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OFFPRINT:
Diehl AKO

Focus on the rear side

Aluminum oxide deposition equipment supports higher cell efficiencies

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Anti-reflection coating tool-makers fight potential induced degradation at its root

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Contacting thin films
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Finally a new idea

With its new inverter Platinum 16000 R3 Diehl AKO manages to climb to the number three spot of the PHOTON ranking. The innovative »Dual-X« technology guarantees high efficiency and low production costs at the same time

Text: Heinz Neuenstein, Anne Kreutzmann

Highlights

- The DIEHL AKO Platinum 16000 R3 is a three-phase, transformerless inverter, which was designed for PV systems with two symmetrical solar strings
- With a PHOTON efficiency of 98.0 percent for medium as well as high irradiation the inverter earns an A+ twice and climbs to the third rank
- The secret to the high efficiency is a technology that is able to combine the voltage of two solar strings in a way that the boost converter has minimal work to do
- If the two solar arrays are not symmetrical or turn out not to be symmetrical over time, this technology has the same downsides as inverters which use only one tracker for two strings – the yield declines because of mismatching

When former Diehl Controls (now Diehl AKO Stiftung & Co. KG) sent their inverter to the PHOTON Lab 4 years ago, it promptly earned an »A+« and was able to claim a bronze medal in the PHOTON ranking (see PI 10/2009, p. 142). In 2009, the Platinum 6300TL's PHOTON efficiency for medium irradiation of 96.8 percent was sufficient for the honor. Since the way we rank inverters changed beginning 2011, Diehl's device needs to make do now with just an »A«, no more additional »+«, but it still makes it into the midfield of the ranking. Given the backstory we were curious to see what the latest creation from Diehl would be able to accomplish. The manufacturer submitted the Diehl AKO Platinum 16000 R3 to PHOTON Lab while signing the standard test agreement which insures that the device comes out of a regular production run. In the end the German company reclaimed the third place (see table, p. 58), a result that should delighten Munich-based Mutares AG as well, since it took over Diehl Controls in April. Meanwhile the decives are still produced by Diehl in the German town of Wangen.

