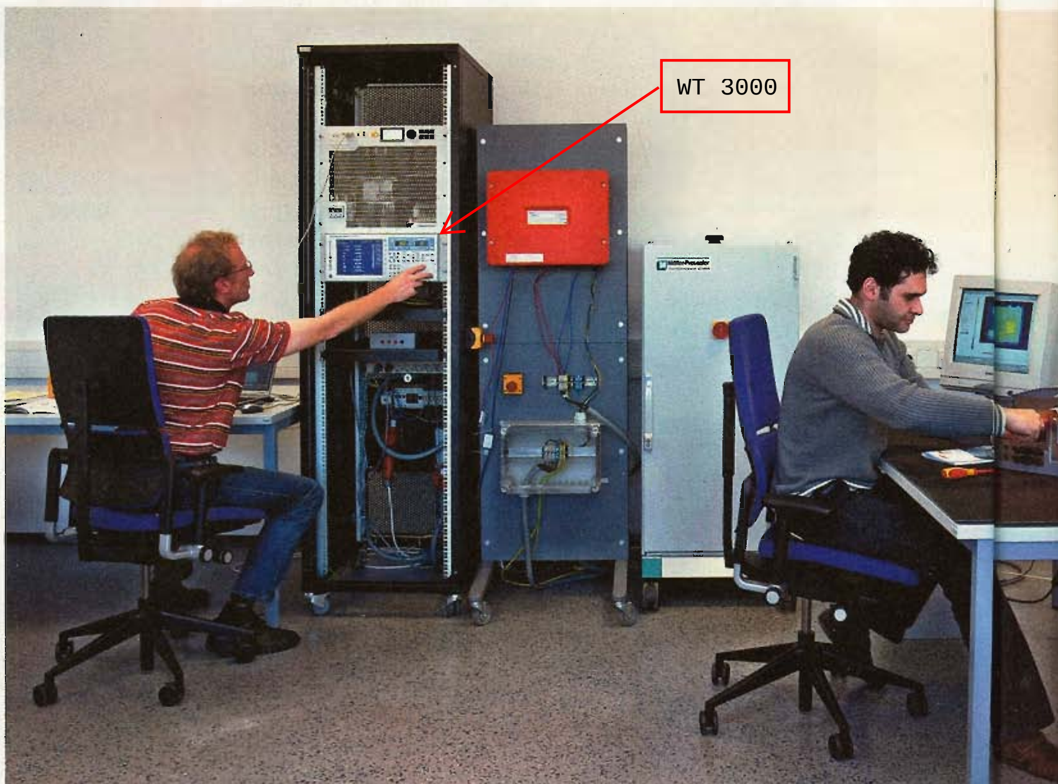
Testing inverters

PHOTON puts on-grid inverters through their paces

In advertisements, every product is outstanding. That's true for inverters, too. Customers cannot expect a manufacturer, even an honest one, to expound upon the less successful sides of a device in its brochures, and data sheets included with a product only tell part of the story. Along the lines of the motto, »Trust is good, control is better,« we have undertaken an effort to examine inverters, studying every aspect of the devices usually left unexplored. In our test, every inverter will show what it has to offer – in the areas of total voltage, power, and temperature.



The moment of truth is upon us: The PHOTON Lab is well equipped to uncover all inverter secrets (from left to right: power supply as simulator of solar generator, power analyzer, mounting wall with SMA SB3800, rotary variable transformer, and PC).

The obvious reason for testing devices is to check whether their performance lives up to the manufacturer's claims. The easiest way to do this would be to simply test the information on the data sheet to see if it's correct. But, except in cases in which a manufacturer is outright lying, this won't actually contribute anything to gaining a deeper understanding of inverter technology. The real problem is that, even if all the data in the data specs is correct, it may still leave out some important information.

That's why some customers are left wondering why their inverter never reaches its specified maximum power, even if the system is configured precisely to its technical requirements. On second glance, the customer might notice that most of the time the inverter operates at the lower end of the approved input voltage range. Although the data sheet claims this is okay, physics and the inverter's design would show otherwise: power is defined as the product of voltage and current. At particular power levels, lower voltage will require higher currents. But some components in the device cannot withstand the current that would be required to reach nominal power. Generally, the inverter »knows« this and adjusts the power accordingly.

