

HUAWEI STRING INVERTER TECHNOLOGY REVIEW

Stage 2 Review

Huawei Technologies

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1 INTRODUCTION

1.1 Scope of Work

DNV GL presents this independent Technology Review of the Huawei inverter series manufactured by Huawei, and configured for sale in the United States.

This report provides information on the company as well as technical due diligence information on the following specific Huawei string inverter products:

- SUN2000-25KTL-US
- SUN2000-30KTL-US
- Smart Logger

Huawei string inverters convert direct current (DC) power generated by the PV modules to grid compliant alternating current (AC) power. The units are deployed on the solar array and placed in parallel directly to the AC grid. The Huawei models reviewed differ in power level.


This report provides information on the company as well as technical due diligence information on the Huawei line of products. This Technology Review report will focus exclusively on the following key topics:

- Company Evaluation
- Technical Product Evaluation
- Performance Evaluation
- Quality and Reliability Evaluation
- Manufacturing Site Visit
- Product Support
- Example Installation
- Summary

1.2 Methodology

In general, this Stage 2 technology review report contains information that would be included in a final Independent Engineering review intended for financial institutions, customers, and project developers. DNV GL is uniquely qualified to conduct this study due to its extensive background and experience in solar power plant independent engineering and technology due diligence work.

This report has been updated to the Stage 2 level based upon feedback from Huawei on the Stage 1 report and the incorporation of additional and updated information. The Stage 2 report is directed to the audience of inverter customers, PV project developers and financiers for the Huawei inverter products.



Information was aggregated from multiple Huawei sources and provided to DNV GL for generation of this report by:

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The primary objective of this Technology Review is to assess factors that would affect the product's performance and reliability in the field. Such factors will include the inverter design, quality of materials, product performance, regulatory compliance, reliability tests, and the quality control processes. Additionally, high level company information is included to support the reader in understanding Huawei background and capabilities.

1.3 Assumptions

This report summarizes the DNV GL assessment of the covered products and relies on the accuracy of the information provided by Huawei. Huawei has been reasonably open and forthcoming in providing the data that DNV GL has requested. Additionally, DNV GL visited the Huawei headquarters complex in Shenzhen, China, the Songshan Lake Manufacturing Centre, and a nearby installation.

This report is based on some information not within the control of DNV GL. DNV GL believes that the information provided by others is true and correct and reasonable for the purposes of this report. DNV GL has not been requested to make an independent analysis or verification of the validity of such information. DNV GL does not guarantee the accuracy of the data, information, or opinions provided by others.

In preparing this report and the opinions presented herein, DNV GL has made certain assumptions with respect to conditions that may exist, or events that may occur in the future. DNV GL believes that these assumptions are reasonable for purposes of this report but actual events or conditions may cause results to differ materially from forward-looking statements.

2 COMPANY EVALUATION

2.1 Company Overview

Huawei is a multinational company which was founded in 1987 and began manufacturing Information and Communications Technology (ICT) electronic devices in high volume in 2004. As a large, employee owned ICT company; Huawei has subsidiaries in over 170 countries and more than 170,000 employees. The company headquarters is located in Shenzhen, China. The diagram displayed in Figure 1 shows the company's highlights.

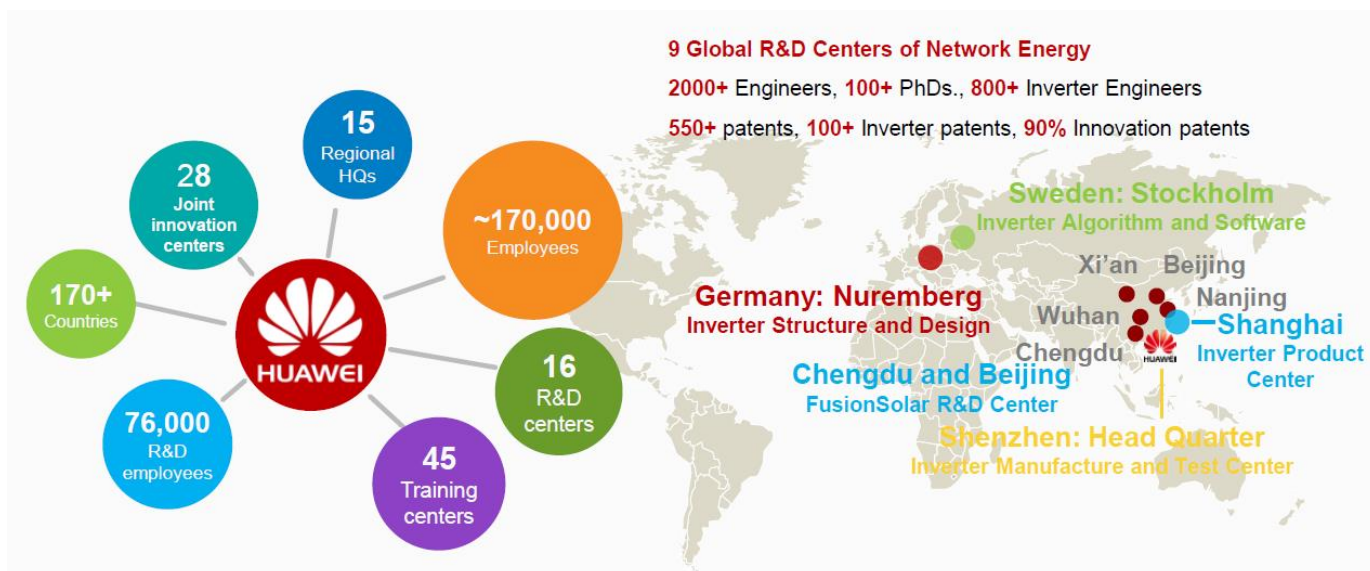


Figure 1. Huawei's Global Team

Huawei has extensive expertise in the fields of information technology, and although all products produced by Huawei should benefit from their established processes and corporate culture, this review will focus on a small segment of their products, specifically the solar string inverters for the North American market. Huawei is recently established in the string inverter markets of China, Germany, Japan, Jordan, Thailand and the Philippines and has had rapid growth. Information was provided to DNV GL showing projects consisting of Huawei string inverters exceeding 4GW in capacity through the end of 2014. The list of installations was reviewed but not independently verified by DNV GL. The two new North American models under review by DNV GL are both revisions of an existing Huawei international model.

2.2 Company Financials and Sales Revenues

DNV GL was provided a copy of the Huawei's 2014 Annual Report that showed total company product revenue of CNY 288,197M (US \$46,515M), an increase of 20.6% over 2013 results. For solar string inverters, a revenue number for 2014 of approximately US \$370M was provided, which included the sales of inverters, monitoring systems, Smart Logger and corresponding wireless devices. DNV GL suggests the reader contact Huawei directly for more detail on their financials as needed. The distribution of the company's total 2014 revenues based on regions, as defined by Huawei, are shown in Figure 2 (note that this is not specific to solar inverters).

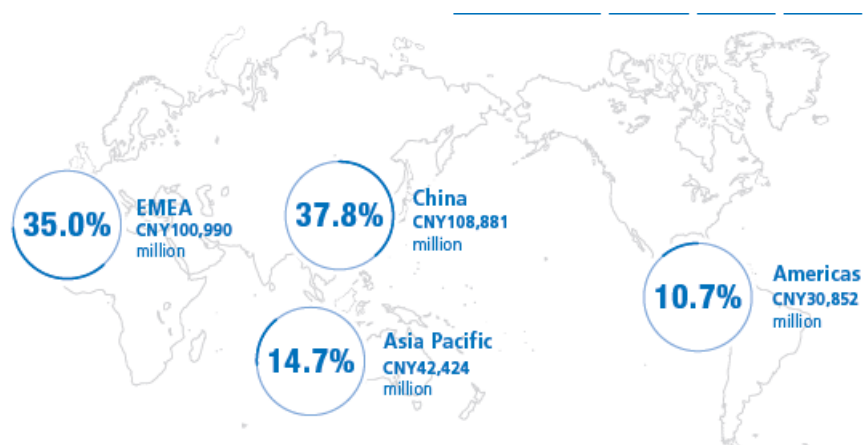


Figure 2. Geographical Breakdown of 2014 Revenues

2.3 Company Product History

Documentation provided to DNV GL shows that Huawei began producing their line of string and central inverters in volume for the Chinese market in 2013 and the international product (outside of North America) in 2014.

See Figure 3 below for the range of Huawei solar inverter products designed for the international markets (outside of North America). Huawei no longer offers central inverter products.

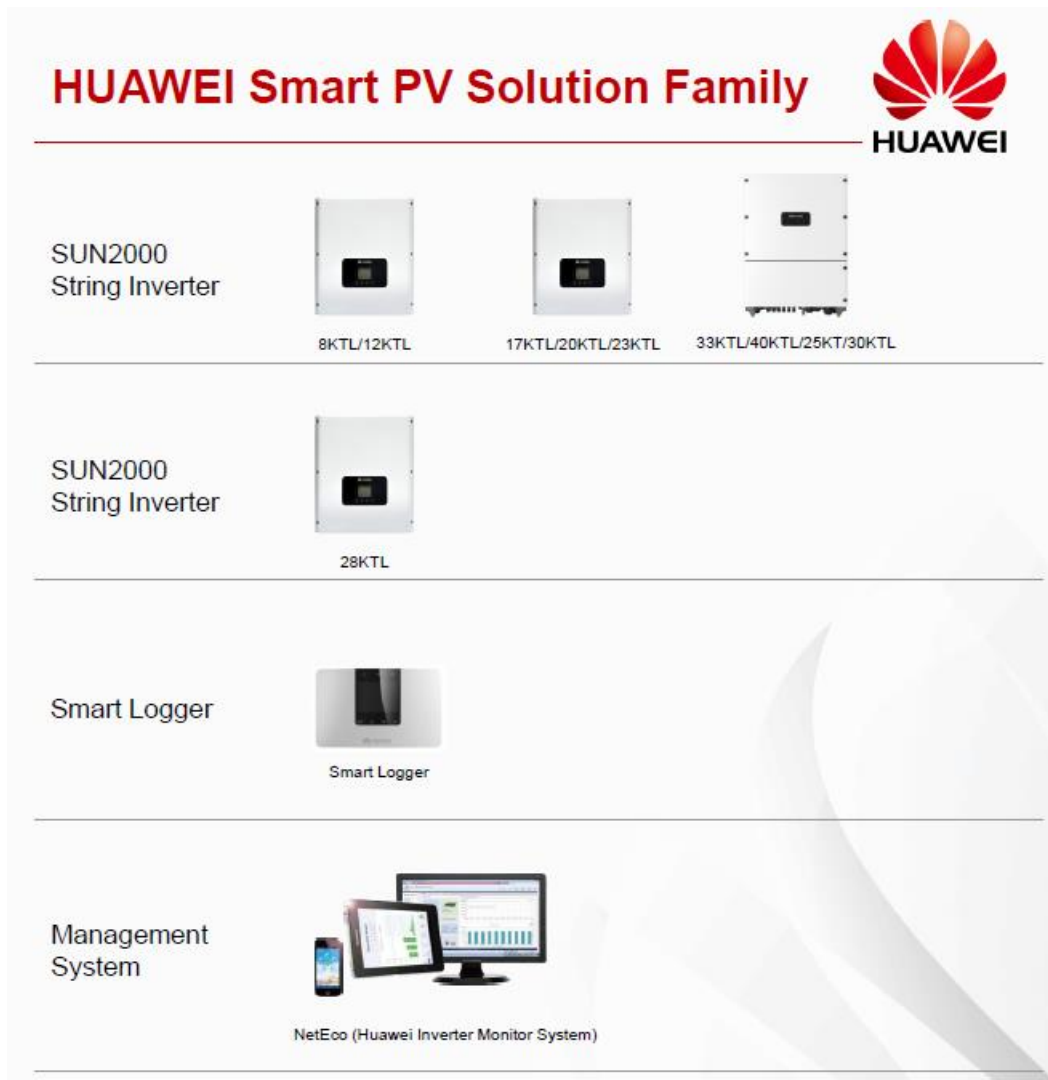


Figure 3. Huawei Product Lines and Accessories for International Markets

The Huawei SUN2000-25KTL-US and SUN2000-30KTL-US String Inverters were designed and configured for North American markets, and are based on the SUN2000-40KTL model. With approximately 683MW of international projects using the similar SUN2000-40KTL, the North American models should benefit from the Huawei experiences from other regions. Figure 4 shows a typical installation for the international inverter model installed in China.



Figure 4. Typical Field Installation of Huawei String Inverters in China

Huawei provided detailed documentation to show 4GW of installed string inverter capacity through 2014, with installations starting in 2013. The first European shipments of string inverters by Huawei occurred in 2014. This is rapid growth in the solar inverter industry. It is expected that the new North American models have benefitted from the knowledge base created by Huawei. Figure 5 shows the information provided by Huawei for their 2014 global status of shipments. Huawei informed DNV GL that IHS indicates that Huawei is the 2nd largest manufacturer of solar inverters in China and is among the top 10 globally at this time.



Figure 5. Huawei Reported Global PV Inverter Locations



2.3.1 North American Installations

Huawei has recently started to deploy the string inverters in the US. The SUN2000-25KTL-US and SUN2000-30KTL-US String Inverters are the first inverters designed by Huawei specifically for the North American market. The compliance testing for these products to UL 1741, CSA-C22.2 and UL 1699B has been completed, making installations in the US possible. Additionally, Huawei is currently booking orders for US installations in the short term.

2.4 Intellectual Property (IP) Evaluation

Huawei presented to DNV GL an extensive list of inverter-related patents submitted in China, Europe, and the United States. The patents represent a significant investment by Huawei in protecting their inverter technology. DNV GL views Huawei's active program of IP protection positively. Huawei indicated that they have used their technical team to do the preliminary patent analysis, and prior to launching new product sales, the R&D team works in cooperation with the legal group to do a search for patents that they could possibly be infringing on.

While intellectual property issues have been limited in the solar inverter area, DNV GL recommends protecting developed IP and doing thorough patent searches to ensure that others' IP is not being infringed upon.

3 TECHNICAL EVALUATION

This section provides a summary and general overview of Huawei solar inverter products, a discussion of the inverter topology, environmental characteristics, power quality, and grid support features.

In general, Solar PV inverters are devices that convert the DC power supplied from a solar PV array into AC power that is fed into the utility grid. Solar inverters maximize the energy out of the PV modules and perform the interface to the grid to meet the utility interactivity requirements.

3.1 Huawei Overview

The Huawei series of field-installed solar string inverters presently includes 12 primary models ranging in power rating from 8 kVA to 40 kVA continuous AC output power. These 1000 Vdc maximum input voltage inverters operate with a three phase output and are designed for outdoor larger scale PV plant operation. The "US" designation indicates that those products meet the North American standards from a Nationally Recognized Testing Laboratory (NRTL) as discussed in section 5.2 of this report. A photo of the SUN2000-25KTL-US inverter designed and tested specifically for the North American market is shown in Figure 6 below as a reference. This report focuses on the inverters intended for the North American market - the newly developed 25kW and 30kW inverters.



Figure 6. Photo of the SUN2000-25KTL-US Huawei Inverter

Huawei lists the following set of key features for their solar string inverter line:

- 6 strings intelligent monitoring
- Real-time operation monitoring
- Adaptive Edge MPPT for fast tracking
- Max. efficiency 98.6%, CEC efficiency 98.0%
- Arc fault detection (according to UL 1699B)
- Integrated DC disconnect, safe and convenient for maintenance
- Ground fault protection
- Outdoor application rating of NEMA 4

The two Huawei string inverter models under review use Amphenol Helios H4 connectors for the DC inputs, similar to many international inverters models, and micro-inverters installed in the US. For installations in North America, the H4 connectors are acceptable for use in locations where the inverters are not readily accessible by the public, such as rooftop locations, fenced utility installations and commercial sites. Huawei also offers a blue plastic external enclosure, as shown in Figure 7, for protecting the DC connections in locations where enclosed DC connections are preferred.



Figure 7. Enclosed DC Connections

The electrical specifications for the Huawei 25kW and 30kW Inverters are shown below in Table 1 and Table 2 respectively.