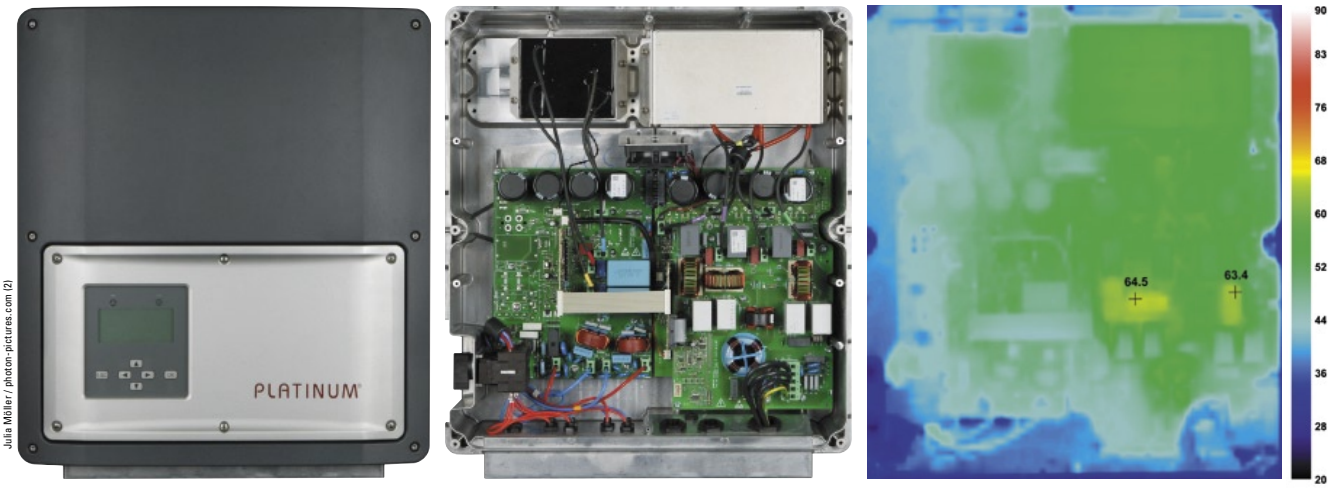
Construction

Five devices with nominal power ranging from 6,000 to 15,000 W (AC) are part of the Diehl R3 series. Neither of the inverters of this family use a transformer. The tested device with 15,000 W nominal power is designed compact and well thought even though it needs no less than 7 circuit boards. The power element is attached to 3 circuit boards alone: The DC and the AC side EMI filter components as well as the output bridge are placed on one of these circuit boards each. The corresponding control unit circuit boards are mounted in an 90 degree angle onto the DC EMI filter and the output bridge circuit boards. The power transistors and diodes are integrated into modules which have been mounted from the solder side of the circuit board and are clamped onto a cooling element below it which serves as part of the aluminum housing. The housing also features a cooling element on the outside working passively.

On two of the 3 big circuit boards you will find the components of the boost converter and a sinusoidal output filter. An internal fan makes sure the heat does not get trapped in the inside. The display is mounted to the inside of the housing's front, just like the interface circuit board. The display circuit board connects to the AC EMI filter circuit board via a cable. The housing itself comprises of two parts. The backside is made of aluminum, the front of PUR foam with an extra lid for the connectors and clamps section. The entire device features protection class IP 66, making it suitable for installation both indoors and outdoors.

An automatic disconnect unit ensures operation is safe by checking the grid for the correct voltage and frequency ratios. Furthermore, an insulation test is carried out on the solar generator, and the grid side is monitored for leakage current. The device status is communicated by the display and two LEDs.

The electrolytic capacitors used in the power element, as well as those for the control electronics, have a temperature class of 105 °C, and are therefore well-suited for coping with ambient temperature. The solar generator is hooked up using two times two MC4 connectors, with a



Julia Möller / photon-pictures.com (2)

▲ The Platinum 16000 R3 is the most powerful inverter of Diehl AKO's R3 series. The 15 kW inverter is compact in size and has intricate circuitry under the hood. The thermographic camera reveals only parts of it – and what it shows turned out to be no reason to worry.

screw connection being used to attach the network cable to covered terminal blocks. There is also an internal DC disconnect on the left side of the housing. The Diehl 16000 R3 uses an RS232 interface to communicate with a PC as well as two RS485 and one BUS interface to communicate with up to 50 other Platinum inverters.

Operation

The device is delivered to the user well packaged in a cardboard which is mounted to a wood crate. It is mounted to the wall using a bracket which is provided as well. Weighing 45 kg, the Diehl AKO Platinum 16000 R3 is a lightweight given his nominal power. If the solar generator has been correctly dimensioned and an external DC circuit breaker has been docked on, the inverter is ready to start operation. It requires 78 seconds to run a variety of tests before connecting to the grid and commencing work.

The graphic display is installed flush with the front cover, features white backlighting, and is easy to read. English, German, French, Italian, Dutch and Spanish can be selected as user languages. Six buttons help to navigate. The configuration »Today« shows a number of values as well as a diagram about the daily yield. The values can be pulled for »Today«, »Total«, »Year«, »Month«, »Week«, »Yesterday«. It the device is set to »Current« mode there are two screens that show the voltages on the AC as well as the currents and the power of the three phases and the DC side. So there are quiet a range of values provided in an easy-to-read fashion. There is also a data logger integrated that can save the data of 30 years.

Instruction manual

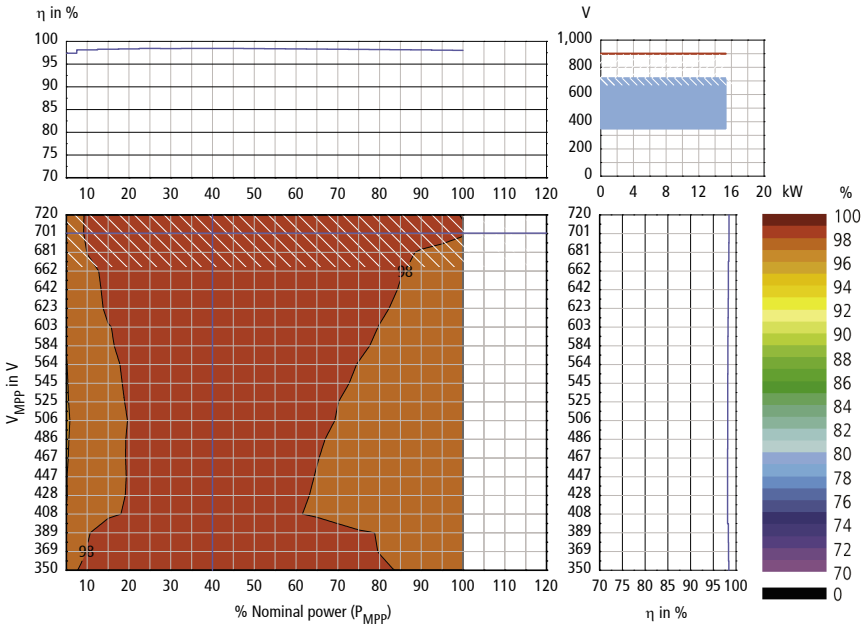
Short and concise operating instructions are enclosed with the device. They are available in English, German, French, Italian, and Dutch. A more in-depth installation manual can be downloaded for the manufacturers web site, it includes general explanations as well as covering assembly, connection, operating characteristics, the status display and fault messages. It also covers how to adjust parameters like date and time among others.