Similar questions are raised in the area of temperature ranges. Although the data sheet says, for example, an inverter can operate in ambient temperatures up to 40 °C, it doesn't say what it will feed in at that temperature. If it's toasting away in a hot attic during the summer, and its cooling mechanism is not adjusted accordingly, operators will be baffled by yields far below expectations.

The PHOTON Lab wants to provide a comprehensive picture of the inverter by testing its behavior under the entire range of its input voltage, nominal power, and ambient temperatures. That's why we are employing equipment that allows us to test all single-phase devices on the markets suitable for 50 Hz grid frequency, as well as triple-phase feed-in devices with power ranges up to 25 kW. The results of PHOTON's test should help operators, planners, and installers to accurately design a system from the very beginning by selecting the appropriate inverter. Beginning with this issue we will present current results from our test series each month (see the test conducted on Fronius' IG 30 on p. 96). These test results will also be included in the annual market survey on inverters, published in the April issue.

What we measure

An inverter's efficiency, an important attribute, is measured with exacting detail. Each device is tested to see how it behaves under an overload of up to 120 percent of specified input power, as well as at the upper edge of the acceptable ambient temperature. Furthermore, the operating temperature inside the device is measured to locate any potential heat islands.

Within the input voltage range, the inverter is tested to find the point at which the device operates at what the manufacturer describes as the inverter's highest power, or Maximum Power Point (MPP). For yield calculations, it's important to know the device's night and own consumption, as well as the voltage at which the device feeds in its actual nominal power. Finally, the test will examine whether the inverter properly displays the feed-in power. The components that measure output electricity and voltage have significant tolerances, and the multiplication of incorrect measurements can produce even bigger errors. These calculations do not suffice for system monitoring, and the discrepancy between what the inverter displays and what the feed-in counter shows can be unsettling for operators.

Guido Schiefer / photon-pictures.com

Apart from its technical characteristics, other aspects can play an important role in the decision to purchase an inverter, for instance, the quality of the components, sturdiness of the packaging, simplicity of operation, the comprehensibility of the handbook, and possibilities for upgrading, and the test also takes these elements into account (see box, p. 94).

The devices for the first test series were purchased anonymously on the open market. In the future, test devices will be purchased directly from the manufacturers. The manufacturers must declare that the devices are identical to normal serial devices and have not been modified. The test devices will later remain in the laboratory for futher control tests. If we discover that a manufacturer has provided us with a modified device, the test results will be rescinded, and the distribution of the test results, in particular by the manufacturer in question, will be prohibited. Furthermore, the nature of the manipulation will be publicized, and the manufacturer will be excluded from any further tests for five years.

How the measurements will be taken

The measuring equipment can provide the inverter with an input voltage of between 0 and 1,000 V, that means to the point of the currently allowed maximum system voltage for most solar modules, as well as currents up to 25 A. The measuring setup consists of a DC power supply that simulates a solar generator by using a microprocessor, a highly precise power analyzer that monitors the inverter's input and output, and a rotating variable transformer attached to the inverter's output, which will allow the adjustment of the grid's voltage level at the point of feed-in. Furthermore, there is an oscilloscope for real-time control measurements, a temperature gauge, and a thermographic camera (see box, p. 93).

During the test, the simulator receives prepared IV-curves using operating software that are put at the inverter's input, thereby simulating the behavior of a typical solar module. The IV-curves are always static and shaped in ideal forms. The voltage and current at the curve's Maximum Power Point (V_{MPP} and I_{MPP}) are altered depending on which inverter is being tested, so that the desired increment in both voltage and power ranges is achieved. The IV-curve's fill factor is a constant 75 percent. Measurement takes place at 20 different voltage values by dividing the input voltage range provided by the manufacturer into appropriate segments.

