

How String Inverters Are Changing Solar Management on the Grid

A GREENTECH MEDIA WHITE PAPER

“The rise of intermittent solar offers challenges and opportunities for how the electric grid is managed, especially when multi-phase string inverters are considered.”

Executive Summary

Solar and wind power are no longer alternative sources of energy. By 2020, solar will dominate new capacity additions globally, and it will bring in \$3.7 trillion in investment in the period 2020-2040, according to Bloomberg New Energy Finance.

The global total for installed solar photovoltaic (PV) capacity in 2017 will be just over 81 gigawatts and will grow to about 112 gigawatts by 2022, according to GTM Research. Projects larger than 5 megawatts will continue to make up about 60 percent of the global market.

As solar PV becomes cost-competitive across most of the globe, more is being asked of these power plants as they are integrated onto electric grids that were mostly designed for one-way power flows and centralized sources of generation. The rise of intermittent solar offers challenges and opportunities for how the electric grid is managed, especially when multi-phase string inverters are considered.

Thanks to falling prices and project developers' growing awareness of the operations and maintenance (O&M) and installation benefits, an increasing proportion of large solar PV projects

built around the world will include multi-phase string inverters. String inverters are already dominant in many global markets including China, the world's largest solar market, and the use of string inverters in large-scale projects in the U.S. is expected to grow by more than fourfold in the next 5 years.

Besides O&M and installation benefits, string inverters are also being embraced because they provide vital grid management benefits. From voltage and frequency ride-through to necessary support for weak grids, string inverters can make it easier for countries like India, the U.S. and China to seamlessly incorporate large amounts of solar in ways that bolster grid stability.

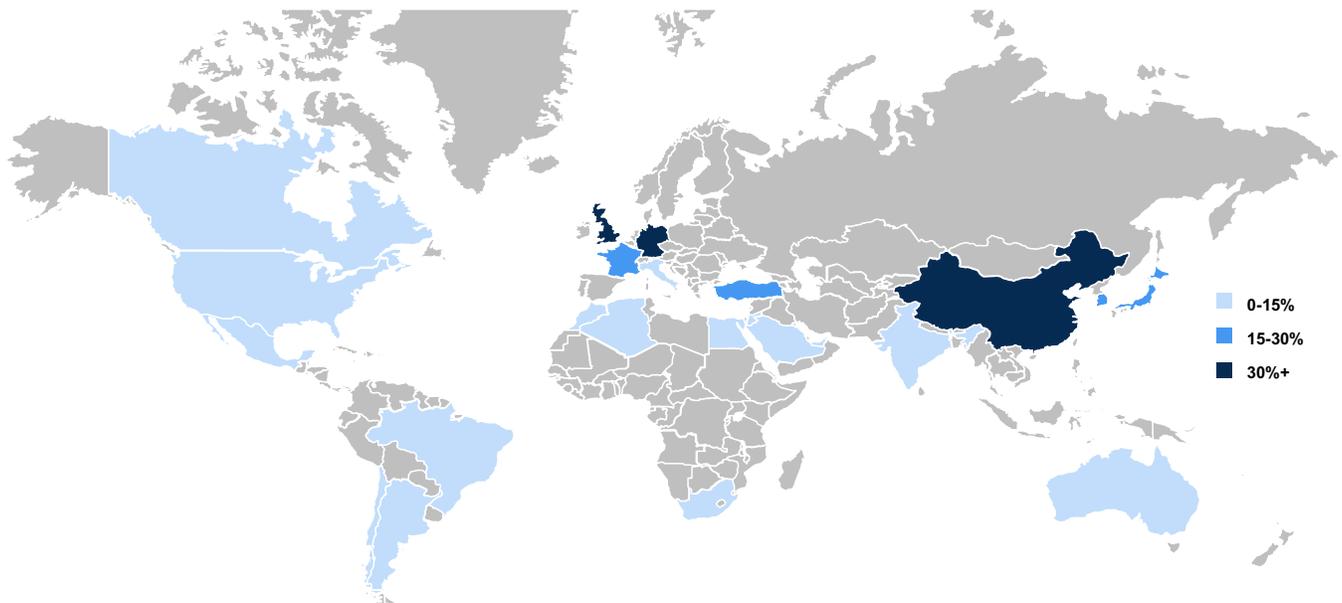
As the world's electric system continues its transition from one dominated by fossil fuels and central station generation to a cleaner and more distributed model, the role of string inverters will only continue to grow – and the world's largest inverter manufacturer, Huawei, is leading the way.

Huawei's combination of resilient string inverters with data loggers, advanced communication technology and cloud-based data analytics represents an early step toward what the

company has termed “the road to the internet of energy” in China. Now, Huawei’s advanced string inverters are also being used across the globe.