String Inverter (SUN2000-25KTL-US)



Technical Specifications	SUN2000-25KTL-US
	Efficiency
Max. Efficiency	98.6%
CEC Efficiency	98.0%
	Input
Max. DC Voltage	1,000 V
Max. Current per MPPT	25A
Min. Operating Voltage	200 V
Full Power MPPT Voltage Range	560 V~850 V
MPPT Operating Voltage Range	200 V~950 V
Rated Input Voltage	730 V
Max. Number of Inputs	6
Number of MPP Trackers	3
	Output
Rated AC Power	25,000 W
Max. AC Apparent Power	27,500 VA
Max. AC Active Power (cosφ=1)	25,000 W
Rated Output Voltage	277V/480V, 3W+PE/3W+N+PE
Rated AC Grid Frequency	60 Hz
Max. Output Current	33 A
Adjustable Power Factor	0.8 LG ... 0.8 LD
Max. Total Harmonic Distortion	< 3%
	Protection
DC AFCI Compliant to UL 1699B	Yes
Input-side Disconnection Device	Yes
Anti-Islanding Protection	Yes
AC Overcurrent Protection	Yes
DC Overcurrent Protection	Fuseless
DC Reverse Polarity Protection	Yes
PV-array String Fault Monitoring	Yes
DC Surge Arrester	Category C
AC Surge Arrester	Category C
Insulation Monitoring	Yes
Residual Current Detection	Yes
	Communication
RS485	Yes
USB	Yes
	General
Dimensions (W×H×D)	550×770×270 mm (21.7×30.3×10.6 inch)
Weight	55 kg (121 lb)
Operation Temperature Range	-25 °C ~ 60 °C (-13°F ~ 140°F)
Cooling	Natural Convection
Operating Altitude	4,000 m (13,123 ft)
Relative Humidity	0~100%
DC Connector	Amphenol H4
AC Connector	Waterproof PG Terminal + OT Connector
Protection Rating	NEMA 4X
Internal Consumption at Night	< 1 W
Topology	Transformerless
Noise Emission (Typical)	< 33 dB
	Standards Compliance
Safety/EMC	UL 1741, UL 1699B, UL 1998, IEEE 1547, CSA C22.2 #107.1-01, FCC Part 15
Grid Code	IEEE 1547, IEEE 1547.1


Table 1. SUN2000-25-KTL-US Huawei Inverter Specification

String Inverter (SUN2000-30KTL-US)



Technical Specifications	SUN2000-30KTL-US
	Efficiency
Max. Efficiency	98.6%
CEC Efficiency	98.0%
	Input
Max. DC Voltage	1,000 V
Max. Current per MPPT	25A
Min. Operating Voltage	200 V
Full Power MPPT Voltage Range	360 V~850 V
MPPT Operating Voltage Range	200 V~850 V
Rated Input Voltage	730 V
Max. Number of Inputs	6
Number of MPP Trackers	3
	Output
Rated AC Power	30,000 W
Max. AC Apparent Power	33,000 VA
Max. AC Active Power (cosφ=1)	30,000 W
Rated Output Voltage	277V/480V, 3W+PE/3W+N+PE
Rated AC Grid Frequency	60 Hz
Max. Output Current	40 A
Adjustable Power Factor	0.8 LG ... 0.8 LD
Max. Total Harmonic Distortion	< 3%
	Protection
DC AFCI Compliant to UL 1699B	Yes
Input-side Disconnection Device	Yes
Anti-Islanding Protection	Yes
AC Overcurrent Protection	Yes
DC Overcurrent Protection	Fuseless
DC Reverse-Polarity Protection	Yes
PV-array String Fault Monitoring	Yes
DC Surge Arrester	Category C
AC Surge Arrester	Category C
Insulation Monitoring	Yes
Residual Current Detection	Yes
	Communication
RS485	Yes
USB	Yes
	General
Dimensions (W x H x D)	550 x 770 x 270 mm (21.7 x 30.3 x 10.6 inch)
Weight	55 kg (121 lb)
Operation Temperature Range	-25 °C ~ 60 °C (-13°F ~ 140°F)
Cooling	Natural Convection
Operating Altitude	4,000 m (13,123 ft)
Relative Humidity	0~100%
DC Connector	Amphenol H4
AC Connector	Waterproof PG Terminal + OT Connector
Protection Rating	NEMA 4X
Internal Consumption at Night	< 1 W
Topology	Transformerless
Noise Emission (Typical)	<33 dB
	Standards Compliance
Safety/EMC	UL 1741, UL 1699B, UL 1998, IEEE 1547, CSA C22.2 #107.1-01, FCC Part 15
Grid Code	IEEE 1547, IEEE 1547.1

Table 2. SUN2000-30-KTL-US Huawei Inverter Specification



DNV GL has a number of comments about the data sheet for the Huawei string inverters for North American Applications.

The FCC Part 15 is to Class A which is appropriate for commercial, industrial, or business installations.

Huawei has indicated that they have used a 25 year design life for their solar string inverters, based on the similarities between the string inverter technology and their well-established telecommunications technology. Huawei noted that reliability is often related to the harshness of the location where the equipment is installed, and the remotely located systems of the Huawei telecommunications equipment survive in environmentally demanding locations.

3.1.1 Accessories

To support the SUN2000 string inverter line, Huawei also devices for communications, monitoring and data logging. Huawei indicated to DNV GH that these include devices for:

- SmartLogger
 - Up to 80 inverters feeding into one Smart Logger
 - Up to 30 devices per RS485 bus
 - MODBUS-TCP for connections to Huawei NetEco
 - IEC60870-5-104 for connections to third-party monitoring systems
 - USB and embedded web for data reading and software upgrade
 - Automatically detecting equipment and assigning RS485 addresses
 - Remote control of active & reactive power
- NetEco
 - Easy data accesses on mobile devices
 - Proactive reports of yields and alarms
 - One-click installation on PC
 - Fault alarms via SMS and E-mail
 - Hierarchical management
 - Up to 25 years data storage with CSV files
- SUN2000 Application
 - Bluetooth communications
 - For monitoring and maintenance
 - Android 4.0 or later

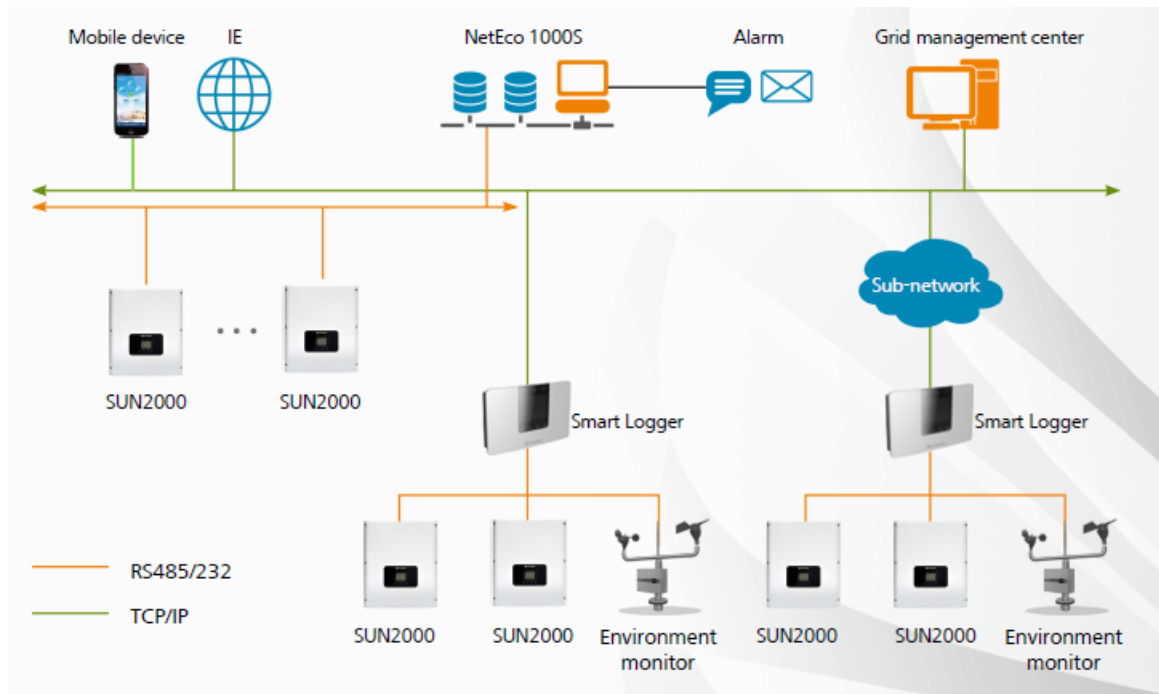


Figure 8. Huawei Network Structure

These accessories will not be reviewed in detail here, but DNV GL views it favorably that Huawei has a suite of complimentary devices that further facilitate the installation, operation and monitoring of plants using the Huawei inverter lines. Specifics of these accessories should be obtained directly from Huawei.

3.2 Huawei Inverter Topology

Huawei provided the high level block diagrams for the three phase transformerless inverter topology that is shown below in Figure 9. The 25kW model includes three separate MPPT circuits configured such that each pair of the six PV circuits is controlled by a separate MPPT algorithm. PV over-current protection is not provided at the inverter since no more than two strings are combined together.

The AC side of the inverter includes an EMI filter, AC Surge Protection Device (SPD) and a relay to provide AC isolation. The three-phase, 480 VAC circuit can be connected as a typical 3- wire configuration, with no connection to the neutral circuit, or as a 4-wire system with a neutral. The Huawei string inverters will operate in either configuration.

The design provides a DC disconnect switch, DC Surge Protection Devices (SPDs), EMI filtering and input current monitoring on the PV side of the inverter. An isolation contactor or relay is not provided as a means of automatically disconnecting the inverter from the DC energy source in the event of an inverter fault. DNV GL recommends that all inverters include a means of automatically disconnecting all energy sources in the event of an inverter problem, by including a relay or contactor on the DC side.

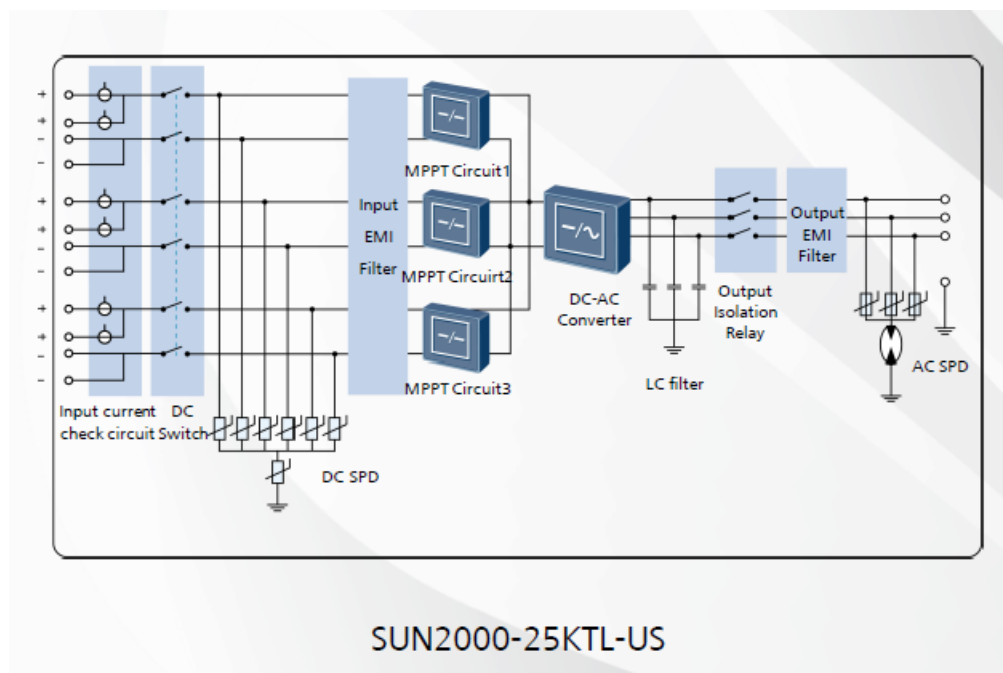



Figure 9. Circuit Diagram of the Huawei Inverter

It should be noted that these units are not-isolated and must be employed with the PV array floating. This system configuration can be susceptible to Potential Induced Degradation (PID) of the PV modules and the system should be designed to avoid this situation. Huawei has developed techniques to mitigate the effects of PID, and can provide a white paper on the topic.

3.3 Huawei Environmental Characteristics

The Huawei inverters are listed in their data sheets as having an enclosure type NEMA 4 with a temperature rating from -25° to 60° C, and 0-100% relative humidity. All models of the Huawei string inverters are designed for outdoor installations. The SUN2000-(25KTL, 30KTL)-US Quick Installation Guide provided to DNV GL suggests that installer read the SUN2000-(25KTL, 30KTL)-US User Manual for product information and safety precautions.

The User Manual states that the inverters should be installed in locations where the ambient temperature is below 50°C to ensure optimal operation and to extend the service life. Additionally, the manual states that the inverter should be protected from direct exposure to sunlight, rain and snow. The User Manual states that the customer can determine whether to add a shade structure, such as an awning, to meet the installation suggestions by Huawei.



DNV GL notes that these installation guidelines are intended to provide for a longer service life with reduced environmental stresses. The installation guidelines do not conflict with the specification but rather inform the user of prudent installation practices. However, Huawei's suggestion that the customer should decide whether or not to supply an awning puts the issue of long term inverter reliability at the customer's discretion.

DNV GL is very positive about the use of natural convective cooling without external fans as an appropriate feature for the Huawei string inverter products. Huawei does employ internal fans to circulate the air intermittently when the internal enclosure temperature is high. Huawei reports that based on the low number of fan operating hours due to its intermittent use, and the characteristics of the fan specified, the calculated life of the internal fans is greater than 25 years.

An important derating factor is the performance of a PV inverter related to the ambient temperature. Huawei provided the graphs shown in Figure 10 for the Huawei SUN2000-25KTL and 30KTL US inverters. The thermal derating, along with any associated with DC voltage and reactive power should be fully considered when applying the Huawei solar inverters. The derate curves in Figure 10 indicate that the thermal performance of the string inverters is affected by PV voltage. Additionally, the derate charts are based on operation with a minimum air speed at the string inverter of 0.5 m/s (1.1 miles per hour). The User Manual clarifies this requirement by stating that the inverter must be installed in a well-ventilated environment to ensure good heat dissipation.

Huawei notes that the string inverters sense the inverter's internal temperature to calculate the external temperature. The string inverters have the ability to limit the output power, when the temperature is too high. Huawei's recommendation to install the string inverters only in locations where the ambient temperature will not exceed 50°C is one means of maintaining a lower temperature inside the inverter.

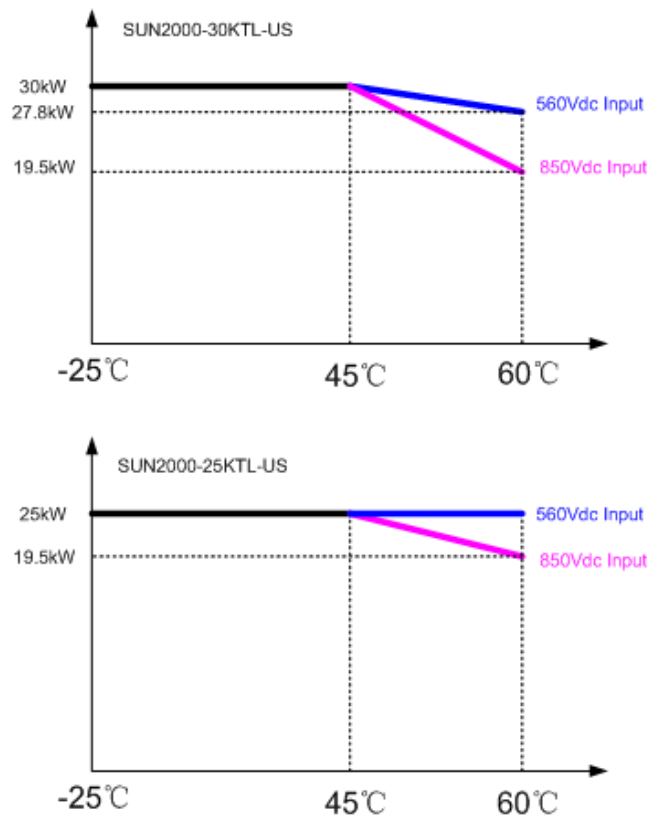


Figure 10. Power versus Temperature Derate curves

The data sheet for the Huawei inverters lists the Maximum Altitude for rated operation as 4000 meters. Huawei provided the chart in Figure 11 for derating for altitude above 4000 meters. The chart indicates that a DC voltage derate of 13 volts per 100 meters is recommended.

