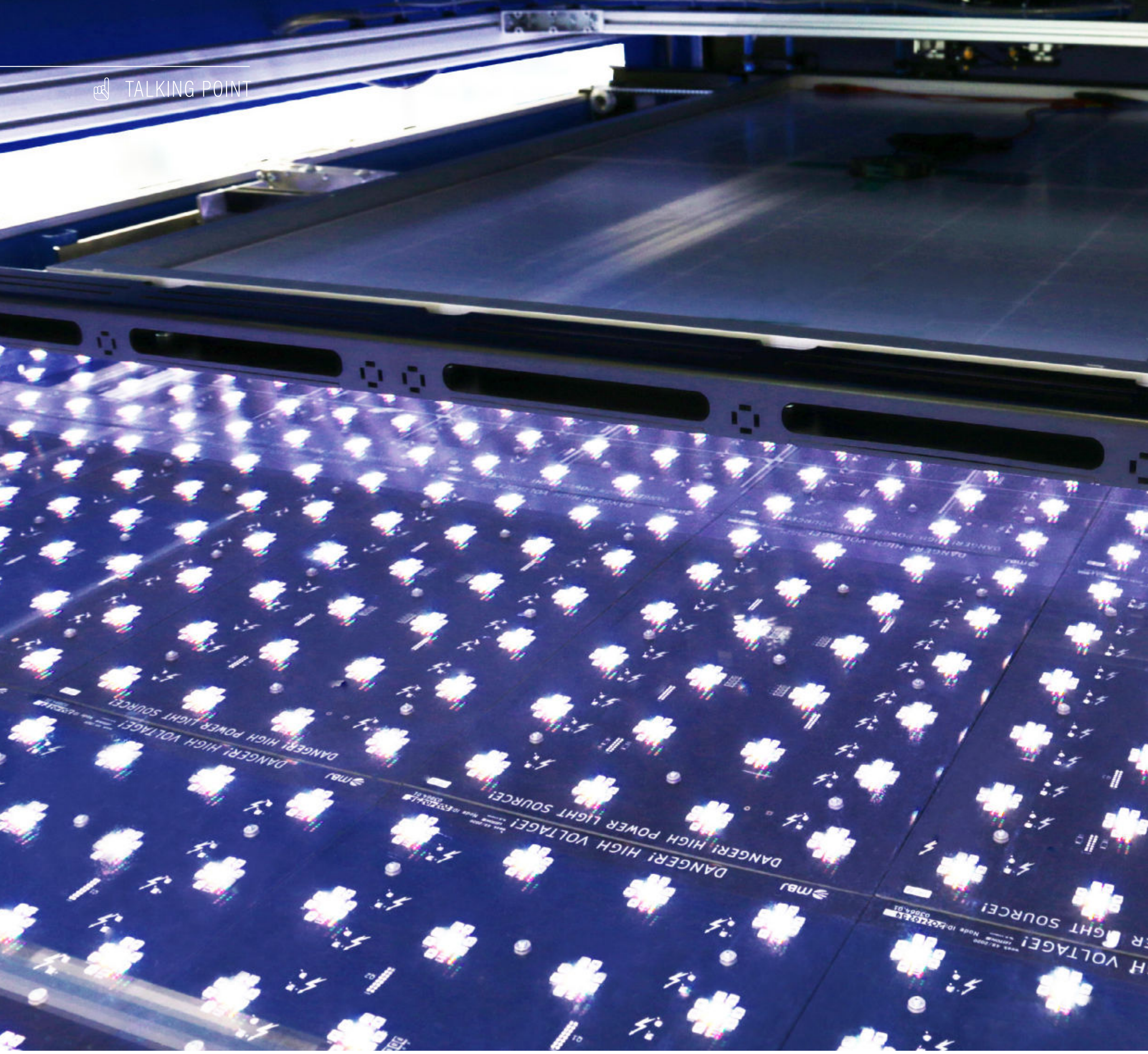

LED sun simulation offers cost savings

A sun simulator is the most important measurement device in the solar industry. It measures the electrical characteristics of solar cells and modules at the end of the production process or in the field. In the industry, the discussion about using Xenon or LED is ongoing for years. The following comparison provides data, not only for the cost saving achieved by using LED but also about the measurement quality.

