in casualties. Fire accidents at PV stations can be caused by a variety of factors, among which arcing is a significant contributor.

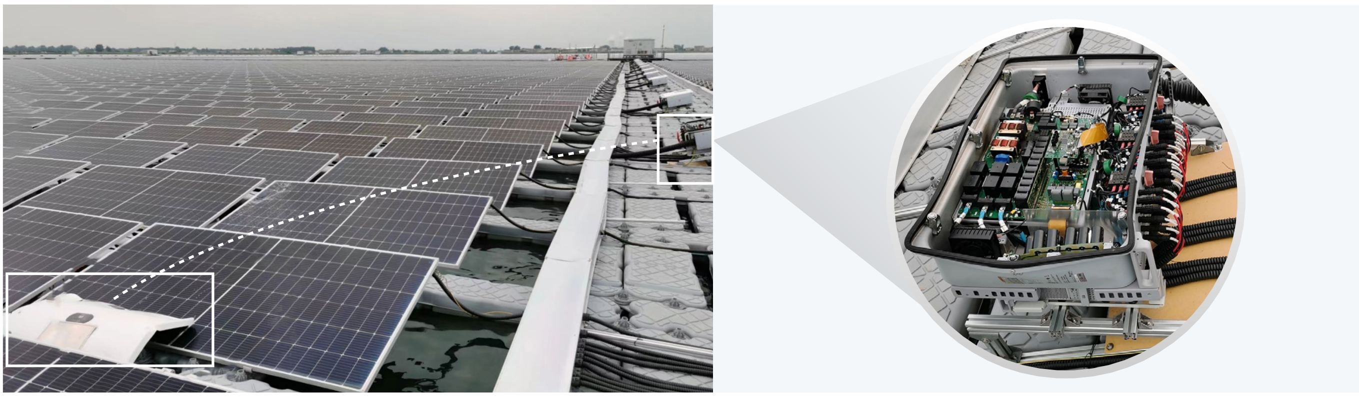

Figure 2 The capacitor explosion in a floating PV power station resulted in the inverter cover blown to several meters away

1.3 Current status of arcing safety within industry

Currently, the arcing safety of PV inverter system mainly complies with IEC 62271-200 "High-voltage switchgear and controlgear, Part 200", IEC 62271-202 "High-voltage switchgear and controlgear, Part 202", and IEC 61641 "Enclosed low-voltage switchgear and controlgear assemblies - Guide for testing under conditions of arcing due to internal faults". These standards cover low-voltage cabinets, ring main units, central inverters, prefabricated substations, and similar equipment. However, there is no global standard for the explosion-proof safety design of string inverters.

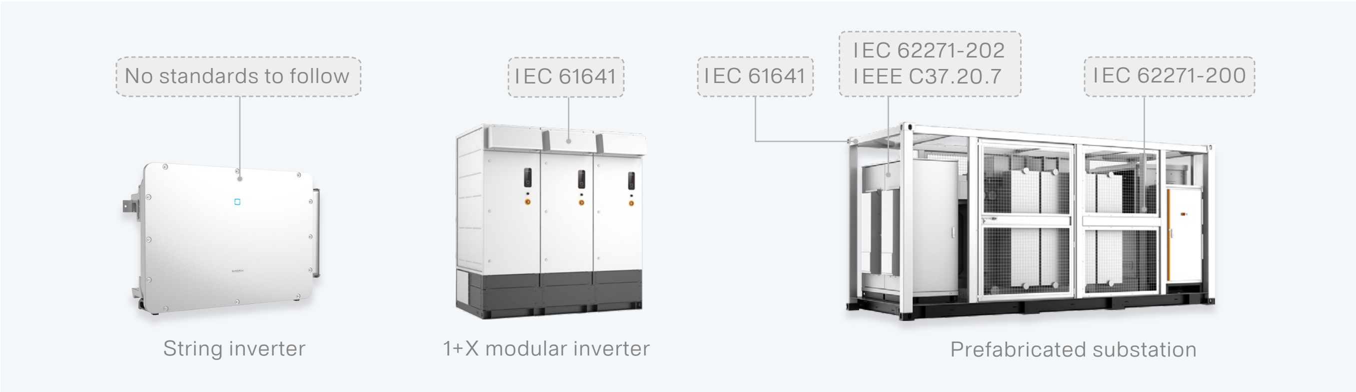

Figure 3 PV Inverter systems and arcing safety standards

Despite these international standards, there are discrepancies in the standards and regulations enforced in different countries and regions, impacting the safety of PV systems worldwide. According to relevant statistics, about 90% medium-voltage equipment manufacturers have not been certified for arcing safety in the world.

Arcing can occur due to various reasons, such as loose or broken connections, aged and damaged insulation materials, as well as moisture and corrosion of the wires. Arcing can be minimized, but cannot be prevented completely. The fire and explosion accidents of the PV power stations caused by arcing have significant and devastating consequences, posing severe risks to the safety of people and property. Therefore, the pressure relief and explosion-proof safety design measures based on the quantitative study of arcing are increasingly concerned by the industry.

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Technical Principles for Pressure Relief and Explosion Protection

2.1 About arcing

Essentially, arcing is plasma with very light mass, and a discharging channel of ionized high-temperature gas. In the process of burning and discharging, the temperature in the arc channel can reach tens of thousands of degrees. Under the joint action of electrodynamic force and thermal force, air around the arcing zone expands outwards violently at a supersonic speed due to the strong molecular thermal movement, forming an explosion shock wave. The damage caused by an arcing fault mainly depends on three key factors: magnitude of current, location, and duration. Typically, arcs with larger currents, longer duration, and occurrences at critical locations will be more destructive, which may cause the equipment to melt, burn, or explode.

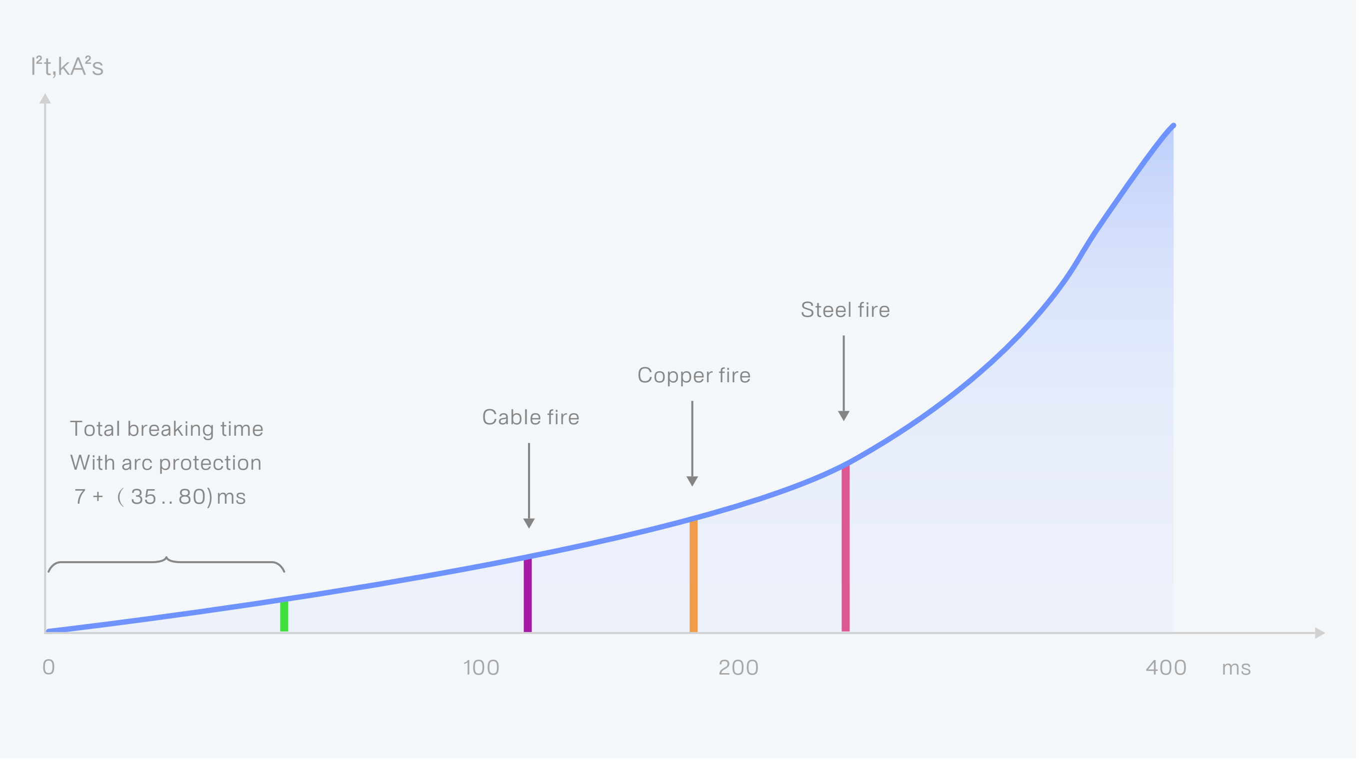

Figure 4 Short-circuit current and arcing time

The arcing fault poses a major threat to equipment and personal safety, including direct and indirect injury. The direct damage is sudden and destructive: There will be high temperatures, strong arcs, and energy release at the moment of arcing, with the temperature at the light center up to 20,000 to 35,000 °C, resulting in equipment burnout, short circuits, and electric leakage. These will seriously affect the normal operation and service life of the equipment. When it comes to personal safety, there may be risks such as burn and electric shock, or flying debris due to equipment explosion, which will endanger life.