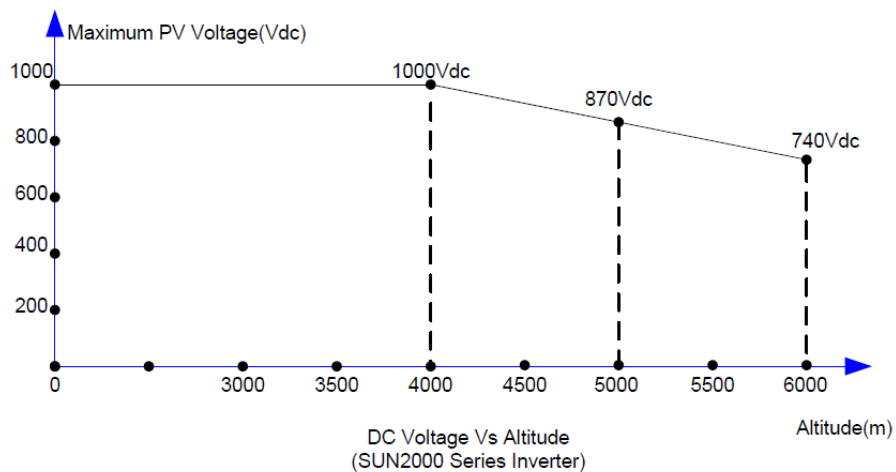


Figure 11. Voltage Derate Curve for Altitude

The chart in Figure 12 shows derating for maximum working temperature for altitudes above 2000 meters at a rate of 0.6°C per 100 meters. Note that the maximum working temperature for rated power operation in the chart is 45°C.

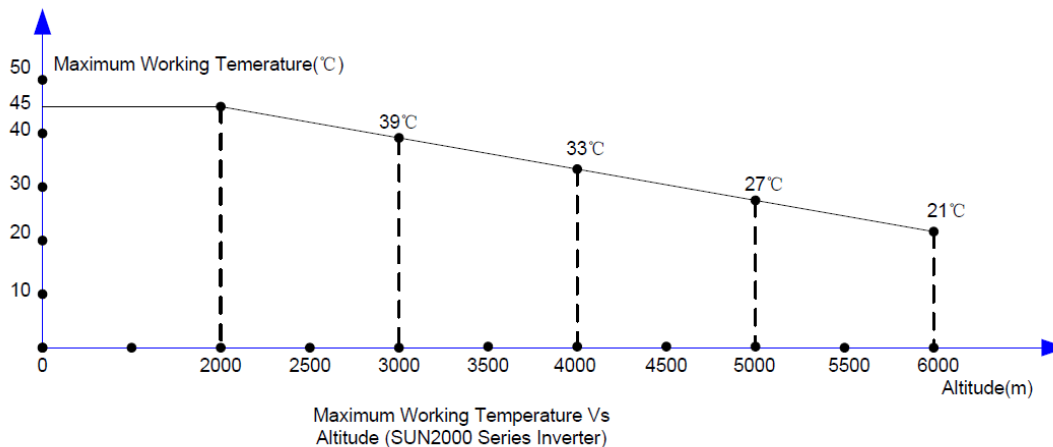


Figure 12. Temperature Derate Chart for Altitude

3.4 Huawei Power Quality and Grid Support

The Huawei string inverters also implement the interface to the utility grid. This includes functionality for providing high power quality and grid protection. In the US and other North American markets, these requirements are defined in the UL-1741 “Standard for Safety Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources.” This standard covers a variety of conditions that the inverter design must address in order to be installed and connected to the grid safely.

The Huawei inverter specifications list the Total Harmonic Distortion at less than 3%, which is well within the IEEE 519 power quality requirements.

The ability of an inverter to operate off unity power factor can be expressed in several ways. The term “power factor” is the ratio of real power to apparent power in an electrical circuit. The reactive power capacity of the Huawei string inverters is listed on the specification sheet as -0.8 to +0.8 power factor. Figure 13 shows the limitations in real and reactive power when the string inverter operates off unity power factor. The apparent power limit for the SUN2000-25KTL-US is 27.5kVA, and for the SUN2000-30KTL-US the limit is 33kVA. The shaded area indicates the allowed operating conditions for real power under the various power factor conditions. To summarize the information in the diagram, the inverter will deliver rated real power from unity to +/- 0.91 power factor. With a power factor setting of less than +/- 0.91, real power will be sacrificed to deliver the necessary power factor. DNV GL views positively that the Huawei

string inverters have reactive power capabilities which may become important for larger installations in North America.

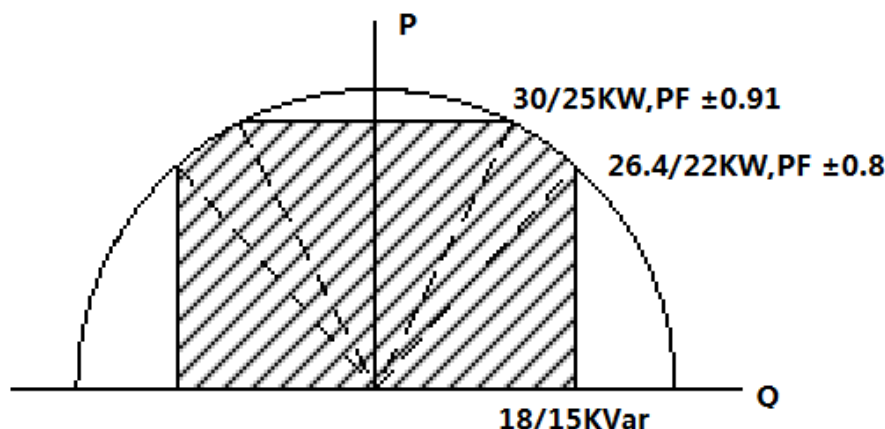


Figure 13. Reactive Power Capabilities of the 25kW and 30kW Huawei String Inverters

It is important to understand that the string inverter will limit the output power whenever the internal temperature exceeds the limit. The inverter will run hotter when the ambient temperature is high, when the PV voltage is within range but high, and when the power factor is off unity. Also, power limiting is most likely to occur at or near rated power. And, any combination of high power, high ambient temperature, high PV voltage, and non-unity power factor will together add to the inverter's internal temperature. Installations where these various stresses occur simultaneously should be discussed in detail with Huawei to fully understand the risk of under-performance due to thermal limitations.

DNV GL is comfortable with the overall technical feature set of the Huawei inverter products; however it is recommended that the detailed derating information be reviewed for consideration in the specific application being deployed.

3.5 Huawei Product Efficiency

One of the key metrics for PV inverters is the DC-to-AC electrical conversion efficiency over the full range of operating powers, measured at the various typical DC input voltages. Generally, the conversion efficiency is not constant, but depends on the actual power level and DC voltage. It is relevant to know the efficiency at various operational levels.

It should be noted that Huawei does not specify a limit to the DC to AC power ratio. Due to recent reductions in the cost of PV modules, systems with higher DC to AC power ratios are becoming more viable when the levelized cost of energy (LCOE) is considered. Rather than limit the DC to AC ratio, Huawei states that the limiting factor is the short circuit DC current limit for each MPPT connection. Huawei anticipates that the typical DC/AC ratios encountered in the US will be acceptable provided that the short circuit current limit is not exceeded. DNV GL suggests that system designer consult Huawei for the short circuit current limit when designing systems with high DC/AC power ratios.

The Huawei data sheet lists the peak efficiency as 98.6 % for the two models, 25kW and 30kW, reviewed in detail by DNV GL.

3.5.1 Huawei CEC Ratings

An important efficiency measurement is a blended average that is used in California and across North America.

Senate Bill 1 (SB 1) directs the California Energy Commission (CEC, Energy Commission) to establish eligibility criteria, conditions for incentives, and rating standards for projects applying for ratepayer funded incentives for solar energy systems deployed in the State of California.

Three specific expectations established by SB 1 must be met for the ratepayer-funded incentives:

- High quality solar energy systems with maximum system performance to promote the highest energy production per ratepayer dollar.
- Optimal system performance during peak demand periods.
- Appropriate energy efficiency improvements in the new and existing home or commercial structure where the solar energy system is installed.

The inverter test protocol developed by the Energy Commission to determine inverter performance data shall be used along with the UL certification for safety and reliability. The inverter test protocol ensures that the reported performance data of efficiency at the full range of operating conditions (power and efficiency at the full range of possible voltages) along with the night time tare loss for each inverter provides full performance information and enables hourly estimating of the overall performance of the system.

Eligible inverters are listed with the Energy Commission.

The following are inverter eligibility requirements:

Inverters shall be certified to UL1741 standards by a Nationally Recognized Testing Laboratory (NRTL).

Performance data (Maximum Continuous Output Power, Conversion Efficiency, and Tare Losses) tested in accordance with "Performance Test Protocol for Evaluating Inverters Used in Grid Connected Photovoltaic Systems by a NRTL shall be reported for each inverter.

<http://www.gosolarcalifornia.ca.gov/equipment/inverters.php>



Huawei lists the CEC efficiency for the two models under review as 98.0%. DNV GL verified the listings and representative test curves shown in Figure 14 and Figure 15 below. An average CEC efficiency of 98.0% for a 25kW or 30kW string inverter places the Huawei inverters among the best regarding inverter efficiency performance.

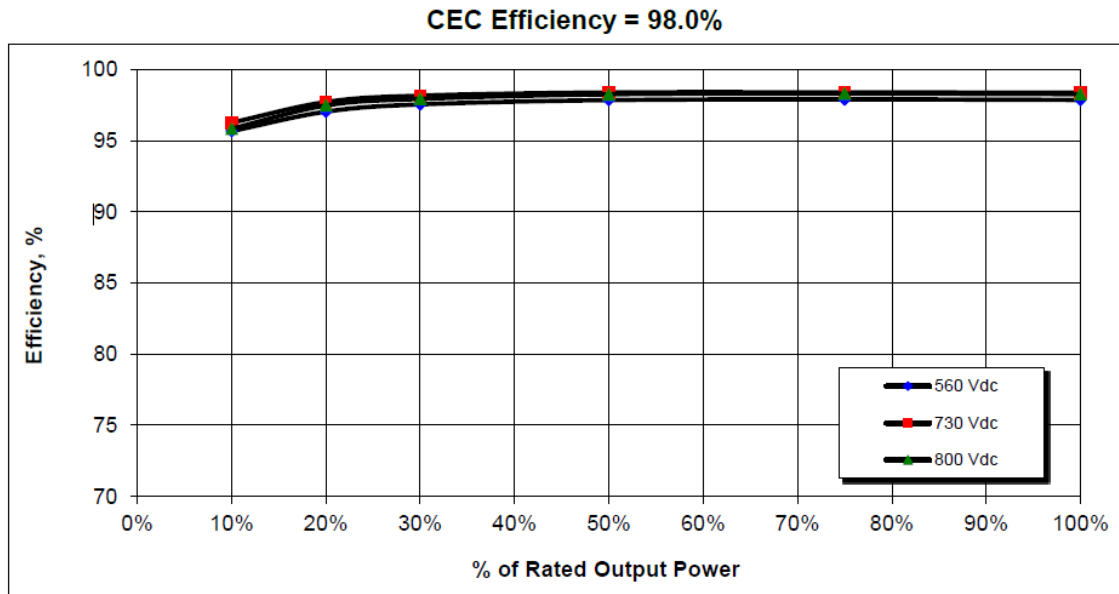


Figure 14. Huawei SUN2000-25KTL-US CEC Efficiency

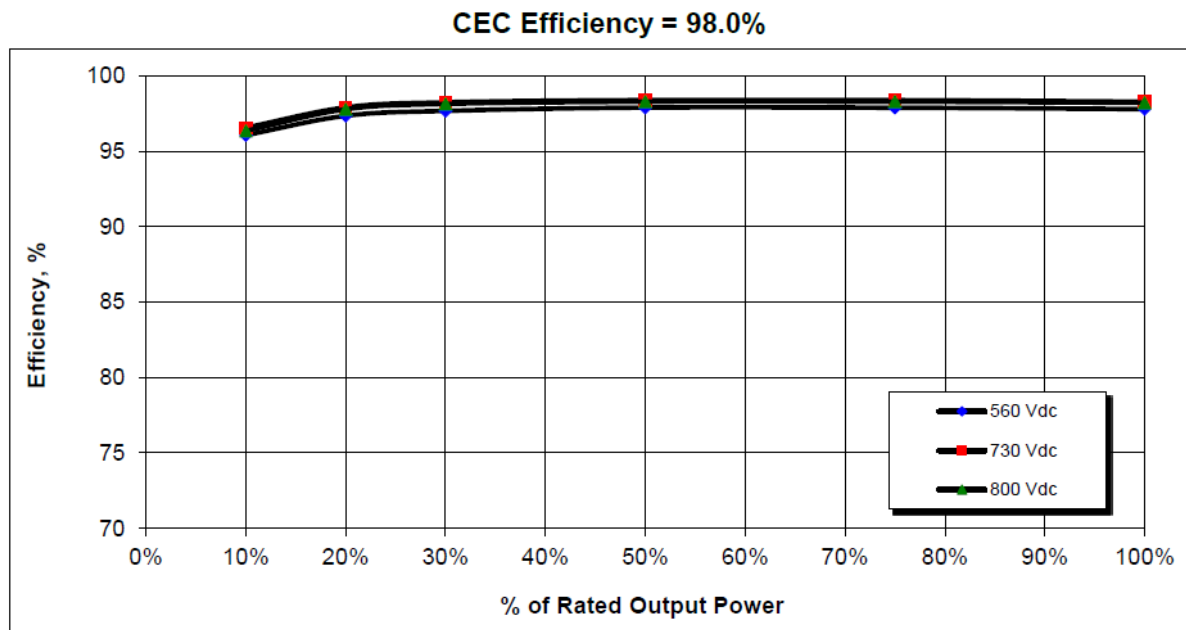


Figure 15. Huawei SUN2000-30KTL-US CEC Efficiency

3.6 Huawei Maximum Power Point Tracking (MPPT)

A key metric contributing to the inverter energy production is the MPPT effectiveness. The MPPT is the algorithm that is implemented in a PV inverter to capture as much energy as possible from the PV array by continuously operating at the highest power level supported by connected modules operating at the solar irradiance and temperature at the time of conversion.

The data sheets for the two models under review indicate a MPPT range of 560 to 850VDC. Huawei states that the inverter can start at a DC voltage of up to 1000 volts. The DC voltage will then be pulled-down to operate within the MPPT range. It should be noted that the data sheet indicates that the inverters can operate down to 200Vdc. Below 560Vdc, the Huawei string inverters will operate off of the maximum power point but details of this operating range were not provided to DNV GL. The DC voltage range should be considered when designing systems utilizing the Huawei PV inverters.

Huawei provided a test report for the SUN2000-33KTL string inverter, an established design within the same inverter family as the two inverter models under review. The MPPT Static Efficiency over all CEC power and voltage levels equaled or exceeded 99.9%. Dynamic MPPT efficiency was 99.9% at a slow ramp rate of 0.5 W/m²/s, dropping to 98.9% at the faster 50 W/m²/s ramp rate.

Huawei provided the data shown in Figure 16. as evidence of the validation of their MPPT algorithm.

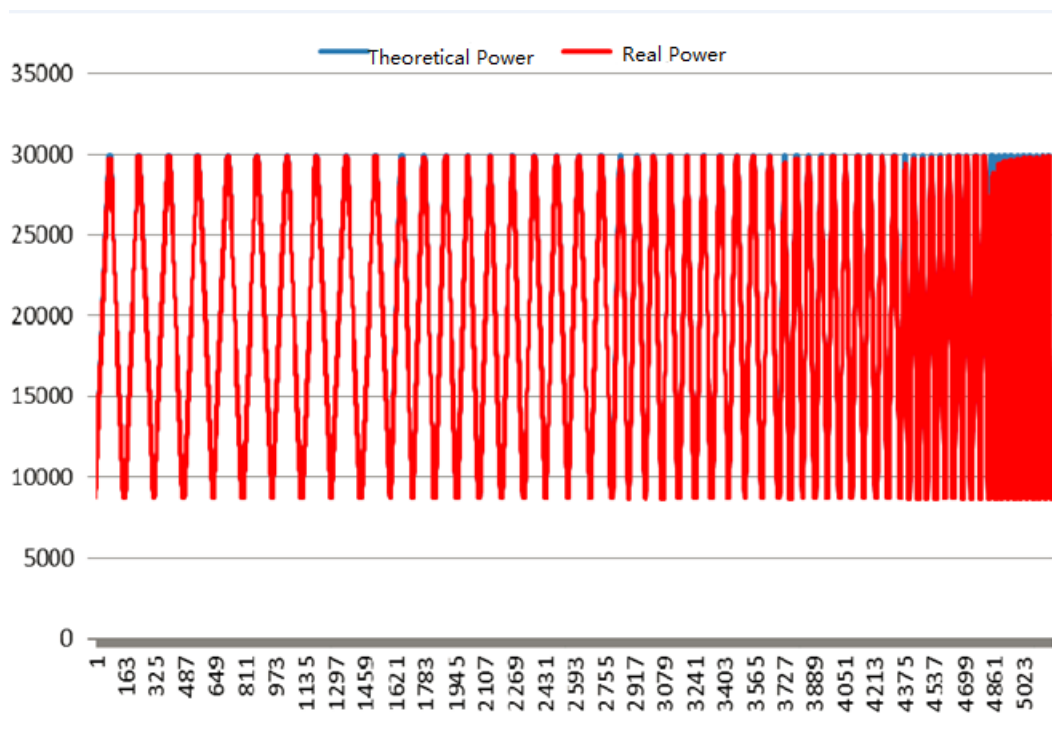


Figure 16. MPPT Dynamic Efficiency Test Data

Further, Huawei provided a Photon test report resulting in an A+ / A+ rating for the 20kW, 3-phase string inverter, which is well above the industry average. A summary of the resultant MPPT and conversion efficiency findings by Photon is shown in Figure 17 below.