For a long time, the most common light source for a sun simulator were Xenon flash tubes. They have a spectrum closely matching the sun light, providing the means to measure the power output of a PV module without exposing it to the real sun light.

For some years now, LED technology has offered a real alternative. Furthermore, it will be the logical next step for PV production equipment. LEDs are already available in many different colors and the continuous and fast improvements in technology makes even a broad range of wavelengths affordable. This offers further possibilities for LED based sun simulators.

With a combination of different LEDs, it has been possible for years to create a spectrum close to the sun, even exceeding the possibilities of Xenon flash tubes. Many more advantages like longer lifetime, lower cost of ownership and excellent stability over time are additional benefits of a LED sun simulator.

However there are still a lot of questions and discussions about the topic: can we really exchange Xenon with LED? Is the measurement as accurate? What are the benefits? Is it really less expensive?

Taking the data of one example, inline A+A+A+ LED sun simulator this article will give answers and data to show that LED is indeed the better choice already.

Benefits of using a LED sun simulator include a longer flash pulse and significantly more repeatable light output; plus long, stable pulses allow measuring all types of solar modules, including cells with capacitive effects, e.g. PERC, heterojunction, TOPCon or even perovskite.

Other benefits include an unbeatable lifetime and spectral stability, with more than 10 years without light source exchange saving significant money and time. Additionally, it provides a higher measurement accuracy.

Users can also enjoy a faster return on investment by saving money on flash tubes, maintenance downtime and measurement inaccuracies.

It also has excellent spectral performance: spectral coverage, match and deviation are as good as Xenon, allowing very accurate measurements but with less inaccuracy over time.

Spectral performance

Much discussion in this area centres around the spectrum of an LED sun simulator and how well it compares to the Xenon spectrum.

The spectral performance, such as the spectral match, the spatial non-uniformity and the temporal instability are the key for a high-quality sun simulator. The IEC 60904-9 Ed. 3 defines how and under which conditions a solar cell or module has to be measured, providing limits for quality classes. The quality classes A+, A, B, C are based on how well the spectrum of the sun simulator matches the afore mentioned three criteria of spectral match, spatial non-uniformity and temporal instability.

The IEC standard refers to the 1.5 air mass (AM) sun spectrum. The 1.5 AM describes the resulting spectrum after the sun light has passed through earth atmosphere at an angle of 48.2° with respect to the zenith. The closer the spectrum matches the 1.5 AM spectrum the more accurately the device can measure how much power a solar cell or module will produce in real sun light.

Spectral match

The spectral match describes how well the irradiance output over six different wavelength bands matches the one from the sun light. It will be given as percentage of the total irradiance.

As LEDs emit light only in a narrow wavelength band, single colour, rather than a wide spectrum, the spectrum has to be built out of several different LED types to create a matching 1.5 AM spectrum. The MBJ LED panel with a variety of LED types provides such a light source. The spectrum starts in the UV range around 300 nm, covering the full visible spectrum and moving into the infrared region up to 1200 nm. And most of these wavelengths are absorbed and converted into electricity in a solar cell or solar module.

Mixing different LED colours allows the unique possibility to influence the spectral match of the LED light source. It allows to electronically control individual LED channels. The individual control also helps keeping the inhomogeneity over the full flash area at a very low percentage. Using LED panels additionally has the huge advantage that the size of the measurement area can be scaled easily. The individual LED panels can be arranged next to each other to create really large uniform flash areas or to form custom flash areas.