The indirect injury is potential and persistent. On one hand, the arcing fault may trigger a chain reaction to further damage the equipment and systems around, resulting in equipment faults and shutdowns in a larger scope. This will bring about a major impact on production and operation.

2.2 Technical challenges for arcing pressure relief and explosion-proof safety

1. The quantitative study of arcing is insufficient and products lack forward design

As a key to enhancing electrical safety, optimizing equipment design and promoting technological innovation, the quantitative study of arcing is increasingly valued within the industry. However, in the face of continuously changing PV market demands and technical requirements, the research on the arcing characteristics, behaviors, impact and other aspects of PV inverter system is still relatively shallow and passive within the industry.

On one hand, there's an inadequate understanding of arcing within the industry, leading to challenges in conducting quantitative research. Imperfections in the theory and analysis methods further hinder in-depth quantitative studies of arcing.

On the other hand, there's a deficiency in arcing safety design. Generally, the design process should start with the forward design of a product via data simulation, quantitative research and similar methods, and then carry out relevant tests. Through continuous optimization of this process, the arcing problem will be solved more efficiently, thereby improving the quality and safety of products. Besides, the cost of arcing test is relatively high, and the forward design can reduce the number of tests and the cost. However, most of the current technological innovations are only passive local rectifications based on the problems found in product tests, and later tests may not be able to detect all problems.

2. High protection and fast arc discharge is difficult to balance

There is a contradiction between the protection requirements of the product and the arc discharge channel. Due to the harsh installation environment, the PV equipment generally needs to have a protection class above IP65, that is, a strong completely closed structure to prevent dust, rain, etc., for the safe and reliable operation of products in various environments.

In order to improve the structural strength of products, heavier or complex materials and designs are generally used. Such an over-strengthened design not only affects the transportation and installation of the product and makes it more difficult to open or disassemble the product, resulting in inconvenient operation and maintenance, but also limits the discharge path of arc and affects the rapid discharge of the internal arc.

To discharge the arc rapidly, it is necessary to plan specific channels or arrange weak points for the equipment, so that the energy can be quickly released through these zones in the event of fault. However, this conflicts with the goal of IP65.

As a result, the research and development personnel are required to seek a balance between the structural strength of electrical equipment and rapid arc discharge capacity when designing products. They must ensure that the equipment has excellent protective performance, while also designing appropriate arc discharge channels to safely dissipate arcs and prevent damage to the equipment.

3. The conflict between large arcing energy and small space is difficult to resolve

Considering the space utilization efficiency of power stations, economic benefits, transportation and installation convenience, as well as the technology trends of a higher integration and modularization level, PV inverters are usually designed with a compact structure. However, such compact design limits the arcing diffusion space, and therefore, the arcing energy is concentrated in a limited space to have a larger explosive force, increasing the risk of fire and equipment damage. How to solve the conflict between compact structure design and arcing diffusion risk? This is also a key challenge we face today.

In summary, during the research and development of pressure relief and explosion-proof safety technologies of PV inverter systems, key challenges such as insufficient quantitative research on arcing, lack of quantitative impact assessment methods of arcing, conflicts between high protection level and fast arc discharge, and conflicts between compact design and risk of arcing diffusion, must be addressed. The key to solving these problems is to find the right balance between technological innovation, ensuring safety and improving space efficiency. This requires in-depth research and innovation, with the complexity of the design and security requirements taken into account to ensure the overall performance and security of the system.

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Pressure Relief and Explosion-proof Safety Design of Sungrow's Inverter Systems

3.1 In-depth quantitative arcing research and an end-to-end comprehensive assessment

In the research and development phase, the quantitative study of arcing is the key to the safety, compliance, efficiency, and innovation of a product's system design. Based on the independently developed integrated design and simulation platform, Sungrow employs the fluid-structure interaction simulation technology to support the research and analysis of arcing overpressure, structural strength, and pressure relief structure for the pressure relief and explosion-proof safety design, thus guaranteeing the application of various emerging technologies. The following section takes a low-voltage cabinet as an example to introduce the key quantitative research steps such as arc energy calculation, blast wave pressure simulation, and strength evaluation in detail, so as to provide in-depth reference for the industry and market.

1. Arc energy calculation and blast wave pressure simulation

During the arc flash formation and extinction process, the internal pressure will not continue to increase thanks to the timely opening of the pressure relief port although the energy is constantly replenished. Therefore, we mainly focus on the impact of the initial shock wave by using the FSI (fluid-structure Integration) calculation method in the safety assessment. We simulate the process of arc heating air first, which involves the calculation of fluid dynamics. We then analyze the impact of the heated air on the cabinet structure, and perform the solid mechanics calculation. This approach ensures comprehensive and accurate assessment.

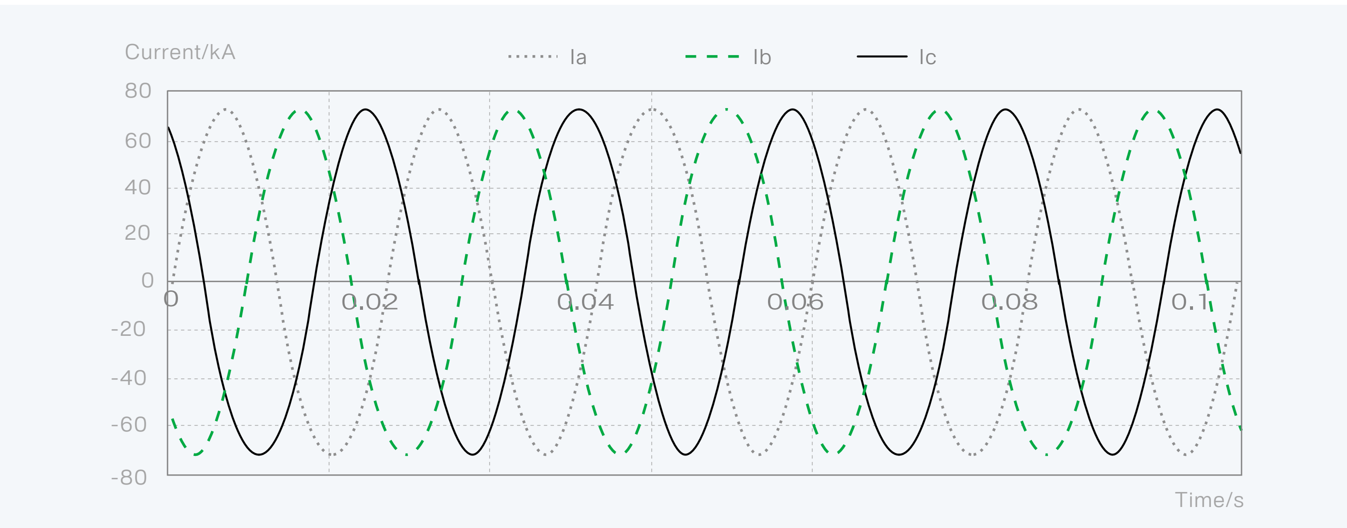
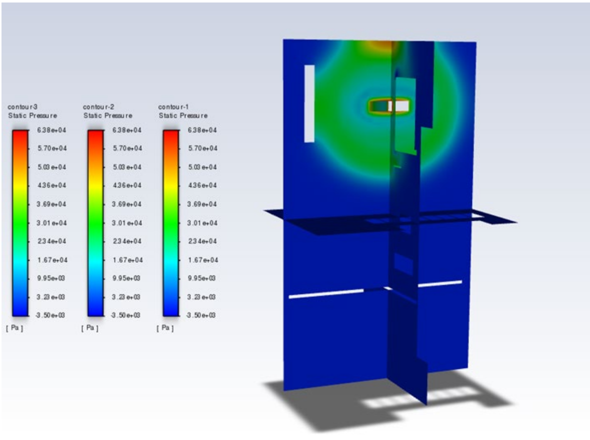


