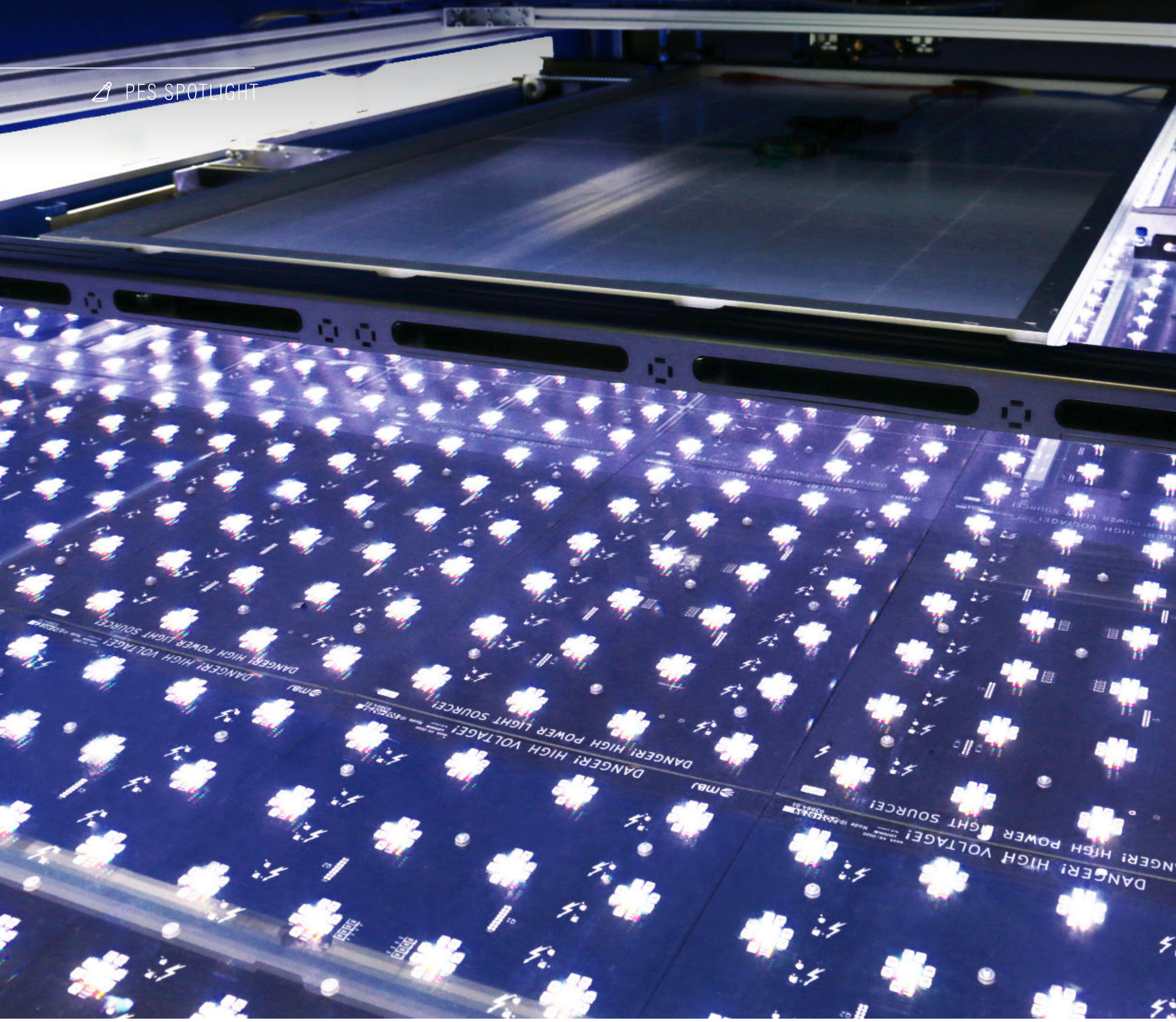

Sun simulator for tandem technology

With solar cell prices plummeting due to overcapacity, the push for cost reduction has intensified. Tandem solar cells using perovskite layers promise efficiency gains from 26% to 34%, but measuring these cells accurately requires overcoming hysteresis effects. XENON simulators struggle with this due to their short flash durations, while LED simulators offer extended, stable flashes and precise spectral matching. MBJ Solutions provides advanced LED based simulators that meet these demands effectively.

