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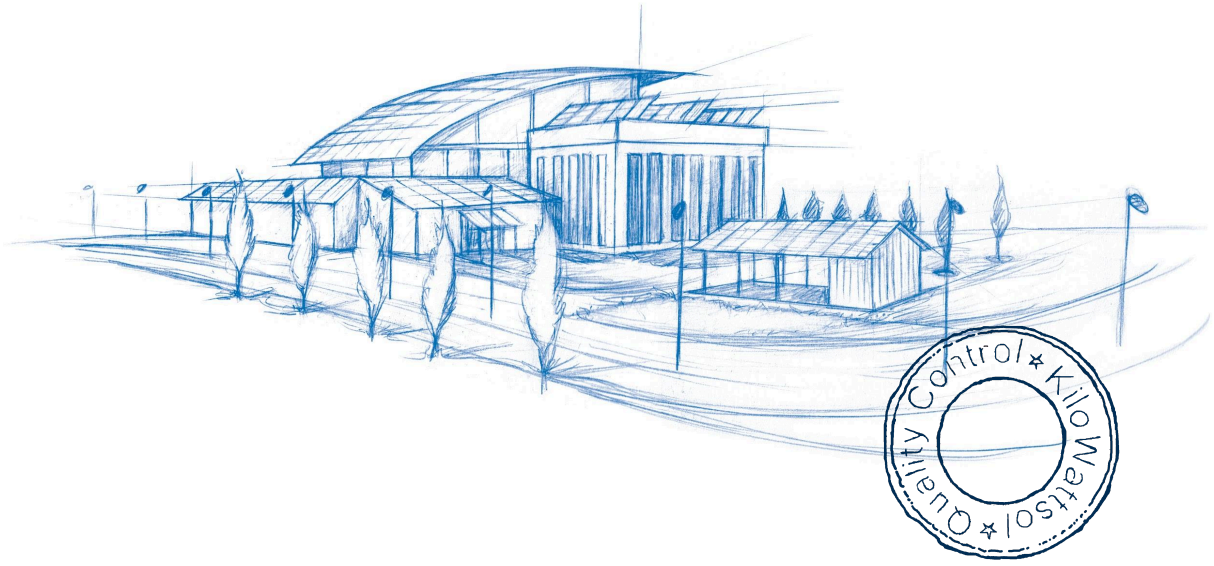
SOLAR EXPERT

In collaboration with

SuperGrid Institute *and* HUAWEI



Residential and C&I Safety White Paper

Report 91218 version 1.0 - En - edited on 8th March 2024
Client : Huawei France

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Executive Summary

Photovoltaic (PV) plants, operating at high voltages, inherently pose electrical risks that can compromise system efficiency and endanger individuals. Prioritising safety measures is crucial to mitigate these risks and safeguard both assets and personnel. With the observed energy crisis driving increased interest in self-energy generation, particularly in France, where businesses and individuals are embracing photovoltaic technology, adherence to stringent safety standards is imperative for sustainable industry growth. To ensure the success and sustainability of the inevitable expansion of the PV industry in France, it is imperative to establish and adhere to appropriate standards and regulations. With their product, Huawei aims to support this growth characterised by high quality. Indeed, the careful selection of components to guarantee safety is crucial to fostering a robust and sustainable development.

Huawei, an established leader in PV technology since its inception in 1987, is committed to supporting the expansion of the PV industry in France through high-quality products and advanced safety features. Recognising the heightened risks associated with rooftop PV installations in residential, commercial and industrial (C&I) settings, Huawei's focus on robust safety measures and maintenance addresses the unique challenges posed by economic activities and the presence of non-technical personnel near electrical components.

Concerns over risks to personal safety as well as asset damage associated with technological advancements in rooftop PV installations underscore the importance of effective safety features. In a residential and C&I context, the physical and financial consequences of these faults are exacerbated by the frequent presence of non-technically qualified individuals who may access the roof or operate in close proximity to the electrical components of the power plant within these buildings as well as the related economic activities, underscoring the need for robust safety measures to mitigate these risks effectively.

Rigorous testing by esteemed laboratories ensures the effectiveness of Huawei's inverter safety features. Independent third-party assessments, including comprehensive testing by the French laboratory SuperGrid Institute, validate the performance of safety features within Huawei inverters, with a focus on arc fault detection capabilities and shutdown speed.

SuperGrid Institute's dedication to advancing the energy transition in France aligns with the objectives of this report, evidenced by its cutting-edge innovations and contributions to scholarly publications. SuperGrid Institute, with its extensive expertise and state-of-the-art facilities, plays a crucial role in advancing the energy transition in France by addressing technical obstacles and developing cutting-edge innovations. Their comprehensive testing of Huawei's inverters confirms the efficacy of the safety features, further reinforcing the integrity and reliability of Huawei's products.

The successful conclusion of assessments by multiple independent laboratories confirms the effective functionality of Huawei's safety features, positioning them as a trusted choice for the French market's evolving energy needs.

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Rooftop PV (Photo Credit : kiloWattsol)

Abbreviations & acronyms

Acronym	Description
RTE	Réseau de Transport d'Électricité
PV	photovoltaic
KWS	kiloWattsol
APER	Loi d'Accélération de la Production d'Energies Renouvelables
S3REnR	Schémas Régionaux de Raccordement au Réseau des Énergies Renouvelables
LTECV	Loi de Transition Énergétique pour la Croissance Verte
PPE	Programmation Pluriannuelle de l'Énergie
SNBC	Stratégie Nationale Bas-Carbone
HCC	High Council for Climate
COVID-19	Coronavirus disease
C&I	Commercial and Industrial
AC	alternating current
DC	direct current
MPPT	Maximum Power Point Tracking
CAGR	compound annual growth rate
EU	European Union
JRC	Joint Research Centre
R&D	research and development
RSD	Rapid Shutdown
AFCI	Arc Fault Circuit Interrupter
SSLD	Smart String-Level Disconnect

1. Introduction

Objective of the study

As the number one solar inverter manufacturer worldwide, Huawei Technologies Co., Ltd. ('the Client') invests heavily in research & development (R&D) to constantly improve operation and safety of solar systems. This is even more relevant in the residential and Commercial and Industrial (C&I) markets where PV systems are deployed on rooftops.

The safety of the people working under the solar generator, and the diversity of operations is the subject of very serious attention in order to control the maximum number of hazards that could be generated by a PV system.

The latest generation of SUN2000 inverters include a series of defence functionalities providing one of the safest operations on the market.

Scope of the intervention

As technical advisor and solar expert, kiloWattsol (KWS) has been tasked with evaluating the safety features of inverters tailored for the French market. To do so, KWS has ordered tests to be performed by a national laboratory and has reviewed third-party test results pertaining to the safety features of the inverter.

This document outlines the current state of the French photovoltaic market, emphasising the safety hurdles it encounters. Additionally, we conduct a thorough assessment of Huawei as a company, evaluating each pertinent feature they provide to tackle these challenges. The testing process is overseen in collaboration with a nationally accredited laboratory, and we meticulously review the outcomes of these tests, as well as those conducted by various other laboratories.

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Language

This document is written in English as requested by the Client. A French version has also been produced.

Caveat

KWS assumes that all information provided by the Client both verbally or under written format is complete, true and sincere. KWS does not guarantee the accuracy of the information, data or opinions enclosed in this report and does not warrant that the information contained in this report is sufficient or appropriate for any purpose.

Review and Distribution

Version	Date	Recipients	Modification
v1.0 - En	08/03/24	Huawei France	Initial version.

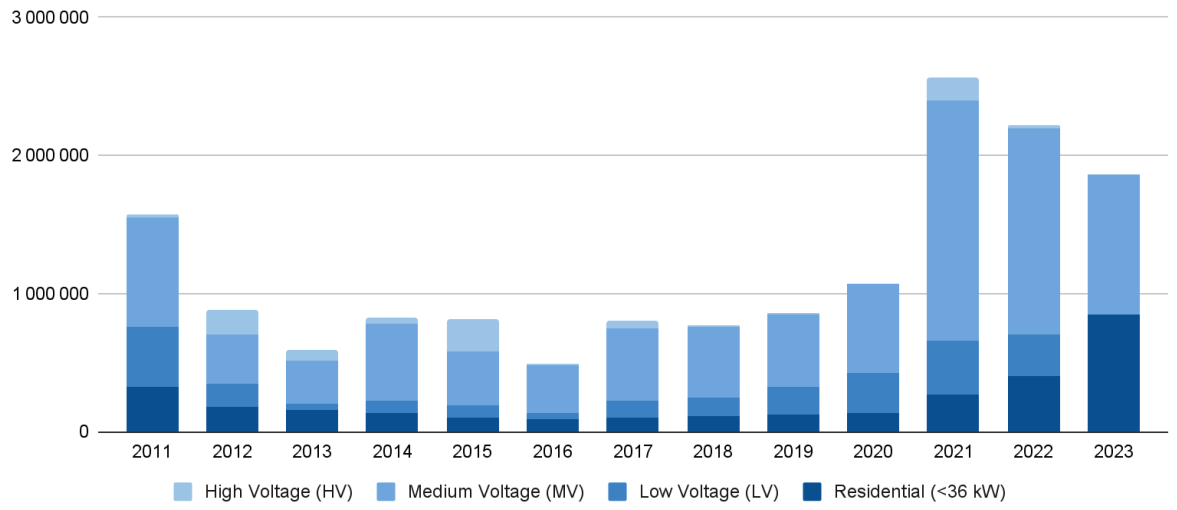
2. Context

In response to the pressing challenges posed by climate change, France, in alignment with global efforts, has proactively embraced an environmentally conscious stance. This commitment is underscored by legislative measures and national objectives geared towards fostering sustainable development. A pivotal milestone in this trajectory is the enactment of the Law on Energy Transition for Green Growth (Loi de Transition Énergétique pour la Croissance Verte or LTECV) in 2015, emblematic of France's endeavour to redefine its energy paradigm. The law articulates a vision of an eco-friendly, energy-efficient, and less fossil fuel-dependent economy.

Foremost among the law's objectives is the strategic transition to renewable energy sources, driven by an imperative to mitigate greenhouse gas emissions. The legislation articulates ambitious targets for the development and integration of renewable energy within the French energy matrix, accompanied by a concerted effort to diminish dependence on fossil fuels, recognised as a primary contributor to emissions.

To operationalise these objectives, the LTECV introduces concrete plans, including the Multi-Annual Energy Program (Programmation Pluriannuelle de l'Énergie or PPE) and the National Low-Carbon Strategy (Stratégie Nationale Bas-Carbone or SNBC).

The multi-annual energy program (PPE) for the period 2019-2028 delineates priority actions aligning with the national low-carbon strategy, strategically managing all forms of energy. This program plays a pivotal role in shaping the nation's approach to energy development, sustainability, and carbon reduction. By incorporating PV prominently into its framework, the PPE recognises the role of solar power as a crucial component of the energy transition. This integration reflects a commitment to harnessing the benefits of clean, renewable energy sources to achieve environmental, economic, and energy security objectives outlined in the program.