Figure 5 Three-phase short-circuit current change during arcing

Given that the short-circuit current is 50 kA, the voltage is 800 V, the duration of arcing is 0.1 s, apply the formula $W=\int_0^{t_1} I_m \sin(wt+\theta)\cdot U_a\cdot dt$(where W is the arc energy, I_m is the max arc current value, U_a is the arc voltage, and T is the arcing time) for calculating the energy of arcing, which can be calculated to be about 6,928,000 joules (about 1.92 kWh), roughly equivalent to the kinetic energy generated by a 15-ton truck traveling at the speed of 110 km/h. In the hydrodynamic simulation, this arc energy is taken as a key input parameter to simulate the pressure change due to heating the surrounding air by the arc, as shown in the figure below. In the arcing stage, the arc burns to release a large quantity of heat, heating the surrounding air to increase the pressure inside the cabinet. In the expansion stage, the pressure inside the cabinet increases to open the arc discharge structure to release the air from the cabinet. In the thermal effect phase, the arc is burning, but the overall pressure of the cabinet does not increase. In addition, set a monitoring point subject to the greatest pressure below the arc discharge port of the equipment (see the below red dot) to measure and record the pressure change there when simulation arcing occurs.



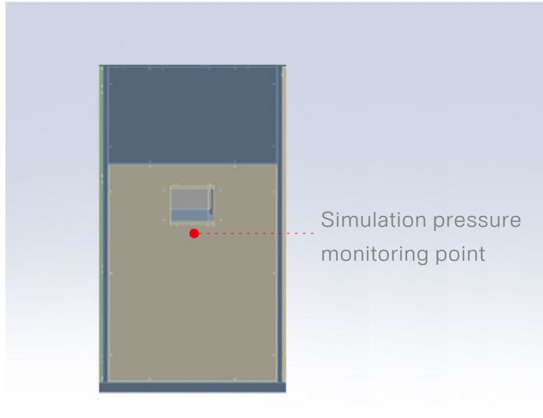


Figure 6 Left: Pressure distribution cloud chart Right: Simulation pressure monitoring point (red dot)

2. Assess structural strength with pressure simulation

According to the simulation results, the cabinet components meet the strength requirements, while the yield strength and breaking strength of the cabinet sheet metal (SGCC) and the cylindrical locks and hinges (SUS304) are within the safe range.

Material	Yield Strength	Breaking Strength
SGCC galvanized steel sheet	235 MPa	470MPa
SUS304 stainless steel	205 MPa	520MPa

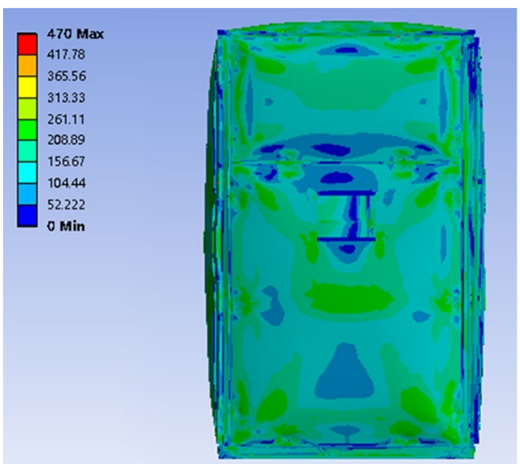


Figure 7 Stress nephogram of cabinet housing

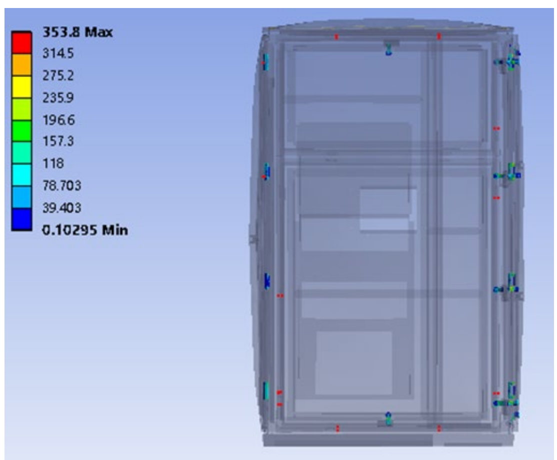
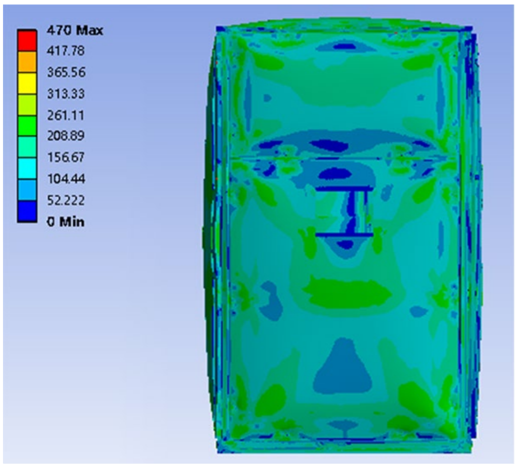


Figure 8 Stress nephogram of door lock hinge

According to the analysis of the stress nephogram, the stress level of the cabinet housing remains below 470 MPa, and there is no red area in the stress nephogram, which indicates that the stress does not exceed the threshold of 470 MPa. Hence, the cabinet housing remains intact without damage. Similarly, the strength of the door lock and hinges does not exceed 520 MPa, and the stress nephogram does not show any red zone over 520 MPa, indicating that the door lock and hinges have a stable structure without damage.

3. Contrast experiment and simulation



Simulation Image


Onsite Test Picture

Figure 9 Contrast images for simulation and experiment site

Basic situation: Verify the accuracy of the pressure relief and explosion protection simulation results provided by Sungrow and the performance of the equipment under the actual arcing conditions, simulate the same conditions to design the experiment, and set a monitoring point at the same location below the arc discharge port of the equipment to measure and record the pressure change there when arcing occurs.

Experimental parameters: Arc Class C, current 50 kA, voltage 800 V, arc duration 0.1 s.

Experiment result: Collect the data at the monitoring points, and compare the simulated theoretical values with the measured actual values.

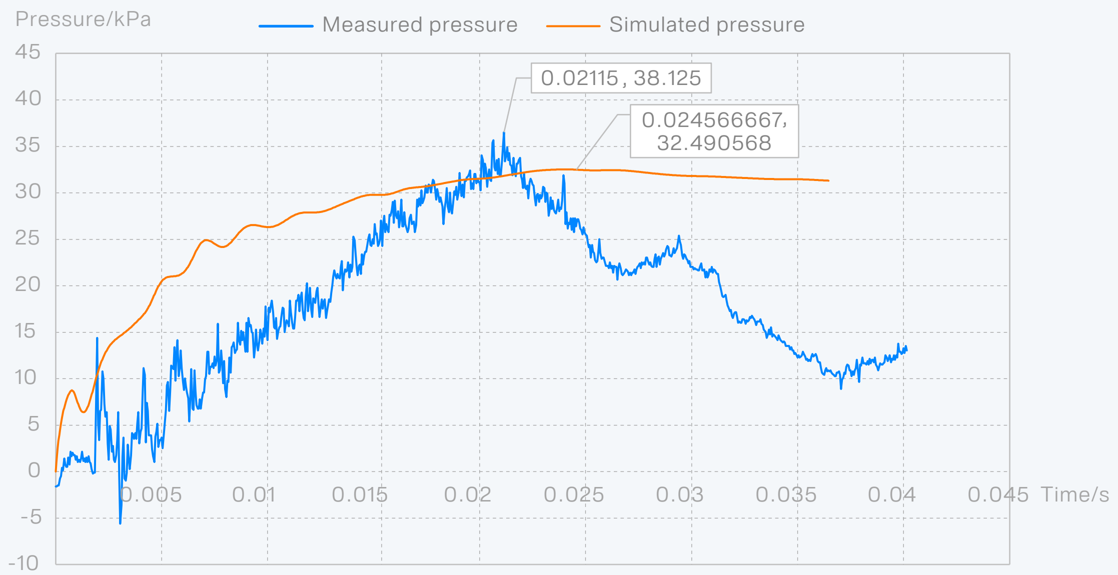


Figure 10 Comparison of simulated pressure and measured pressure

As shown in the figure above, the simulated pressure is 32.491 KPa, and the measured pressure is 38.125 KPa, which are basically consistent with the accuracy of 85.12%. This proves that the above simulation model is highly accurate and effective.