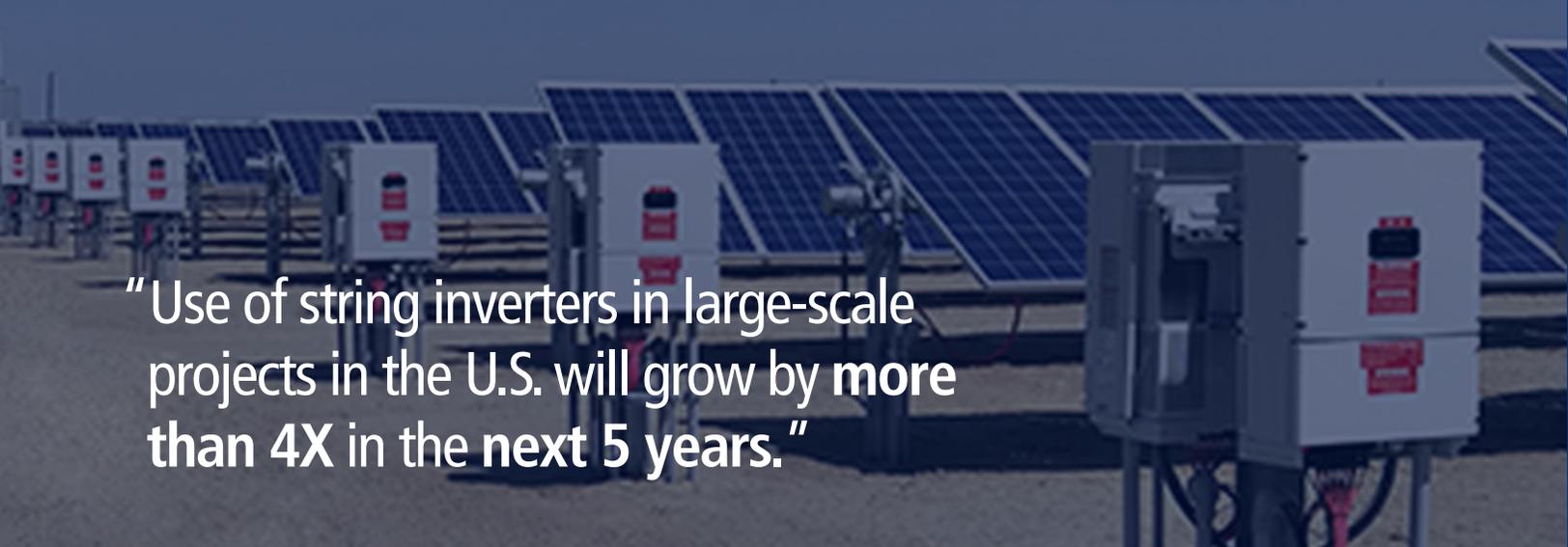
This paper examines where we are on the way to a smarter, more connected and cleaner future and how string inverters are able to provide robust grid management services that are critical to moving us closer to that goal.

Figure 1: Three-Phase String Inverter Share of Utility Projects (5 MW+) in Top PV Markets, 2017



Source: GTM Research

“China, the U.S. and India will remain the three largest markets for solar PV in the next five years.”



“Use of string inverters in large-scale projects in the U.S. will grow by more than 4X in the next 5 years.”

Introduction

As with many aspects of the global solar market, the inverter landscape comprises both country-by-country idiosyncrasies and broad commonalities.

No matter where you look, large-scale solar PV is becoming cost-competitive. China, the U.S. and India will remain the three largest markets for solar PV in the next five years, but their share of global demand will wane as developing regional markets explode. Projects larger than 5 megawatts will remain more than 60 percent of global installations.

String inverter market share is growing globally for large-scale projects thanks to declining prices, a better awareness of their long-term benefits and increasingly high voltage offerings. Across different technologies, prices for inverters dropped between 10 percent and 26 percent in 2016. Leading the way were three-phase string inverters, many of which harness the benefits of new 1,500-volt models, driving prices down by a significant margin.

The growth in three-phase string inverters had been driven by Huawei and concentrated in China's 30-plus-gigawatt market, but string inverters are gaining traction quickly across the

globe and in all market sectors. Huawei was ranked third in market share in Japan in 2016, according to GTM Research, and second in Europe for the same year.

According to GTM Research, the price gap between string and central inverters will continue to narrow over the next five years. When considering both upfront costs and balance-of-system (BOS) costs, Huawei has found its five-phase 1,500-volt string inverter has a cost advantage today of \$0.025 per watt over central inverters in balance of system costs, excluding inverter and central skid costs.

GTM Research forecasts that the competition for utility-scale projects will only increase – particularly as developers better understand the BOS and O&M savings that multiple-phase string inverters offer.

In the U.S. utility-scale market, GTM Research estimates that the use of string inverters in projects larger than 5 megawatts is expected to continue its rise from less than 5 percent in 2016 to **22 percent by 2022**.

In fact, the demands that PV power plant owners and grid operators place on inverters can be expected to expand rapidly if projections of installed solar capacity are met or exceeded. The

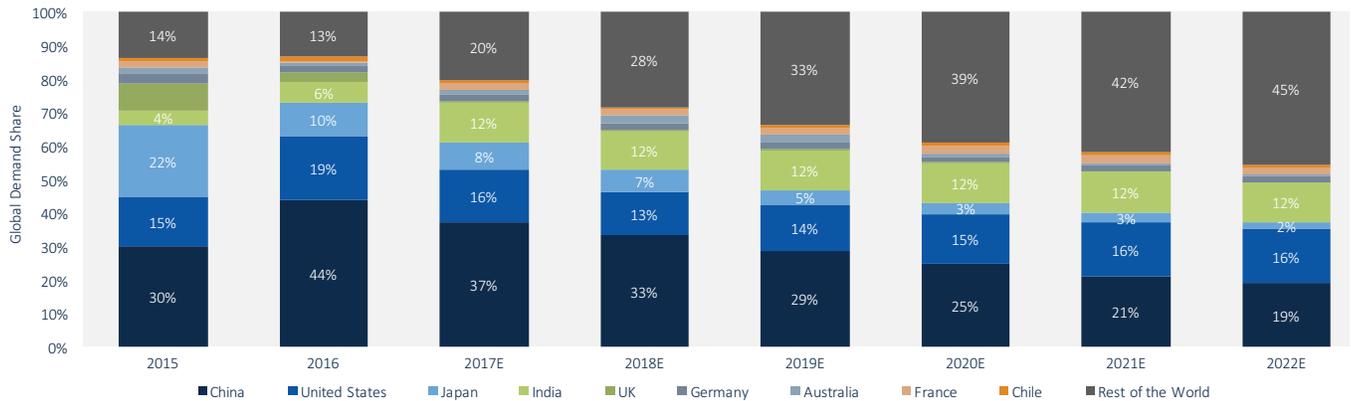
projections for solar penetration underscore the vital role inverters will play as project owners, utilities, regulators and policymakers chart a smooth transition toward a new energy system. This paper will explore this transition and cover the following topics:

- An in-depth look at China’s role as the world’s largest solar market and what that means for integrating large amounts of solar in a way that enhances the stability and reliability of the grid.
- A snapshot of India’s emergence as one of the world’s largest solar markets, with a goal of

100 gigawatts of solar by 2022, and what that means for grid management and other issues in this increasingly important Asian market.

