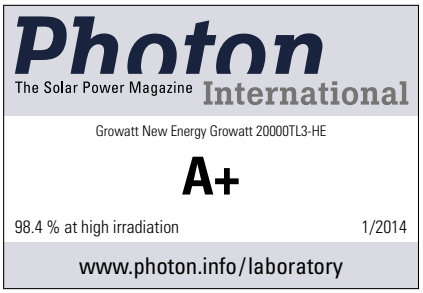
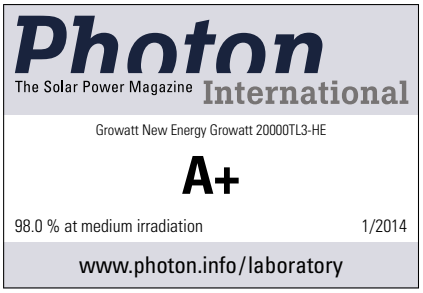




Pushed to new heights

A 20 kW device made by Growatt, the 20000TL3-HE, is only the second inverter tested by PHOTON Lab to achieve a conversion efficiency higher than 99 percent. The device scores third place overall, even without silicon carbide transistors

Text: Heinz Neuenstein, Anne Kreutzmann

Highlights

- The 20000TL3-HE is a 20 kW transformerless inverter featuring three-phase feed-in and one MPP tracker
- The device reaches a conversion efficiency of 99.02 percent – the second-highest value ever measured by PHOTON Lab. Its PHOTON efficiency for medium irradiation totals 98.0 percent, which scores it an »A+« and third place in the PHOTON ranking
- There are still a few weaknesses when it comes to MPP tracking at low voltages and high powers. New firmware should be able to rectify this and could push the 20000TL3-HE even higher up the rankings

When combing through the PHOTON database for all inverters currently available on the market worldwide, only isolated devices can be found whose manufacturers promise a conversion efficiency of 99 percent or higher. Spanish manufacturer Jema Energy SA, for example, specifies 99 percent for its IF-225 TL plus, a 275 kW central inverter. In the category comprised of lower capacities, this issue's test candidate, the 20000TL3-HE made by Growatt, is the only device whose manufacturer promises 99 percent. This device was given to the PHOTON Laboratory in October 2013, and the obligatory test agreement was signed.

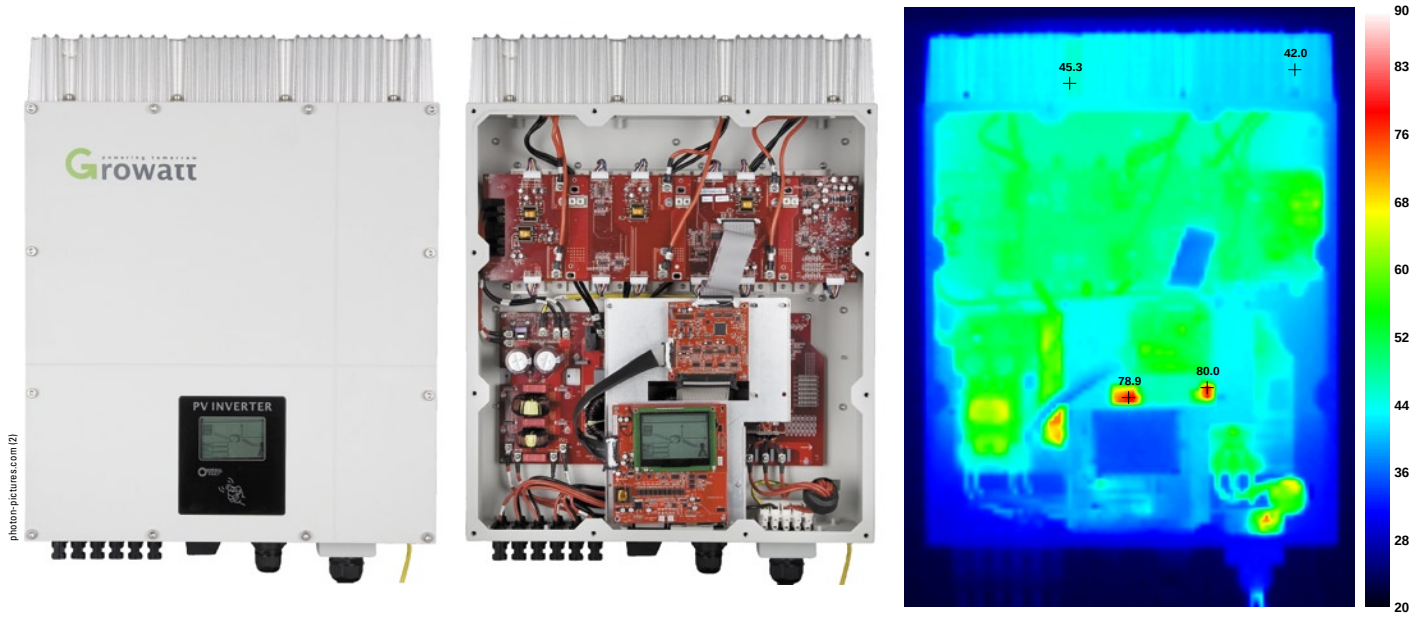
The 99-percent mark was broken for the first time a few years ago by the Sunny Tripower STP 20000TLHE-10, for which its manufacturer, SMA Solar Technology AG, specified 98.5 percent (see PI 12/2011, p. 140). However, the SMA inverter made it to 99.15 percent only after the reverse current diodes had been deactivated – when the protective diodes were operating, its efficiency was slightly below 99 percent. Furthermore, SMA used silicon carbide transistors, while Growatt manages without utilizing this silver bullet.

