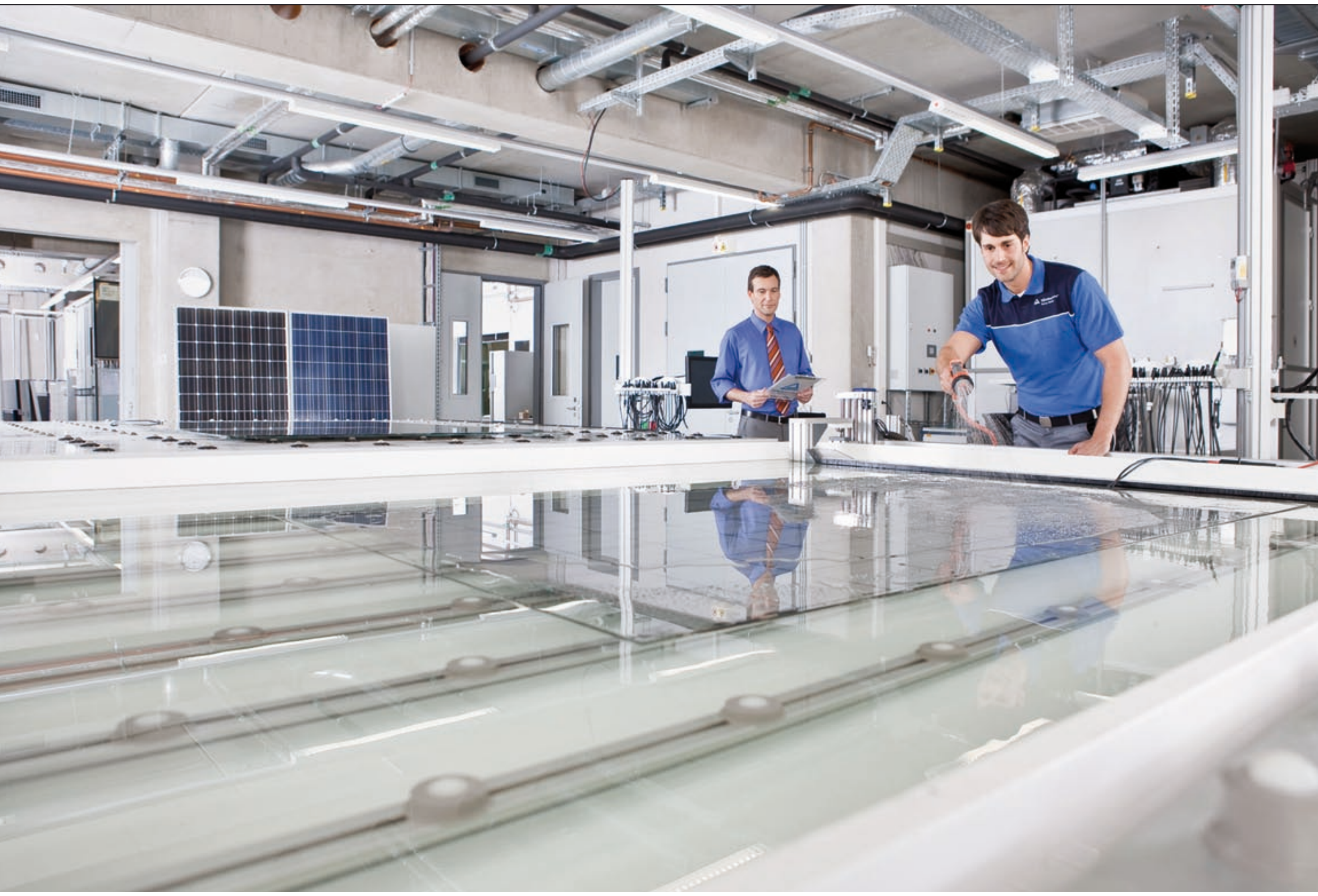


Photos: TÜV Rheinland

In one of the tests, the module is submerged in a water bath at 22 degrees Celsius.

How PV+Test works

Glossary: PV+Test uses a wide range of measurement results and other module properties in its assessment. The assessment scheme shows what experts think makes up a good module.