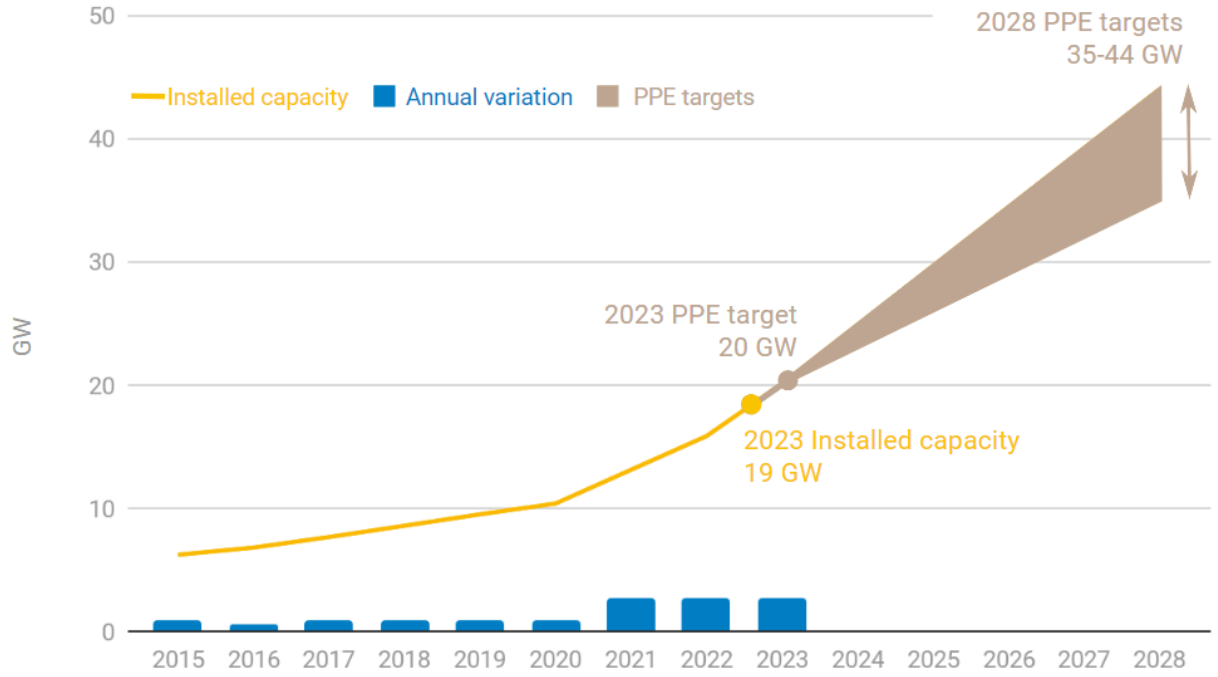
Installed PV power in France by size (kWp)
Source: RTE

The SNBC serves as France's comprehensive roadmap for combating climate change, providing directives across various sectors to transition to a low-carbon, circular, and

sustainable economy. It sets out greenhouse gas reduction targets until 2050, including short- to medium-term objectives known as carbon budgets. France has bolstered its climate policy governance by creating the High Council for Climate (HCC), tasked with overseeing the implementation of the national strategy, ensuring adherence to established trajectories, and acting as an alert system for any deviations.

These plans undergo periodic updates and revisions, attesting to France's dynamic approach in the face of evolving challenges.

The most recent update of the PPE sets forth an ambitious target, aspiring to achieve 20 GW of photovoltaic (PV) capacity by the close of 2023, with a further augmentation to 35-44 GW by the culmination of 2028. Presently, the installed PV capacity in the nation stands at 18.6 GW in December 2023 which is slightly below the established objectives. An acceleration of the production in the coming years is expected. This ambitious trajectory necessitates robust legislative support, manifested through new laws and regulations facilitating the deployment of PV projects. Examples include the acceleration law for renewables (Loi d'Accélération de la Production d'Énergies Renouvelables or APER) in march 2023 that opens access of surface-consuming PV to agricultural lands which make up 52% of the French territory, the regional grid connection schemes for renewable energies (S3REnR) that aims to ensure long term visibility of the renewable energy integration capacity by 2030 and to optimise necessary grid investments or the permission given the PV project owners to sell directly on the market during the current energy price peak allowing them to increase revenues. In addition, APER law of 10/03/2023 states that it is mandatory to have installation of photovoltaic shade structures on half of the surface area for outdoor parking lots exceeding 1500m², with sanctions for non-compliance. The different trajectories of the PPE is presented in the image below.



The different trajectories of PV development within PPE 2
Source: Synthèse PPE 2

The observed energy price peak is caused by the ongoing energy crisis. The energy crisis of 2021-2023 stems from a confluence of multifaceted factors. Firstly, the global economic recovery post-COVID-19 fueled an unprecedented surge in energy demand, driving up prices of

key resources like gas, coal, and oil. Simultaneously, the invasion of Ukraine by Russia from March 2022 intensified geopolitical tensions, triggering disruptions in energy supply chains, especially affecting gas markets. Complex relationships between the European Union, Russia, and the United States turned fossil fuels into a geopolitical battleground. The dynamics were further influenced by the rise in European carbon emission quotas. Notably, France experienced exceptional unavailability of nuclear power plants, contributing to electricity market strain.

In response, businesses and homeowners have increased their interest in renewable energy solutions as a way to mitigate reliance on conventional energy sources and diversify their energy sources, thereby enhancing their resilience to supply chain disruptions and market fluctuations. The most accessible of these energies being solar power, they have naturally turned to photovoltaics to do so.

Solar Panels & Inverters (Photo Credit : kiloWattsol)

The residential photovoltaic segment has played a significant role in driving the strong growth of the photovoltaic market in France, with an 83% increase in installations in 2023 compared to the previous year. In France, there are now 460,000 installations of solar panels under 36 kW. Despite the robust growth in recent years, not all roofs in France have been impacted yet. Approximately 3% of houses are currently equipped with photovoltaic panels. ADEME and RTE anticipate further substantial growth in this market.

In France, significant growth in the photovoltaic (PV) sector has been witnessed over the past two years, resulting in a total capacity of 18.6 GW by December 2023. The objectives for PV development through 2035 were outlined by the French transmission system operator (RTE) in their study report "Bilan Prévisionnel 2023-2035". To accompany the development and strong

growth of technology, various legislative measures, such as the reduction of authorisation timelines, have been enacted, drawing upon the Renewable Energy Acceleration Act.

The observed energy crisis has prompted an awareness of the importance of generating one's own energy among businesses/professionals and individuals. The significant decrease in the costs of photovoltaic modules along with the ease of deployment of the solar technology make it easy for businesses/professionals and individuals to turn to self consumption.

To ensure the success and sustainability of the inevitable expansion of the PV industry in France, it is imperative to establish and adhere to appropriate standards and regulations. With their product, Huawei aims to support this growth characterised by high quality. Indeed, the careful selection of components to guarantee safety is crucial to fostering a robust and sustainable development.

Conclusions and Key Insights

- ***An imminent growth in renewable energy production is anticipated, with a specific emphasis on PV, within the French landscape. Both the Commercial and Industrial (C&I) and residential sectors are awakening to the imperative of reducing energy dependence, with PV emerging as a sought-after and straightforward solution.***

- ***Despite their relative ease of implementation, PV systems are not without risks, as will be elaborated in the next chapter. Given the scale of PV's adoption and its pivotal role in the impending French energy transition, ensuring high-quality growth becomes paramount to establish a robust foundation for this transition.***

- ***Recognising the need for a secure large-scale implementation of PV systems, Huawei presents inverters equipped with safety features meticulously developed for this purpose. This endeavour is geared towards providing the industry with a safe and dependable solution for the widespread deployment of PV solutions across the nation.***

3. Challenges and risks associated with PV systems

While PV systems are generally easy to implement and deemed safe, they inherently carry electrical risks, primarily due to their use of voltages higher than the safety limit for individuals. Consequently, the potential consequences can be severe, posing harm to individuals and jeopardising assets.

Overheating, resulting from factors such as elevated temperatures, leads to component degradation, escalating the risk of operational failure and damage to connected equipment. Environmental factors and pest infestations can further contribute to potential damage to components, compromising system reliability and safety. The threat of irreparable circuitry damage and safety hazards increases with the occurrence of surge and lightning strikes. Installation errors, such as incorrect wiring, exacerbate these risks, underscoring the importance of implementing comprehensive measures to ensure the functionality of solar inverters and, more crucially, to prevent potential harm to individuals and components.

Common inverter faults and physical risks

Risk to individuals

In France, the photovoltaic sector holds a central position in most prospective scenarios, including those of French Renewable Agency ADEME and electric grid operator RTE. In RTE's assessments, an assumption of balanced development between ground-based and rooftop installations is put forth. According to a study of “Solaire PV”, France has the highest economically viable potential for rooftop PV production in Europe[1]. Despite significant advancements in photovoltaic technology these past years and corresponding cost reductions, the risks associated with deployment and commissioning have increased. This is attributed to the enhanced performance of modules, which exhibit higher power capacities, thereby posing a higher threat to the safety of operators.

In PV systems, inverters play a crucial role and the faults associated can pose specific risks to personnel. The risks associated include electrical shock hazards, injuries, burns.

- **Electrical shock**: Inverter faults, such as **internal short circuits or ground faults**, can lead to electrical shock hazards for personnel working on or near the inverters. PV systems frequently experience electric shock hazards due to a decrease in **insulation resistance** in DC cables, a risk that is easily overlooked. This leads to exposure of the conductor within the cable, resulting in electric leakage and observed incidents of electric shocks within the system. This put at risk the personal safety of O&M personnel.

- **Individual safety**: **Electric arc and surge damage** represent common and potentially catastrophic failures in inverters. Inverters are vulnerable to power surges strikes, which can lead to irreparable damage to their circuitry, potentially resulting in fires or

[1] Le solaire photovoltaïque en France : réalité, potentiel et défis, 07/03/2022 version, available on: http://solairepv.fr

explosions. In addition, improper installation may lead to structural issues, such as roof damage or leaks, compromising the safety and integrity of the residence.
C&I and Residential photovoltaic systems are positioned on the consumer side. With the development of high-power modules, risks related to safety are increased. In the event of emergencies such as fires observed on rooftops, access to the roof is needed by firefighters to address the issue, exposing themselves to risks associated with excessively high voltage.

- **Fire hazards**: Inverter faults, especially those related to **overheating or electrical malfunctions**, can lead to insulation breakdown, reduced efficiency, and an increased risk of fire hazards. Fires in the vicinity of electrical equipment pose serious risks to personnel, and appropriate fire suppression systems and emergency response plans are necessary to address such situations.

Solar Panels on fire (Photo Credit : Terry Harris)

Asset damage risks

The risks associated with assets in a PV system due to inverter faults can have significant implications for the overall operation and efficiency of the power plant. Inverter faults that can pose risks to assets in photovoltaic power plant include the following:

- **Reduced Energy Output**: Inverter faults, such as **DC-AC mismatch** or **component failures**, can lead to a reduction in energy conversion efficiency. This translates into lower energy output and potential financial losses for the plant owner.

- **Fire Hazards**: Certain inverter faults, particularly those related to **overheating or electrical malfunctions**, can pose a fire risk. Fires can cause extensive damage to inverters, nearby equipment, and even the entire PV power plant infrastructure.
    - **Arc fire**: Arcs are a major contributor to fires in photovoltaic (PV) systems, with over 60% of PV plant fire incidents attributed to DC arcs, according to the TÜVRheinland report. Arc fault events in PV systems arise from factors such as worn electrical insulation, component ageing, mechanical stress, overheating, and damaged wires or connectors. Direct current arc faults, categorised into series arcs, ground arcs, and parallel arcs, require specialised protective equipment for cessation. Series arcs result from continuity loss in system

components, ground arcs occur when poorly insulated DC cables contact the ground, and parallel arcs stem from faults in the insulation system between positive and negative conductors in close proximity within the same DC circuit.

