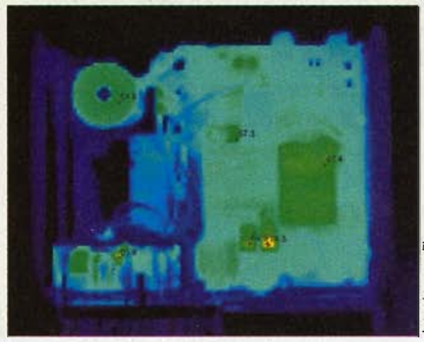
# Peak efficiency with three peaks

## Testing Fronius' IG 30 inverter

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**Premier candidate: Fronius IG 30 is the first inverter to undergo PHOTON Lab's test. Middle, the opened inverter; right, the heat image during standard operation – everything looks good.**

Austrian company Fronius International GmbH's IG 30 was the first product to undergo PHOTON International's inverter test. For the most part, the test confirmed the information provided by the manufacturer, but it also revealed a technical peculiarity.

### Construction

Fronius' IG 30 inverter is designed for high input voltage. It belongs to the Austrian company's IG product series (IG 15 to IG 60 HV). In addition to solar technology, Fronius also produces battery charging systems and welding technology. Its output power ranges between 2.5 and a maximum of 2.65 kW. Fronius suggests a power of between 2.5 to 3.6 kW on the input side. According to the manufacturer the maximum efficiency is 94.5 percent, while the European efficiency is 92.7 percent.

The device adheres to protection type IP 21, and is thus suited for use indoors. It is equipped with an ENS and contains a temperature-driven, speed-regulated fan. Its housing consists of individual plastic components built upon a chassis made of aluminum plates. Although these metal sheets have sharp edges, for the most part they are covered with plastic housing. The basic version uses six circuit boards arranged in two layers and orientations. Several large components are placed outside the circuit board, and are also installed in two layers. Several single and multiple way cables connect these components to one another. While this makes the device compact, it also complicates its mechanical construction, and therefore increases the potential for failures – the more connections, the more points of attack for chance and corrosion.

The internal device fan uses ball bearings, and according to the instruction manual, Fronius estimates that its lifespan is 20 years. The fan manufacturer itself claims its product has a lifespan of 70,000 hours at a device temperature of 40 °C. Of course, this temperature will not be constant, depending on where the inverter is installed, and the fan, which is regulated by temperature, does not always operate at maximum speed. The inverter should only be installed in clean areas, otherwise the fan can clog with dust and malfunction. In the event of a defective device, only qualified personnel can replace the IG 30's fan.

The electrolytic capacitor in the power element belongs to the 105 °C temperature class, which gives it a longer lifespan. All the other electrolyte capacitors in control electronics aren't subjected to such high loads, so they comply with the 85 °C temperature class for reasons of cost.

### Operation

The customer receives the IG 30 well packed and protected. A mounting plate is included for installation on the wall – the module hangs on the plate, which is affixed by a screw. At first, the plate is unscrewed from the device and then attached to the wall. The attachment screw, which holds the inverter and the mounting plate together, is not easy to find and difficult to reach.

In connecting the inverter to the grid, it became clear that one needs a very long screwdriver, nimble fingers, and a lot of patience. Furthermore, because of the lack of space and the sharp edges, the installer should be prepared to find a few abrasions on his fingers at the end of the day.

Using a standard device as supplied by Fronius, putting the inverter into operation is simple. If the solar generator is designed properly and equipped with an external DC isolating switch, all you have to do is connect the inverter. After about 50 seconds, it connects to the grid and begins feeding in. The display is clear, with backlighting, and is operated using four buttons. Although it can display all kinds of measurements, including grid size, it doesn't show input voltage. Furthermore, it is not possible to display multiple measurements simultaneously for a better overview. At just 9 kg, the device is rather light – one person can easily handle it.