When a manufacturer takes part in a test, the experts from PV+Test purchase five modules of the specified type on the market. In contrast to the usual certification process, the manufacturer is not able to control which modules are going to be tested.

TÜV Rheinland starts off with a sunbath. In accordance with the IEC standard, the panels have to be exposed to 5 to 5.5 kilowatt-hours of insolation per square meter before the first test is conducted so that any initial degradation processes have been completed.

Now the actual test can begin. First, the experts determine output parameters and analyze electrical safety. Then two modules undergo thermal cycling testing, while two other modules go through the damp heat test before being sent to the mechanical load test. Here, PV+Test measures some 25 module values and assesses a wide range of other properties. The analysis conducted by the experts at PV+Test reveal what they think makes up a good module.

Each of the properties investigated gets a score ranging from zero to ten, and each score makes up part of the total score on a weighted basis.

A crucial aspect is whether the product lives up to the manufacturer's claims. A module receives top marks if it performs the way the experts would like it to in a particular property – in other words, the way the latest technology should work today.

To make these differences clear, PV+Test further breaks down the assessment into six subcategories. The total number of points and the total score are given at the end.

A module is expected to get at least half of the possible assessment points. Otherwise it fails the test. In this test, all of the modules passed. The worst photovoltaic module tested in the first round got 67.71 of 100 points, which is satisfactory; the best module got top marks (very good) with a score of 91.3.

The parameters assessed

Performance parameter/output: The module's nominal output is decisive in determining the array's yield. To compare the nominal output of various modules, they have to be tested under standard test conditions (STC). Here, the modules are exposed to 1000 watts of light intensity per square meter. Germany, for example, only reaches that level on very sunny days, which is why low-light performance is crucial for an estimation of a module's performance under real-world conditions in Germany.

The composition of the spectrum of light is also controlled under standard test conditions. It is designed to mimic the sunlight that is changed by passing through a certain mass of air before it reaches the module. The mass of air increases as the angle of light incidence decreases; in other words, the light has to pass through more air in the atmosphere before it reaches the ground. The IEC standard requires the spectrum at an air mass of 1.5, which is given when light is incident at an angle of 48.2 degrees to the surface. This value also rarely occurs in practice. The angle changes, as does the spectrum over the course of the day – and from one season to another.

The third value under standard test conditions is cell temperature, which is set at 25 degrees Celsius.

Performance parameter/output tolerance: If you buy modules with a nominal output under standard test conditions of, say, 200 watts, you will naturally be interested in knowing how closely the modules you buy match the nominal output. As manufacturers cannot guarantee that the modules perform exactly at the level of their nominal output, they give an indication of output tolerance – a range within which the modules should perform. Some manufacturers promise a "positive tolerance range"; in other words, module output will always peak above nominal output. In the example given above, a positive tolerance range would mean that customers can rely on all of the modules peaking at or above 200 watts. Given that customers benefit from positive tolerance ranges, PV+Test gives extra points for them in its assessment.Manufacturers who do not offer positive tolerance ranges instead provide a lower limit for a module's peak output. Most crystalline modules have a tolerance of minus three percent. In the aforementioned example of a 200 watt module, customers can be sure that no module will drop below a peak output of 194 watts. But the effect is worse than these figures might suggest when modules are in series connection, which they usually are, even if only one of the modules dips down to 194 watts. The weakest module in the row determines current, and hence the output of the other modules. A slight dip in tolerance can therefore be costly. The greater the negative tolerance range, the fewer points PV+Test awards in this particular category.

Most manufacturers also provide a ceiling for the tolerance range. Plus three percent means that none of the modules has a peak output exceeding 206 watts. While this figure can be important when selecting an inverter, it is not as critical as the lower value.

Performance parameter/deviation from nominal value: The PV+Test experts at TÜV Rheinland measured the modules' nominal output, which is directly related to an array's yield. Customers have to be able to rely on modules having an output within the indicated tolerance range – and hence within what the manufacturer says. If that is not the case, zero points are awarded in this category, which has the greatest weighting (ten percent) of any item in the assessment.

But PV+Test goes even further in this category by only awarding the full ten points if measurements reveal that the module is more than one percent over its nominal output. That is also good for customers. The results of the first test round show that it can be done.