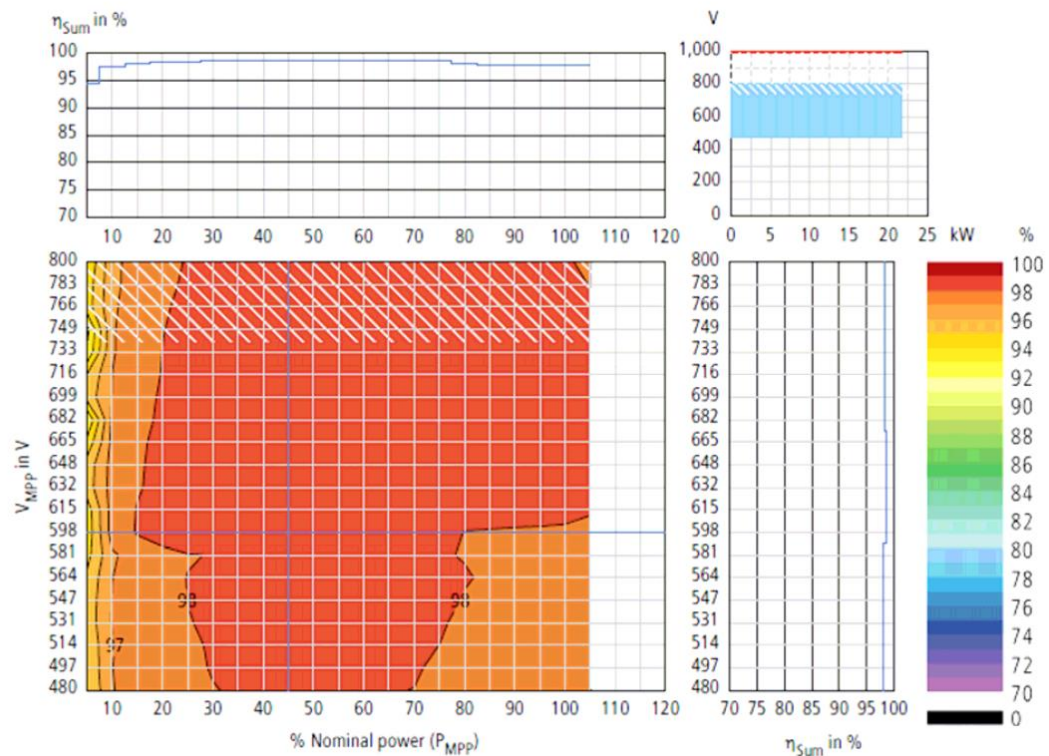


Figure 17. Photon Test Report Results Showing Overall Efficiency of 20kW Product

DNV GL views this MPPT performance positively. The combined efficiencies (MPPT and conversion) support a high level of energy harvest and compare favorably to other products on the market.

4 QUALITY AND RELIABILITY

4.1 Reliability Evaluation

High reliability of PV inverters is critical for the successful operation of PV power plants. Inverter reliability has historically been an issue and is an important focus in the supplier decision making process by PV inverter customers.

DNV GL views achieving inverter reliability as a set of processes throughout the design and operational lifecycle and encompassing three primary facets for completeness:

- Design for reliability
- Reliability testing
- Field reliability history

4.1.1 Design for Reliability

A number of elements go into design for reliability. These include component selection and de-rating, analytical reliability calculations, and failure mode analysis. Additionally, the Engineering processes used to design a new product provide the control gates necessary to assure that design guidelines are met.

The Huawei E2E (End-to-End) Product Development Process includes the R&D Process Framework shown in Figure 18. This design process is a phase gate controlled method for disciplined product development. The Huawei Quality Management System describes and controls the product development processes in detail.

R&D Process Framework

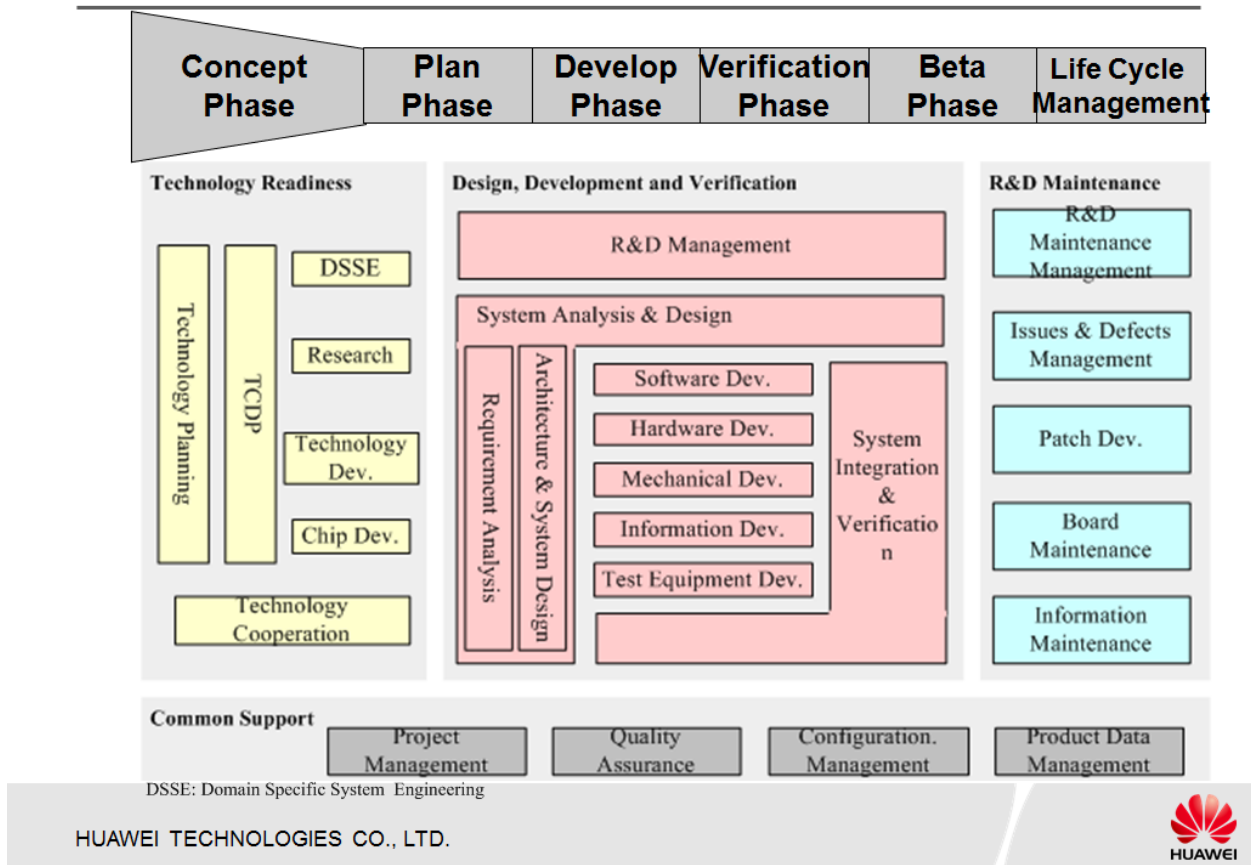



Figure 18. Huawei's R&D Process Framework

The SUN2000-25KTL-US and the SUN2000-30KTL-US are both based on the SUN2000-40KTL international model which has been shipped in significant volume. Compliance requirements and differences in the application of the inverters created the necessity for design changes to the North American model. The new North American models benefit from a breadth of string inverter experience over a limited timeframe in China and Europe predominantly. The changes incorporated for North America constitute new features without extensive field experience (both in terms of volume as well as field run time). These changes include:

- Greater spacings in the power distribution circuit
- Component changes to UL Listed and Recognized parts
- Power de-rating from the 40kW international model to accommodate higher DC to AC power ratios
- Integrated Arc Fault Circuit Interrupter (AFCI) circuit into the inverter design

DNV GL recognizes that when a new model is based on a redesign or modification of an existing inverter, the design process is sometimes altered appropriately to focus on verifying and validating only the specific



design changes. That being said, the field learnings and collected field and laboratory data from the legacy designs should support improved practices when new versions are delivered.

4.1.2 Component Selection and De-rating

In addition to designing for low stress on components, the individual component selection is critical. One area that can have a significant negative impact to the reliability and lifetime of an inverter product is the use of components with known wear-out mechanisms. This typically includes mechanical components such as fans, and components subject to aging such as electrolytic capacitors. DNV GL views the use of natural convection cooling with no cooling fans positively based on the impact on product reliability.

Electrolytic capacitors incorporate a liquid/gel electrolyte that will eventually be lost through evaporation and drying out over time. Both high operating temperatures and repeated temperature cycling exacerbate electrolyte loss, suggesting that inverters can be a challenging application for this type of capacitor. It is the general opinion of DNV GL that electrolytic capacitors can be used in long term reliable inverter products in designs where they are applied with low stress levels. Huawei reports that electrolytic capacitors are used sparingly in their design.

4.1.3 Mean Time Between Failure (MTBF)

DNV GL believes that an important analytical approach for evaluating the reliability of an inverter is to calculate the product MTBF. DNV GL believes that consistently using a rigorous analytical reliability approach is important and that the primary benefit of the MTBF methodology is to identify components that are most negatively impacting the product reliability.

Huawei provided DNV GL the Huawei Inverter MTBF Report. For the calculation, Telcordia SR-332 (parts count method) was indicated to be used. Figure 19 provides the summary sheet indicating the Failures in Time (FIT) Rate and the resulting MTBF in hours. The reference temperature for the MTBF calculation was 40°C, where the average area ambient temperature is expected to be 25°C.

The MTBF Prediction Report reviewed by DNV GL was updated in August, 2015 to include details regarding the stress factors of temperature, voltage and environment. Huawei states that the MTBF calculation is specific to the North American products; however it does not include added components such as the AFCI. DNV GL does view favorably that Huawei makes reliability calculations for the Huawei inverters products.

Total	6717	FIT	$MTBF1 = MTBF0 / (\Pi H * \Pi T * \Pi S * \Pi Q * \Pi E)$
MTBF with Factors	238208	Hours	
Operation Time Factors every day(ΠH)	0.417		
Operation Hours/Day	10	Hours	
Temperature Factors(ΠT)	Table M list		
SR-332 Reference Temperature)	40	°C	
Average area temperature	25	°C	
Stress Factors (ΠS)	Table Q list		
Device quality Factors (ΠQ)	1	Level II	
Environmental Conditions and Multiplying Factors (ΠE)	1.5	GL. Ground, Fixe	
Calculated MTBF (Years)			27

Figure 19. Huawei Inverter MTBF Summary Data

4.1.4 FMEA

Failure Mode and Effects Analysis (FMEA) was one of the first systematic techniques for failure analysis. It was developed by reliability engineers in the 1950s to study problems that might arise from malfunctions of military systems. An FMEA is often the first step of a system reliability study. It involves reviewing as many components, assemblies, and subsystems as possible to identify failure modes, and their causes and effects. For each component, the failure modes and their resulting effects on the rest of the system are recorded in a specific FMEA worksheet. There are numerous variations of such worksheets.

A successful FMEA activity helps to identify potential failure modes based on experience with similar products and processes - or based on common physics of failure logic. It is widely used in development and manufacturing industries in various phases of the product life cycle.

Huawei provided a Design FMEA for the SUN2000-30KTL-US as evidence of their efforts to analyze string inverter failure modes. Within the DFMEA, approximately 100 failure modes were reviewed for severity, probability of occurrence, and the ability to detect or control the failure mode.



4.2 Product Testing

A second critical area for validating and estimating product reliability includes the testing of the components, subsystems and final assembly of the inverter products. This section of the report highlights the data provided to DNV GL in regards to this topic.

4.2.1 Design Verification Testing (DVT)

Huawei has an extensive set of reliability testing laboratories known as the Huawei Global Reliability Center. Inside these facilities there are a host of environmental chambers for Thermal Cycling, Damp Heat, Ultraviolet, Humidity Freeze, Dust, Salt Fog and other testing needs. DNV toured these facilities as part of the site visit and witnessed a number of ongoing tests in the chambers for both inverter and other product devices. The facilities are shared across multiple product lines, but highlight product reliability testing capabilities in house. The below outlined tests were performed in the Huawei Global Reliability Center.

Huawei provided the following documentation as evidence of their Design Verification Process for inverters:

- Halt Test Report
- Thermal Performance Test Data (models SUN2000-33KTL and SUN2000-40KTL)
- MPPT Test Data (models SUN2000-33KTL and SUN2000-40KTL)
- Power Quality Measurements

Huawei provided the documents listed above as evidence of Design Verification Testing, however a summary document that details the verification of all features and specifications was not provided for review.



Figure 20. Huawei Test Chamber

4.2.1.1 Highly Accelerated Lifetime Testing (HALT)

Highly Accelerated Life Testing (sometimes referred to as HALT) is a method of testing electronic equipment in a relatively short amount of time to determine that it will have reliable performance over its expected operating life. This is done through the use of test chambers and techniques to apply stresses on the components that are beyond those that it is expected to normally encounter. This typically includes high and low temperatures, temperature ramping, and vibration. The equipment is exposed to the high levels of stress and then issues are addressed as they are found. DNV GL believes that HALT testing is a critical part of the development process for a highly reliable product.

The document, "SUN2000 V200R001C02 HALT" describes the following four HALT stress categories performed on three samples of the SUN2000-30KTL-US model:

- Temperature step stress test
- High temperature step stress test
- Vibration step stress test
- Comprehensive stress test

The chamber used to perform the HALT is shown in Figure 21. DNV GL views the performance of the HALT on the entire inverter unit positively. Note that the North American specific features did not go through HALT testing as it was done on the international model solar inverter. This includes the AFCI and other product changes. DNV GL recommends that the final “-US” line of inverters be HALT tested and any improvement opportunities found be implemented.



Figure 21. HALT Test Chamber

DNV GL visited the Huawei Global Compliance & Testing Center (GCTC). Testing there was performed for HALT and performance of the solar string inverters including such items as high altitude environment testing. Figure 22 shows a photo of the significant amount of test equipment at the GCTC and Figure 23 shows an environmental chamber as an example. The Huawei GCTC facility is quite impressive.



Figure 22. Huawei GCTC Test Equipment



Figure 23. Huawei GCTC Environmental Test Chamber

4.2.2 Field Failure Analysis

The Failure reporting and Corrective Action System (FRACAS) is Huawei's primary tool for identifying root cause for field failures and investigation. DNV was shown an example of how Huawei uses this system for driving to root cause on a known manufacturing defect which resulted in field issues. The root cause of the issue was determined and multiple changes to product handling, tooling, and manufacturing were implemented to drive the defect out of the system design. DNV supports the use of such a system for identifying root cause and driving process changes into implementation.

4.3 Regulatory and Standards

4.3.1 Applicable Standards

For the North America markets, the UL-1741 Standard is the "Standard for Safety - Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources." It is based on the IEEE 1547 "Standard for Interconnecting Distributed Resources with Electric Power Systems." A UL1741 listing is generally required for all PV inverters that connect to the utility grid in North America and employed in residential or commercial sized systems. Certification to this standard involves a series of design inspections and tests. Especially challenging are the Anti-Islanding, grid protection, surge, and EMI testing requirements.

Below in Table 3 are the major testing standards for North America.