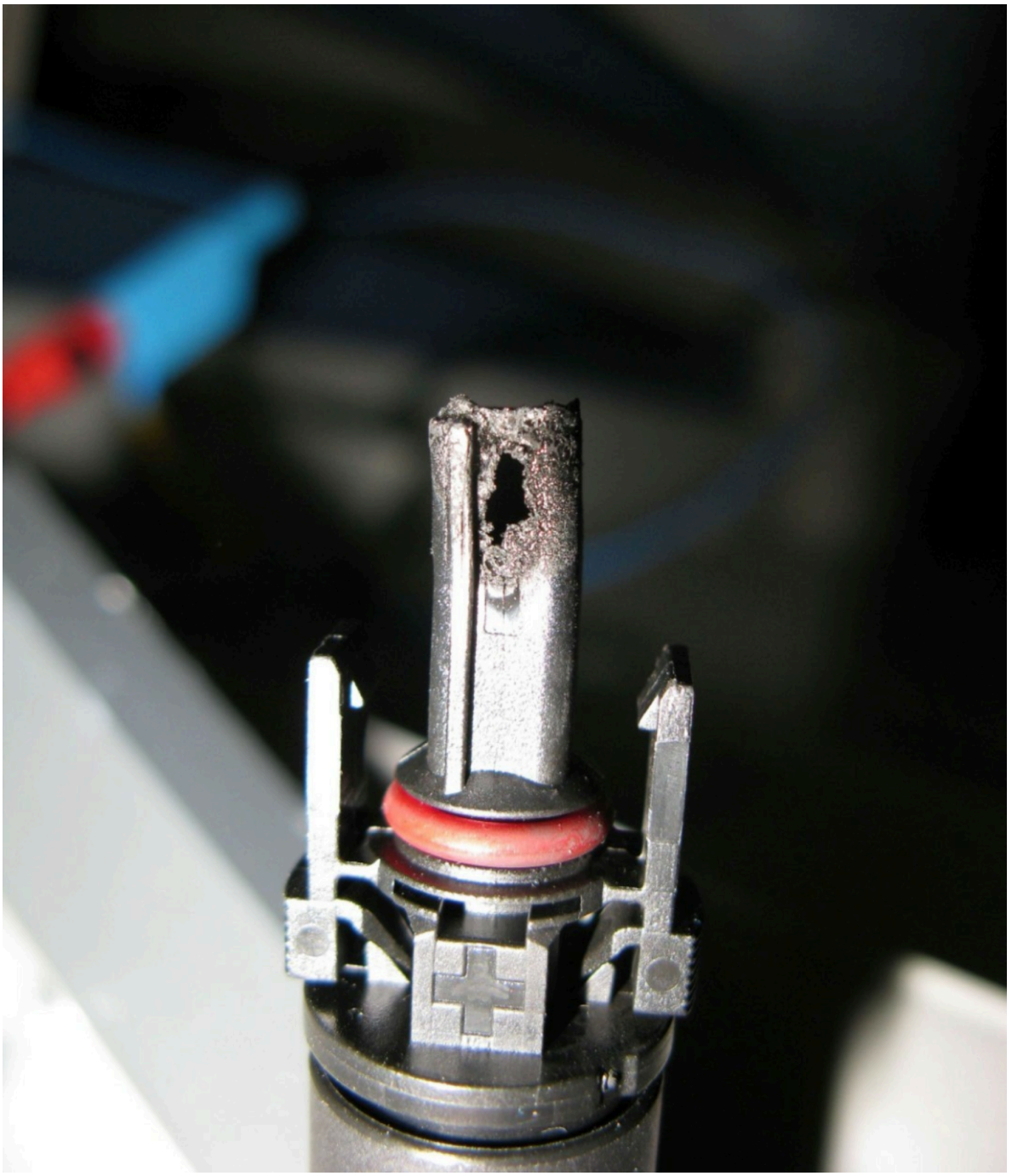
- **Grid Interconnection Issues**: Inverter faults may disrupt the proper synchronisation of the PV power plant with the electrical grid. This can result in grid instability, potential power outages, and damage to the plant's grid-tie equipment.

Device damage risks

Inverters in a photovoltaic (PV) power plant are critical components responsible for converting direct current (DC) generated by solar panels into usable alternating current (AC). Various risks associated with inverters can impact the performance and reliability of the device. Common inverter faults contributing to these risks include:

- **Equipment Damage**: Internal short circuits, DC faults including ground faults, or overheating in inverters may result in physical damage to the inverter components. This can lead to increased maintenance costs due to more frequent replacements, affecting the overall asset lifespan.
    - **Overheating**: Excessive heat generated within the inverter due to factors such as poor ventilation, high ambient temperatures, or cooling system failures can lead to a reduction in efficiency and, in extreme cases, permanent damage to the inverter components.
    - **Short Circuits**: Internal short circuits can occur within the inverter, leading to electrical imbalances, potential damage to the inverter components, and disruption of normal operation.
    - **Ground Faults:** A direct current (DC) ground fault refers to the undesirable scenario where current flows through the equipment grounding conductor in circuits that carry DC power (prior to the inverter). Ground faults pose considerable safety concerns, including the risk of arc faults and, in instances of high voltage, arc flashes. Beyond being a safety hazard, ground faults also present a fire hazard, as the short-circuited current heats bare metal, potentially leading to combustion.
    - **Other DC Faults:** DC faults are the most common inverter failure. One of the DC-side accidents of PV plants is electrical accidents of inverters. This can be caused by many factors such as **DC Reverse Connection**, **DC ground faults**, **Electrical Insulation Fault** and **DC/AC Terminal Contact Fault**, leading to overheating and burning of the inverter.
      Reverse polarity of the string is one of the problems during the construction process of PV systems.The occurrence of PV String Reverse Connection arises when the terminals of the input PV string cable are connected in reverse. This leads to disparate voltages among PV strings under the same Maximum Power Point Tracking (MPPT), causing reverse current injection. This often leads to equipment damage, energy generation reduction or fire in some cases.
- **Voltage Instabilities**: Inverter faults may cause voltage fluctuations or instability, affecting the stability of the electrical grid and potentially damaging connected equipment.

- **Communication Failures**: Inverters often rely on communication systems to transmit data and receive commands. Communication faults can lead to difficulties in monitoring and controlling the PV system.



PV module plug connectors damaged by flashing arcs
(Photo Credit : Fraunhofer ISE)

In summary, inverters manifest numerous faults that can significantly impact the safety of both assets and individuals within the context of the power plant.

The following table summarises the common inverter failures and their related risks.

		Related risks					
		Electric shocks	Fire	Equipment damage	Communication failures	Downtime	Disconnection from grid
Common faults	Short circuit	x	x	x	x	x	
	Surge damage	x	x	x	x	x	
	Electric arcs	x	x	x	x	x	
	Electric malfunction		x		x	x	x
	Overheating		x	x	x	x	
	DC faults	x		x	x	x	x

Summary of risks related to common inverter faults

Financial and insurance risks in the French context

In addition to the risks of physical damages to individuals and equipment presented above (electric shock hazards, fire hazards and communication failures), the dysfunction of a PV plant poses financial risks.

Financial losses

Damage to PV panels, inverters, or other components can lead to a permanent decrease in energy production, directly impacting the efficiency of the solar power system and causing it to generate less electricity than intended.

Repairing or replacing damaged components may require operational downtime, resulting in a temporary loss of energy production and potential disruptions for users or businesses relying on solar energy. Additionally, damage to communication and monitoring systems can exacerbate the situation by delaying detection of downtime.

The reduced energy production and potential downtime can result in financial losses for the owner of the PV asset and negatively impacts its economic performance.

The impact of a defect or incident in a rooftop PV plant is heightened by the economic activities taking place within the building. Given that buildings hosting rooftop power plants typically accommodate various businesses, any disruption or damage has the potential to multiply in consequence due to the interconnectedness of these activities and the PV plant overhead.

Moreover, the risk is exacerbated by the potential frequent presence of non-technically qualified individuals who may access the roof or operate in close proximity to the electrical components of the power plant within these buildings. The combination of economic activities and the regular presence of non-technical personnel amplifies the potential repercussions of any defects or incidents, underscoring the need for robust safety measures and diligent maintenance practices to mitigate these risks effectively.

Insurance

Depending on the extent and nature of the damage, the owner may need to file insurance claims for repairs or replacements. This process can be time-consuming and may result in increased insurance premiums.

Insurance plays a crucial role in the operation and management of photovoltaic plants. In France, Insurance companies involved in providing coverage for photovoltaic (PV) systems face a range of risks. The insurance coverage for PV plants typically involves several aspects to protect against various risks.

- Property Insurance:

Coverage for physical damage to the solar panels, inverters, and other equipment caused by events such as fire, hail, windstorms, vandalism, or theft.
Business interruption coverage to compensate for lost revenue during the repair or replacement of damaged equipment.

- Liability Insurance:

Public liability coverage protects against third-party claims for bodily injury or property damage that may occur on the PV plant premises.
Products liability coverage may be necessary to protect against claims arising from the malfunction of solar panels or related equipment.

- Performance Guarantee Insurance:

This type of insurance ensures that the PV plant meets its performance guarantees, such as a specified level of electricity production. If the plant fails to meet these guarantees, the insurance may provide compensation.

- Natural Catastrophe Insurance:

Coverage for damages caused by natural disasters such as earthquakes, floods, or other events that may be excluded from standard property insurance.

- Cyber Insurance:

With the increasing use of digital technologies in PV plants, cyber insurance can protect against risks related to cyberattacks, data breaches, and other cybersecurity threats.
Environmental Liability Insurance:

- Coverage for environmental damages that may occur as a result of the PV plant's operation.

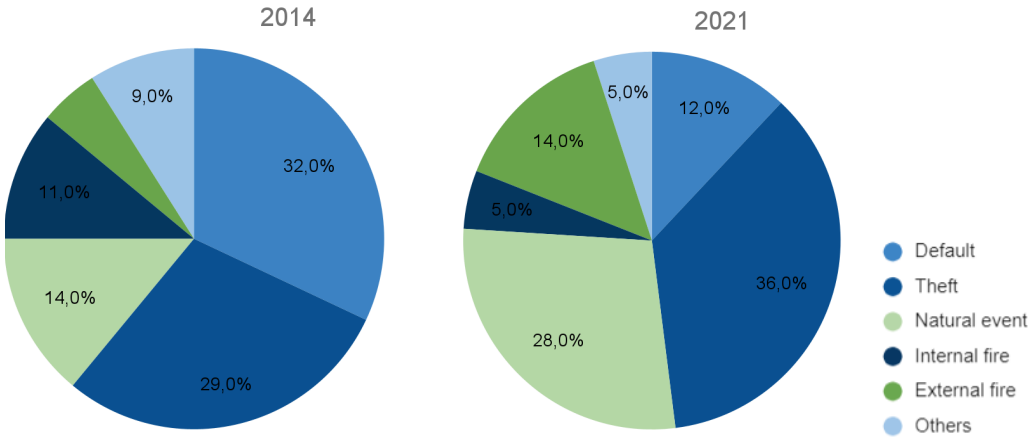
- Protection for employees in case of work-related injuries or illnesses.

The specific insurance needs of a PV plant can vary based on factors such as location, size, technology, and local regulations. It's crucial for PV plant owners and operators to work with insurance professionals who understand the unique risks associated with solar energy projects to ensure comprehensive coverage.

The insurance company MSIG has shared insights into insurance concerning photovoltaic power plants. A notable impact of losses is observed in insurance related to security in photovoltaic plants. An analysis was conducted to compare the distribution of insurance

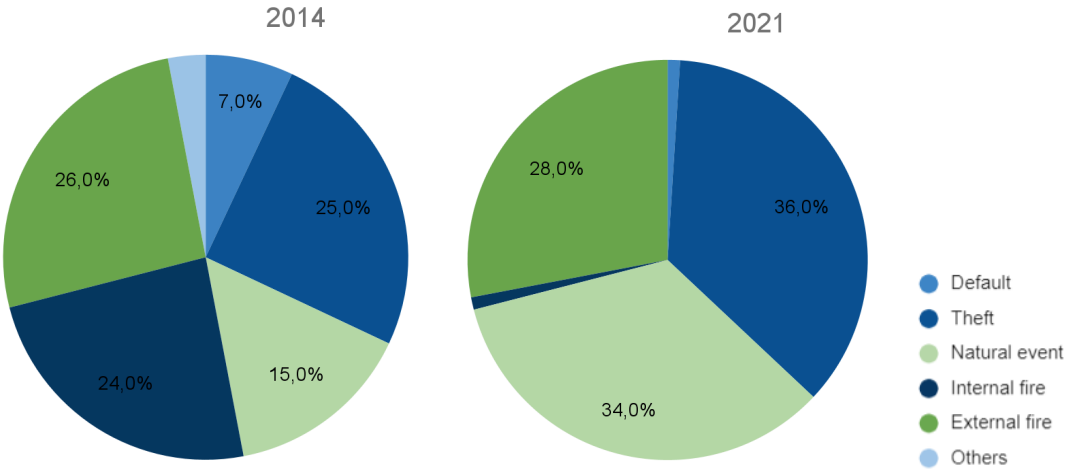
claims for photovoltaic plants between 2014 and 2021. There is a discernible rise in property insurance claims attributable to fire incidents, increasing from 16% in 2014 to 19% in 2021.