Under certain circumstances, deviations between good and not-so-good modules within a batch may compensate for each other on paper, which is why the penalty is moderate in the assessment. For instance, a module whose output is one to three percent worse than indicated on the datasheet nonetheless still gets eight of ten assessment points.

Performance parameter/fill factor: The fill factor is a measure for the characteristics of the current-voltage curve. The lower the undesired serial resistance (in contacts, for example), and the less leakage current from parallel resistance, the greater the fill factor. Ideally, the fill factor would be 100 percent, but not a single system achieves that value. For module developers, the fill factor is very important, but in principle, it is not relevant for customers. In the end, the only thing that matters is the actual value of the output at the maximum power point.

Performance parameter/efficiency: The efficiency indicates how good the cell and module technology used is. If you want to install an array with a certain output – say, five kilowatts – the roof space you need depends on array efficiency. The greater it is, the less roof space you need. In contrast, efficiency only indirectly affects the return on your investment. After all, the ROI directly depends only upon the money invested and the power produced. A technology with lower efficiency may even provide a better return if the cost drops faster than module output. PV+Test therefore does not evaluate efficiency. Efficiency is calculated by measuring module output at a given module surface area under standard test conditions at an insolation of 1,000 watts per square meter. It therefore reflects the module's power output relative to the incident solar radiation.

Performance parameter/relative efficiency reduction under low light: Obviously, solar panels generate less electricity under low light conditions. The interesting question is how much less. In a country where low light is not uncommon, power yield largely depends upon low-light performance.

Nominal output is measured at an insolation of 1,000 watts per square meter. At a fifth of that level (200 watts per square meter), a module's output has generally fallen below a fifth of its nominal output. A measurement of efficiency reduction under low light tells us how much output has fallen. Low-light performance depends upon the cell and module technology used. If the efficiency loss is zero percent, PV+Test awards the full ten points. If efficiency decreases below minus five percent, the module gets zero points in this category.

Performance parameter/relative efficiency reduction at 50 degrees Celsius: A module's output drops when the module heats up; as a result, the array's yield and return decrease. In general, modules operate at a temperature around 50 degrees Celsius – and hence far above the standard temperature of 25 degrees at which nominal output is measured. The drop in efficiency here shows how great the effect is.

PV+Test determined the temperature coefficient from which the change in efficiency can be measured when the module heats up. The full ten points are awarded if the temperature coefficient is greater than -0.41 percent per Kelvin. At this value, efficiency at 50 degrees Cel-

POWER MEASUREMENT: THE DEVIL IS IN THE DETAILS

A key question in the assessment of the solar panel is its actual electrical output both at the time of delivery and after aging. To the dismay of experts at institutes and manufacturers, there are limits to the accuracy of such measurements, and increasing accuracy is a very complicated task.

Generally, experts measure a module's current-voltage curve in a fast flash test. Based on that outcome, they calculate the electric power (as the product of voltage and current) at the operating point at which it is highest (the maximum power point, MPP). The flashes are designed to reproduce as accurately as possible the light intensity and light spectrum under standard test conditions. Nonetheless, minor deviations remain. The experts therefore simultaneously conduct another measurement using a calibrated reference cell and then calculate for corrections.

Even if the same module is measured several times in a row, the findings will vary by around 0.5 percent. This reproduction inaccuracy can be seen, for instance, if you compare output before and after the aging tests. You therefore have to be careful to give the module tested the benefit of the doubt and take the better performance.

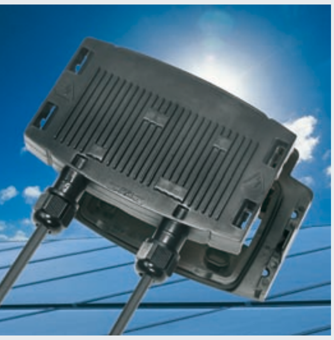
The absolute measurement deviations at TÜV Rheinland are comparable to those at other test institutes at around 2.4 percent. This value applies if a module's performance measurement conducted by one institute is compared to the measurement of the same module conducted by another. If, however, the measurements performed by a single institute on different modules are compared, you do not have to take the same absolute measurement inaccuracy into account. In order to create a ranking of the panels' output deviations from their indicated nominal output, a tolerance of no more than plus/minus one percent is assumed.