### Instruction manual

The instruction manual is very extensive – and available in several languages, including English, French, German, Italian, Spanish, as well as Korean. In addition to general explanations, it also offers support for malfunctions or interruptions through comprehensive status logs with corresponding diagnoses and explanations. The customer receives detailed instructions on how to operate the display with its various modes. The display itself only »speaks« English, albeit with a manageable vocabulary for non native speakers.

### Circuit design

The energy from the PV system travels through an EMI filter to the DC-DC converter, which operates using phase shifting. In this case, the input DC voltage is hacked into square blocks of alternating current. The downstream high-frequency transformer, which boosts the hacked voltage, is typical for Fronius. At the same time, the transformer also creates galvanic isolation. In other inverters, an output transformer does this job. Then, the direct voltage, following rectification and filtering, reaches the inverter output bridge. This hacks the direct voltage again and creates a sinusform output voltage with 50 Hz grid frequency (in Europe) through a pulse with modulation and subsequent filter. The ENS then monitors the grid voltage, frequency, and impedance, as well as the direct current portion, and shuts down the system in the event of a failure. Any radio interference is filtered with an output filter, which is located right in front of the grid terminal.

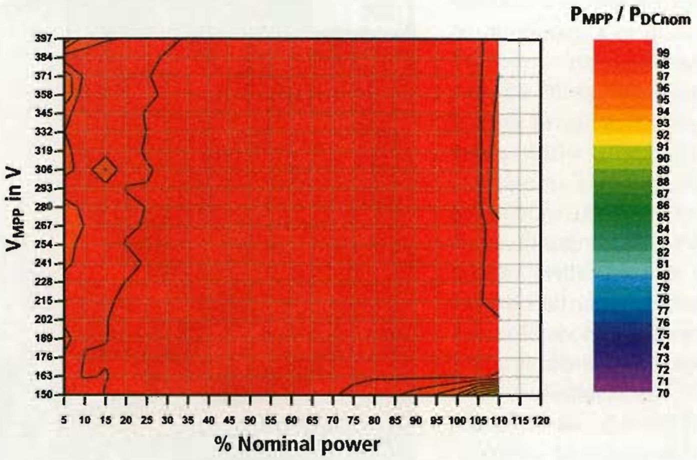
### Measurements

**Efficiency:** Efficiency is presented as a function of input voltage $V_{MPP}$ and input power $P_{MPP}$. To do this, the input voltage range, within which the IG 30 finds its Maximum Power Point, is divided into 20 steps, each with 13 V, and the DC power range in 24 steps, each with 5 percent. The power PDC is standardized to the inverter's nominal input power PDCN and given as a percentage of the nominal power. Thus, 100 percent would represent a nominal power on the input side of 2,700 W.

The 20 × 24 measurement curves are the basis for charting the efficiency in a color diagram. The color spectrum and its conversion into measurements are shown next to the diagram.

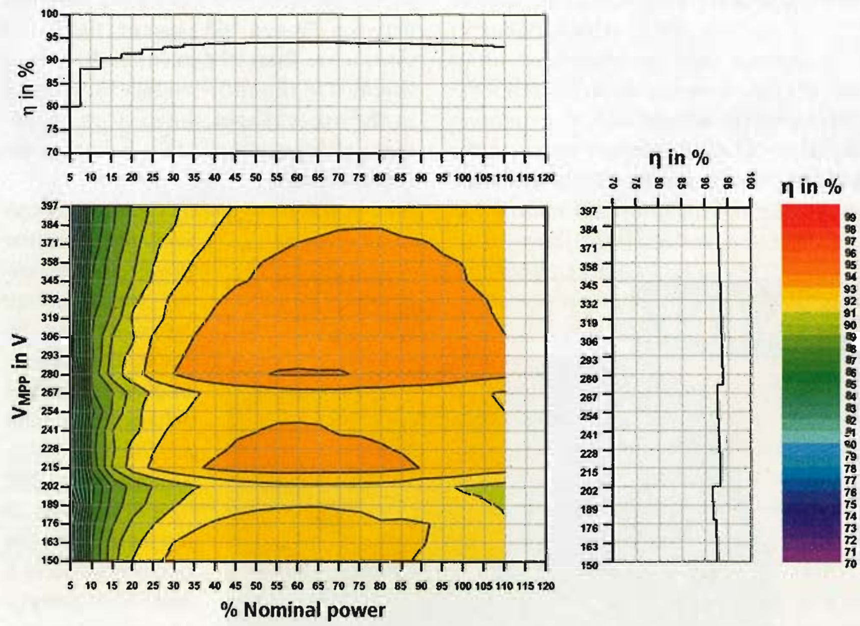
At first, the diagram shows how the inverter's maximum efficiency of 94.05 percent (orange) can only be reached in a very narrow range around 280 V, while efficiencies between 93 and 94 percent (dark yellow) are represented in a much broader range. But there's something else that makes this diagram interesting. In the color diagram, the two-dimensional areas with higher efficiency are interrupted twice by channels with lower efficiency. The efficiency is not, as one would expect, a single peak, but rather three peaks. This only makes sense if you know that the IG 30 has a technical peculiarity: the high-frequency transformer on the primary side