Furthermore, the power range is divided into steps of 5 percent, thus with a power range from 0 to 120 percent, there are 24 steps. This results in a pattern of 20 × 24, that means 480 measuring points. At each of these measuring points, 256 different measurements are taken to average out potential measuring tolerances. Before the measurements begin, the inverter is given between 2 to 3 minutes to find an IV-curve's Maximum Power Point. With the help of a power analyzer, every measurement precisely documents what enters and exits the inverter: the analyzer simultaneously measures voltage and current in the inverter's input and output and then calculates the apparent power, idle power, and efficiency. The instantaneous efficiency is calculated from the relation between the input and output power.

The relation between the specified input power (P_{MPP}) and the inverter's accepted power (P_{DC}) gives us an idea of the inverter's static MPP tracking – that means just how close the inverter's power comes to its stated DC nominal power.

An optical control performed by the oscilloscope occurs at the same time as the measurements, and the data about feed-in power is noted in the inverter's display. The measurements are collected in an Excel spreadsheet. A PC steers the measuring setup by controlling the duration of the measurement, gathering the data, and evaluating it.

In addition to this standard procedure, every inverter is exposed to more harrowing conditions. Packed under an insulated barrier, the inverter has to demonstrate how it handles rising temperatures. The efficiency is measured in relation to the temperature, and up to the temperature the inverter can feed in at full power. The measurement always occurs at the input voltage at which the inverter has its maximum thermal loss, thereby testing the worst-case scenario. A thermographic camera and temperature gauge measure the heat distribution inside the inverter.

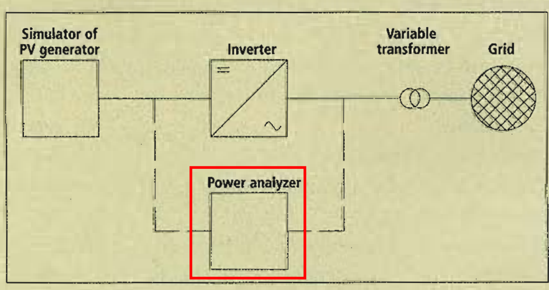
How the data is evaluated

A 3D diagram summarizes the measurements – the input voltage is displayed against the input power, with the third dimension produced by a color scale representing the efficiency at each of the 480 measuring points. Depending on the level curve, as it is known in geographic maps, the diagram will show areas where the efficiencies are equal. The color scale represents steps of 1 percent – a finer breakdown would make it difficult to differentiate between shades of color. Subtler gradations within a single percentage point are represented by two intersecting lines, one running vertically along the voltage axis and the other horizontally along the power axis through the »peak« (the area of maximum efficiency). The resulting profiles

Laboratory equipment

The quality of test results depends to a great extent on the type of test equipment. PHOTON uses the best equipment available on the market. Details are as follows:

DC power supply
Regatron AG, Topcon quadro 20 kW, type 1153-208, with specially amplified power supply for 32 kW



Block diagram of the measuring setup.

Power analyzer
Yokogawa Electric Corporation, WT3000, sampling rate: 200 kHz, measuring precision: +/- 0.02 percent

Rotary variable transformer
Möller-Preussler Transformatoren GmbH, custom designed according to PHOTON's specifications, based on series 832, size 2912, voltage can be manually adjusted