Manufacturers of solar cells and modules are experiencing an unprecedented drop in prices due to excessive overcapacity. As a result, there is a strong push to lower the cost per unit of power. While incremental improvements have been achieved with PERC and TOPCon technologies, a more significant advancement is necessary. Tandem solar cells that use a perovskite layer on a silicon wafer offer the potential to boost efficiency from the current 26% to 34% with relatively minimal effort.

The increased efficiency of solar cells also leads to higher capacity, which can cause hysteresis effects when measuring maximum output power. Hysteresis refers to the phenomenon where modules with high capacity exhibit discrepancies in power measurements: too little power is recorded when measuring in the forward direction (Isc to Uoc), and too much power is recorded when measuring in the reverse direction (Uoc to Isc).

This effect is already significant with HJT and TOPCon. The longer flash duration of an LED sun simulator helps to reduce this effect, but even with a flash duration of 200 ms and a linear increase in voltage, the deviation between forward and reverse measurement in TOPCon modules can easily reach more than 1%, see Figure 1.

XENON based sun simulators struggle to provide prolonged flashes, which exacerbates the hysteresis effect. In production lines, where there are stringent demands on cycle time, the flash duration is typically limited to well under 100 milliseconds. In contrast, laboratory conditions can accommodate flash durations of 100 milliseconds or more, but this requires adequate cooling time. Additionally, in a laboratory setting, the shorter lifespan of the XENON lamp due to extended flash durations is less of a concern.

To address these issues, manufacturers of XENON sun simulators developed several techniques years ago to compensate for hysteresis effects, even with short flash durations.

One approach involves measuring the current voltage characteristic curve in segments to simulate a longer flash duration. However, this method is primarily suitable for laboratory settings, where measurement time is less critical. For time sensitive production processes, alternative methods can be employed.

One method to compensate for this effect is to calculate a corrected power value using measurements taken in both the forward and reverse directions. However, this approach has the drawback of requiring either two separate flashes or a single flash with the voltage swept at twice the normal speed.

Another method involves reducing the rate of voltage change during the flash at the Maximum Power Point (MPP), see Figure 2. This slower voltage ramp mitigates the capacitive effects and, with a constant sampling rate, provides more measurement points at the MPP, resulting in a more accurate determination of the MPP.

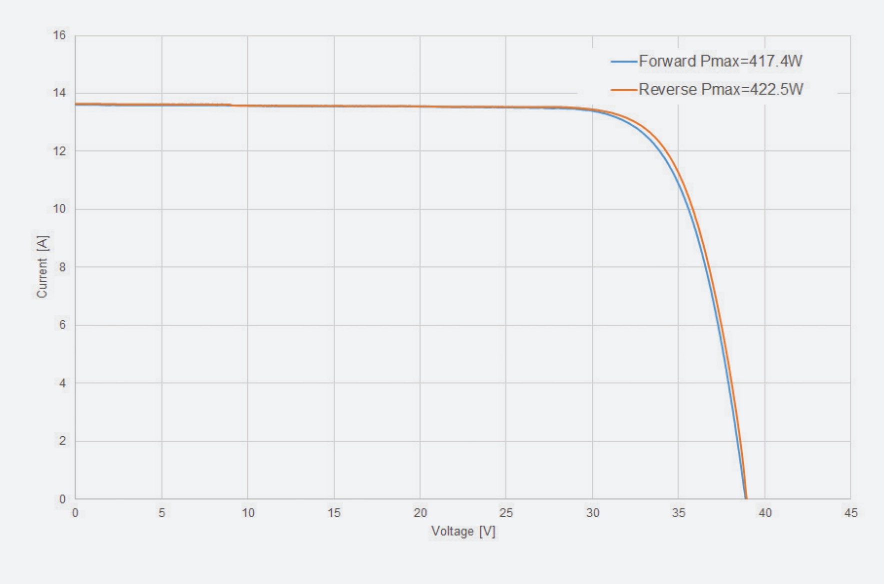

Figure 1: IV curve showing the hysteresis effect

With a flash duration of 200ms, the difference between forward and reverse measurements can be reduced to 0.3%.