Standard	Title
UL 1741	Standard for Safety Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources
IEEE 1547	Standard for Interconnecting Distributed Resources with Electric Power Systems
CSA 22.2N. 107.1-01	Safety Requirements for General Use Power Supplies (Canada)

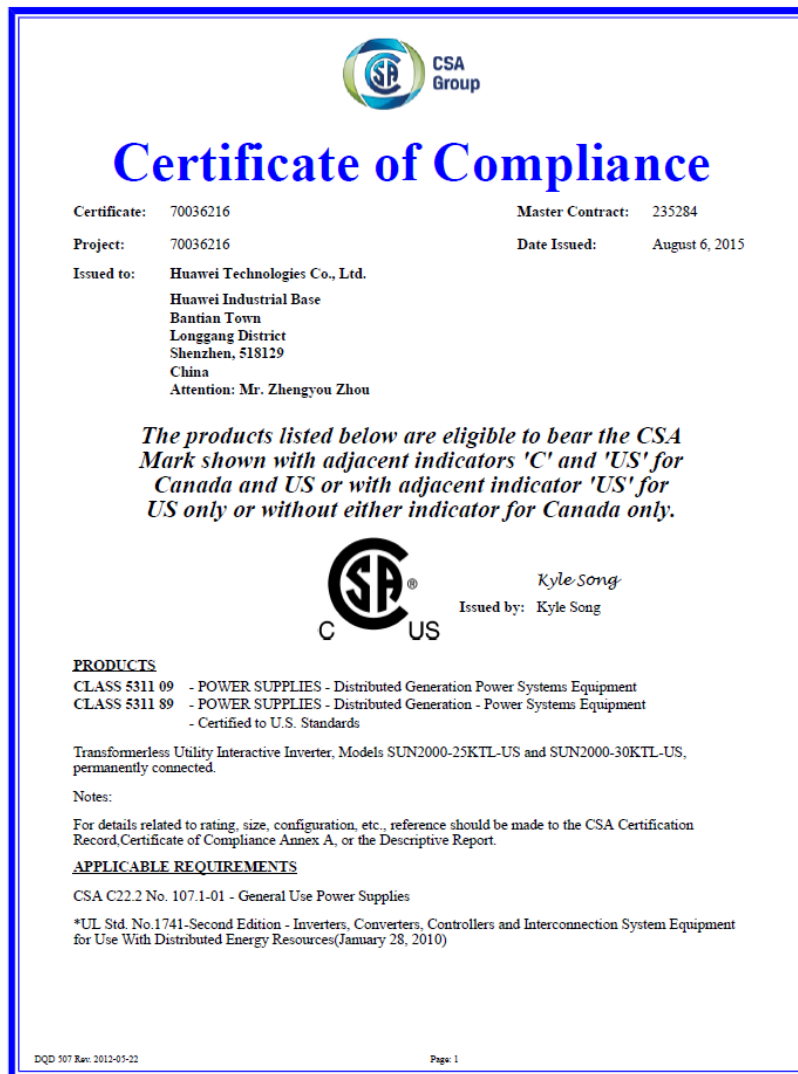
Table 3. Testing Standards for North American

For Huawei's international inverter models, the list of applicable standards is extensive. Note that the North American models are not tested to all of these standards; however the Huawei international inverters models combined with the North American models have been evaluated against the following standards:

EN61000-6-2, EN61000-6-3, EN61000-3-11, EN61000-3-12, EN/IEC62109-1, EN/IEC62109-2, VDE-AR-N4105, VDE0126-1-1, BDEW 2008, G59/3, AS4777, NB/T 32004-2013, UTE C 15-712-1, C10/11, IEC61727, IEC62116, RD1669, EN50438, MEA 2013, PEA 2013, GB/T 19964-2012, UL 1741, UL 1699B, IEEE 1547, CSA C22.2 #107.1-01, FCC Part 15

4.3.2 Regulatory Test Reports and Certifications

DNV GL reviewed the Descriptive Report and Test Results written by CSA and the Certificate of Compliance to the applicable standards for North America (August 6, 2015) as shown below in Figure 24.



The image shows a 'Certificate of Compliance' from CSA Group. At the top center is the CSA Group logo. Below it, the title 'Certificate of Compliance' is written in a large, bold, blue font. The certificate contains the following information:

- Certificate:** 70036216
- Master Contract:** 235284
- Project:** 70036216
- Date Issued:** August 6, 2015
- Issued to:** Huawei Technologies Co., Ltd.
Huawei Industrial Base
Bantian Town
Longgang District
Shenzhen, 518129
China
Attention: Mr. Zhengyou Zhou

Below the issued to information, there is a paragraph in italics: *The products listed below are eligible to bear the CSA Mark shown with adjacent indicators 'C' and 'US' for Canada and US or with adjacent indicator 'US' for US only or without either indicator for Canada only.*

Below this paragraph is the CSA Mark logo, which consists of a circle containing the letters 'CSA' and the letters 'C' and 'US' outside the circle. To the right of the logo, the name 'Kyle Song' is written in a cursive font, and below it, 'Issued by: Kyle Song' is written.

PRODUCTS

- CLASS 5311 09 - POWER SUPPLIES - Distributed Generation Power Systems Equipment
- CLASS 5311 89 - POWER SUPPLIES - Distributed Generation - Power Systems Equipment
- Certified to U.S. Standards

Transformerless Utility Interactive Inverter, Models SUN2000-25KTL-US and SUN2000-30KTL-US, permanently connected.

Notes:

For details related to rating, size, configuration, etc., reference should be made to the CSA Certification Record, Certificate of Compliance Annex A, or the Descriptive Report.

APPLICABLE REQUIREMENTS

- CSA C22.2 No. 107.1-01 - General Use Power Supplies
- *UL Std. No.1741-Second Edition - Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources(January 28, 2010)

At the bottom left, it says 'DQD 507 Rev: 2012-05-22'. At the bottom right, it says 'Page: 1'.

Figure 24. NRTL Certificate of Compliance to UL1741 and IEEE1547

4.4 Quality Systems Evaluation

All top tier inverter manufactures employ Quality Management Systems (QMS) to ensure industry accepted management, product development, and manufacturing practices. DNV GL looks closely at the level of certification and QMS systems implemented as a key indicator of the potential quality and reliability of the products being reviewed.

4.4.1 Quality Systems Overview

The Huawei quality program consists of three fundamental elements:

- Huawei Quality Management System
- E2E Product Development Process
- Huawei Agile Software Development

4.4.2 Huawei Quality Management System

Huawei has implemented and maintains a Quality Management System as depicted in Figure 25, which fulfils the requirements of ISO 9001:2008, TL 9000 R5.0/R5.0 and ISO 14001:2004. The ISO 14001 standard covers the environmental management systems. The certificates are shown in Figure 26. Huawei indicated that the most recent annual ISO 9001 audit had taken place in mid-August 2015 and that there were a number of non-conformances (as is typical for this type of review) and the audit was successfully passed.

Architecture of Quality Management System

A professional QMS has been built covering core business fields to assure quality of products and services.

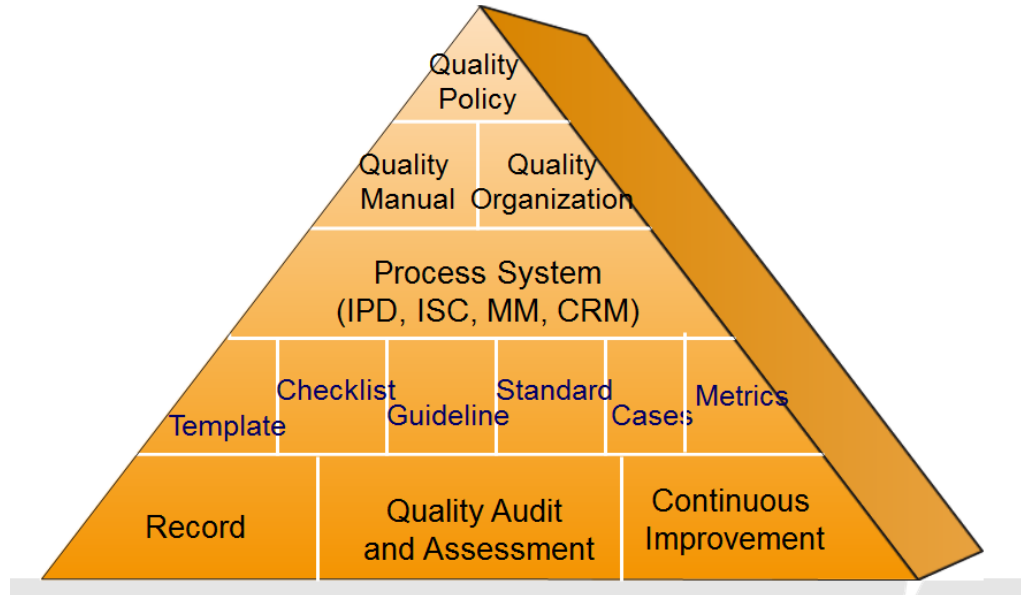


Figure 25. Huawei's Quality Management System Architecture



Figure 26. ISO 9001, TL 9000, ISO 14001 and OHSAS 18001 certificates

One unusual aspect of the Huawei organization is that the Quality department reports to Manufacturing management structure. DNV GL notes that it is best practice to separate this reporting to avoid conflicts of interest.

4.4.3 E2E Product Development Process

The Huawei End-to-End (E2E) Product Development Process encompasses all aspects of product development from the initial Strategy Planning to managing returns in support of the resulting fielded products. The chart in Figure 27 illustrates the coordination of the various processes addressed by Huawei's development process.

End-to-end Processes System Architecture

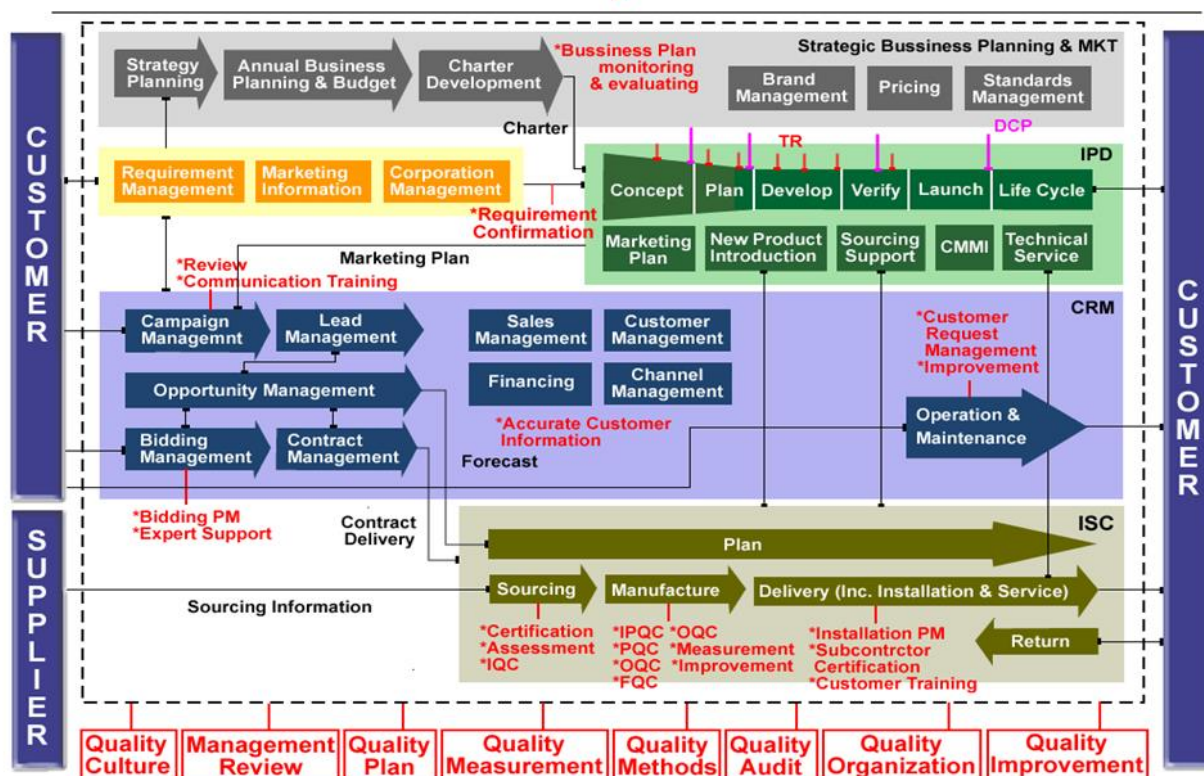
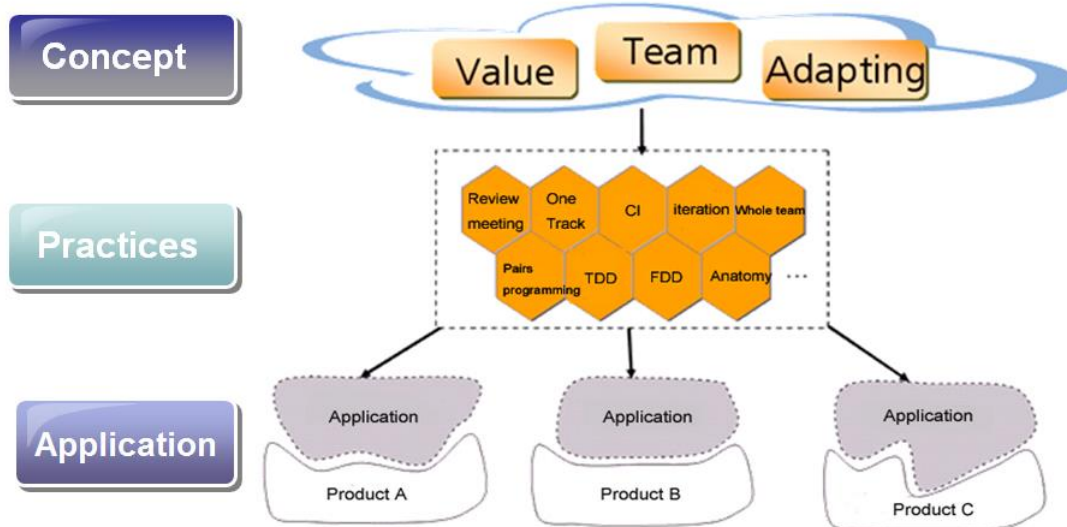


Figure 27. E2E Product Development System Architecture

4.4.4 Huawei Agile Software Development

Huawei has developed an iterative software development style as illustrated in Figure 28.

Our Understanding: Concept + Practices + Applications



- ✓ **Concept is the core of agile**
- ✓ **Practices is the experience accumulated**
- ✓ **Application is using the experience flexibly according to the project's actual situation**

Figure 28. Huawei's Approach for Agile Software Development

4.5 Product Field History

The data shown in Figure 29 through Figure 32 below summarize the Huawei's string inverter field history, starting in January of 2014. The histories of both the V1 series and the V2 series are over-laid in Figure 29 and Figure 30.

Figure 29 shows the high number of string inverters shipped over the first 18 months of deployment, with the V1 quantity exceeding 160,000 units while the V2 series was approaching 40,000 units as of June, 2015. This chart shows both a steady and impressive ramp-up in fielded units while at the same time highlighting the limited time in operation for both V1 and V2 series inverters. Also of interest is the converging of V1 and V2 cumulative failure rates to approximately 0.49%.

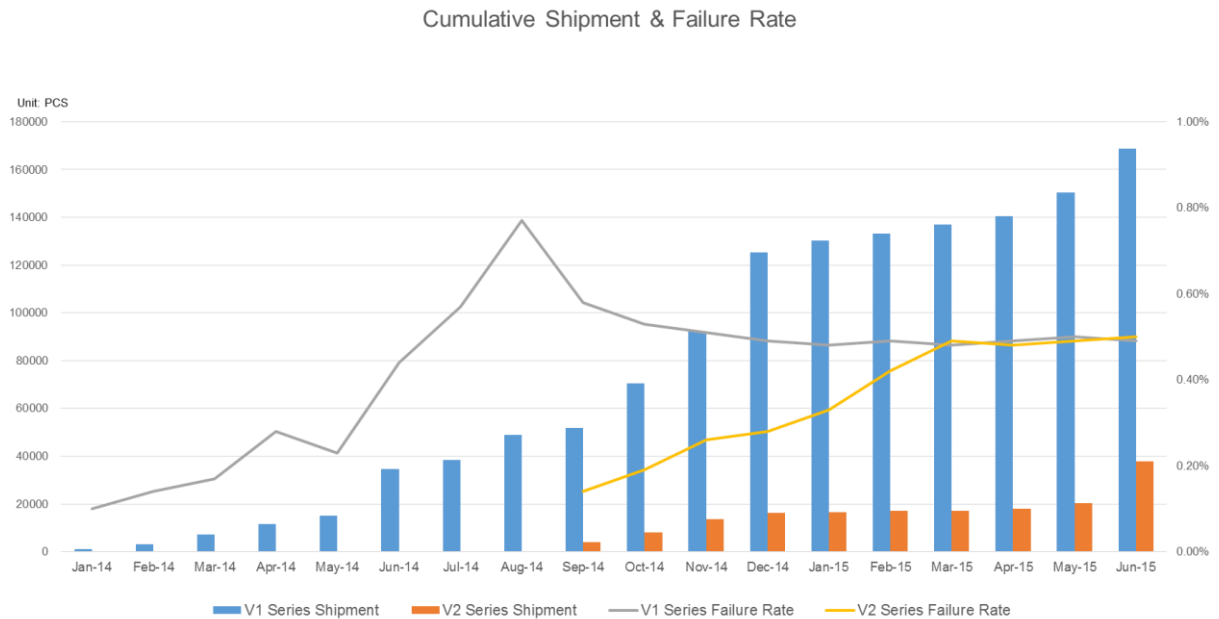


Figure 29. Cumulative Shipments and Failure Rates for V1 and V2

Figure 30 shows the Deployment Failure Rates for both V1 and V2 version, not on a cumulative basis, but rather a monthly failure rate. The data in this chart indicate that Huawei has some installation and/or product issues, and is now experiencing less short term failures of installed units.

