www.photon-international.com

Photon

The Solar Power Magazine International 11-2011

Extracting oil with solar

Petroleum producers explore clean solar steam to pump more dirty crude from aging reservoirs

US natural-gas boom
The price against which wholesale solar competes gets cheaper with gas oversupply

CIGS lives on
Ongoing advances for highest-efficiency thin-film recipe despite Solyndra's famous flop

New European markets
The 12 latest members of the EU lack sustainable, long-term PV policies

Silicon thin-film tools
Survey shows improvements for absorber deposition equipment but little demand

Small, but perfectly formed

Eltek Valere's Theia 4.4HE-t proves that inverters with transformers can still achieve excellent efficiencies

Highlights

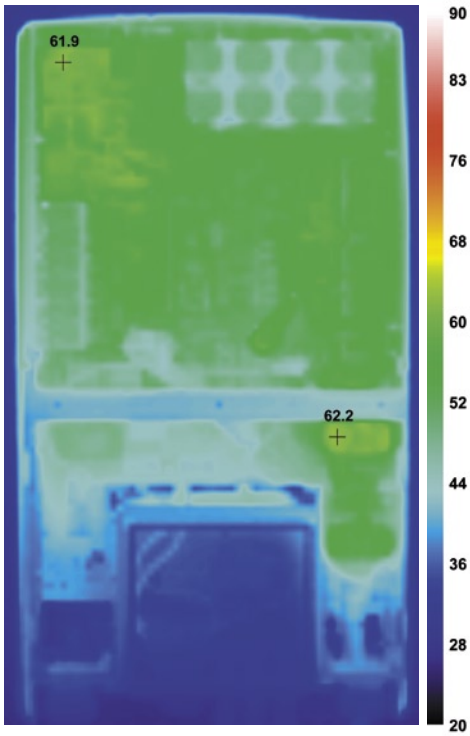
- Eltek Valere's Theia 4.4HE-t is a single-phase inverter with a transformer and has a DC nominal power of 4.6 kW
- The device's MPP range stretches from 230 to 480 V
- The maximum overall efficiency was recorded as 97.2 percent
- The European efficiency reaches 96.8 percent, while the Californian efficiency came in at 96.9 percent
- The PHOTON efficiency for medium irradiation was 96.5 percent, while it reached 96.7 percent at high irradiation

Once upon a time, inverters with transformers were the standard, but today – at least on the German PV market – they are almost an endangered species. Wherever possible, solar installers prefer using transformerless inverters. Inverters with transformers are considered heavy, complicated and, above all, are thought of as having inferior efficiencies when compared with their transformerless counterparts. The advantages they offer, such as independent current circuits, which allow for various grounding concepts, are of little interest if the modules being used do not require galvanic isolation. However, the Theia 4.4HE-t from Norway-based Eltek Valere AS shows that the apparent disadvantages do not always apply. The single-phase inverter, which PHOTON Lab acquired with the usual standard agreement, follows a three-stage concept and uses a modern high-frequency transformer that not only reduces weight and material usage, but also achieves very good efficiencies. So it appears there's hope for inverters with transformers after all.

Construction

The inverter is part of the Theia range, which includes devices with AC nominal powers between 2,000 and 4,400 W. All of the models have a transformer and a single-phase feed-in. The test candidate has a very compact, well-arranged design. There are four circuit boards, a power element circuit board that takes up almost all of the device's internal space, a control circuit board installed vertically, and a combined control and display circuit board in a protected space behind the device's cover. The large power element circuit board holds all the power element's components: those range from the DC and AC clamps, and the corresponding EMI filters to the auxiliary supply mains adapter, the power semiconductors, and the intermediate circuit's electrolytic capacitors. The power semiconductors are discrete – they are attached to the component side, bent 90° and then clamped to the cooling element below with spring clips. Sine-wave filter chokes, capacitors and the high-frequency transformer are located below the base of the housing and embedded in a plastic case.