- A breakdown of the U.S. as a collection of markets rather than one monolith and the dynamics and drivers of advanced grid management in the largest U.S. solar market, California.
- Huawei’s long-term approach to FusionSolar, which envisions a far more integrated grid that includes the benefits of smart inverters beyond solar.

Figure 2: Top Solar Markets’ Global Demand Share by Installations, 2015-2022E



Source: GTM Research

“ Huawei brings its massive scale, worldwide reach and long legacy of technology innovation to the inverter business.”

Scale and Innovation in String Inverters

A key driver of the rapid emergence of three-phase string inverters is the scale and innovation of the world’s largest inverter manufacturer, Huawei. In 2016, Huawei accounted for 24 percent of all inverters shipped worldwide and 60 percent of the global share of three-phase string inverters, according to GTM Research.

Huawei was founded in 1987 and entered the PV inverter market in 2013. In 2016, the company was the largest inverter manufacturer in the world based on shipments, primarily due to its domination of its home market of China. Huawei has expanded aggressively outside its home base, shipping nearly 3 gigawatts to international markets in 2016, according to GTM Research, particularly Europe and Japan.

Huawei brings its massive scale, worldwide reach and long legacy of technology innovation to the inverter business. It is a global technology giant that ranks as the world’s third-largest smartphone manufacturer.

The company manufactures not only smartphones, but also the underlying information and

communications technology infrastructure. In that capacity, Huawei was able to find success and achieve growth by putting a premium on reliability. Across its business divisions, Huawei is a member of more than 360 standards organizations, industry alliances and open-source communities. Nearly half of the company’s 180,000 employees focus on research and development.

When Huawei first entered the inverter industry, it made both traditional central inverters and string inverters. Initially, the company made central inverters for utility-scale projects that ranged in capacity from 250 kilowatts to 1.2 megawatts. But a few years of experience in the solar industry and feedback from customers led the company to focus its efforts entirely on string inverters.

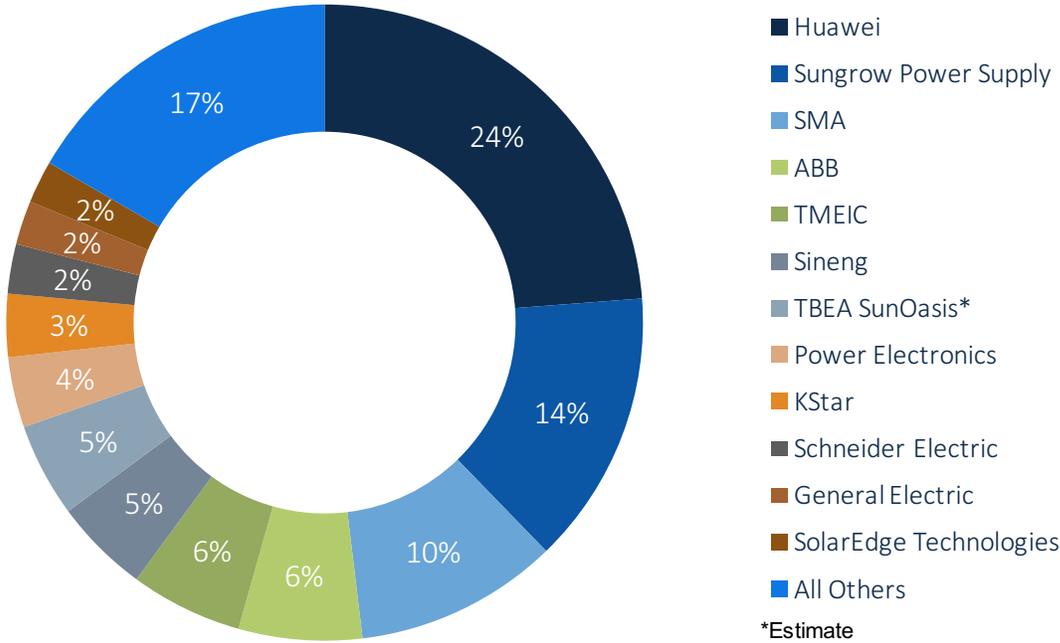
What the company heard from its customers was that central inverters were lacking when it came to reliability, often requiring significant, time-consuming and expensive maintenance. Components such as cooling fans were prone to performance issues, leading to downtime that impacted generation and revenue for plant operators. In addition, maintaining plants with central inverters required specialized and highly trained service personnel to diagnose and repair problems in the field.

In contrast, because string inverters are so much smaller than central inverters, the loss of one or two devices means only a loss of a small amount of generation. Lightweight string inverters can also be quickly and easily replaced.

By focusing exclusively on string inverters, Huawei can leverage the experience and

resources it has built up over the decades designing and building telecom infrastructure that can operate reliably in the harshest conditions. The rationale to only manufacture string inverters also dovetails with Huawei's overall vision for the energy system of the future.

Figure 3: 2016 Global PV Inverter Market Shares by Shipments (MWac)



Source: GTM Research

Figure 4: The Revolution of Intelligent Devices Is Here



Source: Huawei

Solar's Journey From Mainframe to Smartphone

Huawei's vision for the future of energy, in many ways, follows the path of the information technology industry. Marc Andreessen, famed venture capitalist and founder of Netscape, once proclaimed, "Software is eating the world." It was meant as a compliment.