Circuit design

The transformerless, three phase inverter features two DC inputs but only one MPP tracker. The energy from the photovoltaic array passes through an EMI filter and enters the next stage. Instead of a traditional boost converter Diehl uses a newly patented circuit designed dubbed »Dual-X« which relies on the PV system having two perfectly symmetrical arrays in order to fully unleash its efficiency. The »Dual-X« circuit uses – like a symmetrical boost converter – one symmetrically divided storage throttle, a capacitor and two recovery diodes in the positive and the negative cable respectively. The voltage from the solar generators is used in a way that this special boost converter has minimal work to do which lead to a better efficiency. The topology comes with a number of advantages. For one the storage throttle can be undersized, the power semiconductors are less stressed and as a result the switching losses are lowered. The switching modulation process helps optimizing the conversion efficiency through the input voltage.

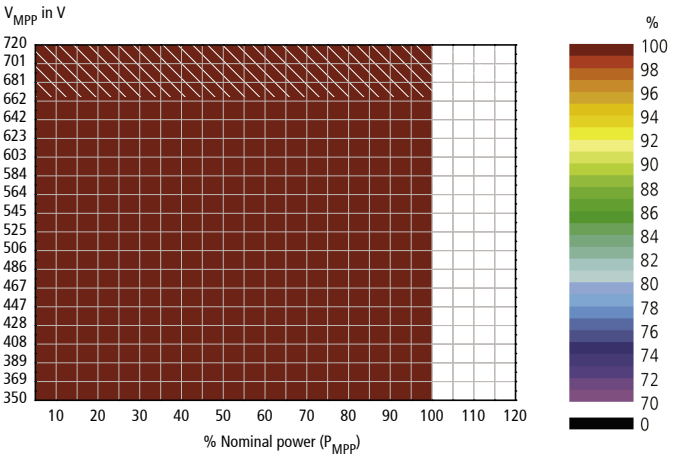
Conversion efficiency

The conversion efficiency amounts to over 98 percent over a wide range. The maximum comes out at 98.5 percent for 40 percent nominal power and 701 V MPP voltage.



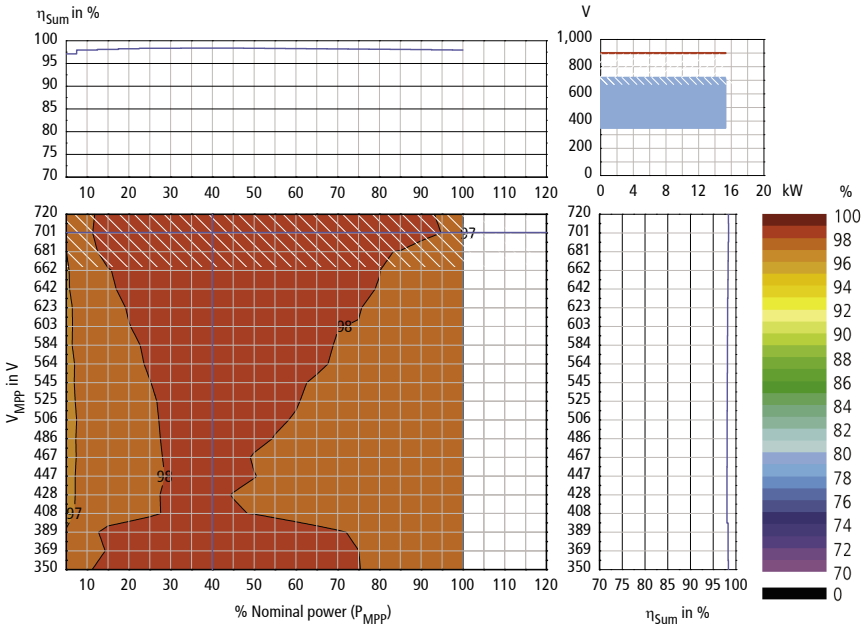
× MPPT adjustment efficiency

Nice and smooth: The MPPT adjustment efficiency never falls below 99 percent.