A small internal fan is integrated into the circuit board. The display emerges from a gap in the front cover. The housing itself consists of the base section, which serves as the mounting platform, the upper cover containing the display, and the lower section, which covers the clamps. These pieces are made of die-cast aluminum; a plastic compartment contains the DC clamps. The housing has an IP 65 protection type, and is therefore watertight and can be installed outdoors. An automatic grid-monitoring unit ensures safe operation, since it checks for proper voltage and frequency. A



Romana Brentgens / photon-pictures.com (2)

▲ Cool and effective: Thermographic images reveal temperatures up to 62.2 °C when the inverter is operating – that's a safe level and was recorded in one of the chokes. The electrolytic capacitors in the power element also operate at normal temperatures.

display and three LEDs indicate the device's operational status.

The electrolytic capacitors in the power element and control electronics have a temperature class of 105 °C and are therefore well-suited to handle ambient temperatures. The device's circuit board has a conspicuously large amount of glue, which was used to affix heavy components. Temperature-monitored varistors are used in the DC input and AC output. Installers can use three pairs of MC4 connectors to hook up the PV system; the grid connection cable is fed into the housing via a cable gland and then directly attached to clamps on the power element circuit board. The device also has an internal DC disconnect. For communications purposes, the unit is equipped with an Ethernet port, an embedded webserver and a CAN bus.

Operation

The device is well-packaged in a box, with Styrofoam shells surrounding the inverter. A wall bracket facilitates installation. At 21 kg, the Theia 4.4HE-t is rather light considering its DC nominal power. Once the solar generator is properly configured and the internal DC disconnect is switched on, the inverter can begin operation. It takes around 39 seconds for the unit to run a series of tests before connecting to the grid.

The graphic color display is flush with the front cover and illuminated. The information is well-structured and very easy to read. It takes between 60 and 99 seconds before the display shuts off and is completely deactivated.

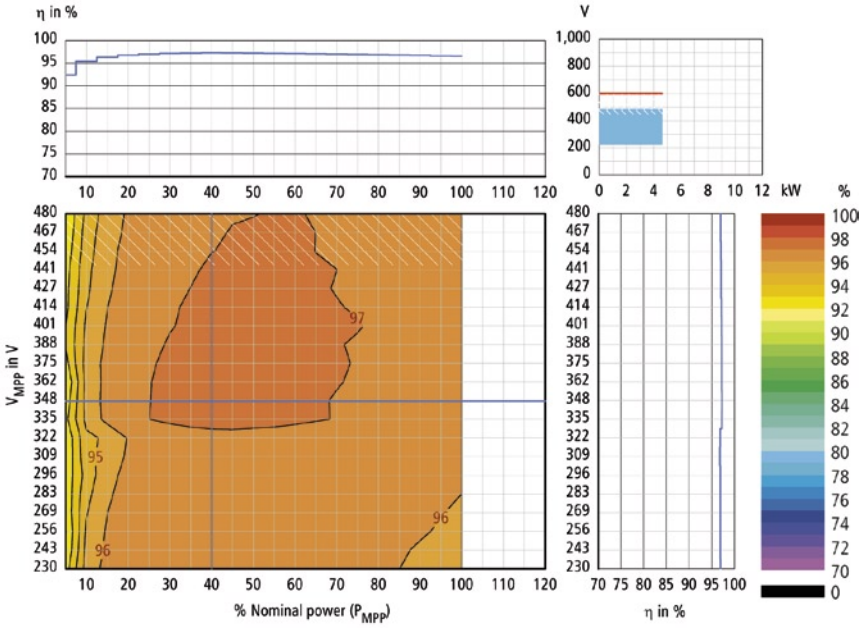
The display menu is available in English, French, German, Italian and Spanish. In the future, the company is planning to add Chinese, Czech, Dutch, Polish and Portuguese. The LEDs show the inverter's operational status and are activated using six touch-sensitive sensors. A considerable number of measurements and extra data are therefore at the user's disposal.