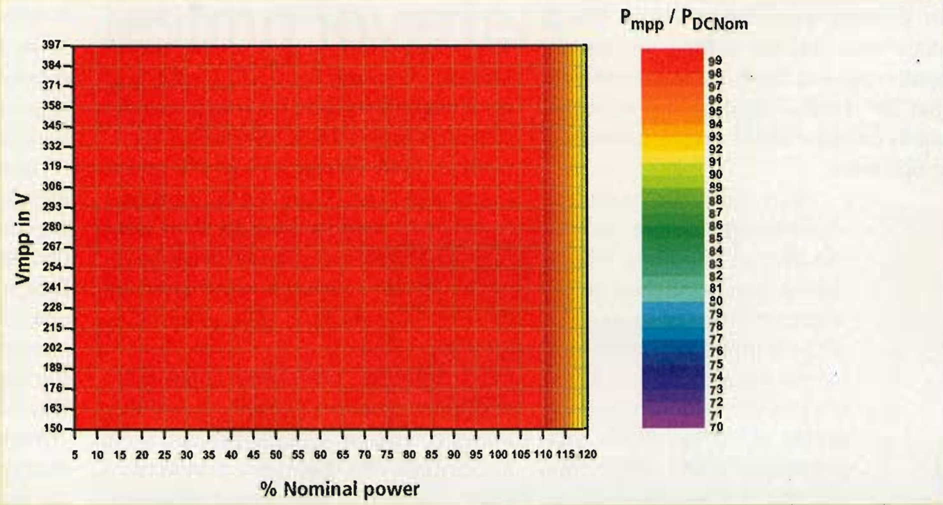
Oscilloscope
Tektronix Inc., TDS 3014 B

Temperature gauge
Dostmann Electronic GmbH, P600, measurement range: -200...+850 °C

Thermographic camera
Fluke Deutschland GmbH, Ti20

Scope of an inverter test

Every inverter undergoes a standard test procedure. During this test, first the device's design, operation, and instruction manual are examined, then the circuit design is discussed, and finally, a number of measurements are conducted.



The 3D diagram for the static MPP tracking charts the MPP voltage against the input power. The third dimension in the form of a color scale shows how much of the power offered can be accepted by the inverter.

Design

This portion of the test is concerned with circuit boards, components, protection type, housing (construction design and materials), arrangement of components, internal construction, component quality, and upgrade options. The device is examined and all noticeable problems documented.

Operation

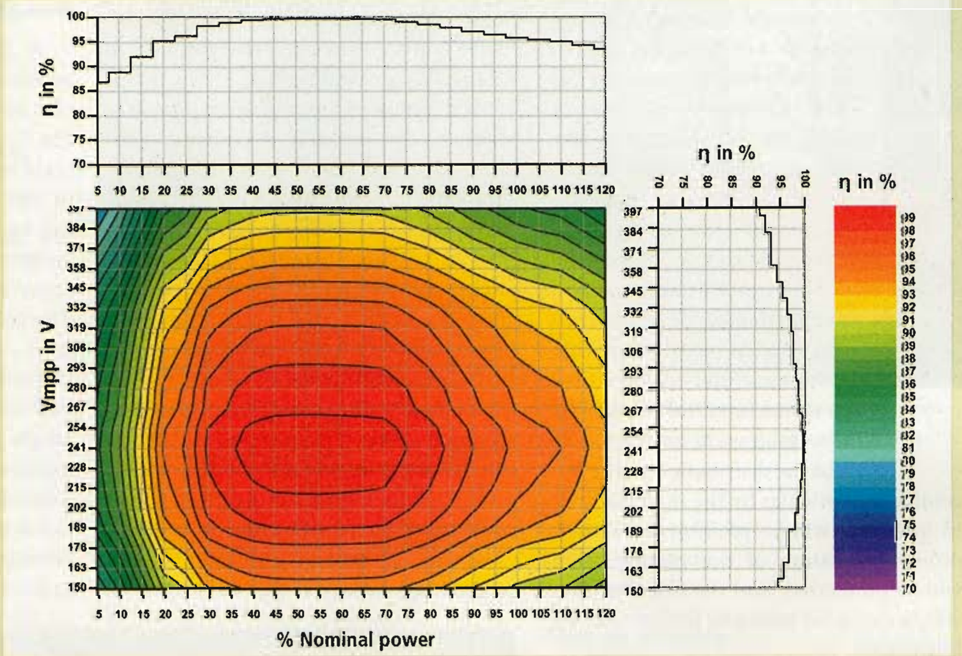
This category includes information on packing quality and wall mounting (type and operation), weight, connection to grid feeder, pre-configuration (if available), duration until grid connection, duration until location of MPP, and display (language, handling, overview, and displayed values).

Instruction manual

Breadth and language, but also additional information like support in the event of a failure, are taken into account.

Circuit design

This category explores the nature of how energy from a PV system feeds into a grid – that means what circuit principles the inverter uses.



The 3D efficiency diagram shows the input voltage compared to the input power. The third dimension is a result of the color scale, which emphasizes the area of equally high efficiencies according to a level curve. The curves at the top and right of the diagram show a horizontal and a vertical cross section through the maximum efficiency.