Of course, very good conversion efficiency is, on its own, not an adequate criterion for judging what is a very good inverter overall. Being able to break the 99-percent mark, however, shows that the manufacturer is playing in the technological major league.

Construction

The 20000TL3-HE is one of two three-phase transformerless devices in the HE family (HE stands for »High Efficiency«). Along with the inverter tested for this report, with its nominal AC capacity of 20,000 W, there is a slightly smaller 18,000 W device in the series.

The construction of the 20000TL3-HE is highly compact and production-friendly. The power element is housed on three circuit boards, two on the lower level directly on the cooling element, and one on the second level. This level is also where the control and communication circuit boards are installed, with



photon-pictures.com (2)

▲ Small, low in weight, compact and highly efficient: The 20000TL3-HE, a 20 kW inverter made by Growatt, achieves high maximum efficiencies despite its rather Spartan equipment features. The thermographic image shows component temperatures of up to 80 °C on the circuit boards (on the surface of the grid disconnect relay). The two electrolytic capacitors that are visible are, in contrast, in the green or, in this case, the blue part of the temperature scale.

the display connected to the latter. The power semi-conductors all feature a discrete design and are fitted from the solder side. They have been screwed onto a cooling element below them, which protrudes through a cutout in the base of the housing. The control and communication circuit boards are interconnected by flat ribbon cables. Their plug-in connectors have been affixed with a silicon-like adhesive that has not been cleanly applied in this case. The DC input and the AC output with the interference filter components, the gird disconnect relay, the fault current monitor and the automatic circuit breaker are on the lower power element circuit board.

The three chokes for the AC-side sine-wave filter are installed in a separate compartment in the upper part of the housing. This compartment is a half-shell made of cast aluminum with small cooling fins in which the chokes are positioned. The half-shell is fully cast, ensuring the thermal coupling of the chokes to the surface of the housing is optimal. Unfortunately, this also couples it acoustically, so the device emits an appreciable amount of noise. This upside-down half-shell is fitted onto the upper surface of the housing. The device features passive cooling only, with no fans being used, a consequence of the high efficiency. The cooling element is a complex high-performance cooling element with hollow fins molded into an extruded aluminum baseplate, with the fins also made of aluminum. The housing is formed by a welded frame made of steel sheet and is protected by a cover made of thick aluminum plate. The housing is therefore comprised of four parts, and it features a IP 65 protection type.

The display is found behind a cutout in the housing cover and is covered by transparent film. The device status is indicated by the display and an LED.

The electrolytic capacitors used in the power element belong to temperature class 105 °C, a good choice for the prevailing ambient temperatures. Varistors have been utilized in the AC output to limit overvoltage, but not in the DC input.

The solar generator is connected using six pairs of PV connectors made by Amphenol. There is only one block terminal covered by a small, separate cap for connecting to the grid.