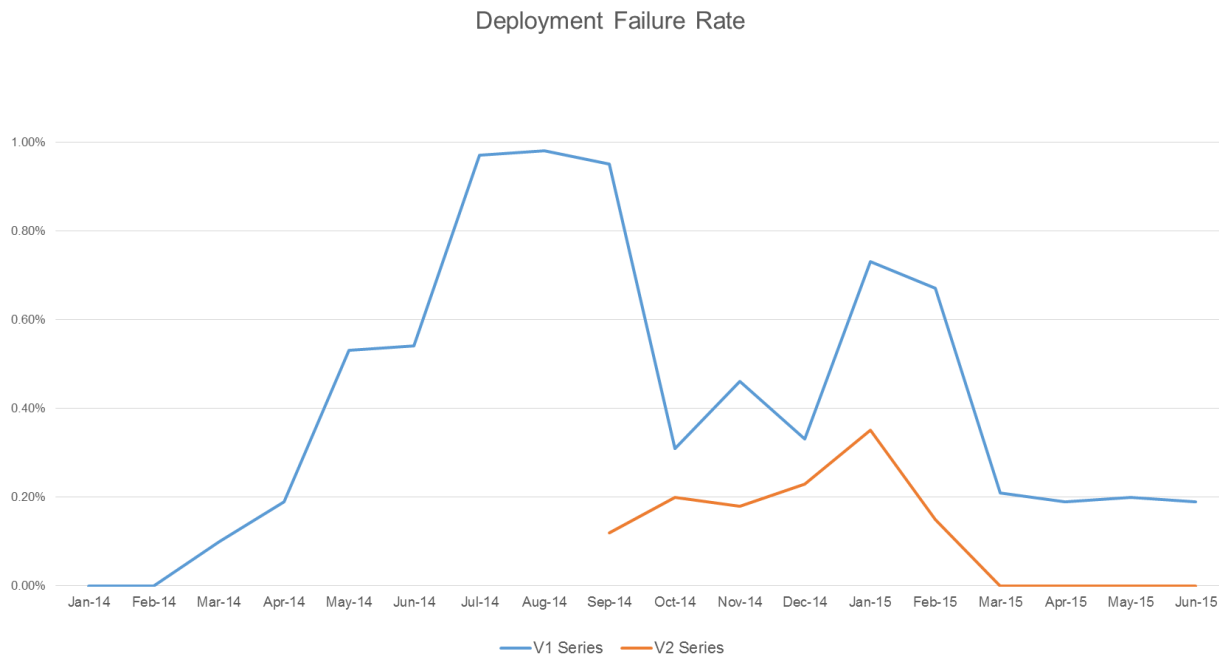


Figure 30. Deployment Failure Rate for V1 and V2

The Pareto Chart in Figure 31 for the V1 Series reveals installation issues as the primary failure. Such problems are often addressed by more detailed documentation and minor design changes to improve the installation process. Since the failure rate for V1 shown in Figure 30 improved over time, it is assumed that these installation issues were address and improved by Huawei, however specific information on this topic was not provided.

One improvement that is noted is that the LCD display has been removed from the V2 units.

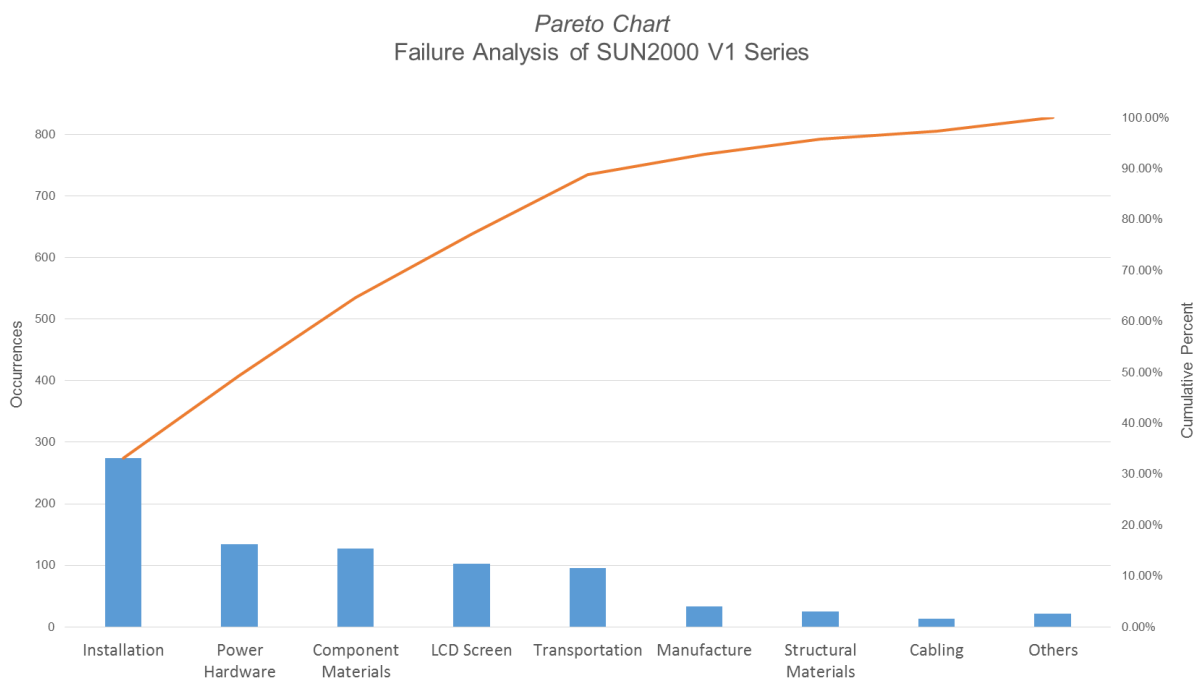


Figure 31. Pareto Chart of V1 Series Field Failures

The Pareto Chart in Figure 32 for the V2 Series exhibits less installation problems, with problems with component materials causing the most field failures. Since the V2 series was introduced later than the V1, the V2 series appear to have benefitted from the V1 installation experiences.

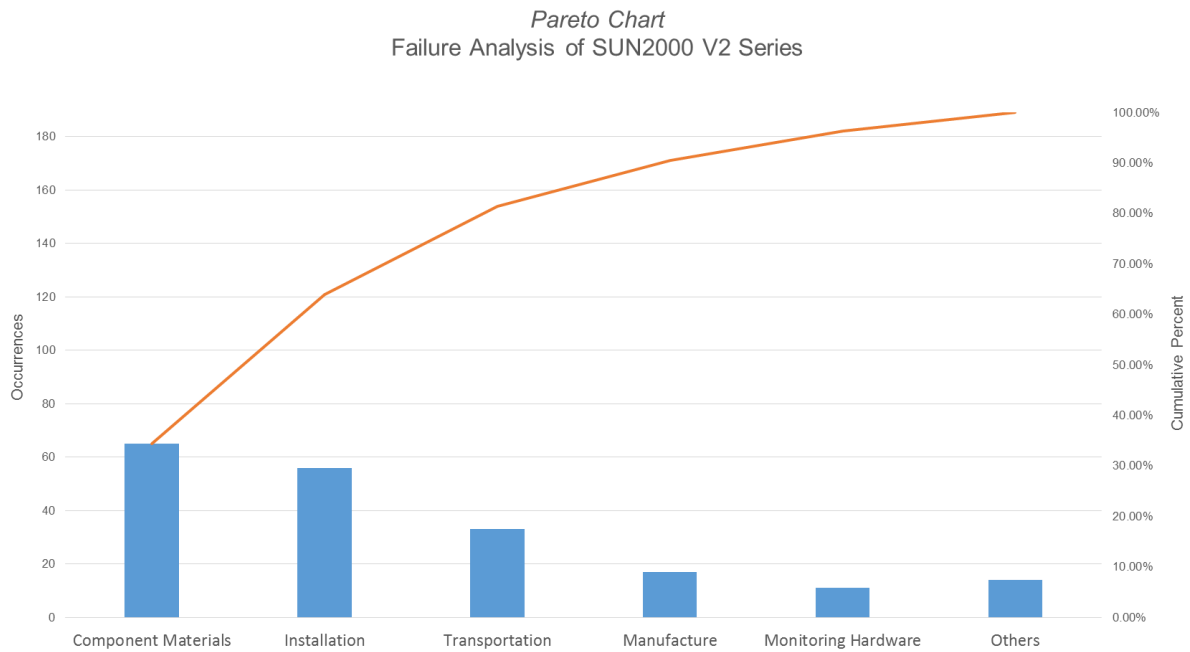


Figure 32. Pareto Chart of V1 Series Field Failures

To summarize the string inverter field experience represented in these four charts, the volume of inverters fielded is more than adequate to gain valuable initial product reliability data. The average duration of field operation for this entire group of inverters is only about nine months, which is inadequate to measure long term inverter reliability. The rate of failures since introduction in January 2014 is acceptable, representing installation problems and infant mortality. It does appear that installation problems were, and may continue to be an important area for potential reliability improvements. The charts do indicate a trend towards improving reliability over this relatively short term of field history.

DNV GL views positively that Huawei monitors and records this data. It is also noted that the SUN2000-25KTL-US and SUN2000-30KTL-US products are not included in these data; rather it is for the similar international products. The North American products are based from the V2 design.

5 MANUFACTURING FACTORY VISIT

5.1 Overview

The primary manufacturing facility for the Huawei inverter products is located in Shenzhen China. This set of facilities encompasses the assembly for the Huawei inverter product lines from PCB through to complete inverter products. Huawei indicated that there are approximately 20,000 employees working at this location. Huawei leverages a vertical integration structure for these inverter devices, manufacturing and assembling from the component level up through the final working inverter products. They also informed DNV GL that they make use of contract manufacturers as needed to support volume needs. Huawei has an automated procurement system for warehouse management, incoming quality inspection and test facilities, the manufacturing lines, and final test and troubleshooting locations inside a common set of buildings on campus. An overview of the campus layout is shown in Figure 33 below.

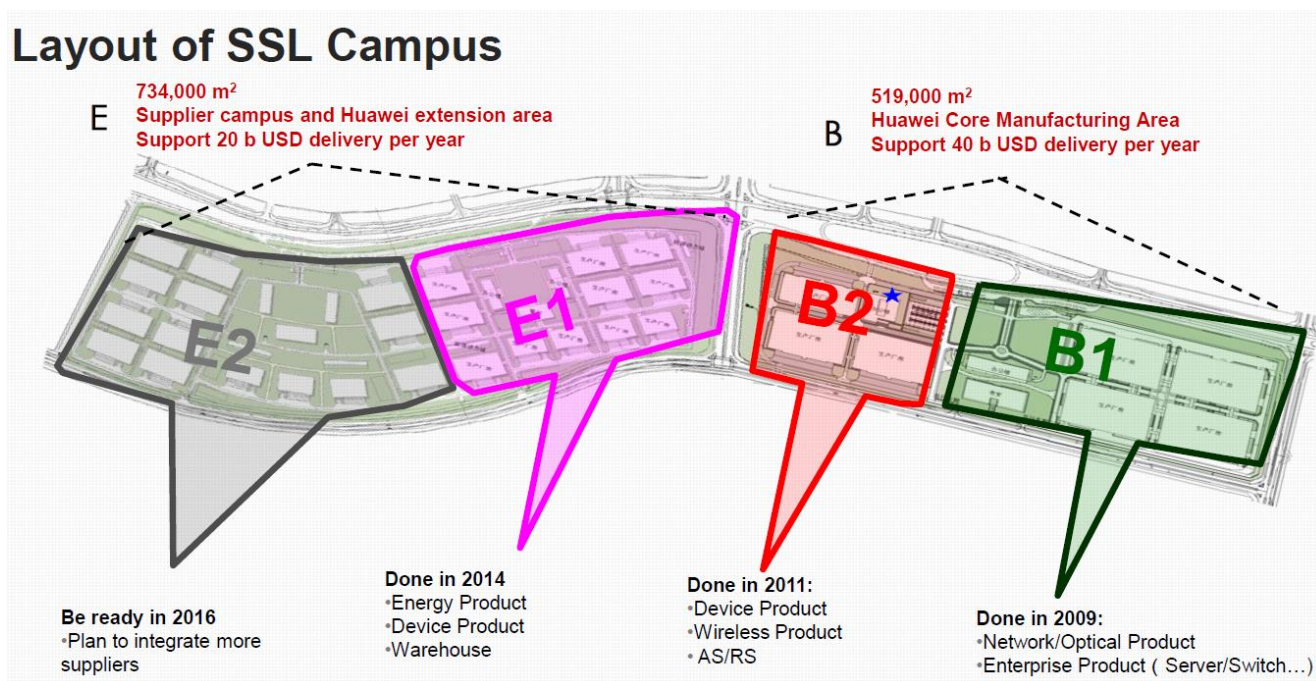



Figure 33. Huawei Factory Campus Layout

It is important to note that DNV GL only visited the Huawei factory. After the visit, Huawei indicated that they use a significant amount of contract manufacturing for their solar inverter products. In fact, a majority of the Huawei solar inverters are manufactured by outside contract manufacturers. DNV GL did not visit these facilities.



The key processes for the production of a PV inverter by Huawei are:

- Incoming Inspection
- Printed Circuit Board Assembly (PCBA)
- PCBA Test
- System Assembly
- System Test
- Packaging and Delivery

The Huawei inverter manufacturing areas can be split into three separate distinguishable portions: Incoming quality inspection and test, PCB assembly, and final assembly and test of the completed inverter systems.

The production of the SUN2000-25KTL-US and SUN2000-30KTL-US products began volume production in September 2015. DNV GL viewed the production of SUN2000-33KTL units during the factory visit.

5.2 Incoming Quality Inspection and Test

Huawei has a set of labs devoted to incoming product inspection and test at the manufacturing facility visited by DNV GL. These laboratories are utilized for the PV inverter components as well as other Huawei products. The incoming quality inspection leverages an organized system for assuring incoming products are appropriately managed. Samples of incoming parts are inspected by the quality teams, and in certain cases are tested in the quality assurance laboratories. Non-conforming products are physically separated and labeled with color coordinated sheets. The quality team can take an x-ray of components (capacitors, resistors, integrated circuits), as well as perform physical tests to verify product conformance to specifications. Additionally, reliability testing of select samples of incoming products is performed in these laboratories. This includes: cabling assemblies, integrated circuits, capacitors, optical isolators, among others. The quality laboratories include a number of environmental chambers dedicated to evaluating incoming parts and components. DNV GL views the incoming material quality capabilities of Huawei to be above industry standard. A picture of one area of the incoming quality laboratories is shown below in Figure 34.



Figure 34. Quality Inspection Laboratory

There were a number of the quality inspection machines in use during the time of the DNV GL factory visit. An image showing some of the inspection equipment is included below in Figure 35.



Figure 35. Incoming Supplier Quality Inspection Equipment

Although a great deal of incoming inspection is still completed manually, the processes and procedures for handling materials were in place to promote a good tracking system for conforming and non-conforming incoming products.

5.3 Inverter PCB Assembly

The inverter PCB assembly area was shared with other Huawei products, and consisted of multiple lines for production volume purposes. The material handling of components is automated from warehouse through to the surface mount (SMT) and through-hole assembly lines. Conveyor systems enable the flow of incoming components, and the assembly is highly automated. An image of the PCB manufacturing area is shown below in Figure 36.