Measurement

The main portion of the inverter test consists of extensive measurements. The details are as follows:

- Efficiency measurement: Efficiency is displayed as a function of input voltage V_{MPP} and input power P_{MPP}
- European efficiency: MPP voltage range in which the European efficiency is reached
- Processed power: The power demanded of the solar generator by the inverter (adjustment efficiency)
- Feed-in of nominal power: Whether the inverter can feed in its nominal power over the entire input voltage range defined by the manufacturer
- Indicated output power: Comparison of the indicated output power in the inverter's display with the measurement from the power analyzer
- Operation at higher ambient temperatures
- Overload behavior
- Own consumption and night consumption
- Thermographic images for recognition of component overload

Comments from the manufacturers and summary by the editorial staff

The test results are presented to the manufacturer. Moreover, the editorial staff provides a summary assessment of the device. A comparative assessment, for instance in the form of grades, will only be introduced after a larger number of inverters have been tested.

from the level curves are – spatially correct – folded towards the top and to the right. The curve above the map therefore shows the efficiency versus the nominal power. The curve to the right of the map shows how the efficiency changes along with the feed-in voltage. To read the right curve more easily, the magazine can be turned 90-degrees clockwise, so the curve runs from right to left and the input voltage can be traced from lower to higher values.

When examining efficiencies, naturally, everyone tends to say: »the higher the better.« But it's more important to expand this view and ask: what does the »peak region« look like? Is the peak high with its flanks steep? Or is it lower, like a rounded hill with a subtler decline? Installers can learn a great deal about how the entire system should be designed from the nature of a peak. And anyone halfway informed about electronic technology will be able to easily predict how well an inverter will behave under various input voltages and load conditions.

A high, but very narrow peak means that a few volts to the »left« or the »right« will result in significant decreases in efficiency from the optimum. This is even more problematic when you think that the voltage as well as the power of a solar generator deviates drastically during the course of a single day and year. Hence it's quite difficult to achieve a reasonable annual yield with an inverter that has a small range but potentially very high efficiency. To the contrary, an inverter with a broad range but lower peak can accept a wider portion of what a module can offer and therefore deliver a good output. Depending on how broad the range of a high efficiency is, the installer can decide during system configuration just how many more (or less) modules should be connected serially in the solar generator. This increases flexibility during system planning. The inverter's European efficiency is calculated according to the specified definition, and shown in the diagram in its relation to the V_{MPP}.

A second 3D diagram contains the power offered by the simulator of the solar generator in relation to the power required by the inverter, and shows what percentage of the power the inverter actually further processes by using a color scale. The diagram reveals whether the inverter is getting the most out of the modules. Apart from inverter efficiency, this information, often called the MPP adjustment efficiency, is one of the most important values. A good efficiency alone is not enough to ensure a PV system's high annual yield if the power demand lags far behind the module's potential. In praxis, the MPP adjustment efficiency should constantly be very high over the entire input voltage and load range. Values of between 98 and 100 percent are acceptable; values under 97 percent should not be tolerated.

Finally, the inverter's data regarding output power is compared to the power analyzer's measurements at the inverter's output. A diagram of this data shows how accurately the inverter displays the feed-in power.

What the test doesn't reveal

When building an inverter, the choice of components for a device has a dramatic effect on costs. Selecting components of lesser quality will make the device less expensive, but the product's lifespan will be negatively impacted. Because of their internal resistance, electrolytic capacitors that are too small will heat up, and as the case may be, dry out prematurely. Standard capacitors are generally designed for temperatures up to 85 °C. Good capacitors can take up to 105 °C, but they are also more expensive. Furthermore, under conditions of high current the transistors in the power element can overheat. The core temperature, which can't be measured directly, can be projected using an algorithm. PHOTON's test cannot provide much information about the lifespan of a device, since the test does not include a long-term endurance test. At the most, the test can reveal crude design flaws. In this case, thermography can help when the test uncovers hot spots in the device. These hot spots could be the site of more severe errors; at the very least, they show that the device lacks decent thermal design. An inverter may achieve high efficiency, but improperly dimensioned components can make that achievement short-lived.

Despite these limitations, the test results should be very interesting for installers, system operators, as well as simulation software developers. *Andreas Schlumberger*