The graph below illustrates the breakdown of insurance by cause in number during this period. This data underscores the growing significance of addressing risks related to security, particularly those leading to fire, in the insurance coverage of photovoltaic plants.



Occurrences of insurance coverage by cause in 2014 and 2021

An assessment of the value of damages and losses resulting from these causes was also conducted for the years 2014 and 2021. The findings highlight the substantial impact of damages and losses specifically attributed to fires. This underscores the significant financial consequences associated with fire incidents in both 2014 and 2021. The data suggests that addressing and mitigating the risks related to fires is of paramount importance in managing the overall financial exposure and stability of the insured assets, emphasising the need for comprehensive fire risk management strategies within the insurance coverage framework.
The graph below shows the value of damages and losses covered by the insurance company.



Value of insurance coverage by cause in 2014 and 2021

Insurers are increasingly expressing concerns about the potential exacerbation of their exposure to fire risks, particularly in the context of technological advancements such as

rooftop photovoltaic installations. The rapid growth of these infrastructures while optimising space usage, introduce unique challenges in terms of fire safety. The close proximity of solar panels on rooftops, along with potential shading issues, heightens the risk of hotspots and electrical faults that could lead to fires. Additionally, rooftop solar panel installations pose unique challenges in terms of access for firefighting and rescue services, making interventions more complex and potentially more costly.

Conclusions and Key Insights

- ***PV plants, using high voltages, carry inherent electrical risks. These hazards can damage the asset's efficiency and harm individuals. Prioritising safety measures can significantly reduce these hazards, mitigating risks to individuals and property.***
- ***Damage to PV components leads to irreversible energy production reductions, impacting system efficiency. Repairs may cause downtime, resulting in temporary energy loss and financial setbacks.***
- ***On C&I rooftop PV plants, defects' impact is intensified by economic activities and the heightened probability of the presence of non-technical individuals near electrical components, multiplying disruptions. The risk underscores the need for robust safety measures and maintenance to mitigate risks effectively.***
- ***Residential rooftop PV installations can pose a threat to inhabitants' security if not installed and maintained properly. Improper installation may lead to structural issues, such as roof damage or leaks, compromising the safety and integrity of the residence. Like for C&I installations, inadequate electrical work, more specifically, can pose fire hazards or risks of electrical shocks, jeopardising the well-being of occupants. Additionally, the presence of high-voltage equipment and electrical components in close proximity to living spaces raises concerns about accidental injuries, especially in family households. To mitigate these risks, it is crucial to elaborate solid safety measures.***
- ***Insurers are increasingly concerned about fire risks linked to technological advances like rooftop photovoltaic installations. The rapid increase of these structures introduces challenges in fire safety, with the close arrangement of solar panels heightening the risk of hotspots and electrical faults leading to fires. Additionally, firefighting access challenges make interventions more complex and potentially costly.***

4. About Huawei

This chapter of the report presents Huawei as a company, including a brief history, its manufacturing capacity and its position in the market.

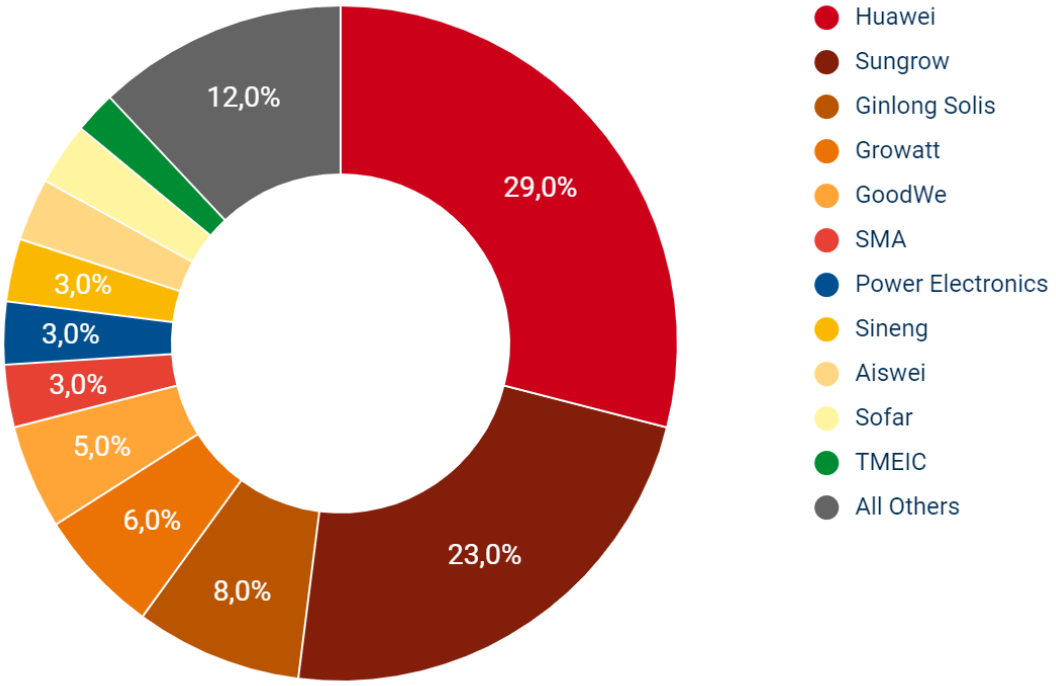
Global Presence

Manufacturer Overview

Huawei, a global powerhouse in information and communication technologies (ICT), stands as a trailblazing leader in the industry. With a rich history dating back to 1987, when Ren Zhengfei established the company, Huawei has evolved from a telephone-switch manufacturer to a global giant in telecommunications, consumer electronics, and solar equipment. Today, Huawei boasts a formidable presence in over 170 countries, employing a diverse and talented workforce of 197,000 dedicated professionals.

Market Dominance

Huawei's supremacy in the market is undeniable. In 2022, as reported by Wood Mackenzie, the company's leading position was consistently maintained, with a 29% market share being secured. This surpassed competitors like Sungrow (23%) and Ginlong Solis (8%). Huawei's continued dominance is underscored by its manufacturing capacities of 180 GW per year and its unwavering commitment to innovation.



Global PV inverter market share rankings by shipment, 2022 (source: Wood Mackenzie)

The analysis conducted by Wood Mackenzie[2] revealed that Huawei experienced a substantial 83% increase in shipments in 2022 compared to the previous year. Additionally, the company demonstrated consistent business growth, achieving a total worldwide shipment of over 300 GW.

Rapid and Sustainable Growth

Huawei's evolution

In just over a decade since entering the AC/DC energy conversion sector in 2007, Huawei has achieved remarkable growth. The company now boasts an annual production capacity exceeding 180 GW of inverters, with an impressive track record of shipping over 330 GW of string inverters. This phenomenal growth has contributed to a compound annual growth rate (CAGR) of 25% between 2017 and 2022, solidifying Huawei's financial stability.

Financial Stability

Huawei's financial prowess is evident through its consistent revenue growth. The Digital Power branch, which contains the photovoltaic department, has shown remarkable expansion between 2017 and 2022, representing a compound annual growth rate (CAGR) of 25% over this period. The following table shows the revenue between 2017 and 2022.

Year	2017	2018	2019	2020	2021	2022
Revenue (US$ billion)	2.03	2.27	3.09	3.73	4.68	7.3

Huawei's revenues 2017-2022

Furthermore, in 2022, Huawei recorded a substantial revenue of £92.4 billion, marking a year-over-year growth of 0.9%. This performance secured Huawei's position as the 44th ranker in the Fortune Global 500, underscoring its financial stability on a global scale.

Global Reach, Experience, and Innovation

Global Reach and Wealth of Experience

Huawei's extensive global presence is not just a matter of geography; it is a wellspring of invaluable experience that continuously informs and enhances its product offerings. Operating in more than 170 countries, the company has navigated diverse markets, regulatory landscapes, and customer demands. This expansive network, spanning the globe, has enriched Huawei's understanding of global dynamics, enabling the company to tailor its products and solutions to meet the unique needs of various regions.

Huawei's commitment to innovation and manufacturing excellence is deeply intertwined with its international experience. The wealth of knowledge amassed from diverse cultural contexts and technical challenges has enabled Huawei to refine and adapt its products to an unparalleled degree. Each market served has provided valuable insights, inspiring constant

[2] Annie Rabi Bernard, Wood Mackenzie, "Global solar PV inverter and module-level power electronics market share 2023"

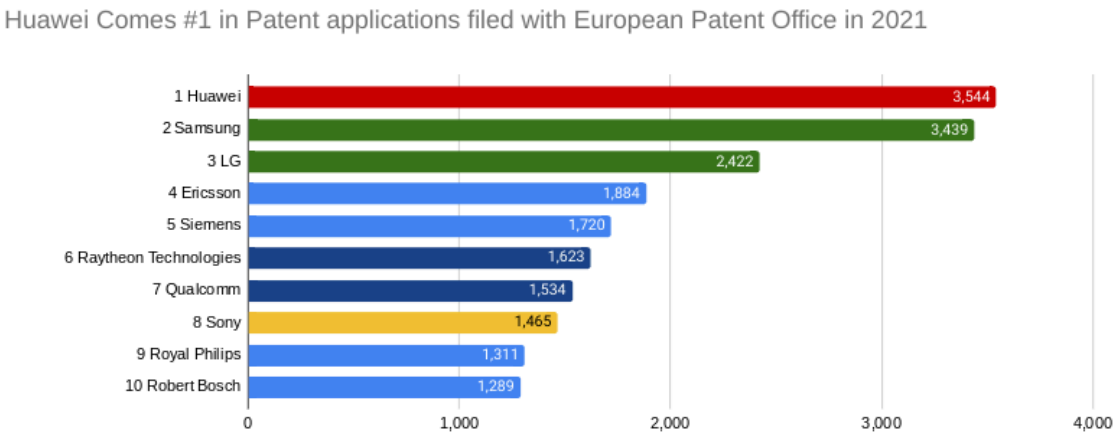
improvements and adjustments that have become hallmarks of Huawei's product development approach.

Innovation and R&D

Innovation lies at the heart of Huawei's success, and this innovation is profoundly informed by the global perspective it has gained through its extensive presence. With over 10% of its sales revenues reinvested into research and development (R&D), Huawei ranks as the 4th largest company in terms of global R&D investment.

The company's 114,000+ R&D employees, over 55% of its total workforce, have contributed to a portfolio of more than 120,000 active patents by the end of 2022. Huawei operates 12 R&D centres around the world, each uniquely positioned to harness local expertise while contributing to the company's global innovation ecosystem.

In recent years, Huawei has consistently demonstrated its commitment to innovation and research. In 2021, it was recognised as the second-largest global R&D investor by the EU Joint Research Centre (JRC) and was first in terms of patent applications according to the European Patent Office (see graph). In 2022, Huawei continued its dedication by allocating over 25% of its total revenue to R&D activities, driving its pursuit of groundbreaking solutions and technologies, all enriched by the company's extensive global experience.



Conclusions and Key Insights

- ***Huawei's journey, from its inception in 1987 has led to its current standing as a global technology giant and is marked by rapid growth and an unwavering dedication to innovation.***
- ***Huawei consistently produces top-tier, bankable products. Bolstered by a dominant presence in the photovoltaic industry and a deep reservoir of practical knowledge, Huawei stands as a pivotal player.***
- ***Huawei's reputation for delivering cost-efficient quality products is a testament to its profound understanding, forged through global engagements and sustained investments in research and development, which has led to important improvements of its products in terms of efficiency and safety.***

5. Presentation of Inverter

Model description

Huawei's Residential and C&I inverters product line have rated powers ranging from 2 kW to 150 kW.

The following table shows the different models for the residential and the C&I sectors.