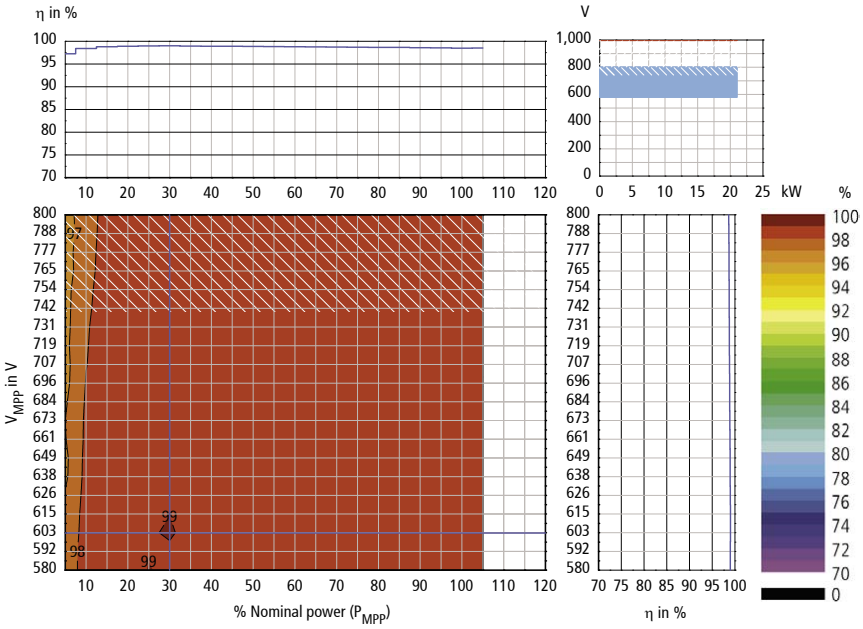
The internal DC disconnect is installed on the bottom of the device. There are no string fuses. All in all, the device is rather Spartan in design. When it comes to communication options, there is an RS232 interface for communicating with a PC and an RS485 interface for communicating with several other inverters along with a monitoring unit. Wi-Fi is available as an optional extra using a plug-in card on the RS232 interface, as is a data logger.

Operation

The device is delivered to the user well packaged and protected by a cardboard box with foam half-shells. The inverter is installed on a wall with the aid of a bracket. The Growatt 20000TL3-HE, which weighs 52 kg, is lightweight in terms of its nominal DC power. Once the solar generator has been correctly dimensioned and the internal DC disconnect has been switched on, the inverter requires approximately another 42

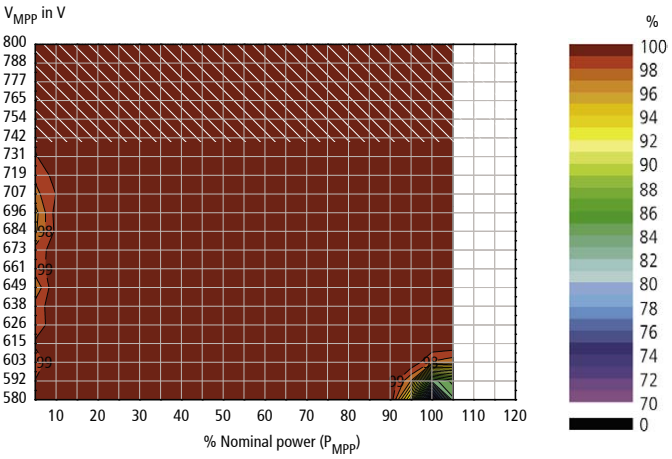
Conversion efficiency

A rare sight: The conversion efficiency exceeds 98 percent over almost the entire operating range. The maximum of 99.02 percent is found at 30 percent of nominal power and an MPP voltage of 603 V. A conversion efficiency of more than 99 percent has only been measured at the PHOTON laboratory once before, when the Sunny Tripower STP 20000TLHE-10 made by SMA was tested.