3.2 Strengthened structure and rapid arc discharge are essential for arcing prevention and control of PV inverter systems

The strengthened structure and rapid discharge of arcing energy are regarded as the two pillars for arcing safety design. In the event of an arcing accident where high temperature and pressure are generated rapidly, it is necessary to ensure the reliability and bearing capacity of the equipment structure, and prevent the blast caused by structural damage or rupture from hurting the operators around. Meanwhile, it is important to ensure that the arc discharge channel is unobstructed to quickly release the arcing energy in the cabinet, so as to protect sensitive electrical components, ensure the reliable operation of the equipment, and avoid more serious accidents such as fire and explosion.

1. Strengthened structure

Based on the above simulation results, we can see that the weak points of the cabinet are mainly distributed in the door lock, door panel, detachable panels where there is large spacing between fixing screws, so the overall structural strength of the Sungrow PV inverter system is mainly enhanced by reinforcing the door panel fixing manner and local structure.

• Reinforcing door panel fixing

Door lock reinforcement: To ensure the stability and safety of the hinged door, Sungrow adopts an innovative anti-drop limit structure to fix the lock, that is, a precise limit structure in the lock bolt and a matching limit slot on the cabinet frame. When the door lock is closed, the limit structure will be precisely inserted in the limit slot. This solution can effectively prevent the lock bolt from falling off when the door is deformed, greatly improving the fixing strength of the door lock and the overall security, and has been patented by China National Intellectual Property Administration (Patent No.: ZL 2021 21831288.9).

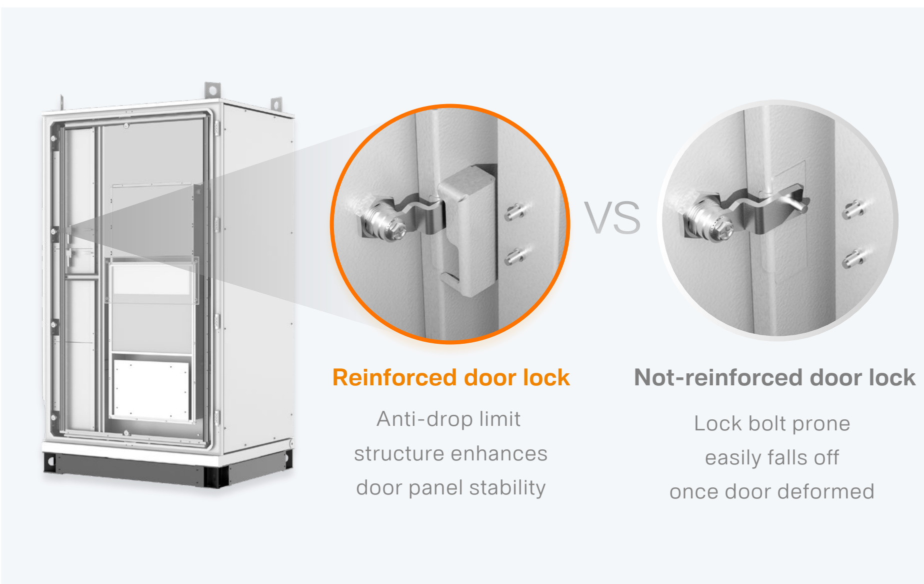


Figure 11 Anti-drop reinforcement of door lock

Figure 12 Letters patent for cabinet side-wall pressure relief design

Bolt reinforcement: To further enhance the fixation strength of the detachable door panel, Sungrow adopts two key measures reinforcing bolt fixation: First, add additional bolt fixing points in the weak zones where the door panel is fixed to effectively enhance the overall stability; Second, strengthen gaskets to increase the contact zone between the bolts and the door panel, effectively dispersing the fixed pressure and further improving the bolt fixation strength.

Figure 13 Reinforcement of door panels

- ## Local structure strengthening

To strengthen the door structure, we strengthen and thicken the physical structure of doors so as to better withstand the high temperature and pressure generated by arcing, and lay reinforcing ribs inside the door panel tightly to improve the structural integrity and enhance the stability of doors under extreme conditions without significantly increasing the weight.

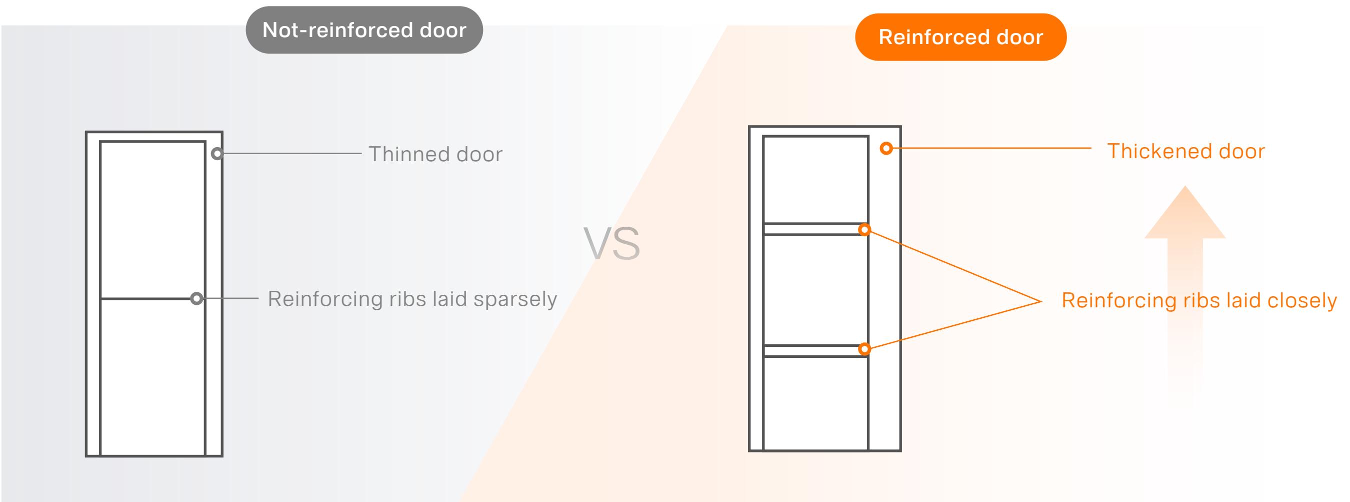


Figure 14 Local reinforcement of doors

2. Rapid arc discharge

After the fault occurs, the arcing energy will continue to accumulate. If it is not guided to a safe area for rapid arc discharge, the heat and pressure generated in the closed cabinet will increase the risk of equipment explosion. Therefore, the design of the arc discharge port opening mechanism is very important.

In the complicated and changeable arcing fault environment, plastic screws or knockout holes are usually used to fix the pressure relief door traditionally. Such a solution has weak adaptive capabilities due to slow reaction and not-timely arc discharging, thus laying hidden dangers. In addition, the pressure relief door cannot restore itself after destructive self-opening, but needs to be manually restored or even replaced if severely damaged.

With rich experience and advantages in technology research and development, Sungrow comprehensively considers the location of the arcing point, the internal structure of the equipment, heat dissipation, safe zone for personnel, industry standards, physical properties of arcing, etc., and arranges the arc discharge ports at optimal positions to ensure that the pressure relief path of each closed cavity can be unobstructed in the event of fault, for safe, reliable and rapid pressure relief.

Figure 15 Dual pressure relief channels and patented door stop pressure relief doors

Besides, Sungrow adopts the patented design of "Door Stop + Hinge" arc discharging technology in the pressure relief scenario firstly in the industry (Patent No.: ZL 2021 2 1829428.9). With the adaptive locking force of door stop where is the weakest point, the sudden rise of pressure and temperature can be sensed within milliseconds so as to automatically open the pressure relief door to rapidly release the energy and pressure inside. The quick opening and auto-closing function of the hinge ensures automatic reset after an arc discharge without the need for replacement or repair, thus reducing the damage to the equipment and improving safety.