Instruction manual

The device comes with an English installation manual, and an instruction manual in English, French, German and Italian. The company has plans to allow users to download the instruction manual in Chinese, Czech, Dutch, Polish and Portuguese. In addition to general explanations on installation, connection, operational behavior and the display, the extensive manual also provides some block diagrams of system configurations. The manual doesn't contain any tips on error messages, but it does explain a number of DC-side grounding options. The installation manual can also be downloaded from the manufacturer's website.

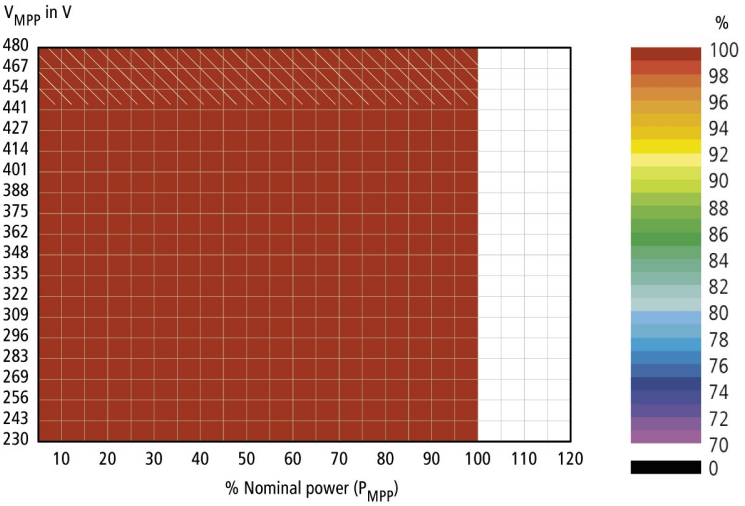
Conversion efficiency

The area of maximum efficiency is wide and located in the middle of the power spectrum. The maximum conversion efficiency of 97.2 percent is reached at an MPP voltage of 348 V and a nominal power of 40 percent.



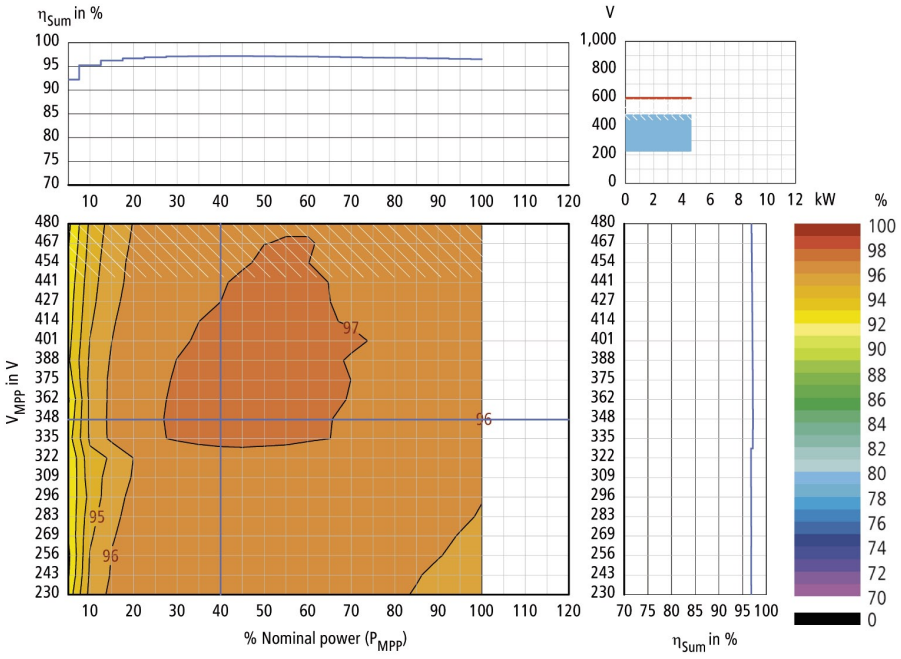
× MPPT adjustment efficiency

Dark red, wherever you look: The inverter's MPPT adjustment efficiency is above 99 percent in all power and voltage ranges.