Figure 36. PCB Assembly Area

Huawei utilizes sound PCB assembly practices including optical inspection (AOI), and modern manufacturing tools. The PCB assemblies are serialized and scanned at multiple stations to better track serial defects and non-conforming products. Additionally, there were many visual tools on display for product conformance, throughput, defect rates, as well as operator and employee mood status. The facility was well organized, orderly and appeared to be following lean manufacturing techniques.

5.4 Inverter Assembly

The inverter assembly, burn-in, and final test areas were clean, well illuminated, and organized. This process includes manual assembly processes. There were visible work instructions displayed on monitors in some of the work stations, however there were non-uniformities from station to station, and approximately half of the assembly stations had no access to the visual operations instructions. All employees were donning appropriate electrostatic discharge (ESD) prevention attire, and the facility was set-up appropriately to ensure all employees tested their ESD gear prior to entering the facility. Bin systems function as storage for sub-assembly preparation, and were co-located with the station operators. New employees are assigned a mentor for the first 3 months of employment, and graduate with a certificate of approval. A photo of the inverter assembly area is shown Figure 37.



Figure 37. Inverter Assembly Area

Empty enclosures enter the line and components and sub-assemblies are added in sequential operator stations. The power switching devices are installed using thermal grease compound applied via a physical screen and manual application. The screen is intended to control thermal compound thickness, resulting in consistent and uniform thermal transfer from the power switching device to the heat sink. A keyed screen could improve the physical location at which the compound is applied, as it appeared non-uniform from product to product (not centered below switching device). The power switching devices were mounted leveraging an electrically powered screwdriver with torque setting. The devices were secured to the heat sink and torque calibration procedures were in place for validating torque settings on the tool (Huawei informed DNV of once per day calibration check). The torque for the power semiconductor devices was checked by the next operator. That verification torque wrench was indicated to be formally calibrated once per year and checked every two weeks. DNV GL suggests more frequent calibration of the equipment for this critical connection. The circuit board and power connections are made in sequential operation stations and ferrules were appropriately crimped and used where necessary. The general assembly of these inverter products followed good manufacturing practices, with the few exceptions highlighted above.

5.5 Inverter Test

Following inverter assembly, the inverters are transitioned into test stations prior to being subjected to elevated temperature “burn in.” There are a number of tests performed at the inverter testing stations including an air test (IP 65 enclosures), as well as a host of functional tests (version control, digital signature, user interface, and shutdown sequence). The testing stations have a suite of programs which can be selected based on end interconnection requirements for the host of final installation locations (Germany, Spain, United States, etc.) The product serial number is scanned as a part of this testing process. An image of one of the testing stations is shown below.



Figure 38. Inverter Testing Station

An additional test performed by Huawei on the solar string inverters is a test of the sealing of the enclosure. The unit is pressurized with air and it is monitored to detect if there are any leaks. DNV GL views this test positively and highlights it as an example of thorough product testing by Huawei.

Sub-assemblies to the PCB level are serialized and provide a means for tracking serial defects. Cabling and cable assemblies were not serialized and as such would be more susceptible to exposure if a defect were found. For products which “fail” the inverter testing process there exists a separate room where technicians and engineers can trouble shoot the products. There were a basic set of engineering tools to accommodate the escalation of non-conforming products in the troubleshooting laboratory.

5.6 Inverter Burn In

Huawei utilizes 2 large environmental chambers to provide elevated ambient temperature “burn-in” of the manufactured inverter products. Each chamber can handle 48 three phase string inverter units per burn-in cycle. The ambient temperature inside the thermal chambers is set to 50°C and the units are operated at 43 Amps output current for 4 hours. An image showing one of the environmental chambers for this testing is shown in the image in Figure 39 below. DNV GL views positively the Huawei use of burn-in.




Figure 39. Inverter Burn-In Environmental Chamber

Following the “burn-in” the units are sent to final test to receive the production line set of tests for compliance with jurisdictional requirements. Control limits for the test criteria were not scrutinized as a part of this DNV GL factory visit; however entry of the tracking details showing sub-assembly and serialized product numbers was validated as part of the site visits. This documentation of the serialized components would allow for Huawei to understand scope and breadth of the impacted units if a serial defect was found in the manufacturing process or later in the field.

5.7 Manufacturing Capacity

Huawei instructed DNV GL that the manufacturing capacity of the current facility would support 30,000 inverters per month. The capacity appears to be constricted by the number of samples which could pass through the burn-in process in the environmental chambers as for each 8 hour shift, a total of 192 inverters



(48 per chamber with 2 chambers) could be evaluated. At five days per week, and with three 8 hour shifts this would result in 11,520 units per month (3X5X4X192) approximately one third of stated volume. At the time of this factory visit there were additional inverter lines being constructed with designs mirroring the existing manufacturing lines. Further, the current facility is large enough to accommodate multiple additional lines and additional environmental chambers from a capacity standpoint. DNV GL did not evaluate if there was sufficient power available to accommodate the manufacturing expansions.

Huawei reports their total inverter capacity at 1.5GW per month. This capacity represents the combination of three manufacturing facilities, including two contract manufacturing locations. The contract manufacturing facilities, Foxconn (capacity of approximate 0.67 GW per month), and Yangtian (capacity of about 0.67GW per month), were not visited by DNV GL, and therefore the manufacturing and quality systems in these two factories are not addressed in this report.

DNV GL views favorably the Huawei manufacturing facility that was visited and the manufacturing processes that were reviewed. Huawei demonstrated good process maturity and employs top level equipment.

6 PRODUCT SUPPORT

6.1 Service Infrastructure Evaluation

Huawei has established a world-wide service organization with a presence in more than 170 countries. The chart in Figure 40 shows the extent of the service organization. Huawei's service infrastructure for international communications and information products is extensive.

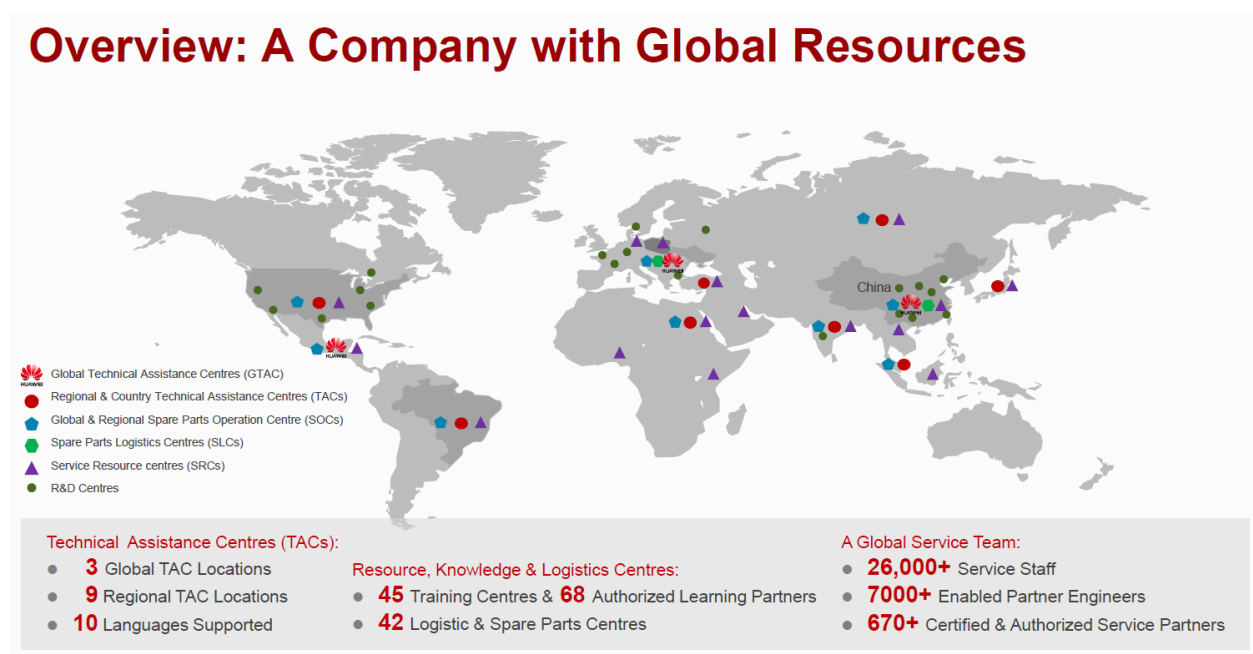


Figure 40. Huawei's Global Service General Capabilities

Huawei provided the following Figure 41 that indicates the extent of their general field service capabilities in the US.

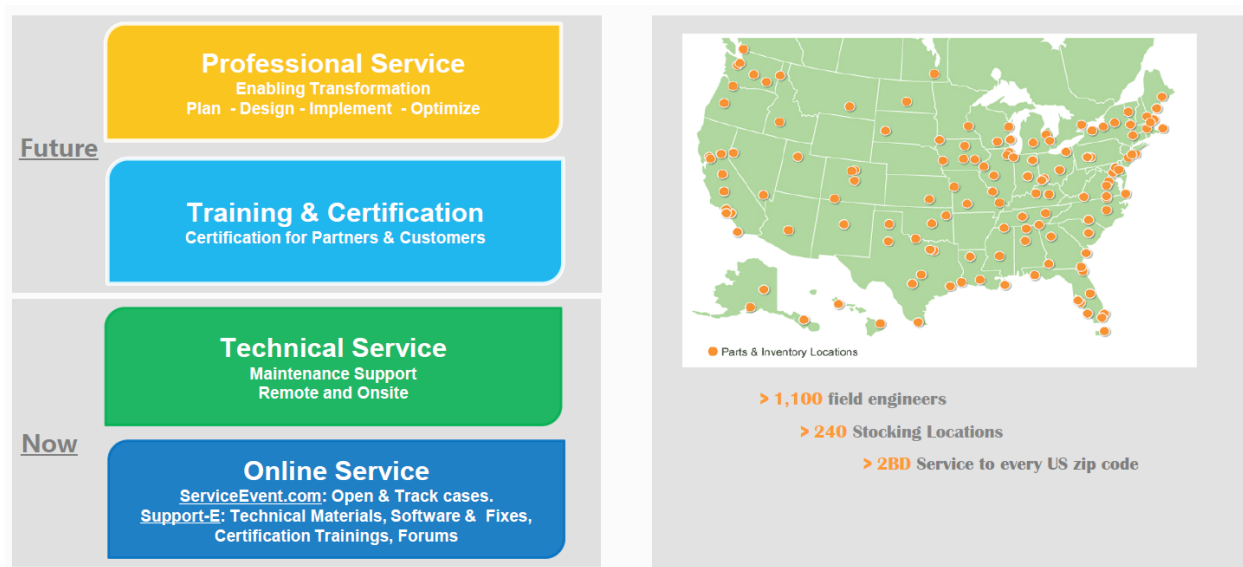


Figure 41. Extend of Huawei General Services in the USA

Regarding the SUN2000 inverter products, Huawei has a dedicated service organization to support the process shown in Figure 42.

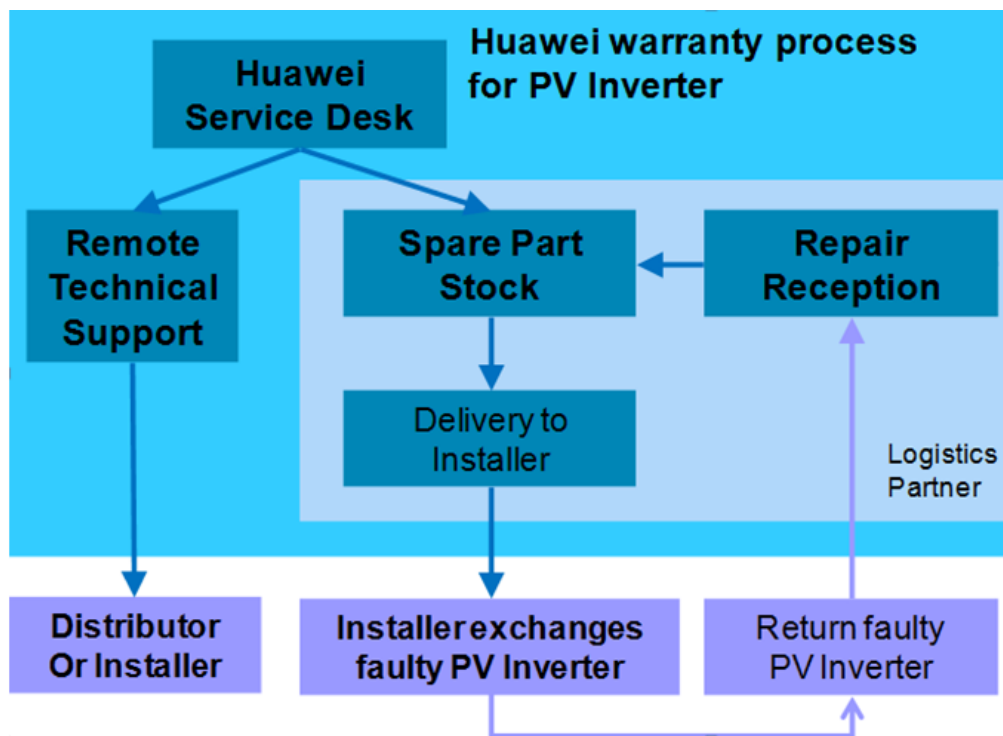


Figure 42. Flow Chart of Huawei's Warranty Process for PV Inverters

The details of where and how to contact Huawei in the US are shown in Figure 43. Huawei states that 110 employees have completed inverter training, with 20 employees identified as highly trained.

Huawei Technical Assistance Center in US

1 877-9 HUAWEI and email: TAC.USA@Huawei.com

The Essential Technical Assistance Center (TAC) provides Huawei with comprehensive TAC services.

Essential TAC Overview

- Primary Site Mechanicsburg PA
- Secondary Site in Andover MA
- Staffed 24x7x365
- Customer web portal for real-time visibility of service event status

Huawei Program

- Validation of Support Entitlement
- Level 1 Help Desk - Huawei trained agents
- Level 2 & 3 Help Desk in partnership with Huawei
- Field Engineer Dispatching
- Part Ordering and Dispatching



Figure 43. Technical Assistance Centers in the US

6.2 Warranty Evaluation

Huawei offers a standard 10 year string inverter warranty which covers replacement in the event of a hardware failure. The 10 year term of this warranty is consistent with the industry average. It was indicated that the warranty can be extended in units of 5 years for up to 25 years. The warranty period for the Smart Logger is only 2 years. The Huawei warranty includes 9hr/5 days a week of technical service with online support. Huawei's commitment is to ship a replacement inverter within two business days of the confirmation of the customer's service request. The customer is responsible for shipping the failed unit back to Huawei within 15 days. Huawei indicated that the replacement units would be stocked at their warehouses in the US.

The warranty commits that the replacement unit provided by Huawei will be functionally equivalent (feature, function, fit compatible, default software version) to the customer's defective unit.

There is a disclaimer with a list of items that are not covered by the Huawei warranty. This includes that the warranty does not cover "failure to operate Huawei-made equipment in compliance with the operation manual of the equipment." DNV GL recommends reviewing this list and considering these restrictions in the evaluation of the warranty. The string inverters are not considered field repairable, and as shown in Figure 42, all in-warranty units are returned to the factory for repair or replacement. Inverters outside the warranty period will be replaced by new inverters, at the owner's expense. This should be considered by inverter owners when making long term inverter warranty and maintenance decisions.

6.3 Product Manuals

DNV GL was supplied with the Huawei SUN2000-(25KTL, 30KTL) - US Quick Installation Guide. This document was reviewed by DNV GL and found to be adequate for the installation and initial start-up of the string inverter, and generally similar in quality to other leading PV industry inverter installation guides products.

The US Quick Installation Guide refers to the User Manual. The 105 page User Manual provides more complete information in an easy to read format, which includes multiple illustrations and diagrams. One feature that is rather unique for the Huawei string inverters is that the inverters can be connected to 480 VAC – 4 wire (3 phases and neutral) or 3 wire (3 phases with no neutral connection.)

7 EXAMPLE INSTALLATIONS

DNV GL visited two PV plants implementing Huawei string inverters, one on the Huawei solar inverter manufacturing facility, and the other at Midea Air Conditioning Company in Guangdong province, China. At each site location DNV reviewed the installation specifics as well as the operational status of Huawei the string inverters. A summary of the findings is listed below.

7.1 Midea PV Plant

The Midea PV plant has a nominal ac output power rating of 7,700 kVA with quantity 30,360 Nampo 255 watt PV modules installed on five separate industrial rooftops. There are 276 total Huawei SUN2000-28KTL 3-phase string inverters installed at this facility. Each inverter had 5 strings of 22 PV modules connected on the DC inputs. The installation of the plant took place in May of 2014. An image overview of the PV plant is presented in Figure 44.