Figure 16 Pressure relief door opens quickly to relieve pressure and then close automatically

Figure 17 Letters patent of cabinet pressure relief port design

3.3 Pressure relief and explosion-proof safety design of ring main units

The operating voltage of a ring main unit (RMU) is usually 10 kV-35 kV. A higher voltage results in greater energy intensity of the arc. Therefore, the ring main unit must be configured with a more complex arc discharge system to ensure that the equipment can withstand stronger energy impact and can quickly guide the arc and release it to the outside.

1.Reinforced design of the ring main unit structure

Based on the calculation and verification with the simulation model, Sungrow adopts innovative structural reinforcement designs and thickening measures in key positions such as the arcing door and the side panel and rear of the ring main unit.

- **Reinforcement and thickening of arc doors**

  The design of "thickened cabinet door + double-row multi-hook lining plate +SMC arc baffle" enhances structural strength for better resistance to arc impact.

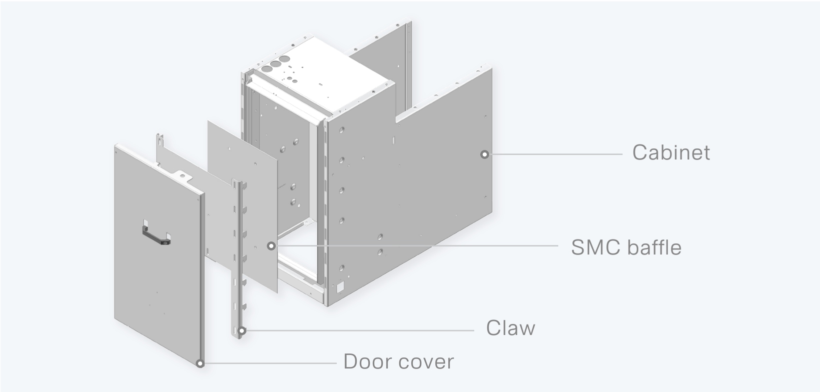


Figure 18 Detailed diagram of cabinet doors

- **Protection of key areas**

Based on simulation verification, the insulation board is arranged to the key area to cover the gas box and the cable chamber, and the reinforcing ribs are added to provide a cushioning confined space to improve the resistance to ablation in case of faults.

2. Design of arc discharge channels for the ring main unit

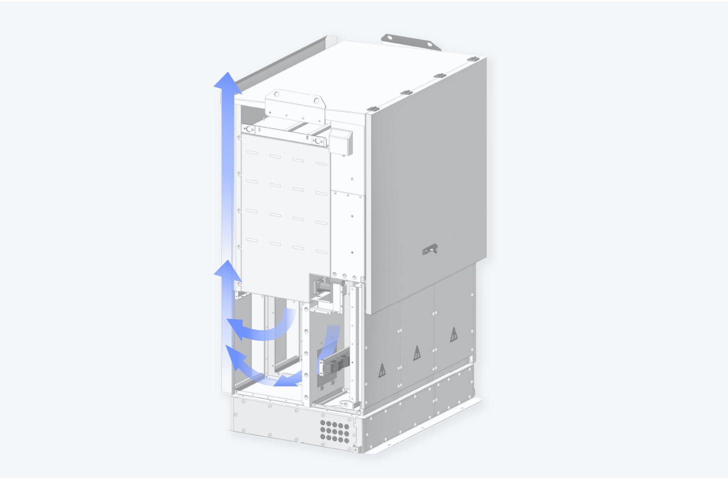


Figure 19 Arc discharge channels of the ring main unit

The ring main unit is designed with an independent arc discharge channel with the fixed edge reinforced by ruffles. The rear arc discharge chamber runs through the unit, increasing the buffer space and reducing the impact strength. The design of top arc-discharging flap + limit baffle can guarantee the protection level, while releasing the pressure generated by arcing to the external environment rapidly and efficiently.

3.4 Explosion-proof safety design of string inverters

Let's take the Sungrow SG320HX-20 string inverter as an example. Based on the simulation calculation and verification of its explosion state, we enhance its structural stability by reinforcing the connection strength and selecting better materials in critical areas, and arrange the pressure relief channels skillfully in the non-critical areas, thus achieving effective balance between the structural strength and safe pressure relief.

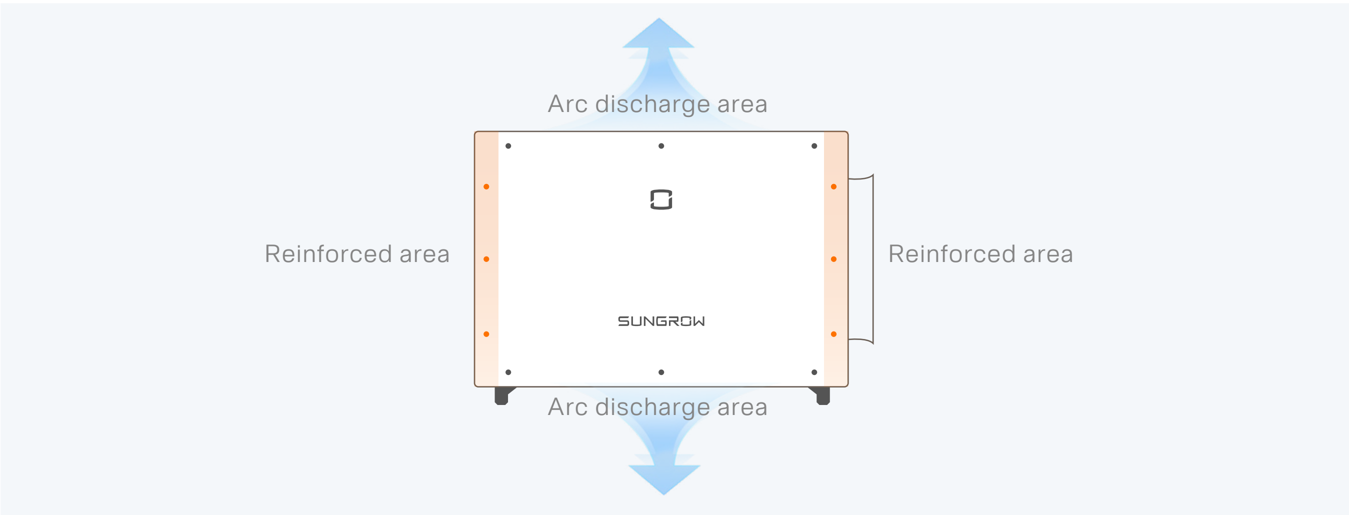


Figure 20 Safety design layout of string inverter

1. Structural reinforcement

Based on the internal impact pressure analysis and the safety standard of structural strength, the left and right sides of the equipment door cover and the cabinet are designed as reinforced areas. The reinforced areas are fixed with reinforcing steel gaskets and self-clinching nuts to enhance the strength of bolt connections and ensure reliable connection with the cabinet on both sides under internal impact forces. This design has been patented by CNIPA (Patent No. : ZL.2022 2 1129860.1).

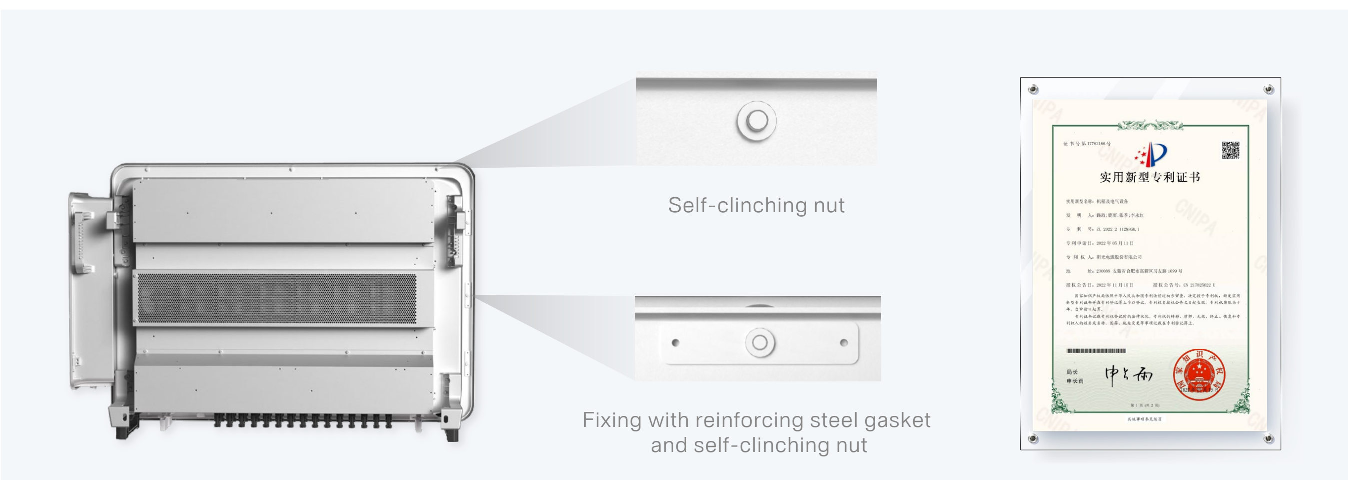


Figure 21 Reinforcement for the door cover and cabinet

2. Blasting pressure relief

Based on the pressure distribution inside the inverter in the case of a blasting fault and the design requirements of the pressure relief structure, the upper and lower sides of the inverter are designed as pressure relief areas. In these areas, the self-clinching nuts are directly connected to the cabinet without reinforcing gaskets, so as to ensure that these areas can be deformed in a timely manner in the case of blasting for effective pressure relief.