= Overall efficiency

The maximum overall efficiency is achieved in a wide, useful range. The peak of 97.2 percent also occurs at a medium MPP voltage of 348 V and a nominal power of 40 percent.



Circuit design

The device being tested is a single-phase inverter with a high-frequency transformer, as well as a tracker at the input. The inverter has a three-stage circuit design: firstly, energy from the PV generator reaches the first power stage – a DC/DC converter – via an EMI filter. The converter controls the high-frequency transformer. The transformer rectifies the voltage blocks and then feeds into an intermediate circuit capacitor. The subsequent output bridge then hacks the DC voltage. This is achieved with a combination of insulated-gate bipolar transistors (IGBTs) and field-effect transistors (FETs). Silicon carbide diodes serve as free-wheeling diodes, and the subsequent filter smoothes the modulated voltage blocks into sinusoidal voltage with a grid-frequency of 50 Hz.

An automatic disconnect unit separates the inverter from the grid in the event that it detects any deviations in grid voltage or grid frequency from predetermined values, or if it detects leakage current on the grid side. An output filter, installed immediately in front of the grid clamp, filters out radio interference.

Despite this three-stage concept and electrical isolation – which allows for DC grounding – the device's efficiency is still very high.

Measurements

All of the following measurements are based on a grid voltage of 230 V. The Theia 4.4HE-t's maximum DC voltage is 600 V and the DC nominal power is 4,600 W. A maximum PV power of up to 5,750 W can be connected to the inverter.

Locating the MPP: At a predetermined IV curve with nominal power and an MPP voltage of 348 V, the inverter needs about 39 seconds to connect to the grid, and another 3 seconds to reach its MPP. The switch from 348 V to 335 V took 5 seconds, while switching to the next higher MPP range of 362 V takes about 15 seconds.

MPP range: The MPP range stretches from 230 to 480 V, which is a normal range. The maximum MPP voltage of 480 V is comfortably removed from the maximum input voltage of 600 V.

Conversion efficiency: The inverter can operate consistently at 100 percent of nominal power within an MPP voltage range of 230 to 480 V. At a maximum DC voltage of 600 V, there is a hatched area in the diagram indicating limitations when used with thin-film modules due to the inadequate distance between the maximum MPP voltage and the maximum DC voltage.

The area of maximum efficiency forms a large plateau at a high level. It stretches between MPP voltages of 335 and 480 V in a nominal power range between 30 and 70 percent. The vertical line at 40 percent of nominal power and the horizontal line at an MPP voltage of 348 V meet at the maximum efficiency of 97.2 percent. Thus, the manufacturer's specs for a maximum conversion efficiency of 97.3 percent were almost achieved during the test. At higher MPP voltages, the maximum conversion efficiency decreases by around 0.3 percentage points, while at lower powers it drops by around 0.4 percentage points. At lower powers below 15 percent of nominal power, this device's efficiency fell by 4 to 5 percentage points. The power factor cos φ at nominal power was about one.