## MPPT adjustment efficiency




This 3D diagram shows how the MPP tracking from the input voltage depends on the actual power. The extended dark red area shows how the IG 30 actually accepts most of the supplied power over a broad range.

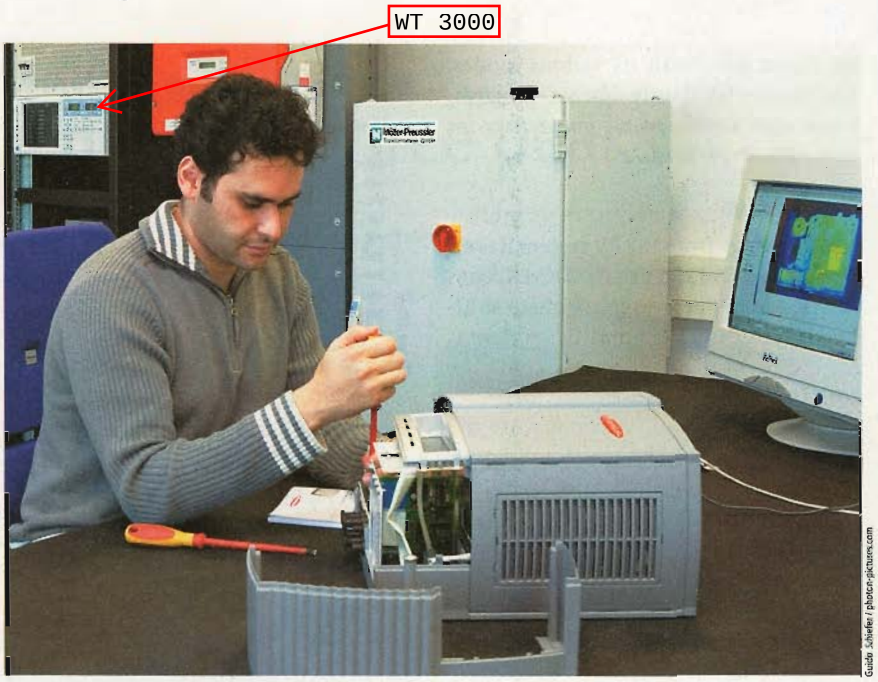
## Efficiency




The efficiency diagram reveals it all at a single glance: The IG 30 has several »maximum« efficiencies. The cross section through the three-dimensional diagram above and to the right show the relationship of the efficiency η to the normalized input power and voltage ($V_{MPP}$).

adjusts itself to the incoming voltage. The coil on the input side is actually divided into sections and comes with three connections. At a $V_{MPP}$ of around 203 V, as well as 280 V, the inverter employs an additional coil packet in the transformer. The vertical line of intersection at 58 percent of the nominal power runs through the maximum achieved efficiency, but, on account of the IG 30's unusual design, it also shows two additional local maxima: right at the start of the input voltage range at 150 V, the $\eta_{max}$ is around 92.7 percent; at a $V_{MPP}$ of around 203 V, the $\eta_{max}$ is 93.5 percent; and at a $V_{MPP}$ of around 280 V the $\eta_{max}$ of 94.05 percent.