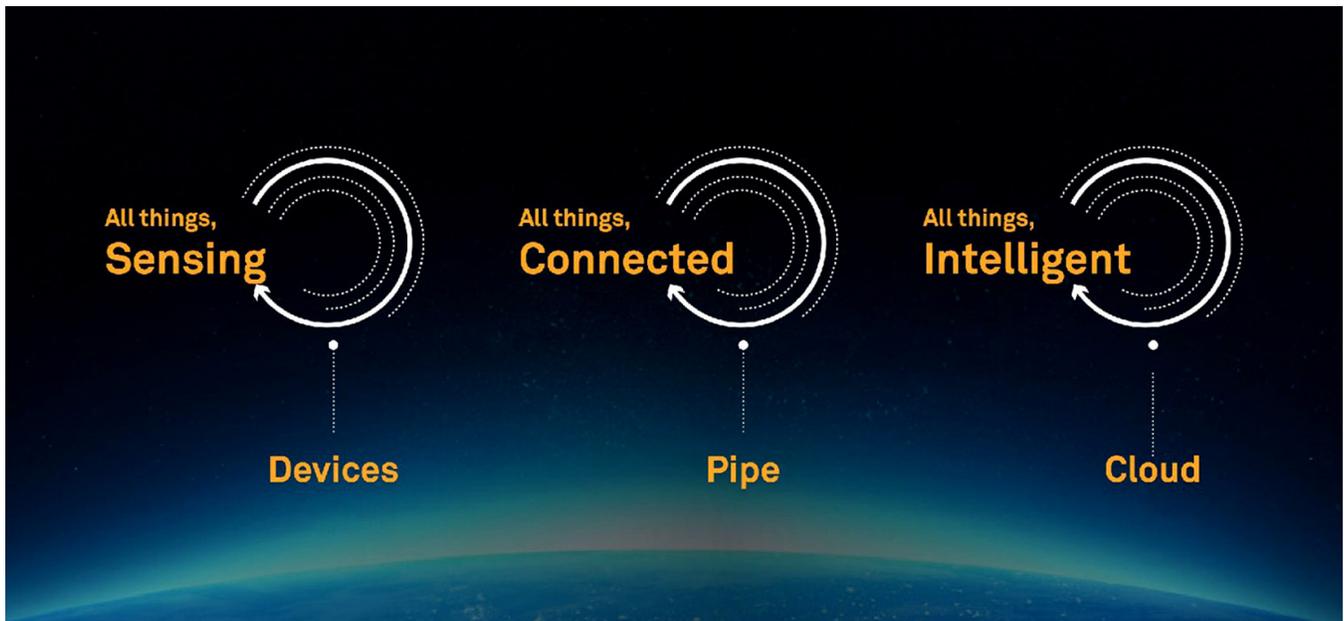
Andreessen was acknowledging that the innovations made possible with apps and cloud-based services are viable only because hardware has largely been commoditized and standardized. Indeed, the growth of the internet has been enabled by the shift from mainframe computers to sophisticated yet simple and modular data centers. By jettisoning expensive, specialized and difficult-to-maintain mainframe computers, the IT

industry has provided a stable hardware platform with which software developers can create and innovate in ways that benefit all of society.

Huawei envisions, and is already working hard to create, a similar dynamic in the global energy industry. In the case of solar, the central inverter is analogous to the mainframe computer. In addition to being bulky, expensive and hard to maintain, central inverters do not allow solar developers and grid operators the opportunity to seize the many benefits from advances in communication, cloud-based services, algorithms and big data analytics that are reshaping so much of the overall economy.

Huawei has already begun to deliver to solar developers and grid operators some of the vast improvements made possible thanks to the digital revolution. For example, Huawei's FusionSolar

Figure 5: The Foundation of Huawei's FusionEnergy Concept



Source: Huawei

Smart PV Solution combines smart hardware with wireless and power line communication (PLC) technologies and data loggers in a way that allows for extensive reporting and analysis.

Huawei's Smart I-V Curve Diagnosis technology provides granular detail about the performance of solar plants down to the string level. This information can then be sent to a control center and analyzed in order to make real-time decisions that address any drop in performance. Power plant owners can monitor and order maintenance to maximize the performance of multiple PV plants across different geographies from one central location.

The combination of string inverters with digital technologies makes the inverter the brains of a power plant. This high value can only be delivered with simple, cheap and standardized hardware

like string inverters. It requires moving away from a model where the most complicated and expensive piece of equipment for delivering electrons and information from a solar plant is the central inverter.

This digitally enhanced future is also one where string inverters will take on a greater role in grid management – something that all inverters are already being tasked with as larger amounts of renewable energy are integrated onto the world's grids.

“In the case of solar, the central inverter is analogous to the mainframe computer.”



“Huawei’s string inverters provide project developers with the **steady stream of information** they need.”

Advanced Solar Management in China

When it comes to solar, 2016 was a year like no other in China. Driven by feed-in tariffs and the central government’s Thirteenth Five-Year Plan, the country installed over 34 gigawatts of PV in 2016, more than double the 15 gigawatts built in 2015. Though this explosive pace of solar development is expected to slow somewhat over the next few years, China will continue to be a world leader in installed PV.

Huawei’s string inverters have a dominant position in the world’s largest solar market. Overall, Huawei’s inverters are used in more than 40 percent of all solar projects installed in China. Huawei is even more dominant in the country’s utility-scale market, and was responsible for more than 70 percent of inverters in the 5.5-gigawatt phase two of the Chinese government’s Top Runner program, which emphasizes the use of high-efficiency PV products.

Besides new installations, Huawei is also active in retrofitting many PV plants that are transitioning from central inverters to string inverters. In China,

developers have been attracted to Huawei’s string inverters for many reasons, including their ability to provide the support grid operators require.

All utility-scale PV power plants in China must pass four grid-connection performance tests to provide grid support: zero-voltage ride-through (ZVRT), low-voltage ride-through (LVRT), a frequency disturbance test, and a power quality test. In the case of LVRT, for example, when the voltage at the point of interconnection with the grid drops as a result of an accident or disturbance, the PV power plant and inverter must output reactive power as required to prevent the fault from spreading.