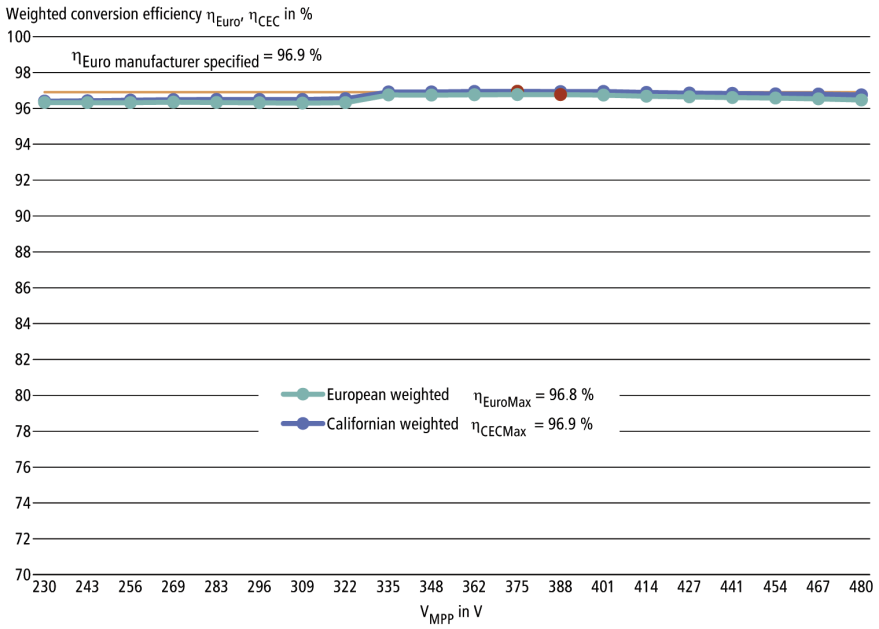
MPPT adjustment efficiency: The MPPT adjustment efficiency is very consistent and high across the entire operating range. It is always more than 99 percent of available power.

Overall efficiency: At a maximum DC voltage of 600 V, there is a hatched area that reflects limitations when the device is used with thin-film modules due to the inadequate distance between the maximum MPP voltage and the maximum DC voltage. The area of maximum efficiency is found at medium voltages and powers. The vertical line at 40 percent of nominal power and the horizontal line at an MPP voltage of 348 V meet at the maximum overall efficiency of 97.2 percent.

Weighted conversion efficiency: The European efficiency reaches its peak at MPP voltages between 375 and 388 V; at 96.8 percent, it is almost identical to the manufacturer's specs of 96.9 percent. The difference between the maximum conversion efficiency and maximum European

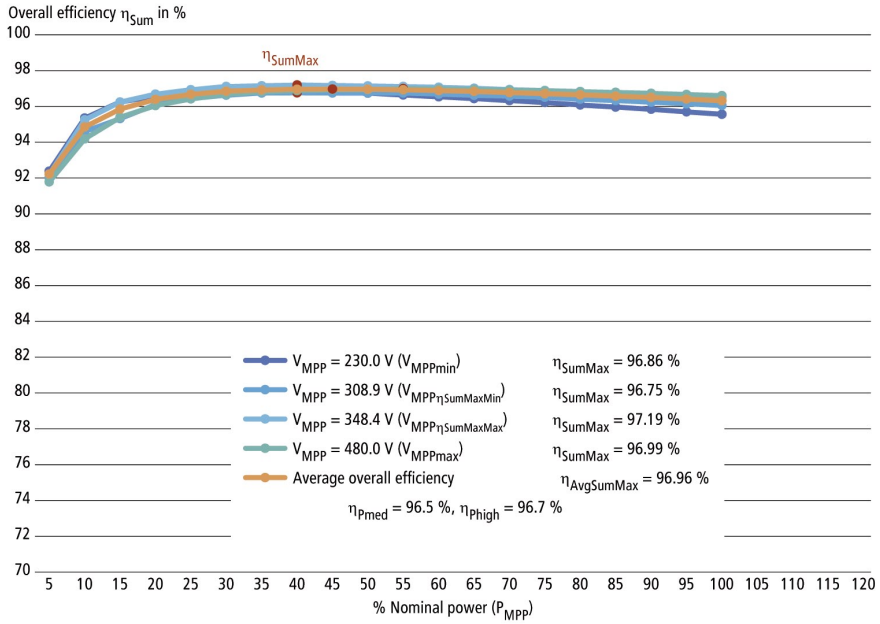
Weighted conversion efficiency

Since the inverter doesn't show any significant weaknesses in any range, the device's European and Californian efficiency are located close together. The European efficiency of 96.8 percent is a tenth of a percentage point weaker than the manufacturer's specs.