= Overall efficiency

Because of the very even MPPT adjustment efficiency, the graph for the overall efficiency is basically identical with the one that shows the conversion efficiency.



Dual-X Technology from Diehl AKO

The array is divided into two symmetrical sub-arrays PV1 and PV2. The voltage of both sub-arrays lies between 50 and 100 percent of the intermediate circuit voltage at the capacitor C. Both sub-arrays are connected to a common boost converter whose design was derived from its basic symmetrical form.

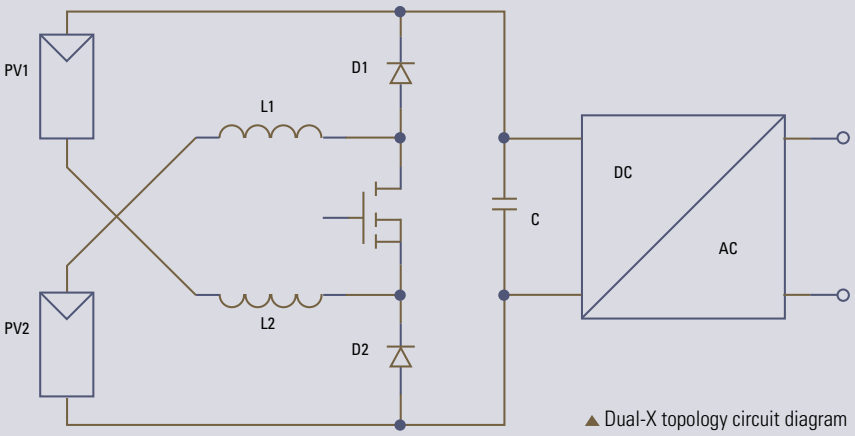
If the transistor T is switched on, both sub-arrays are series connected via the storage chokes L1 and L2; the voltages of the two sub-arrays are added to each other, and the same current flows through both arrays.

If the transistor T is switched off, the currents force both diodes D1 und D2 to conduct the electricity into the storage chokes L1 and L2, thereby parallel connecting the two sub-arrays. The currents from the two sub-arrays are added to each other and their voltages are the same.

In both of these connection states, energy is transferred into the intermediate voltage circuit, in contrast to the classic boost-converter connection. This means that less energy must be cached in the storage chokes, so there is also less circulating reactive power. This means the storage choke can be half of its normal size, the load on the semiconductors is smaller due to reduced currents and voltages, and switching losses are also smaller. The result is higher conversion efficiency.

If the sub-array voltage is exactly 50 or 100 percent of the intermediate circuit voltage, the transistor T will remain continuously turned on (forming a series connection) or continuously turned off (forming a parallel connection). In these states, there are no more switching losses, only conduction losses.

With an array voltage between 50 and 100 percent (of intermediate circuit voltage) and parallel connection, the charging current diminishes, limited by the storage choke L, and the intermediate circuit voltage falls. With series connection, the charging current rises and in turn raises the intermediate circuit voltage. The different turn-on and turn-off times of the transistor T, and pulse width modulation (PWM), allow the desired intermediate circuit voltage to be set. When the transistor T is continuously fully on, there is series connection and when it is continuously fully off, there is parallel connection. *hn*



▲ Dual-X topology circuit diagram

The three phase output bridge uses Neutral Point Clamped (NPC) technology and is followed by a sine filter, comprised of the sine wave chokes and other capacitors, which smoothens the square-shaped voltage blocks into a sinusoidal waveform with the grid frequency of 50 Hz.

An automatic circuit breaker disconnects the inverter from the grid as soon as the grid frequency, or a grid-side DC current, deviate from predefined limits. In addition, the insulation resistance of the solar generator is also monitored. Any radio interference is eliminated by an output filter, which is installed directly in front of the grid clamp.