Huawei inverters, which are equipped with smart PV controllers, accomplish this first by being able to detect a grid voltage drop. But detection is just the start. Huawei inverters also generate reactive power to help support the grid’s recovery, operating within a voltage drop and time range that ensures a fault doesn’t spread.

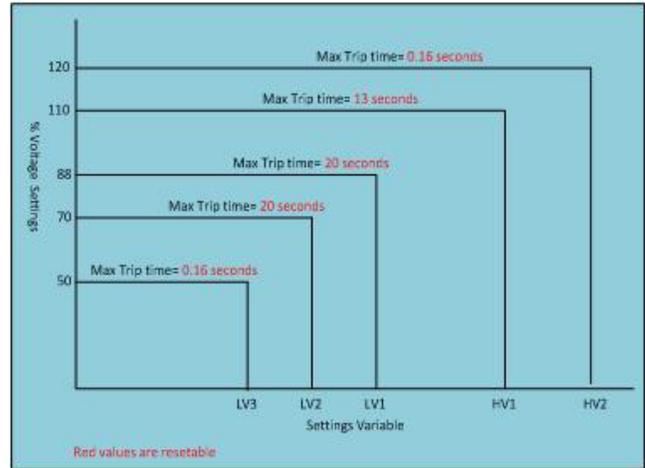
In recent years, there has also been an increased emphasis on inverters in China providing ZVRT. To meet the Chinese Grid Code for ZVRT, PV power plants must continue to operate without breaking away from the grid for 0.15 seconds when the voltage at the point of interconnection drops to 0.

Additionally, the national standard requires that PV plants disconnect from the grid when the voltage at the point of interconnection drops to a value below curve 1. Huawei's SUN2000 inverter was the first smart inverter to pass the ZVRT and LVRT (as well as high-voltage ride-through, or HVRT) tests designed by the China Electric Power Research Institute. The SUN2000 inverter has also passed LVRT and HVRT tests administered by the German Association of Energy and Water Industries, or BDEW.

Huawei's dominance in the Chinese market is the result of more than just grid support and management capabilities. It's also because Huawei's string inverters provide project developers with the steady stream of information they need to make adjustments and repairs at even the most remote power plants – and many of China's largest solar plants are located in deserts and mountainous regions far from urban centers.

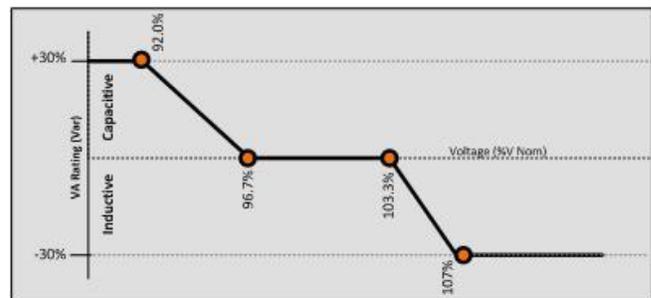
One Huawei customer in China manages approximately 2 gigawatts of solar PV plants from a single central site. For this customer, Huawei exports data on how each plant is operating and ranks them based on how much electricity each produces. By doing this, the plant owner can investigate and address any potential problems that might be limiting generation, as well as potentially share that information with grid operators.

Figure 6: Low-Voltage and High-Voltage Ride-Through Capability of Huawei Inverters

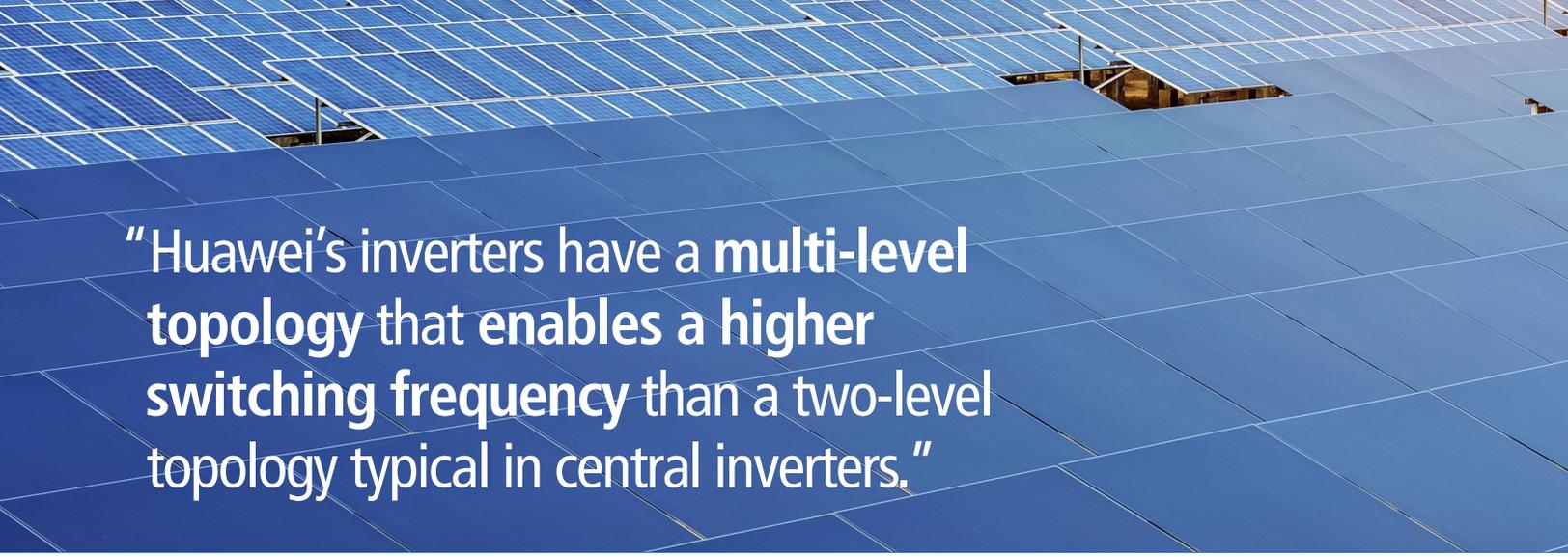


Source: Huawei

Figure 7: Reactive Power Voltage Characteristic Curve of Huawei Inverters



Source: Huawei



“Huawei’s inverters have a multi-level topology that enables a higher switching frequency than a two-level topology typical in central inverters.”