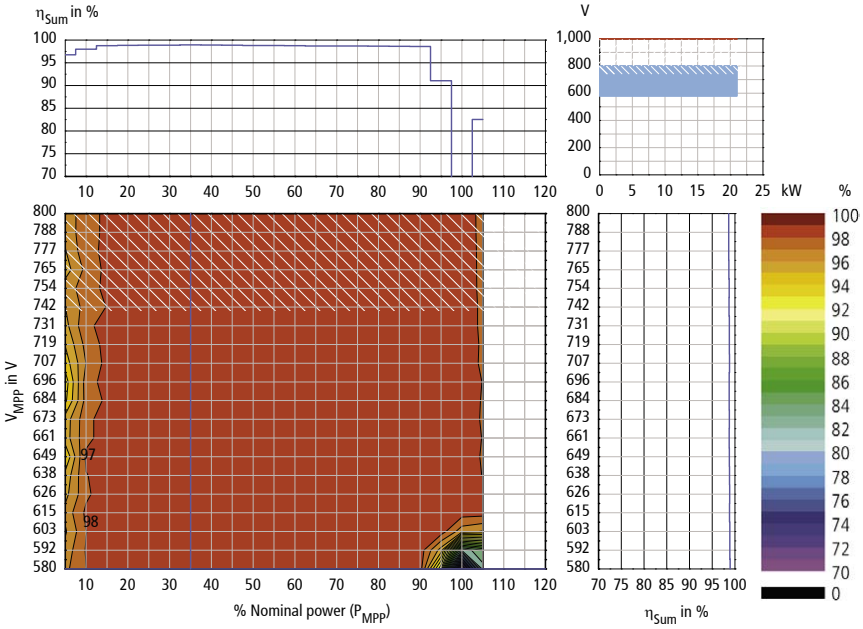
× MPPT adjustment efficiency

A minor goof-up: The MPPT adjustment efficiency is highly uniform, and very high, over almost the entire operating range. At low powers there are problems with the MPP tracking, and the MPPT adjustment efficiency falls below 99 percent and, at times, to less than 98 percent. When MPP voltages are low and DC powers are high, the inverter reacts by reducing power.



= Overall efficiency

The maximum overall efficiency range is found at low voltages and medium powers. The overall efficiency maximum of 98.9 percent is found at 35 percent of nominal power and an MPP voltage of 580 V.



seconds for a variety of tests. It then connects to the grid and starts work.

The graphics-capable display is below the front cover and features white backlighting. It is difficult to read. It is activated by tapping the cover of the housing near the display. The menu is also operated this way. English, German, French and Spanish are available as operating languages.

Along with diverse status and error messages, the following actual values are displayed: DC power, grid frequency, DC voltage, DC current and a bar diagram showing the energy feed-in curve in kilowatt-hours over the course of the day, the week, the year, or as a total. The most important values are therefore provided.

Operating manual

An English-language operating manual is provided with the device. Along with general explanations, it covers installation, information on operating characteristics, maintenance, the display, error messages and instructions for the communication options and a number of block circuit diagrams of a system configuration.

Circuit design

The inverter features a single-stage circuit design. The energy from the PV generator flows past an EMI filter and directly into the intermediate voltage circuit, to which a capacitor half bridge and a three-phase capacitor half bridge are connected. Growatt calls the technology used for this output bridge, which is comprised of an optimized three-voltage-level bridge, »Smart Topology«. According to statements made by Growatt, conventional silicon FETs (field effect transistors) and IGBTs (insulated gate bipolar transistors) are used in the branches of the output bridge, and no silicon carbide transistors have been used. There are mounting points for reverse current diodes, but these have not been installed.

The output-side filter smoothens the modulated voltage blocks into sine-wave voltage with the grid frequency of 50 Hz. An automatic circuit breaker disconnects the inverter from the grid if the grid voltage or grid frequency deviates from the defined thresholds, doing the same if a fault current or a DC component occurs on the grid side. Furthermore, the ground resistance and the discharge current are checked on the DC side. Any radio interference occurring is eliminated by an output filter, which is found directly in front of the grid terminals.

Measurements

All of the following measurements are based on a grid voltage of 230 V. The maximum DC voltage the Growatt 20000TL3-HE can process totals 1,000 V, with the nominal DC power being 20,000 W. The manufacturer recommends connecting a maximum power of 20,800 W.

Locating the MPP: When measuring began, both the DC side and the AC side were switched off. At a predefined IV curve with nominal power and an MPP voltage of 684 V, the inverter requires around 42 seconds before it connects to the grid. Around 88 more seconds pass before the inverter reaches the MPP. It needs 11 seconds to change from 684 V to 673 V, and changing to the next-highest MPP range of 696 V also took 11 seconds.

MPP range: The MPP range extends from 580 to 800 V and is equivalent to that of a normal range inverter. The maximum MPP voltage of 800 V is at a good distance away from the maximum input voltage of 1,000 V.

Conversion efficiency: The inverter can operate at 105 percent of nominal power in the MPP voltage range spanning 580 to 800 V. The efficiency could therefore be determined for this part of the diagram.