Measurements

All of the following measurements are based on a grid voltage of 230 V. The maximum DC voltage of the Diehl AKO Platinum 16000 R3 is 900 V, the maximum generator power is 15,350 W and the nominal DC power is 15,300 W.

Locating the MPP: When measurements began, both the DC and the AC side were switched off. At a predefined IV curve with nominal power and an MPP voltage of 525 V, the inverter needs 78 seconds until it connects to the grid. Another 621 seconds passed before the trackers reached the MPP (the inverter is set-up in a way that it boosts its output power by 10 percent per minute). Changing from 525 V to 506 V took 13 seconds, changing to the next MPP range of 545 V took about 10 seconds.

MPP range: The MPP ranges from 350 to 720 V, which makes the Platinum 16000 R3 a wide range inverter. The maximum MPP voltage of 720 V has a sufficient distance to the maximum input voltage of 900 V.

Conversion efficiency: In the MPP voltage range from 350 V to 720 V the inverter operates at 100 percent of its nominal capacity. The efficiency could therefore be determined for this range. The hatched area in the diagrams at maximum DC voltage of 900 V indicates that there are limitations for thin-film modules due to the insufficient distance between maximum MPP voltage and maximum DC voltage.

The colored diagram shows only two shades because the conversion efficiency is very homogenous over the whole voltage range. The area with efficiencies over 98 percent spans over the whole voltage range. At 40 percent power and 701 V MPP voltage the conversion efficiency maxes out at 98.5 percent, which is even higher than the manufacturer specifies at 98.4 percent. Over the whole MPP voltage range the conversion efficiency only varies by 0.3 percentage points. At little power of less than 15 percent of the nominal power the efficiency drops between 0.7 and 1.3 percentage points. At nominal power, the power factor cos φ was about 1.

Weighted conversion efficiency: The European efficiency reaches its highest value, 98.3 percent, in the 701 V MPP voltage range, which is 0.3 percentage points more than the manufacturer's specification of 98.0 percent. The difference between maximum conversion efficiency and maximum European efficiency amounts to just 0.2 percentage points. The maximum Californian efficiency is the same as the European efficiency.

MPPT adjustment efficiency: The MPP tracking of the Platinum 16000 R3 works perfectly and never shows less than 99 percent adjustment efficiency over the entire operating range.

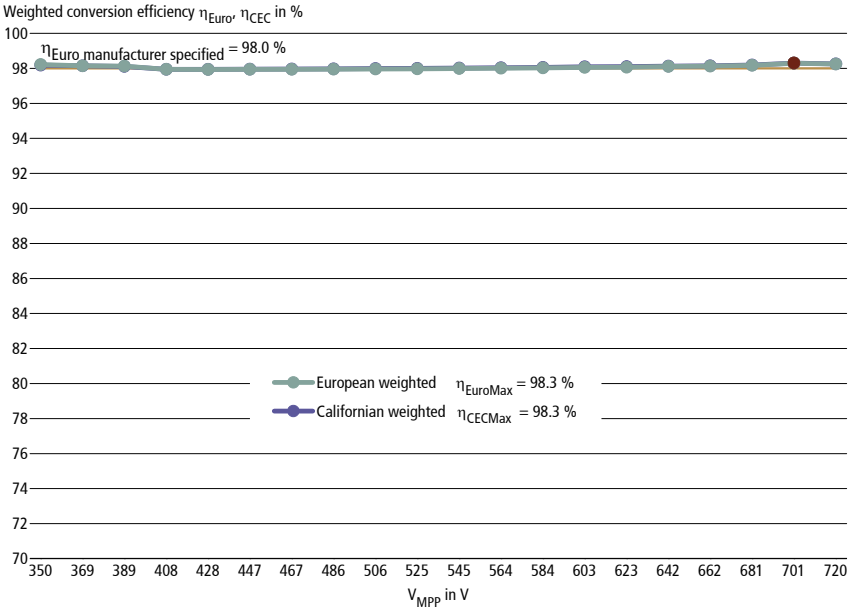
Overall efficiency: Due to the very high MPPT adjustment efficiency, the overall efficiency curve is much the same as that of the conversion efficiency. The overall efficiency maxes out at 98.4 percent.