Figure 22 Top view of string inverter blasting effect

3.5 Pressure relief and explosion-proof safety design of modular inverters

1+X modular inverters operate in environments with high voltage and current, where the complex electrical network and highly integrated equipment may increase the risk of arcing diffusion in the event of an arcing fault. Therefore, the design of the 1+X modular inverter focuses on insulation structure design, AC/DC area separation, rapid pressure relief, etc., so as to prevent arc diffusion and realize rapid arc discharge.

1. Insulation structure design

In order to prevent arc diffusion and ensure the safe operation of the equipment, the insulation design is very important on both sides of the modular inverter, between the positive and negative electrode wiring copper bars, as well as around the copper bar.

• Using reinforced insulation materials

Epoxy resin is used for critical insulation design areas on both sides inside the equipment, PC (polycarbonate) is used between the positive and negative wiring copper bars, the positive and negative fuses, and around the copper bars adopt. Such material is resistant to high temperature and arcing, ensuring that there will be no arcing during the connection and operation of the lines connecting the power supply to the equipment or system.

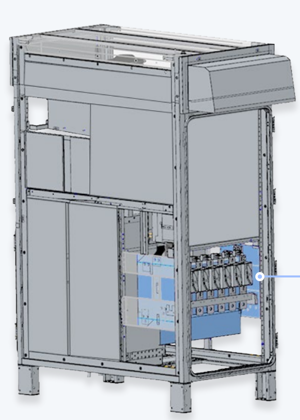


Figure 23 Design of insulation material inside equipment

- ### Protective treatment of metal parts

In order to reduce the probability of arcing and prevent the arcing from spreading, the metal components inside the equipment are treated for protection, where the copper bars are secured by insulation parts and the fixing bolts are protected by insulation caps.

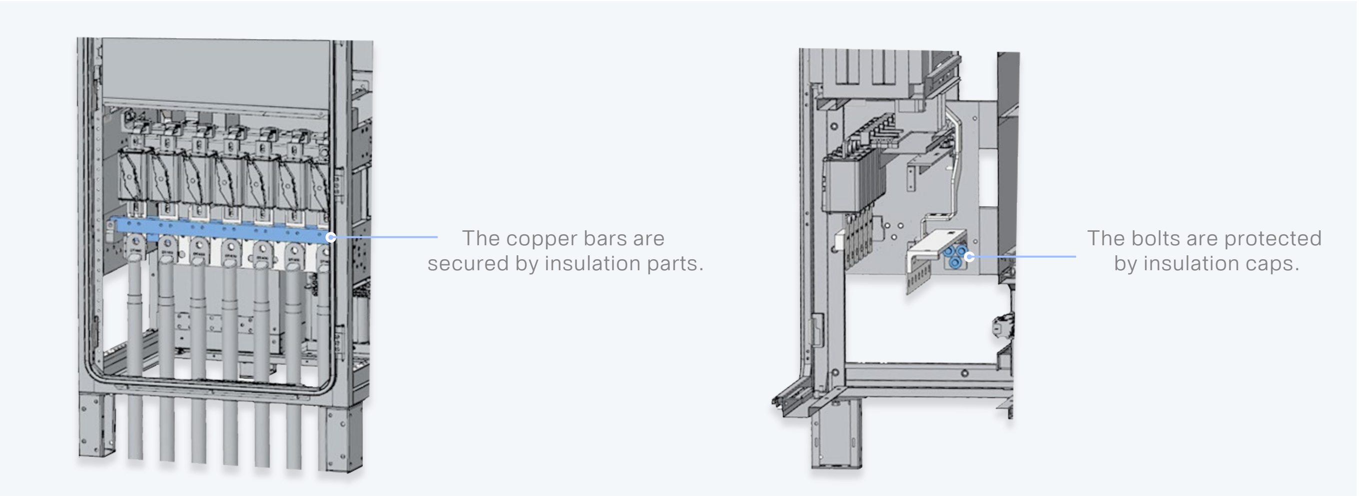


Figure 24 Protection of metal components inside equipment

Compared with the traditional sheet metal fixing manners, fixing the incoming copper bars with insulation angle steel delivers better insulation performance and higher operating safety. In case of short circuits or overcurrent, it can confine the arcing to a specific area effectively and prevent it from spreading to adjacent circuits or devices.
The insulation caps covering the fixing bolts can effectively prevent the current from leaking through the bolts and reduce the risk of short circuit. When arcing occurs around the bolts, the insulation caps can limit the impact of arcing to certain scope, preventing the arcing from spreading to the adjacent conductive parts or metal structures.

2. Separation of AC/DC areas

In the internal design of a 1+X modular inverter, the DC wiring and the DC load switch are located on the front side, while the AC wiring and its circuit breaker are located on the back side. The two main chambers are separated by a sheet metal baffle in the middle to ensure the independence of the AC and DC areas, effectively isolate the fault source and reduce the arcing spread.

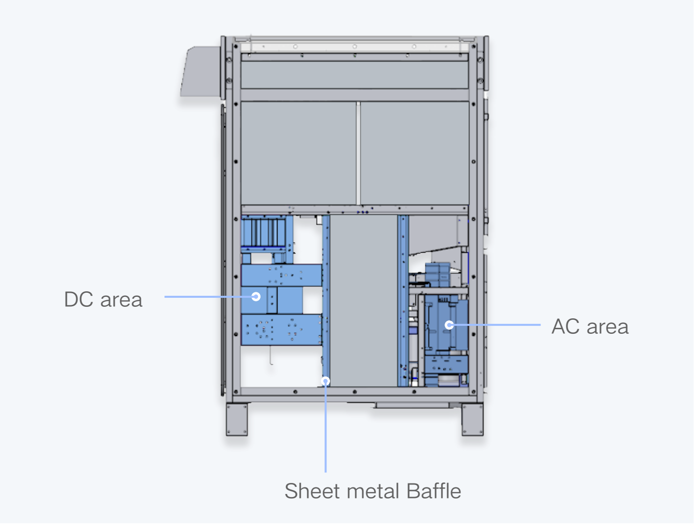


Figure 25 Space diagram of AC/DC area separation layout

3. Design of pressure relief channels

To facilitate the rapid release of the arcing pressure on the optimal path, the 1+X modular inverter has a special pressure relief door in the DC wiring area and a complete inner cavity. When the arcing occurs at any point inside the cavity, the pressure relief door will be opened under the pressure, so as to discharge the energy.

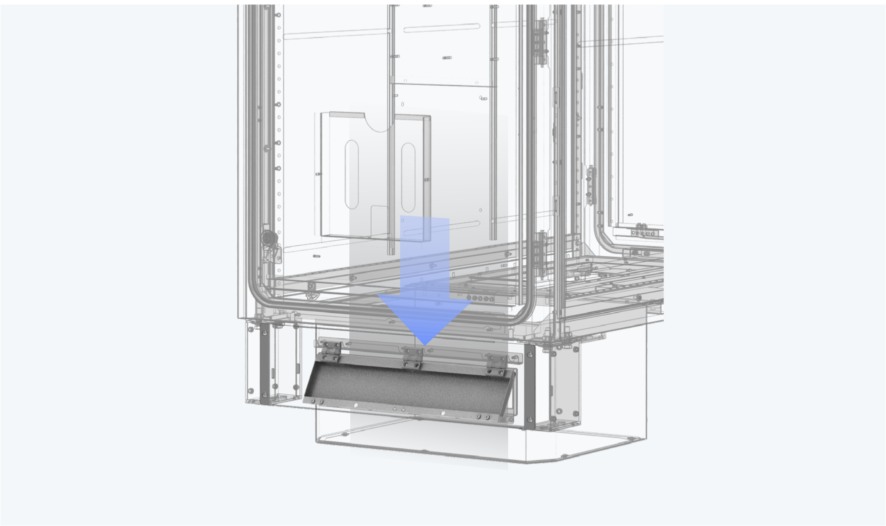


Figure 26 Fault pressure relief design

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Technical Verification and Results

Safety is the cornerstone of the sustainable development of the PV industry. Sungrow, a world-leading supplier of PV inverter solutions, always puts safety first. In order to deeply explore and effectively prove the technical status and performance of Sungrow PV inverter solutions, TÜV Rheinland and Intertek formed a verification team to verify and assess the key arcing and explosion-proof performance of the Sungrow PV inverter system as commissioned by Sungrow.