The horizontal line of intersection travels through the inverter's point of highest efficiency: 94.05 percent at a $V_{MPP}$ of 280 V. The diagram in which the efficiency is plotted against the nominal power shows the course of the efficiency by a minimal $V_{MPP}$ of 150 V and a maximum $V_{MPP}$ of 397 V – in other words, on the limits of the defined operating range – and the paths by which the efficiency reaches its absolute maximum ($V_{MPP}$ = 280 V) as well as its relative minimum ($V_{MPP}$ = 202 V), which shows the minimal peak efficiency at 91.78 percent. The inverter reaches this minimum value under all conditions; the other peaks are only




**Thorough look inside: The IG 30 on-grid inverter from Fronius was the first inverter to be tested in the PHOTON Lab.**

achieved when the solar generator's power »fits« optimally. Thus our measurements did not entirely confirm the manufacturer's claim to a maximum efficiency $\eta_{max}$ of 94.5 percent.

Rather, it seems that the IG 30 only reaches its highest efficiency of around 94 percent when operating within a very narrow input voltage range around 280 V. Although Fronius uses this value as its maximum efficiency in its datasheets, it doesn't explain that installers cannot build systems that can maintain this efficiency over extended periods of time.

**European efficiency:** The definition of the European efficiency is as follows:

$$\eta\, euro = 0.03 \times \eta 5 + 0.06 \times \eta 10 + 0.13 \times \eta 20 + 0.1 \times \eta 30 + 0.48 \times \eta 50 + 0.2 \times \eta 100$$

In this formula, $\eta 5$ represents the efficiency at 5 percent of the nominal power PDC, $\eta 10$ at 10 percent, and so forth. At a $V_{MPP}$ of 280 V, the device will reach the manufacturer's specificed efficiency – and only at this $V_{MPP}$.

**MPPT adjustment efficiency:** If the power $P_{MPP}$ of each of the specified IV-curves is compared with the measured input power at the inverter, it can be seen what portion of the supply from the modules the IG 30 actually accepts. The better the MPP tracking, the more solar power is fed into the grid. This is just as important as a high efficiency. At a nominal power of between 30 and 105 percent, the IG 30 takes more than 99 percent of the power supplied in the entire voltage range. And in the other ranges, the device's adjustment efficiency never falls below an acceptable level.

**Feed-in of nominal power:** The inverter can feed in nominal power in the entire input voltage range defined by the manufacturer.

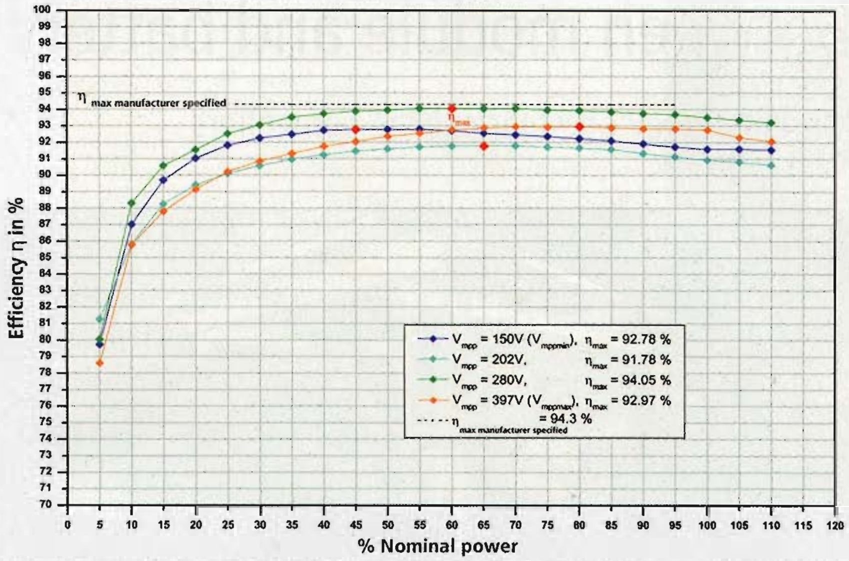
**Displayed output voltage:** Under a constant $V_{MPP}$ voltage of 293 V, the inverter is fed with different powers between 5 and 110 percent of nominal power. By comparing the output voltage shown in the inverter's display with the measurements from the power analyzer, it can be seen that the values from the inverter are always slightly higher than those from the power analyzer. At around 35 percent of nominal power the inverter makes the smallest error and adds 0.1 percent to its value; at 105 percent of nominal power it shows a value 2.41 percent too high. The highest deviation from the actual value, however, is the extreme discrepancy of 5 percent of nominal power, but because of the small amount of energy processed in this range, the figure doesn't carry much weight. This outlier can be explained by signals from the ENS overwhelming the measurements. The active current here is so low that impulses from the ENS cover it up – a typical problem when measuring lower powers ranges.