Another method is to increase the voltage in discrete steps and remain at each step until the current stabilizes. This approach eliminates the discrepancy between forward and reverse measurements, see Figure 3.

These methods do not sufficiently address the measurement errors in XENON solar simulators caused by short flash durations, especially for high capacity modules in production. With the even higher capacities of tandem solar modules, XENON based simulators cannot provide the necessary flash durations for stable operation, which typically require 500 milliseconds or more. XENON technology falls short in meeting these requirements, whereas LED based simulators can achieve the necessary flash durations and perform the measurements much more effectively.

Path to tandem technology

MBJ Solutions has developed electronics that measure HJT and TOPCon modules by gradually increasing the voltage during the flash. This method allows for consistent maximum power values in both the forward and reverse directions. However, for modules with even greater capacities, this approach alone is insufficient. By varying the step size throughout the flash duration, a significant improvement can be achieved.

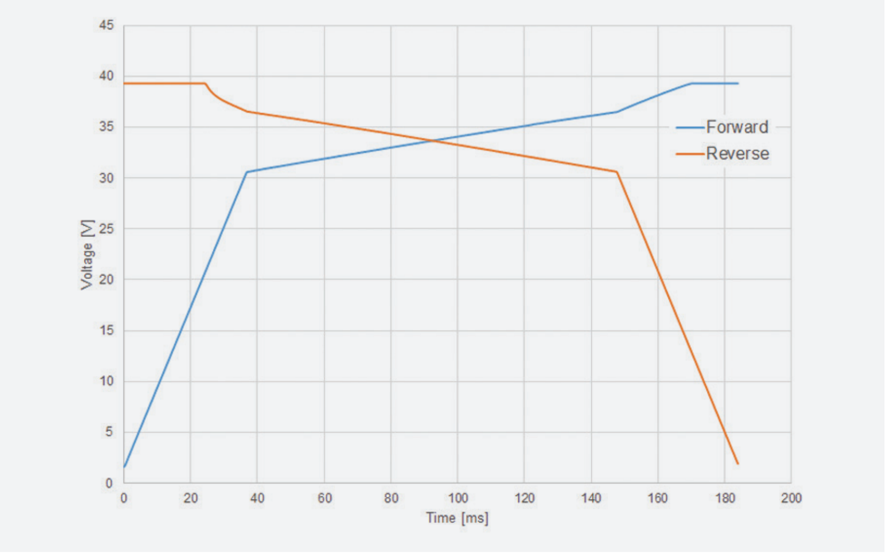

Figure 2: Variable slope for the voltage in forward and reverse direction

By using larger voltage steps at the beginning, e.g., near Isc, smaller steps around the MPP, and then larger steps again, you can capture significantly more measurement points in the critical MPP area. This approach allows for slower changes in this region, reducing capacitive effects and enabling the current to stabilize more quickly. Essentially, this simulates a much longer flash duration.

For example, the measured values in Figure 4 demonstrate a slope around the MPP that mimics what would be achieved with a flash duration exceeding one second. Specifically, a voltage range of 4 V recorded in about 150 milliseconds corresponds to a 56 V range recorded over 2.1 seconds. Additionally, the stepwise variation in voltage helps stabilize the current, ensuring each measurement is taken in a steady state.