At a maximum DC voltage of 1,000 V, there is a hatched area that indicates limitations when thin-film modules are used due to the insufficient distance to the maximum MPP voltage and the maximum DC voltage.

The efficiency reaches more than 98 percent over the entire voltage range and at powers of more than 10 percent. The maximum of 99.02 percent is found at 30 percent of nominal power and an MPP voltage of 603 V. This means the manufacturer's specification of 99.0 percent was reached. Toward high MPP voltages, the conversion efficiency falls by around 0.4 percentage points, falling by around 0.05 percentage points toward low powers.

At low powers of less than 15 percent of nominal power, the efficiency of this device falls by 1.6 to 2.1 percentage points. At nominal power, the power factor cos φ was around 1.

Weighted conversion efficiency: European efficiency reaches its maximum at the lowest MPP voltage and is, at 98.8 percent, another 0.2 percentage points higher than the manufacturer's specification of 98.6 percent. The difference between maximum conversion efficiency and maximum European efficiency only totals 0.2 percentage points. Californian efficiency takes a virtually identical course to European efficiency.

MPPT adjustment efficiency: The MPPT adjustment efficiency is highly uniform and very high over almost the entire operating range – but there are two limitations. At low powers, there are problems with the MPP tracking, and the MPPT adjustment efficiency falls below 99 percent and, at times, to less than 98 percent. When the MPP voltage is low and DC power is high, the inverter reacts by reducing output. This effect does, however, depend on the grid voltage level, meaning the ratio of DC voltage to grid voltage. Because this inverter features a single-stage concept, the DC voltage may not, in some cases, be sufficient to feed in at a 230 V or 400 V level. The adjustment problems in the DC voltage range spanning 580 to 626 V could be eliminated with a slightly lower grid voltage of 225 V, supporting this theory.

Overall efficiency: Overall efficiency, which is the product calculated from conversion and MPPT adjustment efficiency, reaches its highest level at low voltages and medium powers. The maximum of 98.9 percent is found at 35 percent of nominal power and an MPP voltage of 580 V.

Overall efficiency curves, average overall efficiency and PHOTON efficiency: The PHOTON efficiency for medium irradiation totals 98.0 percent, and the PHOTON efficiency for high irradiation is 98.4 percent.

Feed in at nominal power: The inverter feeds in 100 percent of nominal power over almost the entire input voltage range spanning 580 to 800 V and at an ambient temperature of 25 °C.

Displayed output power: At a constant MPP voltage of 684 V, which is the medium range, the output power displayed by the inverter at different powers between 5 and 105 percent of nominal power was compared with the value identified by a power analyzer. At low powers, the display deviates by up to -9.3 percent from the value measured by the power analyzer. At nominal powers of 20 percent or more, the error is still within a range of -3 to -5 percent. The level of accuracy exhibited by the display is therefore insufficient.

Operation at high ambient temperatures: The inverter keeps feeding 100 percent of its nominal power output into the grid without any reductions up to an ambient temperature of around 61.6 °C. The operating point selected was at 20,000 W and an MPP voltage of 684 V. The efficiency fell by around 0.3 percentage points over this temperature range.

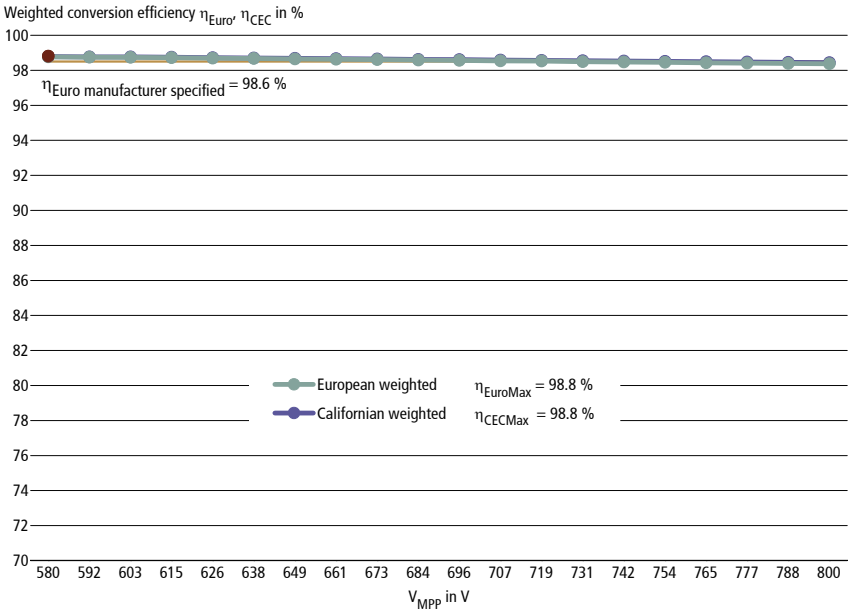
Overload behavior: If the Growatt 20000TL3-HE is fed an overload of 1.3 times the nominal input power, making it 26,000 W, the inverter limits output to a DC power of 20,917 W. This is equivalent to an overload of 4.6 percent. The device therefore features a small overload range. When power is limited in this way, the device pushes the operating point on the IV curve toward higher input voltages. The DC voltage value was around 762 V. The operating point chosen was found at an MPP voltage of 684 V and an ambient temperature of 24 °C.