This figure also corresponds to the results of the last Round Robin Test ("PV Module Output Power Characterization in Test Laboratories and in the PV industry – results of the European performance project", EU PVSEC 2010), in which Europe's main testing institutes were involved. They measure the same modules after each other and compare the results.

The following example shows what this inaccuracy means for the ranking: Let's assume that module A is 2.6 percent above its nominal output; module B, 1.8 percent; and module C, 0.3 percent. With consideration of measurement inaccuracy, you cannot be certain that module A is really 2.6 percent above nominal output – it could also only be 1.6 percent. Likewise, module C might also be 1.3 percent above nominal output. You can therefore only say with certainty that module A definitely has a greater positive deviation from nominal output than module C does. You cannot, however, say that module A deviates more than module B or vice versa.

Another problem is that module manufacturers have to deal with the same measurement inaccuracies when they sort their modules into output classes. Many of them do not take account of these tolerances. As a result, customers may receive modules that are not in line with their own nominal output. Seeing that the accuracy of the flashers used in serial production is much worse than the accuracy of testing institutes, manufacturer indications of output must be taken with a pinch of salt.

Smart connections – our philosophy



With our network – both internally and externally – we generate the conditions to open up new paths: paths that we tread together with our partners and customers.

In our core line of business of photovoltaics in particular, proximity to our customers and a clear focus on quality pay off. We can draw on many years of experience in developing and manufacturing assemblies and complete units for solar module connection technology. By taking our customers' specifications into account, we have built up a whole array of different solutions for PV module connection, including our very latest innovation of an automatable PV junction box, for example.

The KOSTAL Group is a family-owned company with its headquarters in Lüdenscheid, Germany. KOSTAL Industrial Electronics was founded as an independent business division within the KOSTAL Group in 1995.

Smart connections.

KOSTAL Industrial Electronics
Lange Eck 11, 58099 Hagen, Germany
www.kostal.com/industrie

INDUSTRIAL ELECTRONICS

sius drops by 10.25 percent below the level at 25 degrees. PV+Test takes points off if the temperature coefficient is more than three percent smaller than indicated on the datasheet.

Accelerated aging/thermal cycling test: Performance at the time of installation is important, but it is just as interesting to know what the output will be in ten or twenty years. Modules are exposed to the elements, and every change in temperature causes mechanical tension in the module because individual components, such as metal connectors and silicon wafers, expand to different extents when temperatures change.

Of course, the test experts cannot look into the future, but PV+Test can conduct thermal cycling tests in a climate chamber like the ones performed for IEC certification in order to see how durable a module is when temperatures vary. Over around 40 days, the temperature fluctuates some 200 times from plus 85 to minus 40 degrees Celsius and back. After the tests, the experts perform a visual inspection, using electroluminescence to detect any cell damage; they also measure insulation as required for a check of electrical safety, and then they see how much the modules have degraded by measuring their output. All of these parameters were assessed. In accordance with the IEC standard, thermal cycling must not reduce performance by more than five percent. PV+Test accordingly awarded zero points in this category if that threshold is exceeded. On the other hand, a measurement tolerance of 0.5 percent was granted for repeated measurements of module output. PV+Test submitted two samples of each module type to this test. The worse value was assessed.

Like all of the other aging tests, the thermal cycling test does not tell us anything about the module's actual service life, but in all likelihood modules that performed well in this test will have a longer service life than modules that did not perform well. As aging tests are the best way to assess the quality of modules over their service life, these tests collectively make up 25 percent of the score PV+Test gives.

Accelerated aging/damp heat test: In the damp heat test, a module is exposed to 85 percent humidity at a temperature of 85 degrees for a certain period. Under these conditions, moisture might be able to penetrate and even destroy the module. There could be material failure – such as in the rear foil, cables, and sockets – or electric connections might worsen, thereby increasing serial resistance.

The IEC standard specifies that modules must undergo 1,000 hours in that environment. Afterwards, the test experts perform a visual inspection similar to the one for the thermal cycling test. They use test insulation as required for a check of electrical safety, and then see how much the modules have degraded by measuring their output.

PV+Test first collects data for two modules after 1,000 hours. The modules then have to spend another 500 hours in the climate chamber. Over the extended timeframe of 1,500 hours, quality differences that may not have been apparent after 1,000 hours reveal themselves.