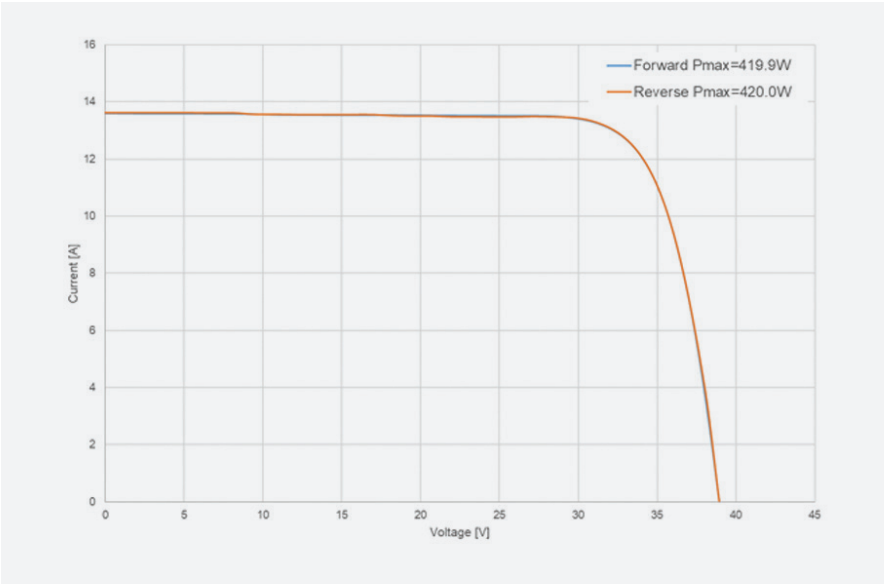

Figure 3: IV curve measured with step wise variation of the voltage in forward and reverse direction

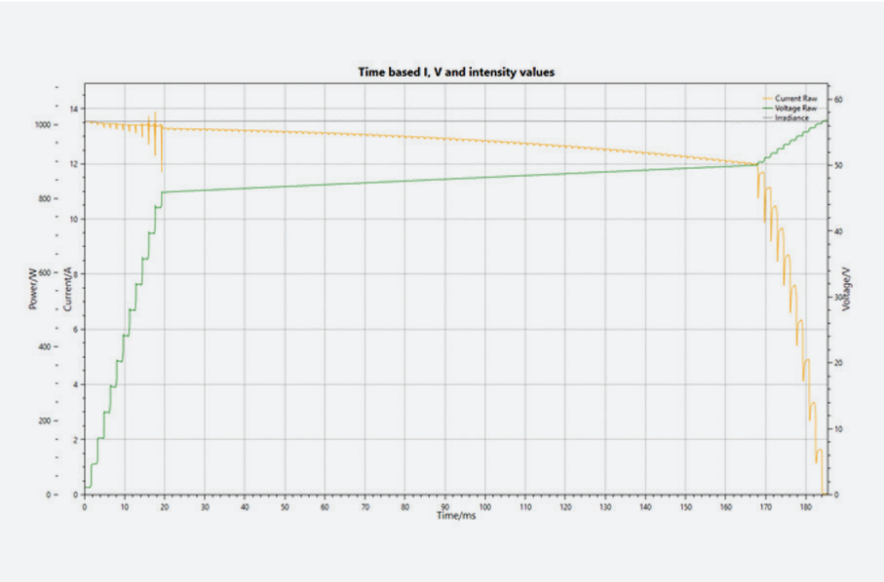

Figure 4: IV curve showing the capacitive effect with different step size for the voltage

Additional advantages of LED sun simulator

The flashes from LED sun simulators are not only longer but also much more stable over time. Long term instability (LTI) typically remains below 0.5%, and the variation in average irradiance from one pulse to the next is less than 0.01%. The main visible variation is due to the slower heating of the LED unit until thermal equilibrium is achieved, causing a slight irradiance reduction of about 1%. This reduction can be effectively corrected with a monitor cell.

The light source has a lifespan of over 10 years, eliminating maintenance downtime and ongoing costs associated with replacing the light source. Additionally, LED sun simulators provide a much more stable spectral distribution, with no spectral drift over time. LEDs offer superior spectral coverage and a closer alignment with the solar spectrum.

During the evaluation, the software checks the current at each step to ensure it is stable before recording the values. This process results in a more accurate IV curve, with additional measurement points around the MPP, see Figure 5. This approach reduces the capacitive effect and enhances the accuracy of MPP determination.