Own consumption and night consumption: The energy consumed by the device in its basic tested state totals around 0.4 W on the AC side and 16.2 W on the DC side, with the manufacturer not specifying a figure for this. At night, the inverter also draws around 0.4 W of effective power from the grid. The manufacturer specifies less than 0.5 W.

Thermography: The thermographic camera shows the inverter from above while it is operating at an ambient temperature of 24 °C at nominal power. It reveals component

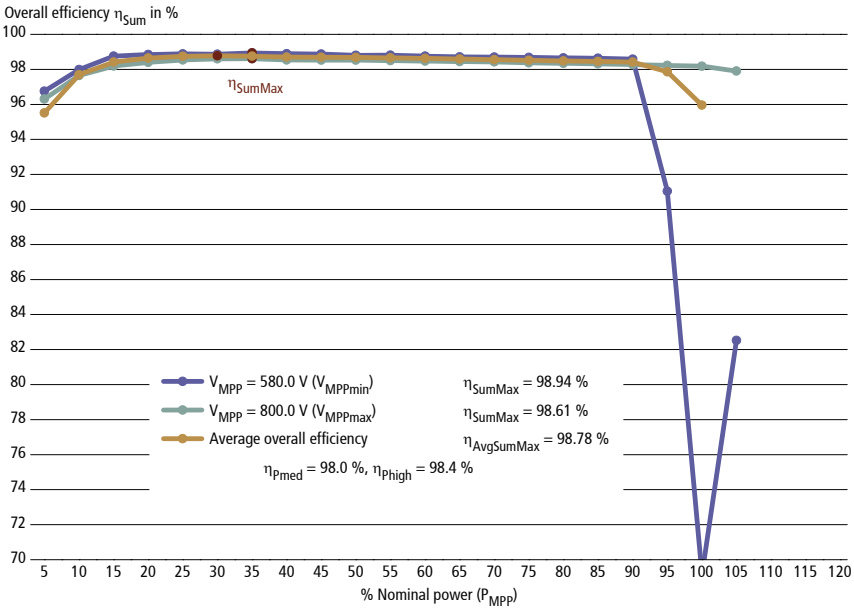
Weighted conversion efficiency

Exemplary: European efficiency reaches a maximum at the lowest MPP voltages and is, at 98.8 percent, 0.2 percentage points higher than the manufacturer's specification of 98.6 percent. The difference between maximum conversion efficiency and maximum European efficiency only amounts to 0.2 percentage points. Californian efficiency follows a curve that is almost identical to European efficiency.



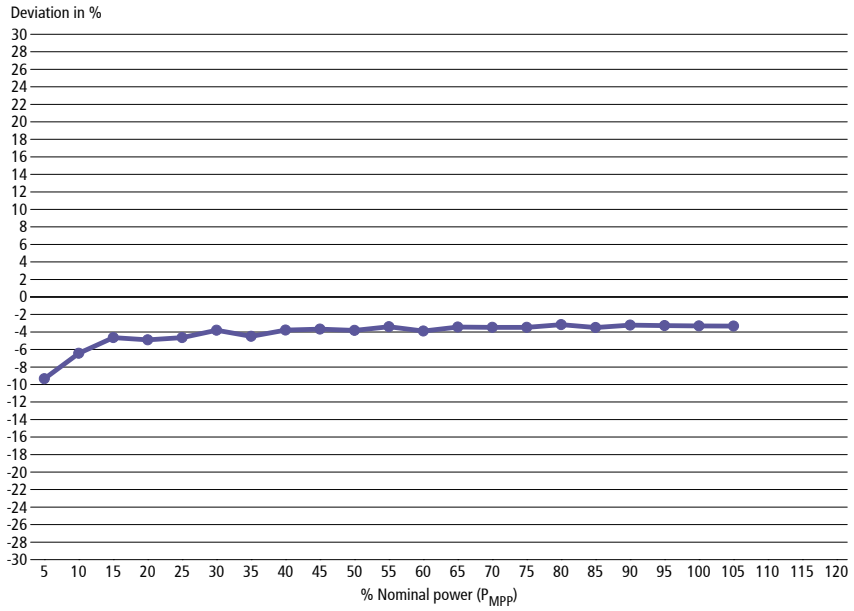
Overall efficiency at different voltages