Test plans and basic content of performance verification

Solution Review

- Determine the test standards for and classes of arcing, the technical solutions , and the design solutions of arc initiation, arc discharge and structure
- Determine the explosion-proof test plan, and explosion-proof and pressure relief designs for products

Performance Verification

- Determine the test location and current value of the arcing test, and check the performance of the equipment after the arcing visually, including operation performance and structural integrity
- Determine the type,concentration and detonation mode of explosive gas

Conclusion

- Compare the technologies and their performance with current global standards and other normative documents to determine performance levels or conformance opinions
- No structural parts fly out during the test

4.1 Certification items

This test aims to verify whether the Sungrow PV inverter system has the above-mentioned capabilities through field verification, specifically in the form of a witnessed test. The items and purposes of this test are shown in the following table:

Test Item	LV Switchgear	Prefabricated Substation	Centralized Inverter	String Inverter
Reference standard	IEC 61641 "Enclosed low-voltage switchgear and controlgear assemblies - Guide for testing under conditions of arcing due to internal faults"	IEC 62271-202 "High-voltage switchgear and controlgear -Part 202" IEC 62271-200 "High-voltage switchgear and controlgear - Part	IEC 61641 "Enclosed low-voltage switchgear and controlgear assemblies - Guide for testing under conditions of arcing due to internal faults"	No reference standard Sungrow defines its own standard that the nothing flies out of the equipment in case of arcing
Certification authority	Intertek	TÜVRheinland XIHARI	Intertek	TÜVRheinland

Table 2 Pressure relief and explosion-proof safety certification items for PV inverter system

4.2 Pressure relief and explosion-proof safety certifications for PV inverter systems

1. Blasting safety certification for LV switchgear

	Criterions	Results
Doors and covers	Correctly secured doors and covers do not open.	Pass
Parts flew of	No parts of the ASSEMBLY are ejected which have a mass of more than 60g except those which are dislodged and fall between the ASSEMBLY and the indicators.	Pass
Holes	Arcing does not cause holes to develop in the external parts of the enclosure below 2 m, at the sides declared to be accessible as a result of burning.	Pass
Indicators	The indicators do not ignite.	Pass
Protective circuit	The protective circuit for accessible part of the enclosure is still effective.	Pass
Arc area	The ASSEMBLY is capable of confining the arc to the defined area where it was initiated.	Pass
Remaining assembly	Emergency operation of the remaining ASSEMBLY is possible.	Pass

Table 3 Blasting safety test conditions of LV switchgear and results

Before the test

After the test

Figure 27 Low-voltage blasting pre- and post- test comparison

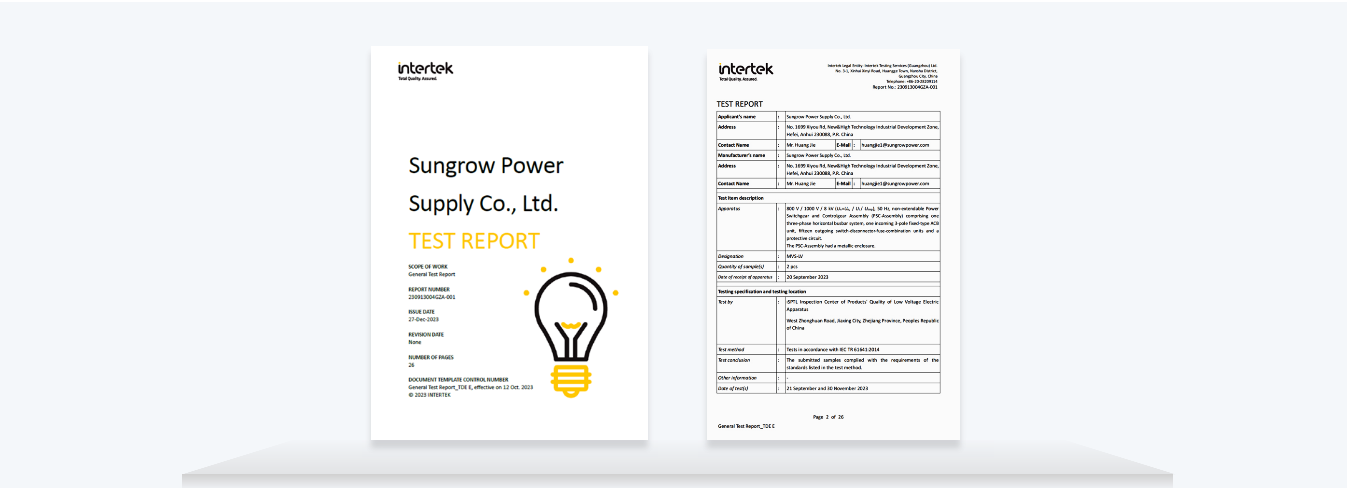

Figure 28 LV switchgear blasting safety certification by Intertek

StandardsTest method: Tests in accordance with IEC TR 61641:2014

Test method: Classification with regard to the protection characteristic: Class C. Permissible conditional short-circuit current under arcing conditions, Ipcarc=50kA rms at 800V, pf = 0.25.

Test conclusion: The submitted samples complied with the requirements of the standards listed in the test method.

2. Blasting safety certification for prefabricated substation

• Blasting safety certification for the ring main unit

Sungrow's ring main units are mainly provided by Daqo, Siemens, Ormazabal, and ABB, which all have passed the blasting safety certification test.

Figure 29 Blasting safety certification reports of manufacturers

Standards: International Standard IEC 62271-200, Second edition 2021-05, subclause 7.105. Internal arc test.

Test method: Internal arc test according to accessibility type AFLR, with an intended arc fault current of 87% of the three-phase current of 20 kA for 1 s.

Test conclusion: The test object fulfilled the criterion of the standard. This internal arcing test is applicable for a classification of the test object according to IAC AFLR internal arc 20 kA 1 s.

• Blasting safety certification for prefabricated substation

According to the test declaration from TÜV Rheinland, the results of the internal arc test (IAC) of ring main units with a pressure relief channel can be applied to a prefabricated substation if the IAC has been carried out in accordance with Annex A of IEC 62271-200 and the other components in the prefabricated substation do not affect discharging arc upward in case of arcing inside the ring main unit. Each prefabricated substation design of Sungrow has been assessed separately by TÜV Rheinland and meets the above requirements, so that the arc discharge report of the ring main unit applies.

TÜVRheinland®
Precisely Right.

To: SUNGROW POWER SUPPLY Co., Ltd.
No.1699 Xiyou Rd., New & High Technology Industrial Development Zone, Hefei, P.R. China

Attention: Mr. Jie Huang

Ref: DECLARATION OF INTERNAL ARC TEST OF MVS8850-LV, MVS9000-LV, MVS8960-LV PREFABRICATED SUBSTATION

The object compact equipment assembly for prefabricated substation with model MVS8850-LV, MVS9000-LV, MVS8960-LV was witnessed by TÜV Rheinland.

The internal arc test (IAC) results for high voltage switchgears could be applied to an identical construction and designation of the high voltage functional unit when it installed in MVS8850-LV, MVS9000-LV, MVS8960-LV which described in TÜV Rheinland report CN2367B6 001 if the following conditions were met:

a) The high voltage functional unit with pressure relief duct had passed internal arc test according to Annex A of IEC 62271-200, and the test arrangements was more onerous than the actual installation conditions in the prefabricated substation MVS8850-LV, MVS9000-LV, MVS8960-LV.

b) The other components in the prefabricated substation do not affect the behavior of pressure relief when internal arc occurred in high voltage switchgear.