String Inverters Bolster a Weak Grid

Huawei’s inverters are also helping project developers and grid operators in important markets outside of China. India, for example, is experiencing a large boom in solar projects as it seeks to build 100 gigawatts of solar in coming years.

India’s grid is characterized by large voltage and frequency fluctuations and high levels of harmonic content – otherwise known as a weak grid, which translates into a weaker grid connection and lower power quality.

Where grids are weak, it is especially helpful to have inverters that can provide support. Huawei’s inverters are designed with a multi-level topology that enables a higher switching frequency than that of a two-level topology typical in a central inverter.

An increased switching frequency provides better control and suppression of the harmonics associated with the weak grid that is common in India. In addition, Huawei’s inverters include technology that actively suppresses harmonics. Another benefit when it comes to harmonic suppression occurs when numerous SUN2000 inverters are installed in parallel.

With this configuration, the inverters are able to automatically adapt and adjust to grid fluctuations in a way that improves not only grid stability and safety, but also the generation capabilities of PV plants.

Advanced Grid Management in the U.S.

In the U.S., the grid may not face the kind of harmonic challenges found in India, but there are formidable challenges arising from the patchwork of jurisdictions that oversees the U.S. power system.

In countries like China and Germany, national standards dictate what power plants connecting to the grid must provide in terms of grid management services.

In the U.S., there are a number of standards and requirements published by national bodies such as the Federal Energy Regulatory Commission and the North American Electric Reliability Corporation (NERC), as well as individual states and utilities. There are also voluntary standards developed by organizations like the Institute of Electrical and Electronics Engineers.

For example, in an effort to ensure that large solar plants don’t disconnect from the grid unnecessarily,



NERC requires that inverters provide a certain level of voltage and frequency ride-through capabilities. In addition, NERC also insists that inverters be able to deliver reactive power support, including an ability to support up to 0.95 power factor.

How California's Rule 21 Is Defining Solar Grid Management

The largest solar PV market in the U.S., California, is a leader in regulations governing how solar projects must be able to interact with the grid. Many emerging U.S. markets will likely base their policy choices on the regulations developed by forward-thinking pioneers in California and other leading states, such as Hawaii. In California, recent regulatory activity has focused on revising the California Public Utilities Commission's Rule 21.

Rule 21 began undergoing revisions in 2013, as the state grappled with how to incorporate increasingly large amounts of solar in a way that benefited the grid, project developers and energy consumers. In some regards, the work of the wide range of stakeholders involved with

revising California's Rule 21 was a reaction to some of the grid problems Germany experienced when it went through its own solar boom. In particular, Germany found that far too many PV systems disconnected from the grid because of an overly narrow frequency setting. Changing those inverter settings was time-consuming and expensive because the process often had to be carried out manually.

The important role of inverters was underscored by the formation of the Smart Inverter Working Group in California, which studied how advanced inverter capabilities could be effectively meshed with not only grid codes and interconnection standards but also industry and safety standards.

The result was a revision of Rule 21 that required new inverters to be outfitted with a series of grid-supporting autonomous functions, including low-voltage ride-through, low- and high-frequency ride-through, volt/VAR controls and ramp-rate requirements. Future phases of Rule 21 will mandate new communications capabilities, as well as dynamic controls and improved dispatch capabilities.

California isn't the only state emphasizing the role of smart inverters in providing grid management support. In the summer of 2017, the Hawaii Public

“Huawei SUN2000 inverters have the ability to provide greater reactive power capability than required by all U.S. grid codes.”

Utilities Commission (PUC) approved a plan set forth by the utility Hawaiian Electric Companies (HECO) to achieve 100 percent renewable energy by 2045. Through different iterations of its proposal to the PUC, HECO highlighted the important role of inverters in achieving a clean energy future in which vital grid stability is maintained.

In a place like Hawaii, the key importance of using inverters with advanced grid management functions is difficult to overstate. If inverters don't have the proper ride-through settings that allow PV systems to continue generating when there is a frequency or voltage problem, there is no plan B. Island microgrids are isolated and can't tap nearby grids for assistance in case of emergency.

There are many other examples of states and grid operators investigating the grid management capabilities of inverters. The utility Arizona Public Service installed approximately 1,600 rooftop residential PV systems on its distribution grid that can be controlled by the utility, thanks to the use of smart inverters. In California, the grid operator CAISO worked with project developer First Solar to test how inverters could help a utility-scale solar system become a stabilizing force on the grid, rather than one that would disrupt it.

Though there have been various results from these different tests and initiatives, the common message about the importance of inverters to grid management is summed up in a 2015 report released by Solar Electric Power Association Alliance and the Electric Power Research Institute. It found that smart inverters could provide a cost-effective tool for utilities to manage grid management challenges, as well as helping to avoid or defer certain grid and electric supply upgrades.

Although the studies in North America are ongoing, Huawei's inverters are able to meet and often exceed all of the existing requirements. Some of the grid management capabilities characteristics of Huawei's SUN2000 inverters include:

- **Active and reactive power control.** All SUN2000 inverters provide sufficient reactive power compensation to maintain a power factor unity at either the maximum output power or a specific power factor range from negative to positive 0.8. This translates into the ability to provide greater reactive power capability than required by all U.S. grid codes.
- **Voltage and frequency protective relay settings.** Huawei inverters can be configured with the default settings required by the eight

different grid codes settings in North America, all of which are significantly different.