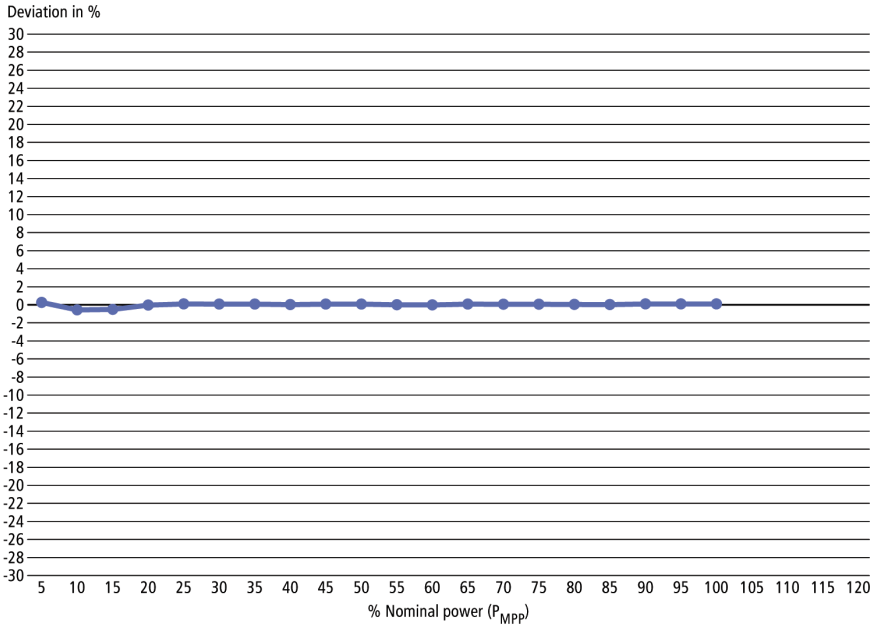
Overall efficiency at different V_{MPP} voltages

Even at lower powers of 5 percent, the inverter reaches a very good overall efficiency of around 92 percent. If the solar generator feeds in more, then the device quickly reaches its maximum efficiency. Only at higher nominal powers can slight weaknesses be seen at a low MPP voltage of 230 V (dark blue line).



Accuracy of inverter display

Worth a look: The inverter's displayed power correlates almost exactly with the actual power.



efficiency is just 0.4 percentage points. The Californian efficiency is 96.9 percent and therefore somewhat higher; it also reaches its peak at MPP voltages of between 375 to 388 V.

Course of overall efficiencies, average overall efficiency and PHOTON efficiency: The PHOTON efficiency at medium irradiation is 96.5 percent, while the PHOTON efficiency at high irradiation is 96.7 percent.

Feed-in at nominal power: The inverter feeds in 100 percent of its nominal power over an input voltage range of 230 to 480 V at an ambient temperature of 25 °C.

Displayed output power: In a series of additional measurements, the inverter was fed with different powers between 5 and 100 percent of nominal power at a constant MPP voltage of 348 V – that is in the medium range. The inverter's output power data was then compared with that of a power analyzer.

The inverter's measured and displayed output power deviates by up to -0.6 percent from the power analyzer's measurements at low powers. Beyond 20 percent of nominal power, the error rate is less than +0.1 percent. Hence, the display is as accurate as a class B meter (previously known as precision class 1).

Operation at high temperatures: If the temperature increases, the inverter continues to feed 100 percent of nominal power into the grid up to an ambient temperature of around 63.3 °C. Once that temperature is reached, the device reduces its power; the selected operating point is then 4,600 W and an MPP voltage of 348 V. Efficiency fell in this temperature range by around 0.4 percentage points. Due to its very wide temperature range of -25 to 65 °C and its IP 65 protection type, this inverter can be installed under a roof or outdoors. The temperature range in which the device can function without any power reductions is guaranteed as -25 to 45 °C. Therefore, there is no need to take any power reductions into account.