This declaration is also based the following documents and drawings:

a) Drawings/Design Documentations from Sungrow (MVS8850-LV, MVS9000-LV, MVS8960-LV).

b) IAC test report (test report No.19-B54, test report No.20-B11, test report No.15-B22, test report No.2015-0127003) prepared by SATS.

c) Statement prepared by ABB Beijing Switchgear Co. Ltd for proving that the existing IAC type test report can cover the arrangement designed by SUNGROW POWER SUPPLY Co., Ltd.

Figure 30 TÜV Rheinland declaration

Tests		Results
Dielectric Tests	Tests to verify the insulation level of the prefabricated substation.	Pass
Continuous current tests	Tests to prove the temperature rise of the components contained in a prefabricated substation.	Pass
Short-time withstand and peak current test	Tests to prove the capability of the main and earthing circuits to be subjected to the rated peak and the rated short-time withstand currents.	Pass
IP level verification	Tests to verify the degree of protection.	Pass
IK level verification	Tests or calculations to verify the withstand of the enclosure of the prefabricated substation against mechanical stress.	Pass
Auxiliary and control circuits	Tests to verify the auxiliary and control circuits.	Pass
EMC compatibility	EMC compatibility tests.	Pass
Sound level verification	Tests to verify the sound level of high-voltage/low-voltage transformer prefabricated substation.	Pass

CERTIFICATE
of Conformity

TÜVRheinland®

Registration No.: AK 50585098 0001

Report No.: CN2367B6 001

Holder: Sungrow Power Supply Co., Ltd.
No.1699 Xiyou Rd.,New & High
Technology Industrial
Development Zone,
Hefei
230088 Anhui
P.R. China

Product: High-voltage switchgear and controlgear
(Prefabricated substation)

Identification: Type Designation: MVS8850-LV, MVS8960-LV, MVS9000-LV
Serial No.:RD180139-001
IEC 62271-202:2022 subclause 7.2, 7.5, 7.6, 7.7, 7.9, 7.10, 7.101, Annex B
IEC62271-212:2022 subclause 7.2, 7.4, 7.6, 7.7, 7.10, 7.101, 7.103, 7.104, 7.106, Annex B
Remarks: 1. Refer to test report CN2367B6 001 for details.
2. For technical data refer to 1.1-1.2.
3. For more information refer to Appendix No.1-CDF

Tested acc. to: IEC 62271-202:2022
IEC 62271-212:2022

The certificate of conformity refers to the above mentioned product. This is to certify that the specimen is in conformity with the assessment requirement mentioned above. This certificate does not imply assessment of the production of the product and does not permit the use of a TÜV Rheinland mark of conformity.

Certification Body

Date 10.05.2023

Wencai Zhang

TÜV Rheinland LGA Products GmbH - Tillystraße 2 - 90431 Nürnberg

Prefabricated substation certificate

Figure 31 Prefabricated substation test description and certificate

Test method: Conduct testing in accordance with the conditions stipulated by IEC 62271-202:2022 and IEC 62271-212:2022 standards.

Test conclusion: Sungrow MV substation has been successfully tested, the test procedure and test results are in conformity with standards and specification.

3. Explosion-proof safety certification for string inverters

There is no standard reference for string inverters, and Sungrow defines its own test standard that no structural part flies out during the explosion test.

Test method	Results
Install the cover plate correctly and secure with installation torque.	• Visual inspection showed damage to the sample components. • Visual inspection showed cracks to the sample components. • Visual inspection showed deformation to sample components.
Purge the interior of the sample with a mixture of hydrogen gas (with a combustible gas concentration of 4.6±0.3% in the air) for 15 minutes until a uniform saturation is achieved.	
Turn on the fan for 20 seconds and then turned off.	
Stable for 5 minutes.	
Turn on the fan for another 20 seconds.	
Ignite without turning off the fan again.	

Table 4 Explosion-proof safety test of string inverter and results

Figure 32 Explosion-proof test report for string inverters

Test Conclusion: The visual inspection showed damage, cracks and deformation to the sample components, without shells or components exploding and flying out.

4. Blasting safety certification for modular inverters

	Criterions	Results
Doors and covers	Correctly secured doors and covers do not open.	Pass
Parts flew of	No parts of the ASSEMBLY are ejected which have a mass of more than 60g except those which are dislodged and fall between the ASSEMBLY and the indicators.	Pass
Holes	Arcing does not cause holes to develop in the external parts of the enclosure below 2 m, at the sides declared to be accessible as a result of burning.	Pass
Indicators	The indicators do not ignite.	Pass
Protective circuit	The protective circuit for accessible part of the enclosure is still effective.	Pass
Arc area	The ASSEMBLY is capable of confining the arc to the defined area where it was initiated.	Pass
Remaining assembly	Emergency operation of the remaining ASSEMBLY is possible.	Pass

Table 5 Arcing test description of modular inverters

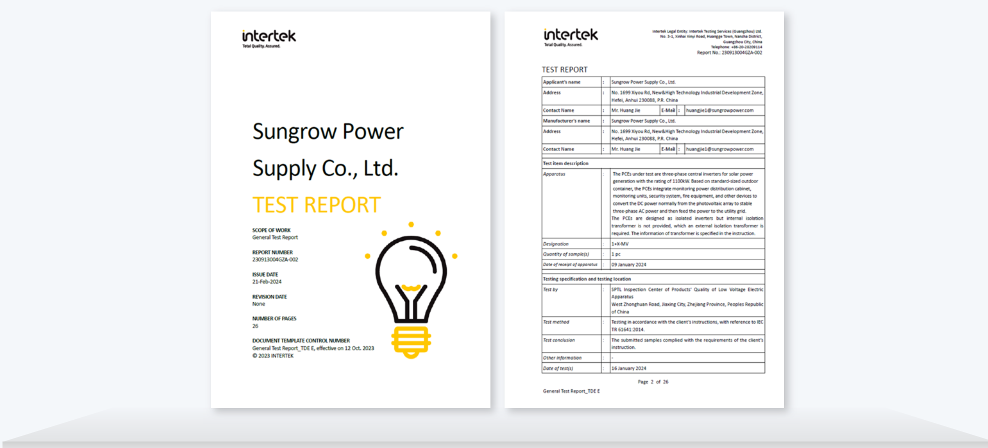

Figure 33 Blasting safety certification for the 1+X modular inverter by Intertek

Test Method: Testing in accordance with the client's instructions, with reference to IEC TR 61641:2014. Classification with regard to the protection characteristic: Class C. ; Ip arc for a permissible arc duration (tarc): 4 kA at 1500 V, d.c. for 0.1 s; Ip arc for a permissible arc duration (tarc): 57.6 kA rms at 660 V, pf = 0.20 for 0.1 s at the supply side of incoming unit FU1. Ip arc for a permissible arc duration (tarc): 57.6 kA rms at 660 V, pf = 0.20 for 0.1 s at supply side of incoming ACB unit QF1.

Test Conclusion: The submitted samples complied with the requirements of the client's instruction.

4.3 Conclusion

Based on the results of technical review and performance verification, the pressure relief and explosion-proof safety technology of Sungrow's PV inverter systems exhibits the following features:

(1) The LV switchgear and modular inverter meet the requirements of IEC TR 61641:2014, with Class C arcing.

(2) There is no standard reference for string inverters. During the test as required by Sungrow, the equipment does not emit explosive debris and remains within a safe range.

(3) The prefabricated substation meets the requirements of IEC 62271-200 "High-voltage switchgear and controlgear - Part 200" and IEC 62271-202 "High-voltage switchgear and controlgear - Part 202".

Figure 34 Application case of Sungrow's pressure relief and explosion-proof technologies

At present, Sungrow's pressure relief and explosion-proof technologies for PV inverter systems have been successfully applied in Europe, the Asia-Pacific Region, North America, Latin America, the Middle East, etc., guaranteeing the safety of global PV power generation.

05

Summary and Outlook

The safety construction of utility-scale PV system is arduous and of great significance. In view of the existence of blasting safety hazards, we need to enhance the safety design during the design and operation of PV systems to avoid damage to equipment, property loss, and personal injuries. However, the whole PV industry still needs to improve the design of PV system arcing safety solutions and the implementation of safety features. Achieving the arcing safety and reliability of utility-scale PV systems requires concerted efforts from the entire industry.

Sungrow has always prioritized safety, employing comprehensive safety design schemes and technological means to ensure the safe operation of utility-scale PV plants throughout their entire lifecycles. With the continuous advancement of PV technologies and safety performance, PV power will play a more critical role in the global energy transition. Sungrow looks forward to collaborating with industry peers to continuously improve safety standards, build highly reliable PV power stations, and contribute more to a future with safe, efficient, and green energy.

SUNGROW

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