Residential		C&I	
Inverters	Optimizers	Inverters	Optimizers
SUN2000-2-6KTL-L1 SUN2000-8-10KTL-LC0 SUN2000-3-10KTL-M1 SUN2000-12-25KTL-MB0	SUN2000-450W-P2 SUN2000-600W-P	SUN2000-12-25KTL-M5 SUN2000-30-36-40KTL-M3 SUN2000-50KTL-M3 SUN2000-100KTL-M2 SUN2000-115KTL-M2 SUN2000-150KTL-MG0 SUN5000-150KTL-MG0	MERC-1100W-P (2in1) MERC-1300W-P (2in1)

Huawei inverter models for the residential and the C&I sectors

Huawei inverter

Safety features

As high-power PV modules take centre stage in the market, the escalation of safety risks from DC faults is evident. It's vital to promptly disconnect current and voltage in instances of line-to-line faults (reverse connection, current backfeed, and bus short circuits), as well as grounding or terminal faults. This proactive measure is crucial for mitigating potential hazards and ensuring the secure operation of photovoltaic installations.

The following table summarises the safety features included in each model:

	Huawei Safety Features		
Inverter model	SSLD	AFCI	RSD (With optimizer)
SUN2000-2-6KTL-L1		✓	✓
SUN2000-8-10KTL-LC0		✓	✓
SUN2000-3-10KTL-M1		✓	✓
SUN2000-12-25KTL-MB0		✓	✓
SUN2000-12-25KTL-M5		✓	✓
SUN2000-30KTL-M3		✓	✓
SUN2000-36KTL-M3		✓	✓
SUN2000-40KTL-M3		✓	✓
SUN2000-50KTL-M3		✓	✓
SUN2000-100KTL-M2	✓	✓	
SUN2000-115KTL-M2	✓		
SUN2000-150KTL-MG0	✓	✓	
SUN5000-150KTL-MG0	✓	✓	✓

Safety features of Huawei inverters

The Commercial and Industrial (C&I) safety solution provided by Huawei is intricately designed to address three core aspects: equipment, asset, and personal safety, utilising state-of-the-art technologies to minimise risks in PV plants.

Device Safety : On the 100KTL-M2 to the 150KTL-M2, Huawei's Smart String-Level Disconnect (SSLD) technology, alongside grounding protection for PV cables and terminal over temperature detection, actively disconnects DC high current and voltage connections, proactively eliminating potential DC faults.

Asset Safety: Huawei employs smart DC arc detection and rapid shutdown (AFCI) technologies to promptly identify and extinguish arcs, minimising the risk of fires and safeguarding valuable assets within PV plants.

Personal Safety: Addressing the crucial aspect of personal safety, Huawei introduces module-level Rapid Shutdown (RSD) technology and module-level insulation impedance fault location technologies in the SUN2000 inverters up to the SUN2000-50KTL-M3. These innovations ensure the swift detection of high voltage at the module level, enhancing overall safety protocols for personnel working in the PV plant environment.

Collectively, these advanced safety features form a comprehensive solution that significantly mitigates risks and positions Huawei as a leader in delivering robust safety measures for commercial and industrial PV plants.

Smart String-Level Disconnect (SSLD)

Common Fault:

In solar power systems, line-to-line issues such as reverse connections, backfeed, and short circuits are common. Traditional mitigation involves the use of a manual switch (DC disconnector) placed between the solar panels and the control box. However, this approach does not consistently prevent hazardous situations, particularly short circuits that may result in fires. Addressing prevalent line-to-line faults like PV string reverse connection, backfeed, and bus short circuits, the industry commonly employs a DC disconnector between the PV string and inverter. Despite its conventional use, this solution relies on manual operation, lacks automatic functionality, and notably fails to interrupt short-circuit currents in case of faults within the inverter or PV string, presenting potential fire hazards.

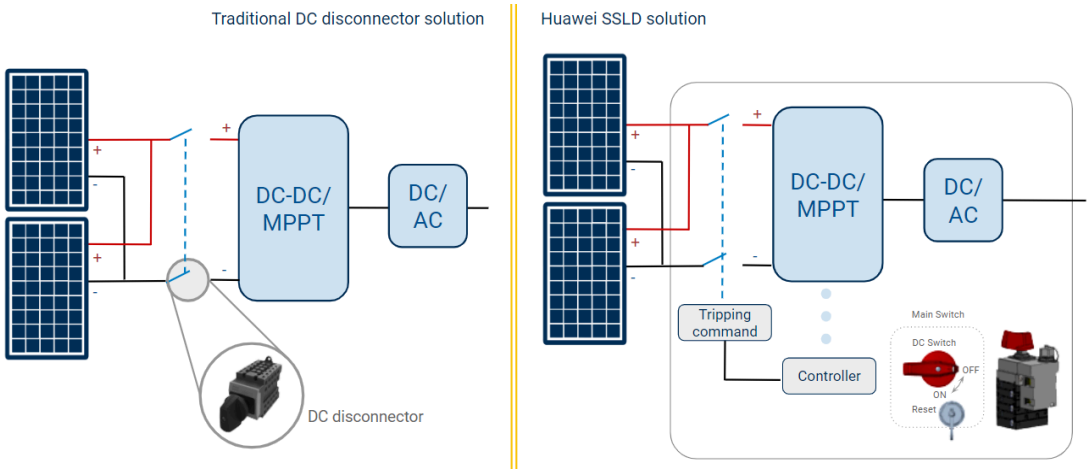
Solution Description and Fault Mitigation:

To address these challenges, Huawei introduces the Smart String-Level Disconnect (SSLD) solution, specifically designed for Commercial and Industrial (C&I) applications. The SSLD solution incorporates advanced technology within the inverter, facilitating real-time monitoring of voltage and current signals from each PV string.

Utilising intelligent algorithms developed by Huawei, the inverter can precisely identify the occurrence and type of faults. In the event of a fault requiring system disconnection, the main control chip transmits a turn-off signal to the SSLD device, which promptly executes the command. Following disconnection, the main control chip verifies the process's completion, activating an exception handling mechanism if necessary to cut off high current and provide an additional layer of equipment protection. This implementation signifies a departure from passive safety measures, marking a transition to active safety protection for the PV system.

In tackling this challenge, Huawei's SSLD solution is tailored for C&I scenarios and integrates advanced monitoring capabilities. It continuously assesses real-time voltage and current signals from each PV string, as well as essential inverter signals and the status signals of the SSLD device. Through cutting-edge intelligent algorithms, the inverter adeptly identifies fault occurrences and types with precision.

The figure below compares a traditional DC disconnector solution to Huawei's SSLD solution.



Traditional DC disconnector solution (left) and Huawei's SSLD solution (right)

Upon detecting a fault necessitating disconnection, the main control chip promptly sends a turn-off signal to the SSLD device, which executes the command swiftly and automatically. Post disconnection, the main control chip verifies the process's completion, with an activated mechanism cutting off high current in case of exceptions. Huawei's SSLD solution leverages digital technologies to proactively send turn-off signals, ensuring rapid tripping and alarms in milliseconds. This active safety measure effectively shields the PV system from faults like PV string reverse connection, current backfeed, and DC bus short circuits, establishing a robust and proactive safety paradigm.

RSD

Common Fault:

Among the most prevalent issues encountered with inverters, overheating and surge damage pose significant threats to personal safety.

Overheating occurs when the inverter operates beyond its specified temperature range, often due to prolonged usage, insufficient cooling mechanisms, or high voltage that surpasses the inverter's limits. This excess heat can compromise the inverter's internal components, leading to performance degradation and, in severe cases, complete failure, thereby posing potential risks to personal safety.

Surge damage, on the other hand, results from sudden increases in voltage, typically caused by lightning strikes, power grid fluctuations, or faulty electrical equipment. These voltage surges can overwhelm the inverter's protective measures, causing irreparable damage to sensitive electronic components and creating hazards for personal safety.

To effectively address these issues and enhance personal safety, it is essential to prioritise proper installation, regular maintenance, and the incorporation of surge protection devices, ensuring the longevity and reliable performance of inverters across various applications.

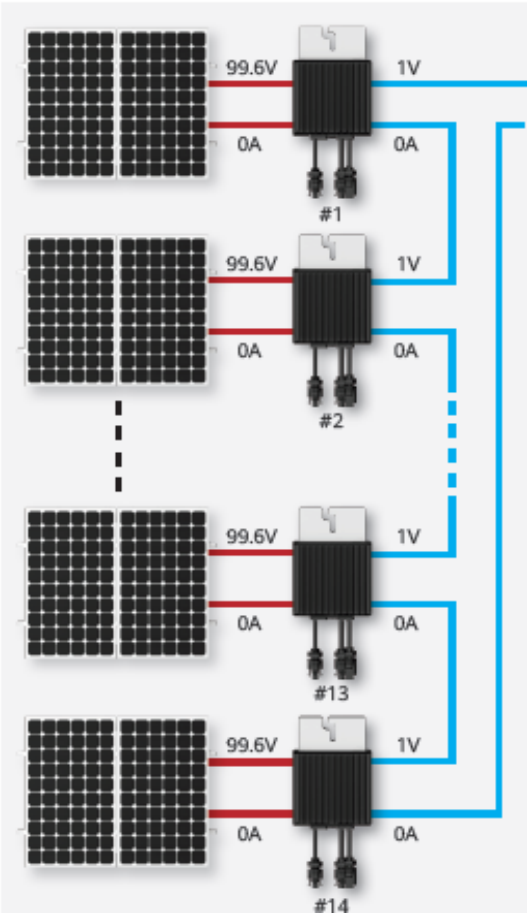
Solution Description and Fault Mitigation:

The evolution of PV technologies implies heightened levels of power, current, and voltage in PV products, posing a threat to the safety of firefighters and O&M personnel. Consequently in the United States of America, the National Electrical Code (NEC) incorporated the NEC 2014 690.12 Rapid Shutdown of PV Systems on Buildings in 2014, establishing stringent requirements for the swift disconnection of PV systems to enhance safety. The rapid shutdown specifically involves quickly shutting down the connection between PV modules. As outlined in the NEC 2017 690.12, the voltage must be restricted to below 30 V and 80 V within 30 seconds of initiating a rapid shutdown for controlled conductors located outside and inside the boundary (305 mm from the array in all directions), respectively.

Traditional solutions, while offering partial safety measures, lack system-level design and present numerous technical challenges, rendering them inadequate to meet the increasing safety demands of PV systems.

In contrast, Huawei’s smart PV solution achieves a rapid voltage cutoff of PV modules to less than the required 30 V within 30 seconds. The Fusion Solar app enables the remote shutdown of connections between modules, eliminating the need for manual site visits. In this context,

the voltage of PV strings is contingent on the number of Smart Module Controllers and their output voltage (1 V each), thereby ensuring personal safety.



Huawei module-level rapid shutdown solution

Source: Huawei & TÜV Rheinland

AFCI

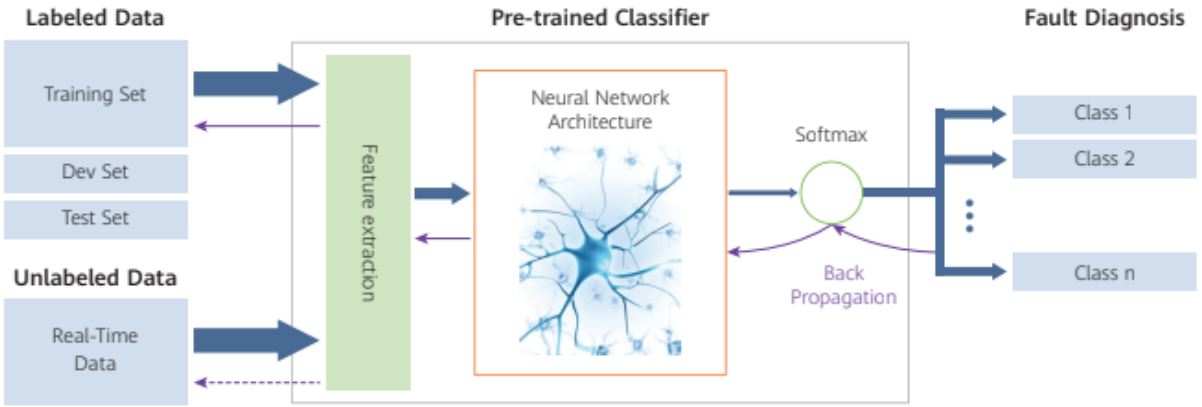
Common Fault:

An arc fault is an undesirable electrical discharge that occurs between conductors, typically within the PV inverter circuitry. This phenomenon presents a serious safety hazard and can lead to equipment damage or even fire incidents within PV systems. An arc fault can arise due to various factors such as insulation breakdown, loose connections, or damaged components within the inverter assembly. When an arc fault occurs, it generates a high-energy discharge characterised by intense heat and light, potentially igniting nearby combustible materials or causing insulation failures. In DC systems, such as PV plants, voltage and current are never zero during an arc fault which means that arcs in such systems do not naturally extinguish. Effective intervention necessitates the utilisation of specialised protection equipment to disrupt these arcs. In Europe, international standard IEC 63027 addresses series arc fault detection and interruption in photovoltaic systems.