Overall efficiency curves, average overall efficiency and PHOTON efficiency: The average overall efficiency curve is determined by averaging all results for the overall efficiency. In order to do so the results for the over all efficiencies are averaged over all voltages steps. The PHOTON efficiency for medium as well as for high irradiation is 98.0 percent resulting in the grade »A+«.

Feed-in at nominal power: The inverter feeds in 100 percent of its nominal power over

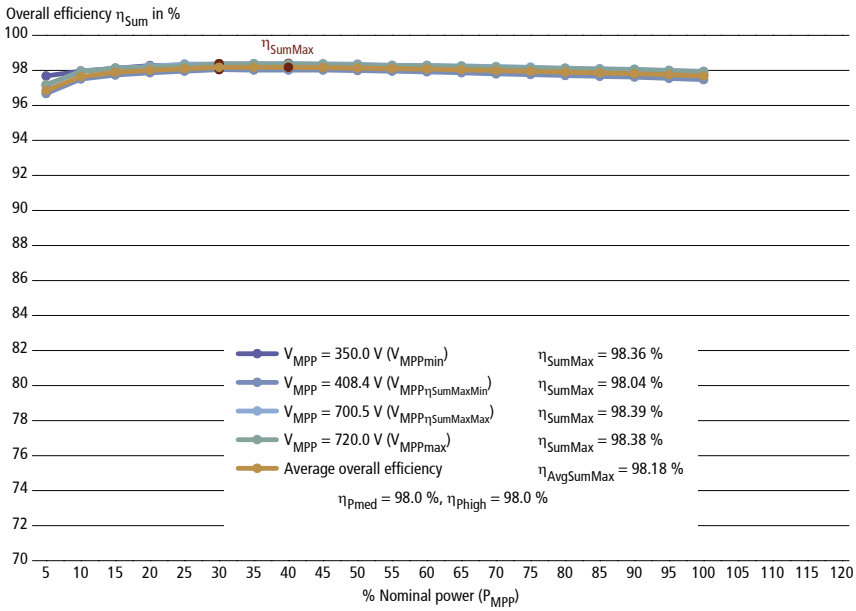
Weighted conversion efficiency

It is rare to see the Californian and the European efficiencies being almost identical. Normally the efficiencies with European weighting are lower because the lower power range of the inverter plays a bigger role. Since the tested device does work equally well over the whole power range, these differences do not exist.



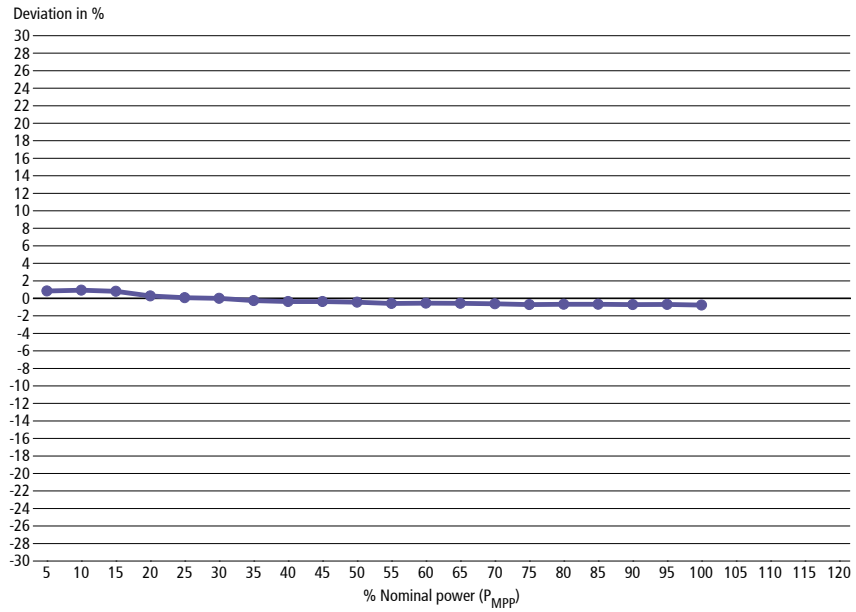
Overall efficiencies at different voltages

The curves for the overall efficiencies at different voltages (as well as for the average overall efficiency) are almost identical as well.



Accuracy of inverter display

It would have been surprising if the display would not have been as well thought out as the rest of the inverter. But there are no surprises there, the display is as accurate as a class B meter.



the input voltage range of 350 to 720 V at an ambient temperature of 25 °C.