When using Xenon bulbs, one or more light tubes are used to illuminated the flash area, more than one bulb especially for large area sun simulators. The spectrum is given by the Xenon flash tubes and can only be modified by applying filters, reflectors and shading elements. Worst case, groups of four to six Xenon flash tubes need to be adjusted to each other without the fine adjustment handle given by an electronic, channel-based LED array.

How close does an LED spectrum matches the 1.5 AM spectrum required by the IEC standard?

The IEC standard requires for an A+ class sun simulator a spectral match of 0.875 to 1.125. In Figure 1 the spectral match of an inline MBJ LED Sun Simulator with 22 LED types is shown. The spectral match is significantly above the requirement with a range of 0.97 to 1.02.

Spectral match Design with 22 LEDs		SPD SPC	23.8% 98.1%
300 - 470 nm	1.02	A+	169.8
470 - 561 nm	0.97	A+	162.1
561 - 657 nm	1.02	A+	170.9
657 - 772 nm	1.02	A+	168.8
772 - 919 nm	0.98	A+	163.7
919 - 1200 nm	0.99	A+	164.8

MBJ Independently measured by TÜV Rheinland

Figure 1 Spectral match of an LED sun simulator with 22 different LED types

For comparison, a perfectly adjusted laboratory Xenon sun simulator reaches the range of 0.95 to 1.05.

Another good indicator for the quality of the LED spectrum are the spectral coverage and the spectral deviation.

Performance comparison XENON vs. LED

	Class A+A+A+ requirements IEC 60904-9 Ed. 3	XENON typical production	XENON best lab	Low-cost LED	MBJ LED Standard Spectrum	MBJ LED Advanced Spectrum
Spectral Match	0.875 - 1.125	0.875 - 1.125	0.95 - 1.05	0.92 - 1.08	0.97 - 1.03*	0.98 - 1.03*
Non-uniformity of irradiance	≤ 1%	≤ 1%	≤ 0.5%	≤ 1%	≤ 0.6%	≤ 0.6%
Short-term instability (STI)	≤ 0.25%	≤ 0.1%	≤ 0.1%	≤ 0.1%	0% (Synchronized)	0% (Synchronized)
Long-term instability (LTI)	≤ 1%	≤ 1%	≤ 1%	≤ 1%	≤ 0.1%	≤ 0.1%
Spectral Coverage (SPC)	n/a	> 97%	> 99%	> 93%	> 93%*	> 98%*
Spectral Deviation (SPD)	n/a	< 35%	< 20%	< 50%	< 44%*	< 24%*
Repeatability (Pmpp)	n/a	< 0.3%	< 0.2%	< 0.2%	< 0.1%	< 0.1%

* Independently measured by TUV Rheinland

Figure 2: Comparison of the key quality indicators for sun simulators

Spectral coverage

The spectral coverage describes how many of the different wavelengths, from the ultra violet region up to the infrared region, are actually used in the simulator, again compared to the 1.5 AM sun spectrum. For the inline LED sun simulator in this example the spectral coverage is larger than 98 %.

Spectral deviation

The spectral deviation describes how much the irradiation for each wavelength in the observed range deviates from the 1.5 AM sun spectrum, counting over shoots as well as levels below the target. For the LED sun simulator in this example, it is below 24 %.

In comparison to a Xenon based sun simulator this is as good as any Xenon production simulator and very close to a Xenon laboratory version, see Figure 2.

On a side note, the spectral values for the LED sun simulator in Figure 1 and Figure 2 are verified independently by TÜV Rheinland.

Spatial non-uniformity

The spatial non-uniformity over the measurement area is also a key to accurate measurements. IEC standard demands evaluation of equally distant positions over the active measurement area. It also defines the overall result to be achieved for the above mentioned quality classes A+ to C. For an A+ class sun simulator the spatial non-uniformity has to be below ± 1 %.

See Figure 3 for a typical non-uniformity matrix of the example LED inline sun simulator. The temperature drift during the measurement has not exceed a corridor of +/-1°C and the measurements were taken with a nominal irradiance of 1000 W/m² and a flash duration of 200 ms.