Solution Description and Fault Mitigation:

Recognising that it is one of the most common faults that can occur in a PV inverter, Huawei addresses arc fault detection challenges by combining AFCI technology with deep learning algorithms continuous learning of diverse arc signatures gathered from inverter data worldwide, leveraging its expertise across various system types and countries. Unlike traditional manual methods, Huawei's solution employs intelligent algorithms to automatically identify arc characteristics, utilising highly non-linear models for efficient signal detection. Integrated with power electronics and inverter topology, the AFCI algorithm dynamically adjusts for cable length and current variations, ensuring high accuracy even with increased parameters. Huawei's solution accommodates diverse scenarios and PV module sizes. Achieving a rapid arc shutdown time of 0.5s enhances safety in critical situations, with additional support for rapid shutdown when optimisers are employed, ensuring power plant safety.

The figure below shows a diagram of the solution.



Logical block diagram of the AI solution

(Source: Huawei)

PV Ground-Fault Protection

Common Fault:

A grounding fault is a severe type of DC fault that poses significant risks. When PV cables become grounded, forming a loop, it can lead to local overheating, electric sparks, or even fires. Unfortunately, the industry lacks comprehensive technical solutions to address this issue.

Solution Description and Fault Mitigation:

In response to the challenge posed by grounding faults, Huawei inverters offer a proactive solution. These inverters detect phase voltage and current to identify if PV modules are short-circuited to the ground. Upon detecting a fault, the inverter initiates an immediate shutdown, turns off the grid connection switch, generates an alarm to prevent inverter damage, and reports the alarm to the app. This approach ensures swift action to safeguard the system from the risks associated with grounding faults.

Module-level Resist Insulation Detection

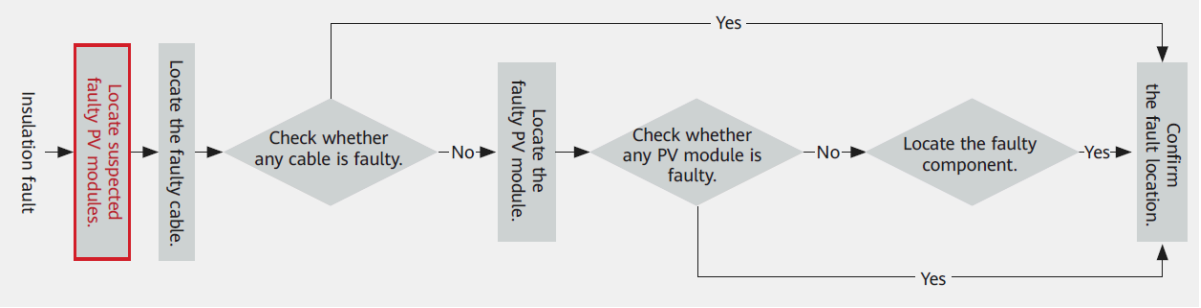
Common Fault:

The decline in insulation resistance is a commonly overlooked issue in PV systems, yet it poses a significant risk of electric shocks. When PV modules, DC cables, or connectors sustain damage or undergo ageing, the insulation resistance tends to decrease, potentially harming the insulation layer. This reduction in insulation effectiveness exposes the conductor inside the cable, leading to electric leakage within the system. Such leakage incidents can result in electric shocks, thereby compromising the personal safety of O&M personnel.

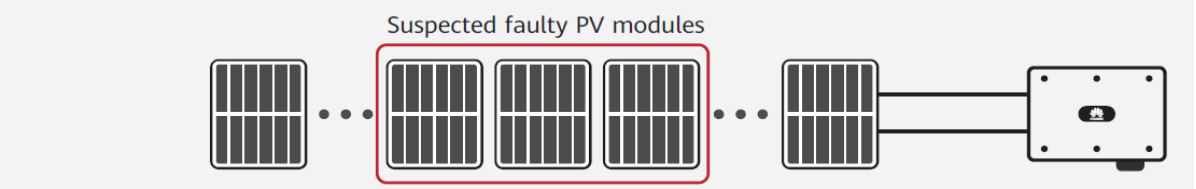
Solution Description and Fault Mitigation:

The IEC 62446-1 and NB/T 32004-2013 standards restrict grid connection when the insulation resistance of inverters is lower than the specified value or the threshold. Conventional solutions generate an inverter shutdown alarm but don't provide any visible warning or locate the fault. This constrains the personnel to inspect all the PV modules connected to the inverter one by one by connecting them to the inverter independently and check whether the shutdown alarm is generated.

Huawei's module-level resist insulation detection allows it to determine the fault location without having to check the whole PV system. It uses built-in intelligence algorithm of the inverter to collect statistics on the insulation resistance of the whole PV system when it is grid-connected. The statistics are presented for the owner as a reference to determine potential insulation risks in the PV system based on the insulation resistance changes, and handle the risks in advance. The FusionSolar app allows owners to detect the insulation resistance online. When the insulation resistance is lower than the threshold, the app generates an alarm and locates the insulation resistance fault point quickly at the module level with the industry-leading precision of ±1 PV module to help
owners eliminate potential electric shocks.



Insulation resistance fault handling process



Suspected faulty PV modules located by the Huawei inverter

(Source: TÜV Rheinland Whitepaper report)

Conclusions and Key Insights

- ***Recognising the critical importance of safety in safeguarding both the PV asset and the individuals involved in its operation and maintenance, Huawei has prioritised advancements in safety measures. Drawing on extensive international industry experience, Huawei has made substantial investments in research and development to enhance the safety features of their PV inverters.***
- ***The safety features of the Huawei inverter intended C&I and residential markets successfully addresses the most common faults important for the French market.***

		Huawei Safety Features		
		SSLD	RSD	AFCI
Common faults	Short circuit	x		
	Surge damage	x	x	
	Electric arcs			x
	Electric malfunction	x		
	Overheating		x	x
	DC faults	x		

Summary of application of safety features

6. Independent Assessment of the Safety Features

Huawei's inverters' safety features have undergone meticulous and exhaustive testing by esteemed testing laboratories to ensure their effectiveness. These tests, initiated by Huawei, adhere to widely recognised procedures and standards aimed at preventing damage and safeguarding against potential injuries.

In a commitment to ascertain accuracy and validate outcomes within the French framework, KWS, serving as an independent third party, has undertaken a comprehensive series of tests. These assessments, conducted by the esteemed French laboratory SuperGrid Institute, examine the safety features' performance, with a primary focus on arc fault detection capabilities and shutdown speed.

Additionally, KWS has conscientiously reviewed reports from two other independent testing laboratories, further reinforcing the rigorous nature of the evaluation process.

SuperGrid Institute Assessment

In order to critically assess the recommended safety features within the inverter, KWS has commissioned the largest direct current laboratory in France, SuperGrid Institute, to conduct a comprehensive series of tests of the Arc Fault Circuit Interrupter (AFCI) and Rapid Shutdown (RSD), two features considered most relevant for the French market.

SuperGrid Institute's mission aligns with the intention of this report, developed in Chapter 2, as it is deeply committed to advancing the energy transition in France through the resolution of technical obstacles in the deployment of sophisticated power grids and the development of cutting-edge innovations to meet various scales of energy sector demands, among other initiatives. Their endeavours actively contribute to facilitating the energy transition by addressing the technical challenges that impede the realisation of future power grids.

With an annual budget exceeding 22 million euros, SuperGrid Institute allocates resources to sustain 8,400 square metres of test platforms and laboratories across two prominent locations in France. Among its 155-strong workforce, over 60 are dedicated PhD scholars who play a pivotal role in supporting the organisation's dynamic efforts in innovation and scholarly publications. Remarkably, SuperGrid Institute has generated in excess of 100 patent applications and contributed 360 international publications.

Operating under ISO 9001:2015 certification, its laboratory boasts extensive proficiency in high and medium voltage direct current (HVDC & MVDC) systems and technologies, pivotal components for the future landscape of energy networks.

Test Description

Arcs represent a significant fire hazard in PV systems, as electrical arcs can reach extremely high temperatures, leading to fires. The Arc Fault Circuit Interrupter (AFCI) function underwent testing to evaluate its capacity to automatically shut down arcs within 0.5s when DC arcs occur.

As PV technologies advance, the voltage levels in PV products continue to rise, amplifying the risks of fire due to high voltage and posing a threat to the safety of firefighting personnel. Huawei inverter's Rapid Shutdown (RSD) function addresses this concern by reducing the voltage below 30V within a 30-second timeframe when coupled with optimisers, contributing to enhanced safety measures.

Test set-up and procedures

Facilities and Equipment

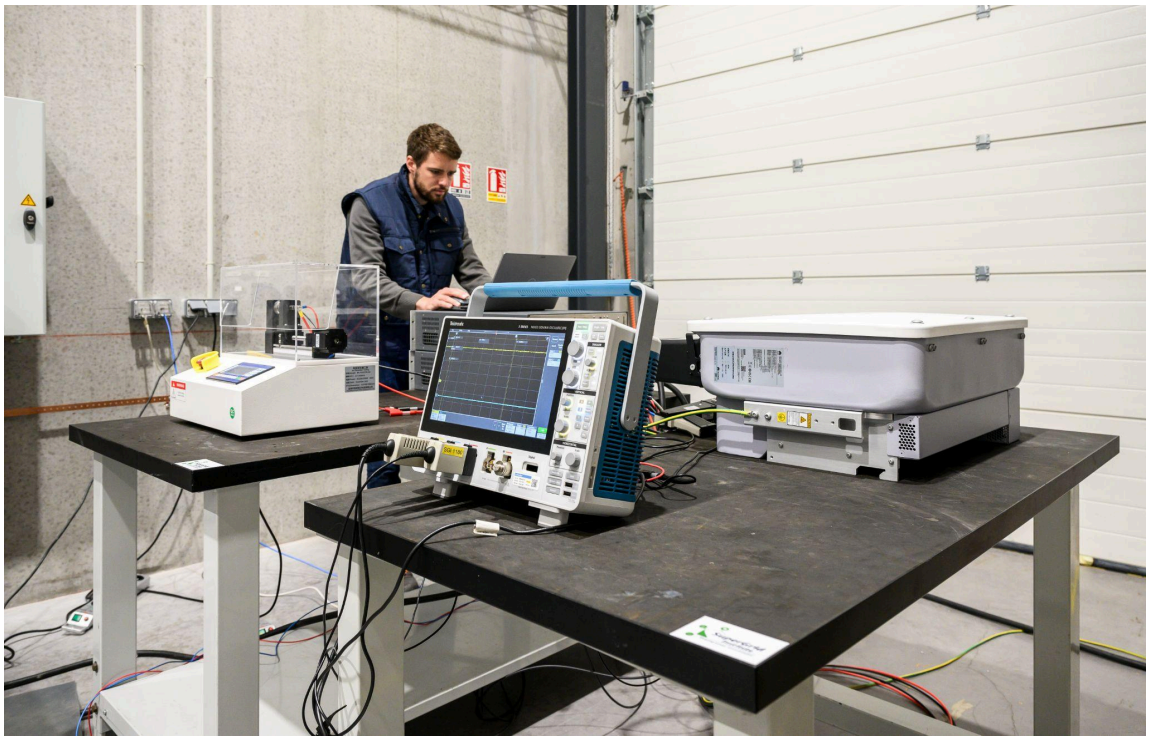
The following measurement equipment was used:

Type	Signal	Brand	Model	Number SGI (internal)	Serial number	Date calibration	End of validity calibration
Oscilloscope	Votages, currents	Tektronix	MD034	SGI1467	C021054	18/04/2023	18/04/2024
Voltage probe	Udc	Tektronix	THDP0100	SGI1180	C030176	18/04/2023	18/04/2024
Voltage probe	Uarc	Tektronix	THDP0100	SGI1818	C033139	06/01/2023	06/01/2025
Current probe	Idc	Tektronix	TCP0150	SGI1378	C021786	05/01/2023	05/01/2026
Current probe	Iac	Tektronix	TCP0150	SGI1218	C012924	18/04/2023	18/04/2024
Mutltimeter	Uopti	Keysight	U1232A	SGI1181	MY58040102	18/04/2023	18/04/2024

Measurement equipment

The inverter software is in version V100R001D02. Communication is done using a smartphone and the FusionSolar application in version 6.24.00.217.