- **Voltage and frequency ride-through.** Huawei inverters are able to detect and respond to voltage abnormalities by either reducing active power output or generating or absorbing reactive power in order to help the grid voltage return to normal levels. The inverters can also momentarily cease power export or continue to export power when it helps maintain grid stability. Similarly, Huawei inverters detect and disconnect from the grid during times of high or low frequency (also known as frequency droop) that fall outside the prescribed frequency-time range.

- **Frequency response.** An advanced function of the SUN2000 inverter is its ability to respond to abnormal voltage or frequency events in a manner that actually assists the grid's return to normal operation. One way the inverter does this is through a reduction in real power when there is over-frequency, which is known as the hysteresis model of frequency response.

One certainty is that future grid codes and regulations will continue to change. The centralized control possible with Huawei string inverters means that adjustments to comply with changes can be accomplished by delivering a software update through a SCADA system. This reduces the need to go to individual inverters to manually update settings, which is cumbersome and expensive.





“One certainty is that future grid codes and regulations will continue to change.”

Solar+: Beyond Mere Grid Management

When Huawei first entered the solar market in 2013, the company’s vision wasn’t simply to become the world’s largest inverter manufacturer. Rather, Huawei saw that the world’s electricity system was undergoing a fundamental transformation from one dominated by fossil fuels and central generation to a more distributed and cleaner model.

The evolution of the global electricity system presents a unique opportunity to Huawei because it necessitates an entirely new and improved infrastructure. For the past 30-plus years, Huawei has delivered the massive, technologically sophisticated infrastructure that has enabled the telecommunications industry to blossom and reinvent how billions of people around the planet communicate each day. Huawei sees its role in the transformation of the global energy system through a similar infrastructure and systems-focused lens that it calls FusionEnergy.

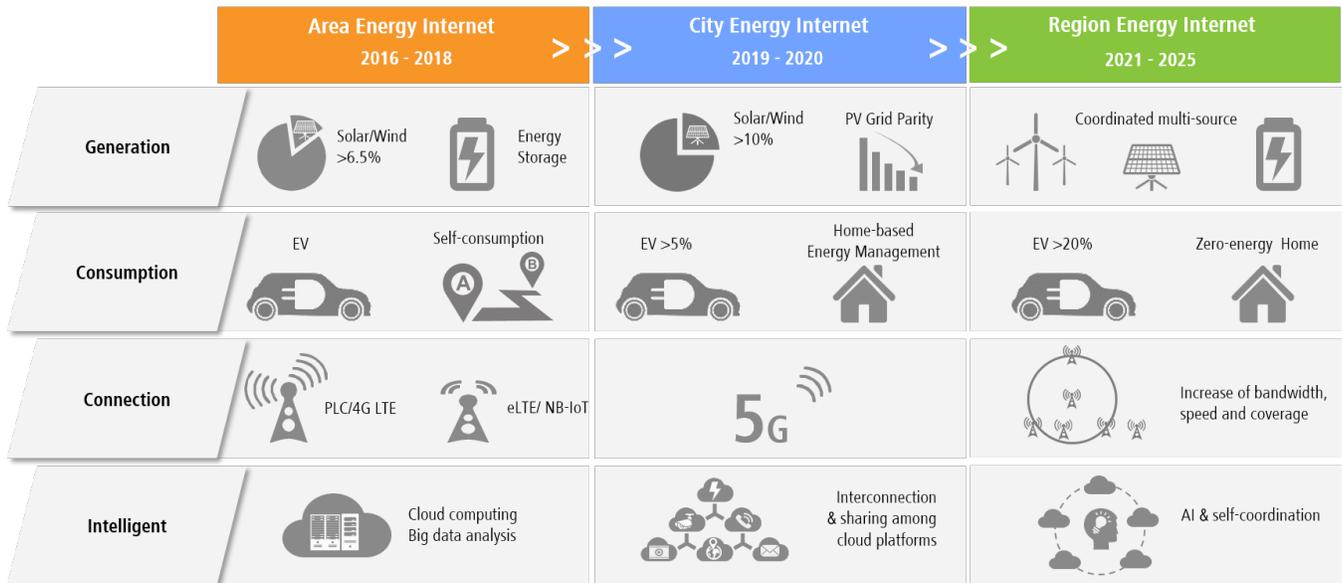
The path that the larger society is currently following is what Huawei refers to as the “road

to the internet of energy,” and this is being driven by the increasing cost-competitiveness and penetration of renewable energy, as well as global efforts to drastically reduce carbon emissions. The steps along the road to the internet of energy include a large increase in grid-friendly renewable energy, especially solar and wind; the integration of sensors and communications technology with sources of both renewable and conventional energy so that all generation sources can be connected to the internet of energy; widespread electrification of industrial and residential consumption, including a rapid mainstreaming of electric vehicles; the establishment of energy system trading platforms that allow a multitude of energy producers to become active; and the creation of a cloud-based platform to share data about overall energy generation and consumption in order to make the entire energy system stable and reliable.

Huawei is committed to playing a meaningful part in this transformation. Its development of inverters that are connected to the cloud and benefit from data analytics is just the first step in this journey.