The typical non-uniformity reached for this type of LED sun simulator is < 0.6%. And the great thing is: due to the scalability and the possibility to adjust individual colour channels it is also possible to reach this result for any larger light area.

Compared to a Xenon sun simulator the non-uniformity of an LED sun simulator is as good as a Xenon laboratory simulator and often up to 50 % better as an inline Xenon production sun simulator, and even more so when the Xenon light tubes come to the end of their lifetime, see Figure 2. It is well known that the spectrum of a Xenon light tube changes throughout its lifetime.

With the above data one can say that the LED spectrum is as good as the spectrum given by a Xenon light tube. Having the spectral part covered let's see where LED really performs much better than Xenon.

A better long-term temporal instability

The long-term temporal instability (LTI) tells how well the irradiance stays in range over a given time period. Using LEDs, it is possible to create long stable pulses, in extreme up to a steady state illumination. To claim a class A+ for the LTI the IEC standard requires less variation in the pulse than ± 1 % over the full flash duration.

In our example of an inline module LED sun simulator the flash pulse is 200 ms long, with the IV-curve being measured in a time window from 10 ms to 190 ms. The irradiance is measured by a build-in monitor cell.

MBJ	1	2	3	4	5	6	7	8
C12	-0,51%	-0,20%	-0,42%	-0,21%	-0,16%	-0,49%	-0,19%	-0,52%
C11	-0,35%	0,21%	-0,05%	0,19%	0,09%	-0,17%	0,37%	-0,03%
C10	-0,38%	0,20%	-0,01%	0,20%	0,13%	-0,13%	0,24%	-0,10%
C9	0,09%	0,57%	0,31%	0,51%	0,50%	0,16%	0,46%	0,23%
C8	-0,28%	0,13%	-0,30%	-0,18%	-0,16%	-0,39%	-0,06%	-0,36%
C7	-0,03%	0,30%	-0,09%	0,04%	0,13%	0,03%	0,40%	0,10%
C6	-0,51%	-0,06%	-0,31%	-0,16%	-0,09%	-0,26%	-0,04%	-0,48%
C5	-0,18%	0,43%	0,16%	0,24%	0,20%	-0,04%	0,22%	-0,12%
C4	-0,32%	0,37%	-0,01%	0,01%	-0,07%	-0,24%	0,13%	-0,11%
C3	-0,20%	0,31%	-0,21%	-0,16%	-0,22%	-0,24%	0,27%	-0,02%
C2	0,00%	0,44%	-0,07%	0,04%	0,07%	-0,05%	0,40%	0,22%
C1	-0,29%	0,35%	-0,01%	0,28%	0,27%	0,02%	0,24%	0,02%

Figure 3: Typical LED sun simulator non-uniformity map

The maximum deviation is less than 0.1 % during the IV sweep, see Figure 4. That is 10x times better than required by the IEC standard! The red marked limit irradiance of ± 1.0 % marks the class A+ limit.

The stable part of a Xenon light pulse is mostly less than 50 ms long and shows an instability of just under ±1 %. One can safely say that LEDs have a big advantage here and even more so with regards to the newer solar cell and module technologies with capacitive effects.