**Operation at higher ambient temperatures:** The inverter can feed in full nominal power at ambient temperatures up to 50 °C across the entire MPP range of 150 to 400 V. At higher temperatures, the device doesn't shut down, but rather adjusts the working point on the IV-curve, reducing the input power and therefore decreasing internal thermal losses.

**Overload behavior:** An overload 1.3 times higher than the stated input nominal power – that means 3,500 W at a $V_{MPP}$ of 163 V and an ambient temperature of 23 °C – limits the IG 30 to a power of 2,968 W. This corresponds to an overload of 10 percent. In this case, the inverter adjusts the working point on the IV-curve to 179 V. At this point, the inverter produces an output power PAC of 2,700 W. Since the inverter doesn't accept any input power above 110 percent of the nominal value, the fields in the efficiency diagram positioned to the right of this value remain in white.

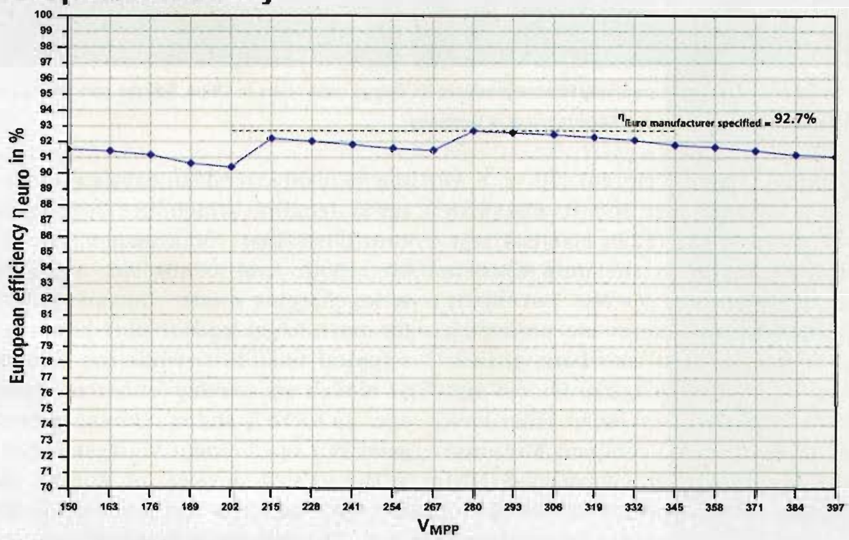
**Own consumption and night consumption:** The device's own consumption in the tested basic configuration is around 2 W. Fronius lists 7 W. This higher value likely refers to an IG 30 equipped with additional performance options. At