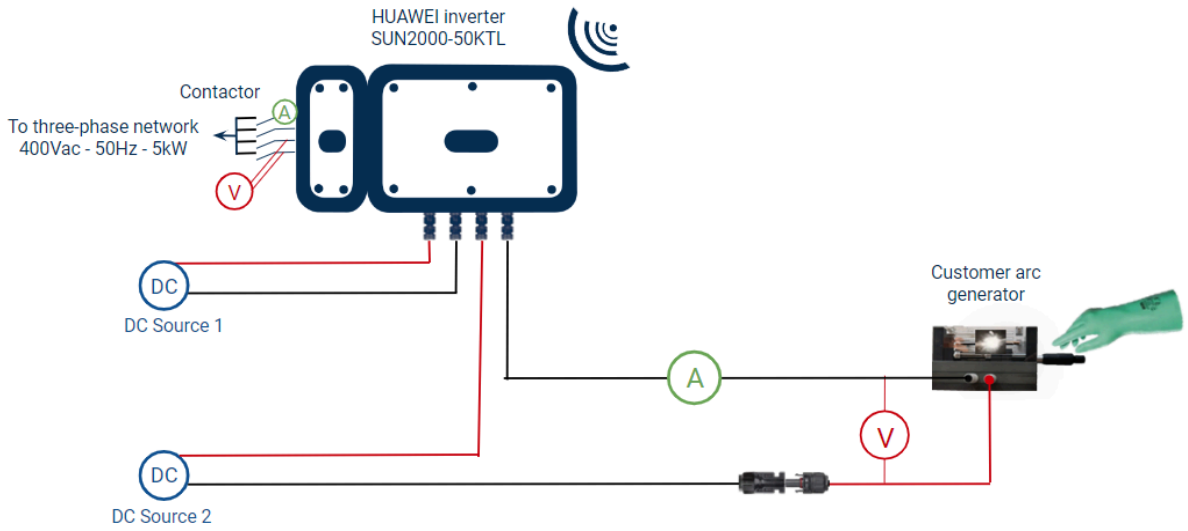
AFCI test procedure



AFCI function test setup in SuperGrid's lab

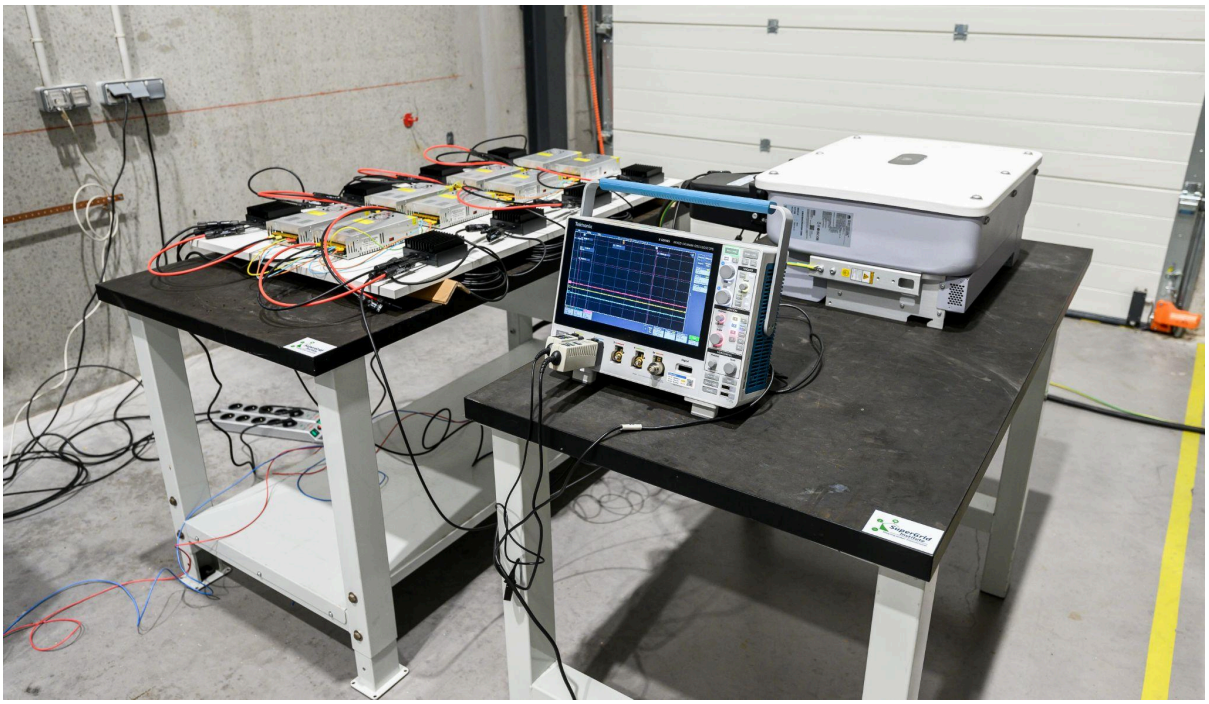
The wiring diagram is shown below. The DC 1 and DC 2 sources are PV emulators of the SM1500-CP-30 model from Delta Elektronika. The DC 1 source is connected to DC input 1 (associated with MPPT1) and DC source 2 is connected to DC input 3 (associated with MPPT2).

The following diagram illustrates the setup of the AFCI function test.



AFCI function test wiring diagram

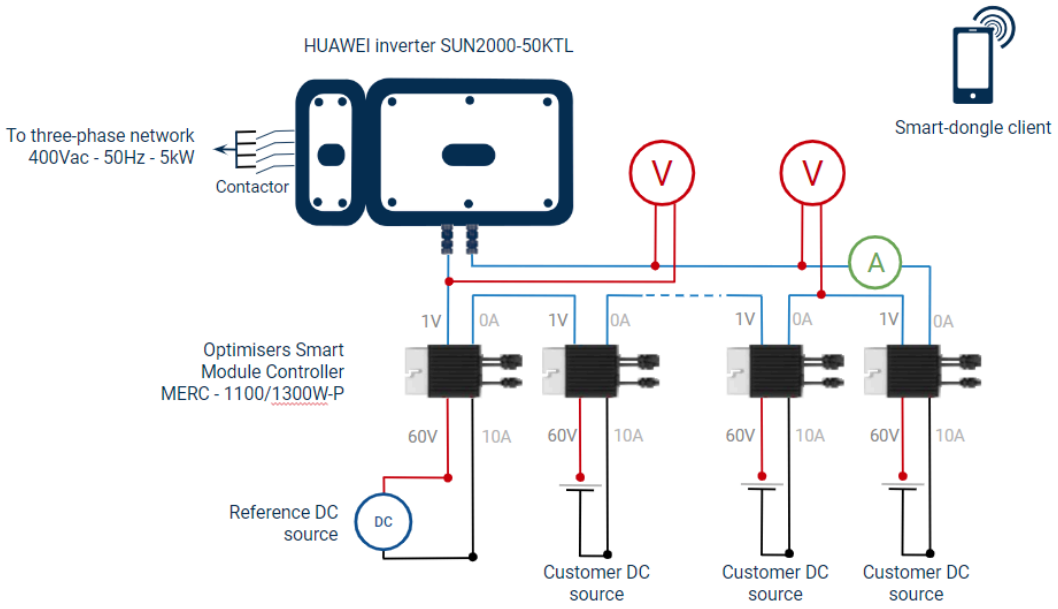
RSD test procedure



RSD function test setup in SuperGrid's lab

For this test, an assembly comprising eight optimisers and seven NUOFUWEI S-60-600 DC power supplies capable of delivering 60V up to 10A have been used. These power supplies operate at a constant voltage, collapse when the maximum current is exceeded, and therefore do not emulate the characteristics of a photovoltaic panel. The eighth optimiser is powered by a supply provided by SuperGrid Institute, enabling the emulation of a photovoltaic panel (Delta Elektronika SM15K). The wiring diagram is shown in the figure below.

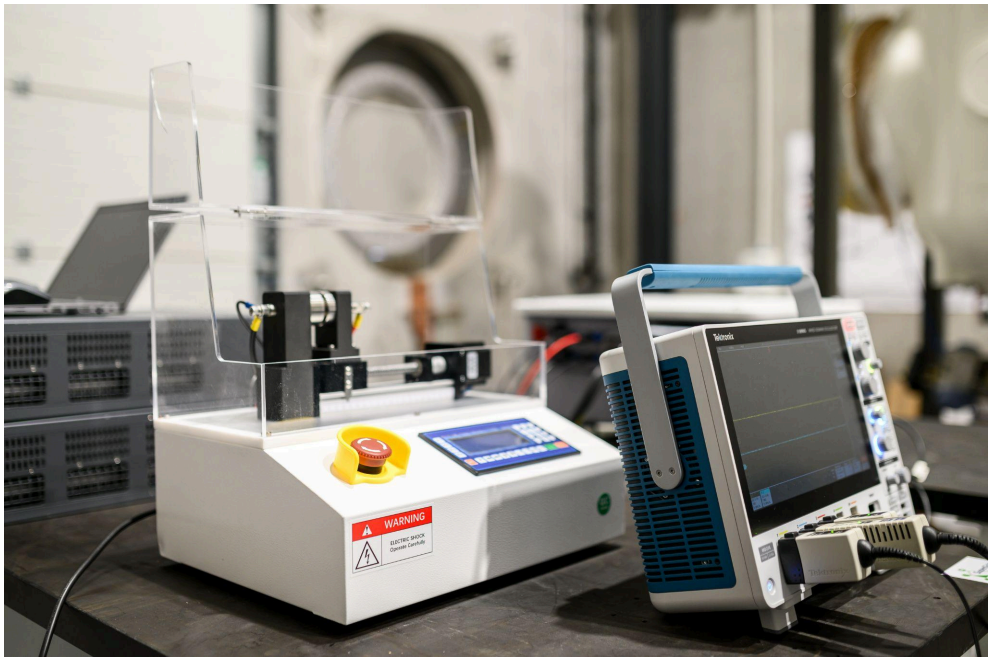
The following diagram illustrates the setup of the RSD function test.