Longer flash times are likely required for perovskite modules, which presents a challenge for XENON flashers but is manageable with LED sun simulators. With effective heat management and careful selection of LEDs, achieving flash durations of 500 milliseconds or even one second is feasible. MBJ Solutions, along with its subsidiary MBJ Imaging, has extensive experience in LED lighting. Ultimately, the decision comes down to evaluating whether the technical effort and investment are justified for the specific application.

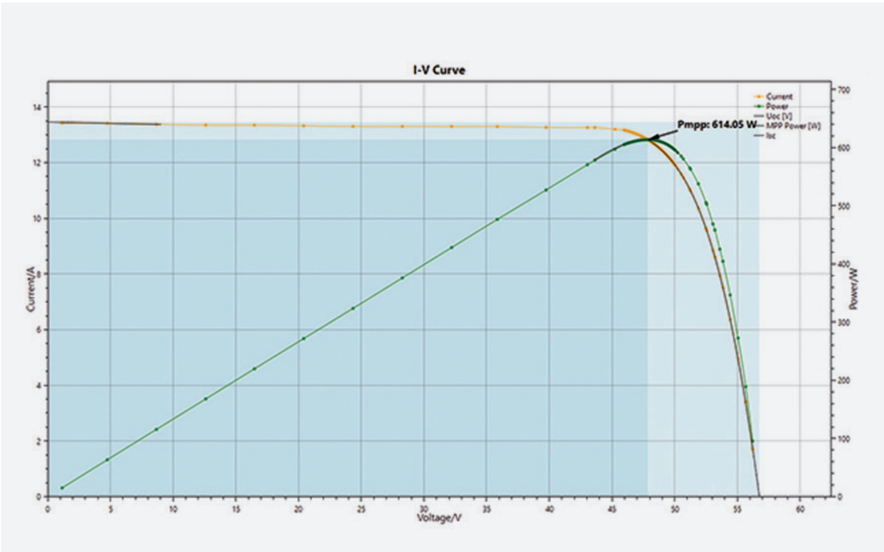

Figure 5: IV curve resulting from step wise voltage variation and smaller steps at MPP

Spectral matching

Spectral matching refers to how well the irradiance of a light source aligns with sunlight across six different wavelength bands, expressed as a percentage of the total irradiance. Since LEDs emit light in narrow wavelength bands, or single colors, rather than a broad spectrum, multiple types of LEDs must be combined to create a spectrum that matches the AM1.5 standard. In theory, six different LEDs can produce an A+ spectrum.

The latest IEC standards have introduced two additional parameters to evaluate this matching: spectral coverage (SPC) and spectral deviation (SPD), which describe how accurately the AM1.5 spectrum is replicated by the light source.

Mixing various LED colors allows for precise control over the spectral match of the LED light source, achieved through electronic control of individual LED channels. This precise control also helps maintain uniformity across the entire flash range to within <1%.

Additionally, LED panels offer the flexibility to scale the measurement area easily. Panels can be arranged side by side to create large, uniform flash areas or to form specific flash zones.

Our extensive experience and dedicated team make us the ideal partner for your photovoltaic projects.