## Efficiencies at different $V_{MPP}$ voltages



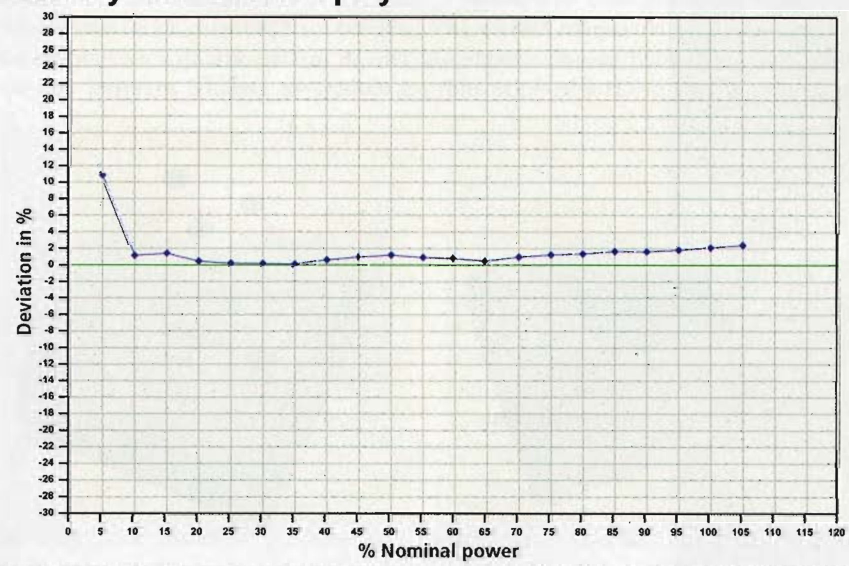

Pictured here are the borders of the defined operating range at 150 and 397 V, as well as the course through the maximum and minimum peak efficiencies at 280 and 202 V.

## European efficiency




The European efficiency's curve also shows the different peaks.

## Accuracy of inverter display




The IG 30's display shows a higher output power than what is actually being fed in for the entire nominal power range. The spike at 5 percent is a result of signals from the ENS.

night the IG 30 takes in an effective power of 0.25 W from the grid. Fronius lists the device's night consumption at 0.15 W.

**Thermography:** Thermographic imaging shows a view from the top of the inverter while operating at nominal power. The heat image was taken at an ambient temperature of 23 °C and shows the internal portion of the device visible from the front. Since the device is constructed in two well-nested layers, the image cannot capture all the components. Nevertheless, it does clearly show that no visible components ever exceed a temperature of 73.8 °C. Hence everything is okay.

**Manufacturer's response:** Prior to publication, the test results were given to Fronius with a request for the company's response. The company has confirmed all of our measurements. The slight discrepancy with the peak efficiency, says Fronius, is »within the range of normal fluctuations you will find in different measurement procedures.« We agree with this evaluation.

### Summary

The most striking characteristic of the Fronius IG 30 is certainly the three different efficiency peaks, the highest being 94.5 percent, although within a very narrow range. This peculiarity, a product of the device's construction, can complicate things for system planners. After all, during the course of a day or an entire year, the solar generator delivers very different voltages, thereby constantly forcing the system beyond the possible efficiency maximum to the valleys that lie between the peaks. The only way to optimally configure the PV system is with the help of a simulation program.

Unfortunately, even Dr. Valentin Energiesoftware GmbH, a leading seller of these types of software programs, hasn't integrated behaviors like those of the IG 30 into its simulation software. But developer Rainer Hunfeld assumes that the effect of multiple efficiency peaks will be limited. Thus any advice about how to best optimize a system depends to a great extent on the basic conditions of the simulation.

Another positive aspect to note is that the IG 30 feeds in its nominal power assiduously up to an ambient temperature of 50 °C. One weak point, on the other hand, is the fan, which can only be replaced by an expert. The IG 30 shouldn't be installed in a dusty space, for instance a barn, otherwise the service provider will have to be called sooner rather than later. All in all, the IG 30 is an easily operated device with a good efficiency. The manufacturer's data sheet was essentially accurate. *Heinz Neuenstein, Andreas Schlumberger*