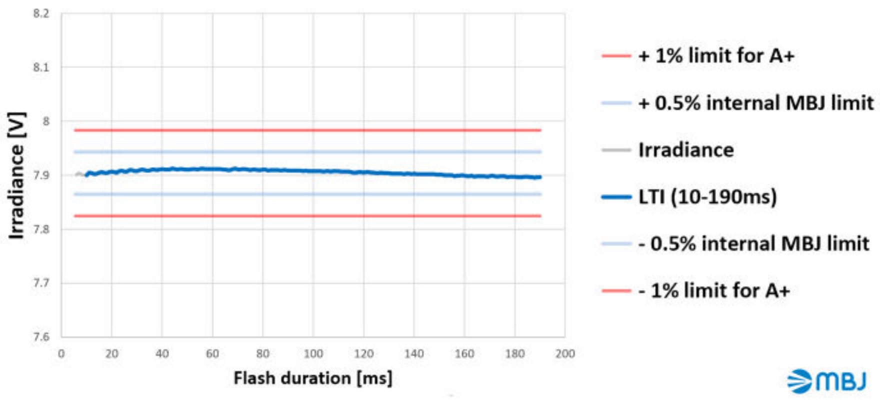

Figure 4: Long-term temporal instability of an MBJ LED Sun Simulator flash pulse

Excellent lifetime

The longer a light source's life is, without significantly changing its intensity or spectral behaviour, the better that is for the measurement system in a production environment. Less down time, less calibration time and less uncertainty in the measurement, directly leading to less operational cost over the lifetime of the production line.

Let's have a look at the lifetime of an LED. When they are operated within the specification given by the manufacturer (electrically and temperature wise) in a steady light mode, the average lifetime of a good quality LED is up to 50,000 hours.

The example LED sun simulator in this article measures three solar modules in one minute, 180 modules in one hour, 4,320 in a day and 1,576,800 in one year. The flash duration for one measurement is 200 ms, the LEDs are driven well within the manufacture's specification.

The effective light ON time of the LEDs in this sun simulator calculates to 315,360 sec or 87.6 hours in a year. That makes 876 hours in 10 years. 876 hours light ON is still very far away from the expected LED lifetime of 50,000 hours.

When 876 hours correspond to 10 years of operation in production it means that with an LED sun simulator, the light source never needs to be replaced under normal circumstances.

A Xenon light tube has a recommended manufacturer lifetime of ~100.000 flashes. When measuring three solar modules in a minute the lifetime is reached in only 23 Days, the Xenon tube should be replaced. Even when stretching the lifetime to 300,000 flashes, although knowing that the Xenon spectrum degrades over the lifetime, a replacement is due after 69 days.

This is a major advantage of an LED light source! Let's add some data for the spectral stability of the LEDs lifetime in our example LED sun simulator.

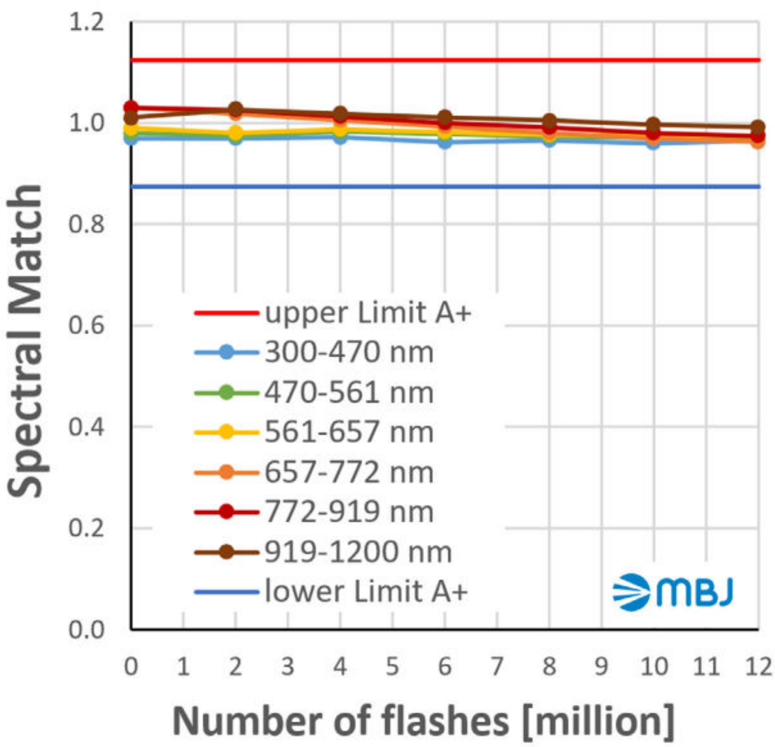

Figure 5: LED sun simulator after 12 Mio. Flashes: excellent spectral stability over all wavelength bands

Accelerated lifetime test of LED light source

As mentioned, it is not only the lifetime but also the spectral behaviour over the lifetime that makes LEDs so perfect for a sun simulator. The IEC 60904-9 Ed.3 requires a spectral match of 0.875 to 1.125 for an A+ classification of a sun simulator.