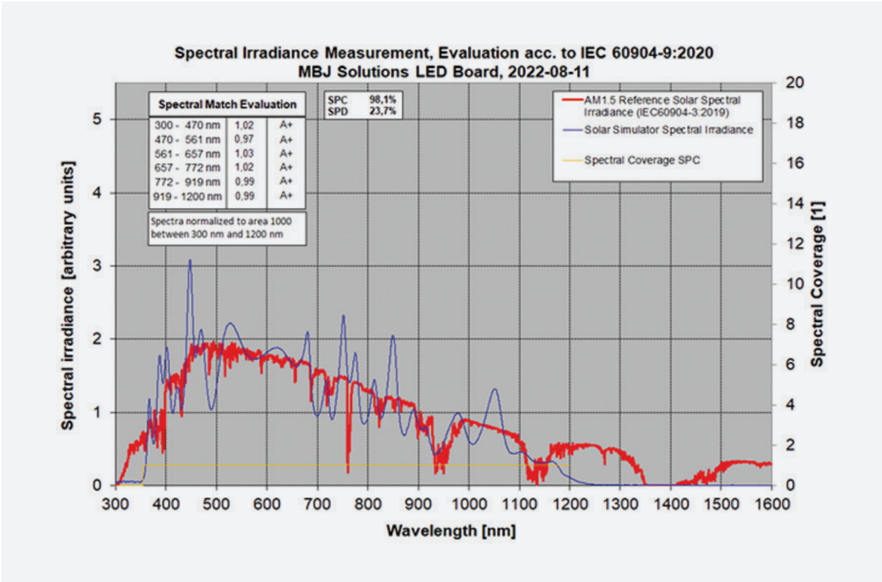

Figure 6: Spectrum of the MBJ sun simulator with 22 LEDs

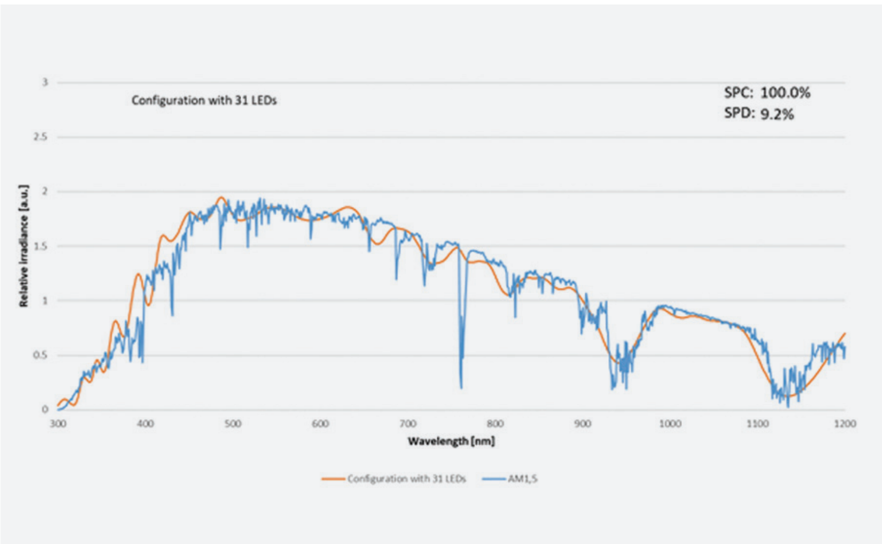

Figure 7: Simulation of a perfect sun simulator based on LED technology

In contrast, xenon lamps used for large area solar simulators typically require one or more lamps to cover the flash area. The spectrum is controlled by the xenon flash tubes and can only be adjusted with filters, reflectors, and shading elements. In some cases, groups of four to six xenon flash tubes must be matched manually, without the fine tuning capabilities provided by electronic, channel based LED arrangements.

A good match

The IEC standard mandates a spectral match within the range of 0.875 to 1.125 for a Class A+ solar simulator. Currently, LEDs are available that cover the required wavelength range of 300 to 1200 nm. Using 22 LEDs, it is possible to achieve an SPC greater than 98% and an SPD less than 25%, see Figure 6.

To achieve nearly perfect spectral matching, approximately 30 different LED types are required. Figure 7 illustrates the simulated spectrum of an LED solar simulator using 31 LED types. This technology allows for a spectral coverage of 100% and a spectral deviation of less than 10%, which is not achievable with XENON technology.

www.mbj-solutions.com

About MBJ Solutions

MBJ Solutions GmbH specializes in developing and selling test and measurement systems for the photovoltaic industry.

We offer a range of products including sun simulators, electroluminescence test systems, insulation and grounding test systems for solar module production, as well as mobile measurement systems for onsite testing of solar modules.

Founded in 2009, MBJ Solutions has sold over 650 test systems worldwide. Our headquarters are located in Ahrensburg, Germany, where we design and manufacture all our products.

Many customers are based in Asia, so we also maintain service offices in Taiwan and India.

Innovation and customer focus are integral to our approach. We serve prominent institutes and manufacturers in the PV industry.

Our extensive experience and dedicated team make us the ideal partner for your photovoltaic projects.