Overload behavior: If the Theia 4.4HE-t is offered an overload of 1.3 times its nominal input power, so 5,980 W, at an MPP voltage of 388 V and an ambient temperature of 25 °C, the device limits DC power to about 4,600 W. This corresponds to no overload range at all at a DC nominal power of 4,600 W. When power limitations take effect, the device moves the operating point on the IV curve toward higher input voltages; the DC voltage adjusts itself to around 390 V.

Own consumption and night consumption: The device's own consumption in its tested construction is around 2.8 W on the AC side and 3.5 to 7 W on the DC side. The manufacturer provides no specifications here. At night, the inverter consumes around 1.9 W of real power from the grid. The manufacturer specifies less than 1 W.

Thermography: Component temperatures on the circuit board are shown to reach as high as 62.2 °C. In this case, it was the surface temperature of a choke. The electrolytic capacitors in the power element all display temperatures in the safe range.

Summary

Eltek Valere's Theia 4.4HE-t offers surprises in a number of areas. It is not easy to build small inverters than can compete with larger devices in terms of efficiency. Eltek has succeeded – and even uses a high-frequency transformer. Thus, the device is a wonderful addition to the ever-smaller range of inverters with around 5 kW of power that are able to function with all cell concepts.

The test candidate's construction is very compact and well-arranged. The maximum conversion efficiency was recorded as 97.2 percent in the medium MPP voltage range. The difference at higher and lower voltages is small – at around 0.3 percentage points and 0.4 percentage points, respectively. Thus, the conversion efficiency's voltage and power dependency is very low. Thanks to the good MPPT adjustment efficiency, the course of overall efficiency is almost identical to that of conversion efficiency.

The manufacturer's specified MPP voltage range is at a comfortable distance from the inverter's maximum DC voltage and can be used without restrictions with crystalline modules. There are limitations, however, when being used with thin-film modules. The PHOTON efficiency at medium irradiation is 96.5 percent, while the value for PHOTON efficiency at high irradiation is 96.7 percent. The small difference between the maximum conversion efficiency and PHOTON efficiency is indicative of the very low voltage and power dependency. When selecting the MPP of a PV system, it is best to choose the middle third of the MPP voltage range.

The inverter has no overload range. As a result, it is important to pay attention to irradiation peaks when configuring a PV system. The display was outstandingly accurate regarding inverter output power. The device's temperature range is very wide; power limitations only take effect above 63.3 °C. The dependence of conversion efficiency on temperature is very low at 0.4 percentage points.

The inverter displays good efficiency levels, despite the inverter's relatively low power and the complex three-step topology with a high-frequency transformer.

The Theia 4.4HE-t ranks in the upper third of the inverters tested thus far and is a very successfully designed inverter. The manufacturer is currently testing different thin-film modules and is cooperating with producers to obtain approval for their products. Eltek also assumes that it will meet the new European low-voltage requirements this fall.

Text Heinz Neuenstein, Matthias B. Krause

Further information

Contacts page 212

Manufacturer's response

Regarding the efficiency testing results, we found that PHOTON Lab's measurements are slightly lower than those performed by ourselves and by the Austrian Institute of Technology (AIT). However, they are within understandable limits in terms of measuring equipment calibration tolerances and production unit component variances.

MAXIMIZING THE POWER OF RENEWABLES

THEIA™ HE-t

Setting a new standard in string inverters

- Unparalleled efficiency and galvanic isolation
- Very easy to install, use and manage
- Suitable for all panel technologies
- Integrated webserver and datalogger
- Superior quality and reliability

Explore at: www.eltek.com/theia
Contact: salesre@eltek.com

ELTEK

Eltek is a global power conversion specialist with industry-leading expertise, technology and products. Drawing on more than 40 years experience in power electronics, we are committed to meeting the power conversion needs of the photovoltaic industry.