Displayed output power: The output power measured and displayed by the Platinum 16000 R3 at a constant MPP voltage of 525 V, which is the medium range, barely deviates from the values recorded at the same time by a power analyzer. The difference does not exceed +/- 0.8 percent. This puts the display precision at the one of a class B meter.

Operation at a higher ambient temperature: Up to an ambient temperature of 53.3 °C the Platinum 16000 R3 feeds in 100 percent of its nominal output into the grid. If the temperature rises further the inverter reduces its output power. The efficiency fell by around 0.2 percentage points in the process. Thanks to the very broad temperature range and IP 66 protection class, just about any spot inside or outdoors – even those that are potentially warm – will be suitable for installation. The fan-free cooling concept also makes the inverter relatively immune to dusty surroundings.

Overload behavior: If the Platinum 16000 R3 is presented with an overload totaling 1.3 times its nominal input power, or 19,890 W at an MPP voltage of 325 V and an ambient temperature of 26 °C, it limits DC power to 15,185 W. This equals an overload of 99.25 percent at a DC power of 15,300 W and means the device features no overload range. The inverter shifts the operating point on the IV curve toward a higher input voltage. The DC voltage adjusted itself to 389 V.

Own consumption and night consumption: The power consumed by the device in its basic tested state was around 1.6 W on the AC side and 10.7 W on the DC side; the manufacturer has not provided any information in this case. At night, the inverter draws around 2.3 W of effective power from the grid. The manufacturer has specified less than 2 W.

Thermography: The thermographic image shows the inverter from above while it is operating at an ambient temperature of 24 °C at nominal power. Due to the multiple layers forming its internal configuration, not all components are visible. Component temperatures of up to 64.5 °C were measured on the circuit boards, which is no reason to worry. The electrolytic capacitors were all in the green area of the temperature scale.

Summary

The Diehl AKO Platinum 1600 R3 features a clearly structured design and turns out to be relatively light and small for a three phase inverter in this power class. The device is compact and well designed even though it features no less than seven circuit boards. Because of its unique topology the inverter should only be used in conjunction with two symmetrical solar generators. The »Dual-X« technology, which the manufacturer patented, allows for very high efficiencies that span very homogenously over the whole working range. The conversion efficiency tops out at 98.5 percent, the European and the Californian efficiencies are only 0.2 percentage points lower. Because of the very high and very even MPPT adjustment efficiency the overall efficiency basically equals the conversion efficiency. The inverter has a wide MPP voltage range and only shows restrictions for the use of thin-film modules in the highest voltage range. When crystalline modules are used there is no such restriction. The inverter does not offer an overload range.

The overall efficiency does only vary by 0.4 percentage points over the whole MPP voltage range. As a result the PHOTON efficiencies for medium and for high irradiation are identically high with 98.0 percent. Over the whole power range the device shows a pretty accurate value for the output power on its display, the temperature range in which the inverter operates is very wide. Only at temperatures higher than 53.3 °C does the device start to limit its output. The conversion efficiency is not very dependent on the temperature and goes down only by 0.2 percentage points. Among those inverters that do not feature silicon-carbide transistors, the Platinum 16000 R3 is the best that we have tested so far.

But when designing a solar system one has to consider that the Diehl AKO Platinum 16000 R3 is not a jack of all trades. The inverter should only be used for systems that consist of two symmetrical strings for which one usually would consider a typical one tracker device. Because as soon as one of the strings shows a behavior that differs from the other – be it because of shadows, a different number of modules or different orientations – the Platinum 16000 R3 has the same problem to handle the situation as single tracker devices: mismatches lower the yield. If one, on the other hand, uses a multi tracker inverter to handle mismatches better, the efficiencies will not be as high as the ones the »Dual-X« technology has to offer. ●

Manufacturer's response

We can confirm that the efficiency measurements for the conversion efficiency and the MPPT adjustment efficiency are identical with what we and independent institutes have been measuring. We feel that we reached our goal to develop an inverter family with proven semiconductor technology and innovative concepts whose performance allows them to match the top devices in the PHOTON test ranking – and we achieved this without using expensive and hard to source silicon carbide transistors. We were able to do so because of our patented »Dual-X« technology, a highly efficient DC input step with symmetrical string assignment.