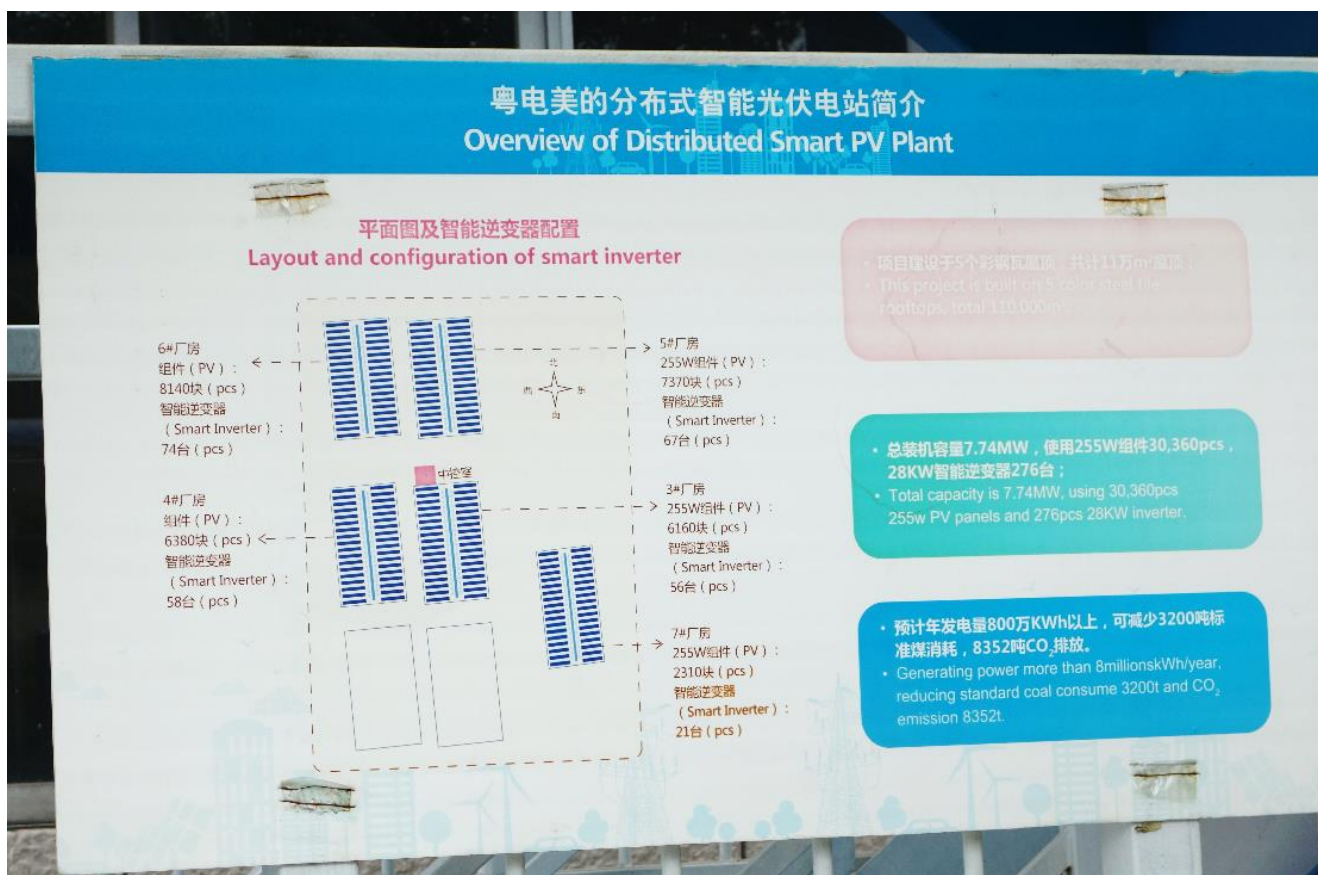


Figure 44. Overview of Midea PV Plant



Figure 45. Rooftop Location of Midea PV Plant

Figure 45 is taken from an inverter location on one of the five industrial rooftops. The background is an adjacent rooftop installation inside the distributed solar PV plant. The line of white rectangles in the background is Huawei 3-phase string inverters. Each of the 3-phase Huawei inverters is installed on the rooftops with a shade structure intact. A photo of the inverter installation is shown in Figure 46 below with the corresponding shade structure as recommended in the user's manual.



Figure 46. Inverter Install at the Midea Site

The wire raceways end below the inverters and the individual string wires along with the AC output wires are fed into the bottom section of the inverter cabinet. The mounting structure is built out of channel steel, and the grounding conductor can be seen in Figure 46 painted green and yellow, running across the mounting structures. All inverters inspected by DNV GL were installed in a similar fashion.

The inverter label for the SUN2000-28KTL unit is shown in the photo of Figure 47 below. These products differ from the units to be sold in North America in similar ways to those described in Section 4.1.1.



Figure 47. Huawei Unit Label

The inverters included a user interface LCD screen with a touch screen functions that present all relevant operational information as follows:

- Instantaneous DC power and voltage
- Instantaneous AC power and voltage
- Daily and total energy
- Fault history



Figure 48. Inverter control panel indicating main inverter status

Note that the LCD display will not be present on the SUN2000-25KTL-US and SUN2000-30KTL-US as with all Huawei "V2" string inverters.

The system was operating during the site visit. Multiple inverters were inspected to validate operational data and make correlations with current output and irradiation. DNV GL views favorably the site that was visited and had been operating for over 1 year with no known issues (Midea staff explained that only a single inverter had been swapped out and it was for testing purposes and not due to device failure). Although the duration of actual run time is viewed as low, the sample size in terms of number of units operational is reasonably high.

DNV GL staff visited the control room at the Midea facility where a third party monitoring system was leveraged to show the aggregate PV plant output. The PV system was operating at 3.5 MW AC power at 857 W/m² of solar irradiation. Individual inverter data was also available and validated the output power for the units witnessed on one of the rooftops. The third party monitoring solution showed that over a 1 year period, the system had logged 9,809 MWh of total energy. An image of the control room and accompanying monitoring capabilities is shown in the corresponding figures below.



Figure 49. Figure Monitoring System Details (from third party)



Figure 50. Individual Inverter Output Power

It should be noted that of the inverters witnessed by DNV GL in the 3rd party monitoring solution, all inverters were online during the detailed overview provided by the system operator at the time of DNV GL's visit to the Midea PV facility. The system operator at Midea expressed that the PV plant had been operating well since inception.

7.2 Huawei Manufacturing Facility Rooftop PV Installation

The second PV installation visited by DNV GL staff was the Huawei inverter factory rooftop system which includes a number of inverters that were connected to multiple PV arrays while they were undergoing environmental tests. The rooftop array is shown in Figure 51 below. It should be noted that the system was being modified at the time of the site visit and not all of the inverters were operational.



Figure 51. PV Array on Huawei Factory Roof

Several inverters undergoing water exposure testing are shown in Figure 52 below. The inverters were housed in plastic enclosures, and subjected to multiple sprinkler assemblies showering the top surface of the inverter cabinet. The duration and specifics of the tests were not disclosed to DNV during the site visit. This does show good engineering practices in terms of validating a host of potential field exposure environments on the string inverter products.



Figure 52. Huawei Inverters Operating in Water Testing

Figure 53 shows a Huawei inverter being tested at elevated temperatures using a series of heat lamps. The duration and specifics of the tests were not disclosed to DNV GL; however these tests again highlight good engineering practices in terms of inverter exposure to a host of potential end installation conditions.

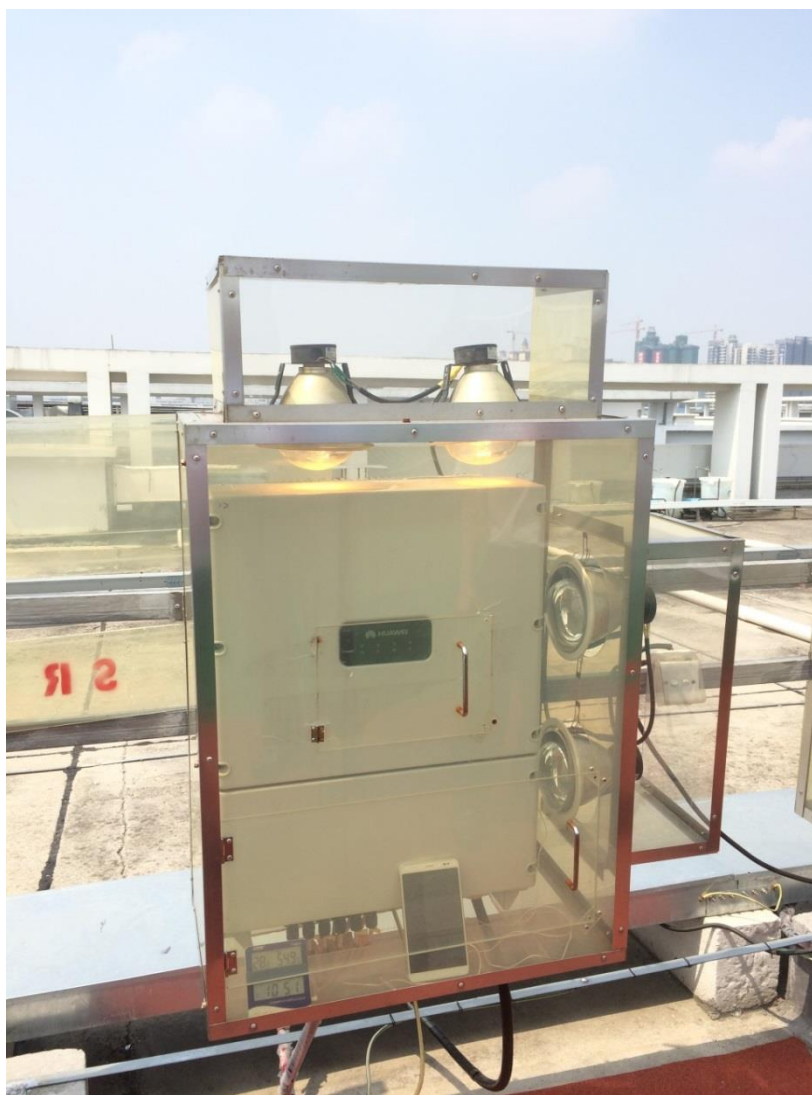


Figure 53. Huawei Inverter At Elevated Temperature

Huawei maintains a control room for monitoring inverter performance at the main manufacturing facility. The monitoring station allows the operators to view installation details down to the single inverter units (AC voltage, ac current, fault history, etc.) inside a larger installation. The operator showcased some of the capabilities of the monitoring solution to DNV during the site visit. There were a number of API's in creation for allowing the monitoring platform to work on a host of end devices (cell phones, etc.) Huawei indicated that there are 18MW of PV systems being monitored by the station.

DNV GL views the unit testing that Huawei is performing on the PV systems at the factory roof very positively. Subjecting the string inverter products to harsh environments can lead to critical product modifications and design improvements.

8 SUMMARY

Huawei Technologies is a very large electronics company based in Shenzhen China, with impressive high-volume manufacturing facilities. Having recently entered the PV string inverter industry, Huawei has developed and manufactured over 4GW's of string inverters for installation primary in China, with large installations in multiple countries.

The SUN2000-25KTL-US (25kW) and SUN2000-30KTL-US (30kW) three phase string inverters described in this report for North America are new models derived from Huawei's 40kW international model, and as such benefit from Huawei's experiences in the solar industry. The two inverter models discussed in this report were just recently listed by CSA to the UL 1741 standard and are now ready for field deployment in North America.

Throughout this report, comments are made that should be reviewed in detail indicating the views of DNV GL on key areas of product design and performance. The comments herein resulted after reviewing extensive documentation presented by Huawei, interviewing key personnel, performing a manufacturing review at the Songshan Lake Manufacturing Centre, and visiting a functioning PV site at that facility and an additional PV plant with the Chinese model Huawei inverters.

DNV GL reviewed the product development and verification data provided by Huawei and found the engineering methods generally acceptable as sound product development practices. The string inverter characteristics and specifications appear to align adequately with North American requirements and expectations. DNV GL does note that the requirements for outdoor installations suggest that including shading of the inverters will provide optimal operation and extend the service life. DNV GL is positive on the cooling system approach which does not require an external fan.

The Huawei manufacturing facility is quite impressive and the methods used are appropriate for string sized PV inverters. DNV GL was particularly impressed with the incoming materials quality inspection and test processes and equipment. Huawei also uses outside contract manufacturers for a significant amount of their solar string inverter product production and DNV GL did not visit these facilities as a part of this Stage 2 Report. Volume production of the SUN2000-25KTL-US and SUN2000-30KTL-US and deployment in the US began recently.

The present Huawei general service infrastructure in North America is extensive, with a subset of the organization assigned to support their solar string inverter products.

Although Huawei has installed a large number of units in a short time outside of North America, the duration of time in the field is short relative to the expected inverter life. Knowledge of product susceptibility to failures and ultimately reliability improves with operating time in the field. Additionally, Huawei has started gaining field experience in the US to augment their international experiences.

APPENDIX A – ABOUT DNV GL SOLAR SERVICES

DNV GL is a recognized leader in solar PV engineering services and our team has well over 400 years of combined experience in this area over the last three decades. DNV GL has provided technical services on commercial and utility scale projects totaling more than 10GW of PV. This extensive project experience has allowed for the development of effective energy analysis, EPC selection, design review, owners engineering, system design, financial analysis, and other important tools which provide an efficient approach to the installation and performance prediction of these systems. DNV GL's experience in technology advancement with module manufacturers, inverter suppliers, balance of system component suppliers, and mounting and tracking system manufacturers provides a unique perspective in integrating these components within a given project. Experience with national and international codes and standards development and work with the US Department of Energy and National Laboratories keeps DNV GL at the leading edge of standards and technology developments. Forensic experience has also assisted DNV GL in improving PV system implementation practices that impact real world systems. This extensive experience allows DNV GL to provide engineering services in an efficient and cost effective manner.



DNV GL Qualifications

This section provides a brief summary of the DNV GL qualifications. Additional details about specific reference projects can be provided to if desired.


PV Technology Evaluations

DNV GL has a long history of technology evaluation and contributions to technology advancement. As system engineers, DNV GL has a unique perspective on the needs and requirements of PV modules (both crystalline and thin-film), CPV systems, inverters, tracking and mounting systems, DAS requirements, combiner boxes, and other BOS components. Confidentiality agreements prevent detailed discussion, but a few recent technology evaluations have included the following:

- Inverter technology review for "bankability"
- Inverter dynamic performance simulation models
- Multi-year field evaluation of new PV modules
- Low, medium, and high concentration CPV assessments
- Thin film module PVSYST model development

PV System Engineering

DNV GL has significant experience in PV systems engineering and product evaluation activities. This includes Independent Engineering for financial institutions and Owner's Engineering for developers and EPCs. DNV GL engineer's experience dates back 3 decades to PVUSA, the earliest utility scale project in the US and to the recent rise of commercial and utility-scale projects occurring over the last 7 to 10 years. DNV GL has worked on over 400 projects in the US, Europe, Asia, Australia, and Canada ranging in size from 10kWp to 350MWp and totaling over 750MWp.



Services generally include a number of the following activities:

- System design review (i.e. reviewing EPC designs) or System design (providing an original design)
- Site assessment
- System energy modelling with first year, and twenty year energy estimates
- Technology evaluation and risk assessment
- EPC evaluation, selection, and monitoring
- Utility interconnection and transmission evaluation
- Site inspections, which may involve a pre-, mid-, and post-construction evaluations
- Contract review of EPC, O&M, and performance guarantee
- Financial modelling and review

DNV GL is also extensively involved in transmission system impact studies for large-scale PV and wind farms. Since 2005, DNV GL has reviewed more than 50 proposed large-scale PV projects ranging in size from 40MWp to 3,000MWp and totaling nearly 9,000MWp, performing some or all of the following tasks:

- Develop dynamic models (PSSE and PSLF) for client's generic and specific PV power plants
- Prepare single line diagrams for the plant's medium voltage distribution and high voltage transmission interconnection system
- Prepare data for FERC Large Generator Interconnection Procedure submission
- Perform power flow, dynamic impact, and conductor thermal studies

Our client list for these services includes major financial institutions, electric utilities, and IPP project developers in North America, Europe, and Asia.

BEW Engineering was acquired by DNV in 2010 and became part of DNV GL in January of 2013. Further information can be found at www.dnvgl.com



ABOUT DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter, and greener.



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