Accelerated aging/mechanical load test: One of the two modules that underwent the damp heat test for 1,500 hours then undergoes a mechanical load test, which simulates snow and wind loads in the lab at PV+Test as with IEC certification.

In the first stage, a pressure of 2,400 pascals – equivalent to 240 kilograms over a square meter – is evenly applied to the entire surface of the module. The same data are then measured as in the other aging tests. Next, pressure is increased to 5,400 pascals. In the IEC standard, this second stage is optional, but the experts at PV+Test believe it is a good idea for regions with a lot of snow and heavy winds.

Documentation: In this category, the question whether the modules have type certification EN IEC 61215 and the EN IEC 61730 certificate, which contains safety standards, plays a decisive role. In addition, PV+Test assesses whether the requirements in IEC 61730 for manu-

The module later undergoes a mechanical load test, which simulates snow and wind loads.

als are complied with. For instance, the manual has to contain information about grounding, interconnection, and other aspects of electrical safety. Other important information includes how many modules can be interconnected in series and in parallel and how the module performs under low light.

Module manufacturers also have to fulfill the requirements in EN 50380 for the datasheet and name plate. The datasheet also has to indicate the nominal operating cell temperature (NOCT), which is measured under precisely defined conditions and roughly indicates the temperature a module has when in operation. In the lab, the module's output is measured at the NOCT, and that figure is given on the datasheet.

Electrical safety/insulation test: The insulation test for IEC type approval is conducted directly after the module is purchased, and then again after the aging tests. Here, the solar panel's two poles are connected, and voltage is applied to the frame at twice the system voltage plus 1,000 volts. The resistance must not drop below 40 megaohms per square meter of module area if the module is to pass IEC certification – and receive points in this category from PV+Test.

This score is crucial because leakage current could otherwise be a safety hazard and possibly cause the inverter to switch off. PV+Test therefore gives a higher score, the greater the insulation resistance is.

A similar test is conducted under wet conditions. Here, the module is submerged in a water bath at 22 degrees Celsius until the water reaches just over the lower edge of the junction box so that it just touches the cable openings. The cable and plug also have to be submerged. A surfactant is added to the water to reduce surface tension. Unlike the dry test, this one is measured with simple system voltage.

After IEC 61730, PV+Test also tests pulse and high-voltage stability. For the test of pulse stability, the module is completely (including junction box) wrapped up in a conductive foil, and a voltage of 8,000 volts applied to the module connections between the foil.

This results in a strong electrical field that modules must withstand without dielectric breakdown. PV+Test also visually inspects the panels to check whether there are air and creepage distances, and examines the quality of plugs, cables, and sockets as specified in IEC standards.

Processing quality/edge test: While sharp edges do not reduce a module's output, they do constitute a risk for installers, who could injure themselves. PV+Test therefore takes some measurements in accordance with UL certification.

A test cylinder is first covered by black material, then by white material, and on top of that by a thin gray synthetic foil. This finger dummy strokes the edges with specified pressure. The module passes the test if the black material doesn't show through (see photo on page 96).

Processing quality/electroluminescence: Electroluminescence reveals what the eye cannot see. On such images, bright areas reveal where cells work; dark areas, where they do not. In this method, voltage is applied to the cells. The functional principle is thereby reversed. Instead of absorbing light and converting it into electrical energy, electroluminescence makes the solar cell convert electrical energy into light, at least in the intact areas. This approach can detect microcracks, for instance. While experts now understand the mechanism in theory very well, the method has not been in practice for long. There is therefore still a debate about how the images should be correctly interpreted in determining service life. Electroluminescent images are especially interesting after the thermal cycling test, in which mechanical loads can cause fractures, and if there are prior damages, they increase. If there are any salient areas, PV+Test reduces the score.

Processing quality/salient visual aspects: This category includes everything eye-catching. For instance, solder strips may not cleanly match cell contact lines, or cells in a string within the module might not be exactly in parallel. While such drawbacks will not reduce yield, they can be perceived as unattractive. In contrast, other visual drawbacks, such as impurities in the module, can detrimentally affect durability. ◆ Michael Fuhs