Test diagram for the RSD function

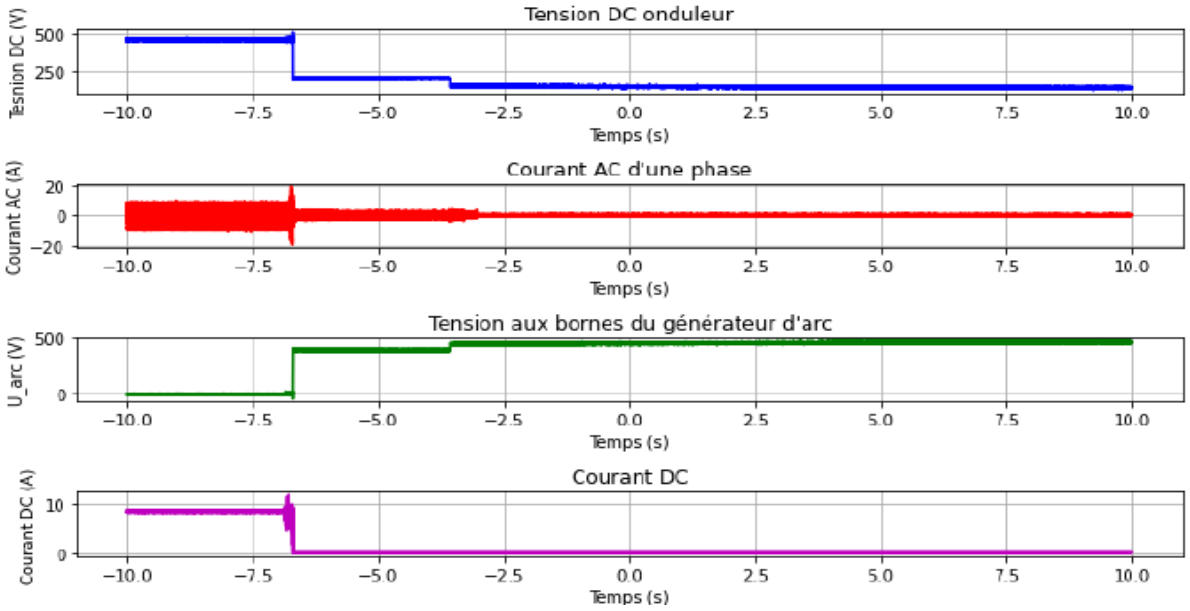
Test Results

AFCI test results



Arc simulator in SuperGrid's lab

The AFCI test was done by adding an extensive length of cable to each terminal of the arc generator. This test was conducted twice, and the additional cables resulted in a total wiring length of approximately 162 m. The oscillogram for the first test is provided in the figure below. The arc was detected, and a fault appeared in the FusionSolar application. The inverter demonstrated its effectiveness as it automatically cut off the arc in about 350 ms. The current was reduced to 0 A, confirming the successful interruption of the arc. The test was successful for the number of times it has been repeated.



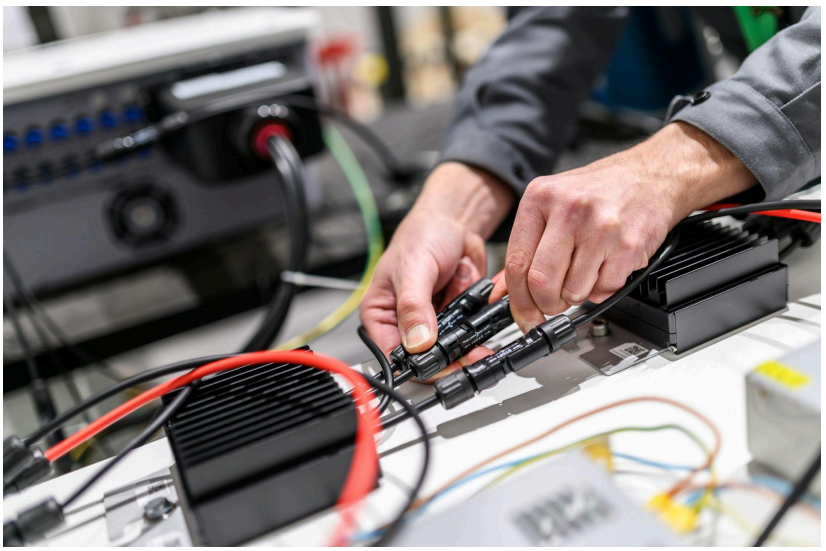
Oscillogram of the AFCI test performed by SuperGrid showing the arc has been detected

Screenshot of the DC arc fault in FusionSolar application during SuperGrid's test

RSD test results

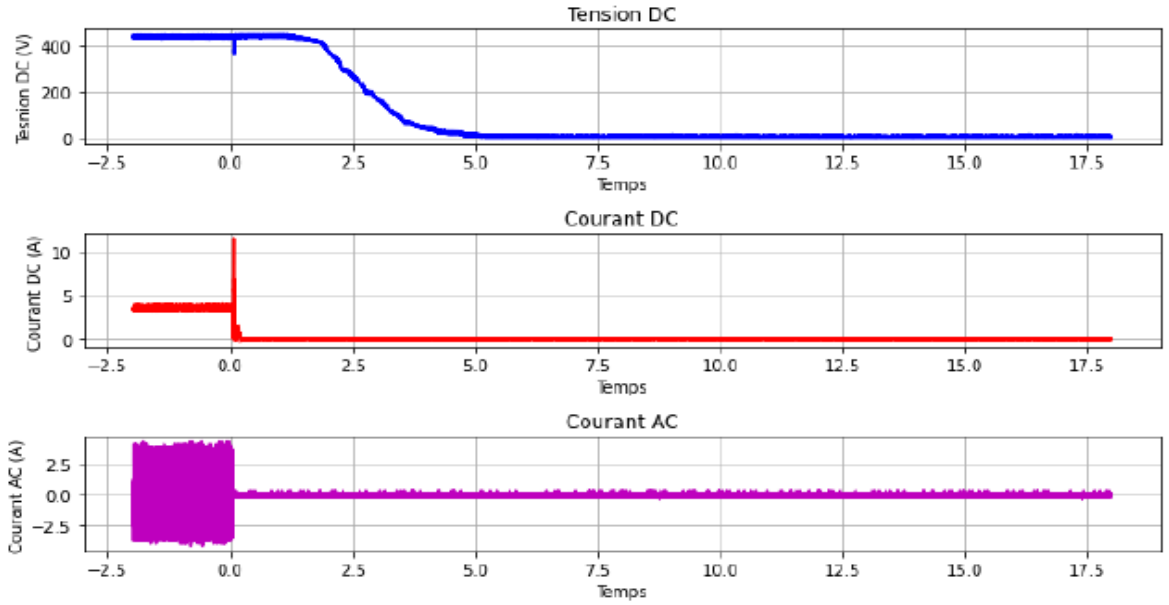
The Rapid Shutdown function was tested in three situations. During these tests, the input voltage for each optimiser was 55 V, and the inverter power was limited to 1500 W. Prior to opening the AC contactor, the DC input voltage was 438 V with a current of 3.4 A.

The time for the AC voltage to decrease from the opening of the contactor to stabilisation at a low level was measured at 4.96 seconds. The measurement of DC voltage and current was respectively 8.00 V and 0 A.



Huawei's smart module controller optimiser for RSD test in SuperGrid's lab

The oscillogram for test #3 is provided in the figure below. All three tests conducted under identical conditions yielded consistent results. The test was successful each time it was repeated. This test validates the functionality of the RSD feature.



Oscillogram of a Rapid Shutdown (RSD) function test

The following table summarises the tests conducted within the SuperGrid Institute.

Feature tested	Objective		Results	
	Test objective	Target	Observations	Conclusion
AFCI	To verify that the inverter can automatically detect and deactivate arcs within a limited timeframe	Target arc cut-off time: **< 0.5 s**	Measured arc cut-off time: **0.35 ms** Measured current: 0 A	The inverter has demonstrated its ability to automatically detect and deactivate arcs within a limited timeframe
RSD	To verify that the inverter can bring the voltage level down within a limited timeframe	Target timeframe: **< 30 s** Target voltage: **< 30 V**	Measured timeframe: **4.96 s** Measured voltage: **8 V** Measured current: 0 A	The inverter has demonstrated its ability to automatically reduce voltage levels within a limited timeframe

Summary of Supergrid test results

Third-party assessments

KWS has also reviewed results reports of tests performed on Huawei's inverter's safety features by two other independent laboratories: TÜV Rheinland and TNO.

TÜV Rheinland

TÜV Rheinland is a globally recognised independent testing, inspection, and certification company headquartered in Cologne, Germany. As an independent third party, TÜV Rheinland has conducted the following tests on Huawei's inverters: Smart String-Level Disconnector (SSLD), PV Ground-Fault Protection, Arc Fault Circuit Interrupter (AFCI), Rapid Shutdown RSD, module-level Resist Insulation Detection.

SSLD test

Description: The Smart String Level Disconnector test aims to verify that the Huawei SSLD device can automatically disconnect faulty DC circuits in milliseconds.

Results: In the SSLD test, a simulated DC overvoltage fault was introduced to a Huawei inverter to assess its capability in disconnecting the faulty circuit within a 15 ms timeframe. The test outcomes reveal that Huawei's SSLD device successfully severed the circuit in approximately 5ms, aligning with the anticipated performance criteria.

PV Ground-Fault Protection Test

Description: The goal of the PV Ground-Fault Protection test is to validate the ability of Huawei inverters to autonomously disconnect malfunctioning circuits in the event of a grounding fault.

Results: A 3 Ω resistor is connected to the ground on the PV side of a Huawei inverter to simulate a short circuit and observe the inverter operation. Following the occurrence of the short circuit, the Huawei inverter promptly disengaged the faulty circuit and transmitted an alarm notification to the associated application.

AFCI Test

Description: The Arc Fault Circuit Interrupter Test aims to verify the effectiveness of the DC arc detection and cut-off device in Huawei inverters, ensuring the rapid shutdown of arc faults within 0.5 s.

Results: To verify the effectiveness of the DC arc detection and cut-off device in Huawei inverters, ensuring the rapid shutdown of arc faults within 0.5 s.

RSD Test

Description: The aim of this test is to confirm that Huawei inverters, when coupled with Huawei optimisers, can efficiently reduce voltage to below 30 V within a 30-second timeframe.

Results: Employing a dry contact to induce a high-voltage fault in a Huawei inverter, the connected optimiser promptly disconnected the circuit in approximately 3 s. Subsequently, the voltage, initially at 430 V, swiftly diminished to less than 30 V, and a corresponding alarm was transmitted to the associated application.

Module-level Resist Insulation Detection Test

Description: The objective of this test is to confirm that Huawei inverters can effectively trigger shutdown alarms and identify faults when the insulation resistance falls below the specified threshold voltage.

Results: Simulating an insulation fault by connecting a 1 kΩ resistor to the ground on the PV+ of a Huawei inverter, the inverter successfully detected and severed the insulation resistance fault. The associated application not only displayed the insulation resistance value but also accurately pinpointed the location of the fault.

TNO

The Arc Fault Circuit Interrupter test was additionally conducted by TNO, an independent research organisation established in 1932 and formally recognised by law as the Netherlands Organisation for Applied Scientific Research. TNO operates a laboratory testing facility designed to assess PV inverters in compliance with the UL1699B-2018 safety standard for testing PV DC Arc-Fault Circuit Protection and incorporates networks to simulate cable length, decoupling of power sources, and PV module conditions.

AFCI Test

Description: The Arc Fault Circuit Interrupter Test aims to verify the effectiveness of the DC arc detection and cut-off device in Huawei inverters, ensuring the rapid shutdown of arc faults within 0.5 s.

Results: The tests were realised at current levels of 3 A and 8 A. The arc generator was positioned at the start, middle and end of the string. All test conditions were repeated ten times. For the 120 measurements realised, the AFCI of the inverter detected the arc and switched off the current within 0.5 s, which is well below the 2.5 s requirement of the UL1699B standard.

Empirical tests realised by independent third parties have proved the reliability of Huawei's inverters functionalities. The safety functions are verified and allow to reduce the equipment faults and hazards that are often encountered in PV systems.

Conclusions and Key Insights

- ***The tests performed by SuperGrid Institute, the largest DC laboratory in France, demonstrated the effectiveness of the Arc Fault Circuit Interrupter and of the Rapid Shutdown feature.***
- ***The assessments conducted by multiple other independent laboratories on the safety features of the inverter have been successfully concluded, confirming their effective functionality.***

About kiloWattsol

France's #1 Solar Expert

kiloWattsol has proudly held the position of France's foremost solar expert since 2007. Operating from our headquarters in Lyon, we have continuously provided unwavering support to industry-leading companies in the solar sector. As a trusted third-party partner for developers, financiers, and manufacturers, we leverage a strong foundation of scientific, technical, and business expertise to cater to our clients' requirements at every stage of their photovoltaic project life cycle. Whether it's financing, construction, operation, or M&A transactions, we are dedicated to serving our clients with excellence.