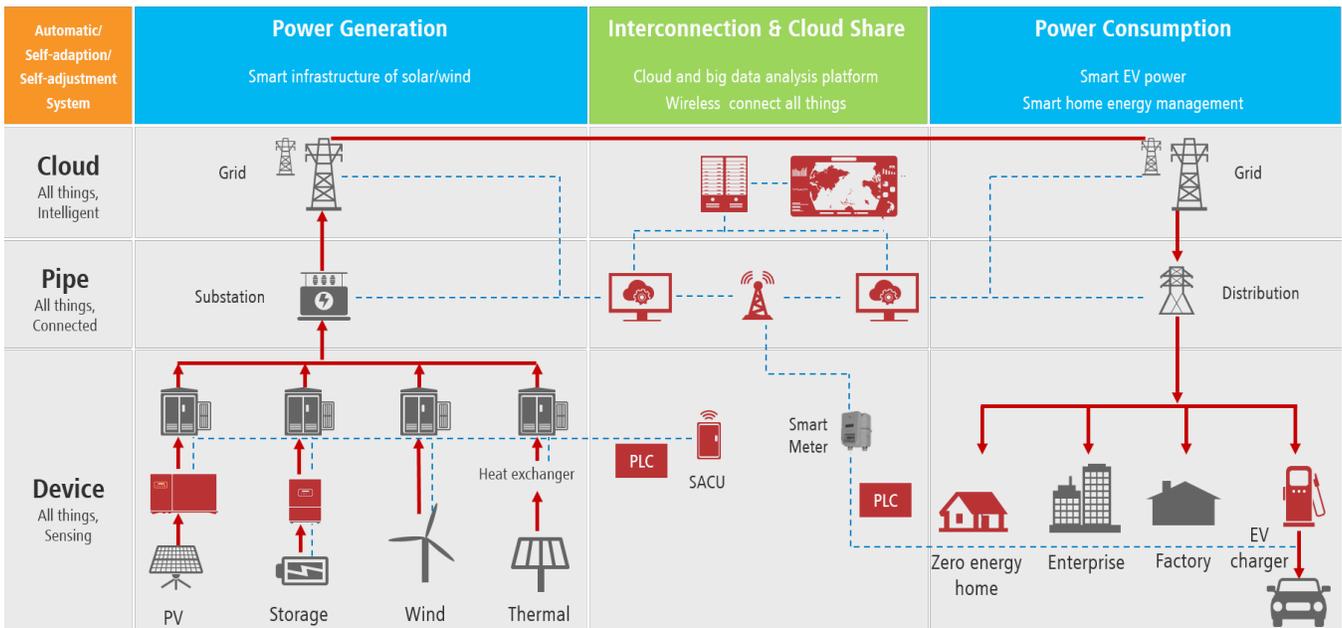
To help drive the innovation that will be required to speed this radical change, Huawei is devoting

Figure 9: Huawei FusionEnergy Roadmap



Source: Huawei

Figure 8: Huawei Road to the Internet of Energy



Source: Huawei

An aerial photograph of a solar farm installed in a hilly, semi-arid landscape. The solar panels are arranged in neat, parallel rows across the slopes. In the background, a range of hills is visible under a clear sky, with several wind turbines scattered across the ridge. A river or stream flows through the lower part of the image, winding through the terrain. The overall scene is bathed in a warm, golden light, suggesting either sunrise or sunset.

**Huawei is focused
on developing
the products and
infrastructure
required to create
a cleaner and more
interconnected and
responsive energy
system.**

significant resources to research and development (R&D). In 2016, the company devoted nearly \$11 billion of its \$75 billion in revenue to R&D. Over the past decade, Huawei has invested over \$45 billion in R&D in the past decade, and has six R&D centers with over 80,00 R&D employees working around the world.

Huawei's efforts are focused on developing the products and infrastructure required to create a cleaner and more interconnected and responsive energy system.

As renewable energy penetration in power markets around the world approaches 50 percent and beyond in some regions, the benefits of granular data, control and communication capabilities will become even more important as a means of balancing distributed generation and consumption.

Looking Ahead

Huawei's smart inverters are one of the first building blocks in the process of creating the internet of energy. Huawei's roadmap to reaching this destination includes an initial step of building smart microgrids in industrial parks, followed by

connecting them in urban centers to create a city-level internet of energy. The final step is to then extend and connect the city-level energy systems around entire countries. To achieve this vision, Huawei is starting by doing everything possible to lower PV costs and improving solar technologies.

On the energy consumption side, Huawei will deliver technologies that make widespread electrification possible, including advanced electric-vehicle charging devices. In terms of communication, Huawei has already combined its 4G and PLC technology with its inverters, allowing for tighter control of solar power plants.

The next step will involve transitioning to 5G in order to achieve even better, higher-speed interconnection among solar plants, electric vehicles and the many other coming assets that will be a part of a distributed energy network. Finally, Huawei is committed to building the cloud-based energy management system that will improve the intelligence, automation and interconnection of the entire energy system.

It's a vision of the future that goes well beyond improving how string inverters integrate with the power grid. But this is where this journey begins.



Huawei Technologies USA, Inc.
20400 Stevens Creek Blvd, Suite 150
Cupertino, CA 95014
fusionsolarna@huawei.com

Copyright © Huawei Technologies USA. All Rights Reserved.

GENERAL DISCLAIMER

THE INFORMATION IN THIS DOCUMENT MAY CONTAIN PREDICTIVE STATEMENT, INCLUDING BUT NOT LIMITED TO, STATEMENTS REGARDING FUTURE FINANCIAL RESULTS, OPERATING RESULTS, FUTURE PRODUCT PORTFOLIOS, AND NEW TECHNOLOGIES. THERE ARE A NUMBER OF FACTORS THAT COULD CAUSE ACTUAL RESULTS AND DEVELOPMENTS TO DIFFER MATERIALLY FROM THOSE EXPRESSED OR IMPLIED IN THE PREDICTIVE STATEMENTS. THEREFORE, SUCH INFORMATION IS PROVIDED FOR REFERENCE PURPOSES ONLY, AND CONSTITUTES NEITHER AN OFFER NOR A COMMITMENT. HUAWEI MAY CHANGE THE INFORMATION AT ANY TIME WITHOUT NOTICE, AND IS NOT RESPONSIBLE FOR ANY LIABILITIES ARISING FROM.

YOUR USE OF ANY OF THE INFORMATION PROVIDED HEREIN.