Third place in the overall list of rankings: The PHOTON efficiency for medium irradiation is 98.0 percent, a level that only two test candidates have exceeded to date. If there were no decline at low MPP voltages (blue curve) and high powers, the result would have been even better.



Accuracy of inverter display

No longer up-to-date: At low powers, the display differs by up to -9.3 percent from the value measured by the power analyzer. At 20 percent of nominal power of more, the error range totals -3 to -5 percent. This is something other inverters are considerably better at.



temperatures on the circuit boards of up to 80.0 °C, measured on the surface of the grid disconnect relay. Two additional temperature markers can also be seen in the upper area, which is the part of the housing where the cast chokes are located. Only a small strip of this die-cast aluminum cap was blackened in the thermographic images made by PHOTON Laboratory. A surface temperature of 45.3 °C was measured there. The other, non-blackened area has an emission factor that is too low for thermographic imaging, so the value of 42.0 °C determined there cannot be accurate. The two visible electrolytic capacitors in the power element are in the non-critical part of the temperature scale. The multi-layer construction of the device only allows the components that are visible to be shown.

Summary

Chinese company Growatt New Energy Technology Co. Ltd. has developed a top device with only a few small weaknesses in the form of its 20000TL3-HE. The inverter features a very compact construction and is production-friendly, and it is very light and small for a three-phase device. The number of additional functions has been kept to a minimum, producing a low-cost device, which can be supplemented by a number of additional external components. The loud operating noises are unpleasant, and the rather imprecise inverter power display is a drawback.

The conversion efficiency is very good and uniformly high over the entire operating range and remains almost consistently above 98 percent. A peak value of 99.02 percent was measured, which confirms the manufacturer's specification of 99.0 percent. Its European and Californian efficiencies are just 0.2 percentage points lower than the maximum conversion efficiency. The very consistent, and high, MPPT adjustment efficiency also results in a high and uniform overall efficiency. A number of weak points in the MPP tracking emerge at low powers and low voltages, as well as at high powers, which the manufacturer intends to tackle by overhauling the software. However, even with these problem areas, the PHOTON efficiency for medium irradiation totals a very high 98.0 percent, with the PHOTON efficiency for high irradiation being another 0.4 percentage points higher, at 98.4 percent, as the problem encountered at low powers are not weighted as highly.

Efficiencies as high as these can only be achieved by devices that do not feature a (loss-prone) boost converter in the DC input. The smaller input voltage range featured by the 20000TL3-HE, which spans 580 to 800 V, also helps. The maximum MPP voltage of 800 V is at a good distance away from the maximum input voltage of 1,000 V; however, there are limitations with the use of thin-film modules.

The choice of a single-stage topology is one reason for the high efficiencies, along with an optimized output bridge, which Growatt has christened »Smart Topology.« Silicon carbide transistors have not been employed. The high efficiency also allows active cooling by fans to be dispensed with. Due to the very wide temperature range spanning -25 to +60 °C, and protection type IP 65, the inverter can be installed under the roof or outdoors. No power reduction was observed at high temperatures.

The 20000TL3-HE finds itself in third place in the PHOTON ranking for the »medium irradiation« category (see table, p. 52 - 54), sharing a place with the Sun2000-20KTL made by Huawei Technologies Co. Ltd. and the Platinum 16000 R3 made by Diehl AKO Stiftung & Co. KG. Weighted for high irradiation, the 20000TL3-HE is able to claim second place, allowing it to overtake the Refusol 020k SCI made by Refusol GmbH, which is equipped with silicon carbide transistors.

Manufacturer's response

We have verified the test results relating to the MPPT efficiency.