To prove the lifetime expectation as well as the effect on the spectral match of the used LEDs, one LED light source of the mentioned inline sun simulator is currently undergoing an accelerated lifetime test.

While the test is still ongoing, the counter shows 12 Mio flashes with a cycle time of 2.7 s, a flash duration of 195 ms and no adjustments to any settings (intensity, spectral shift).

See Figure 5 for the results after 12 million flashes, corresponding to 7,6 years of continuous operation in module production: the spectral match in all wavelengths bands is very stable and still very well within class A+ requirements of 0.875 (blue line) to 1.125 (red line).

In comparison, as already mentioned above, the Xenon lamps lifetime is a lot shorter. It is 100,000 flashes, or 23 days. Following this recommendation, the spectrum is expected to be still close to the 1.5 AM sun spectrum. But when stretching it to 300.000 flashes bevor an exchange, e.g. to save money, the spectrum might well be out of the IEC standard requirement for A+ or might even drop to lower than A. This will lead to measurement uncertainties. In the long run this will cost money as modules might be sorted into lower Wpeak classes as they should have been.

A faster return of investment

When looking at annual cost and the initial investment (CAPEX) it becomes clear that

The degradation of the spectrum is so minor that it is still well within A+ class after years of operation and is expected to stay like that more than 10 years.

an investment into an LED sun simulator is a money saver.

A Xenon light tube should be changed after 100,000 flashes, here we calculate with 300,00 flashes. A Xenon sun simulator use 1, 2, 4 or more Xenon light tubes. When keeping in mind that modules have become larger in size lately we calculate with 4 Xenon light tubes in a typical sun simulator.

300,000 flashes sum up to a max of 69 days of operation. That makes 4 x 6 light bulbs in a year and 240 Xenon bulbs over 10 years. Each light tube costs ~600 USD, in 10 years you have to spend 144,000 USD.

In comparison, there is no need to exchange an LED light source in an LED sun simulator. You will have 0 USD expense for new light sources within 10 years. It will keep its spectral performance over the full time. The degradation of the spectrum is so minor that it is still well within A+ class after years of operation and is expected to stay like that more than 10 years.

As it is known that the spectrum of a Xenon light tube changes toward the end of its lifetime, the often discussed advantage of a better spectrum becomes a disadvantage. And even more so when following the recommended light tube exchange after 100,000 flashes to keep a good spectrum: After 10 years you will have paid 384,000 USD on light tubes alone. With an operation time of 23 days this adds up to 64 tubes a year and 640 tubes over 10 years.

The initial investment for an LED sun simulator could be 100,000 USD more compared to a Xenon sun simulator.

But even with the higher initial cost of an LED sun simulator, the regular maintenance cost for calibration and standard ware parts over 10 years, the return of investment will be reached in far less time as it will be with a Xenon sun simulator. Additionally, an LED sun simulator in module production uses less floor space in most cases.

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Summarising the benefits of an LED sun simulator

Significantly longer lifetime, spectral stability and with that better repeatability over the light source lifetime. Less measurement uncertainties.

Through the significantly longer lifetime, less maintenance hardware cost and maintenance down times. A faster return on investment.

Spectral performance better than class A+ requirement given in IEC 60904-9 Ed. 3 and as good as a XENON based laboratory flasher.

The data shown in this article is drawn from an MBJ Solutions GmbH LED inline sun simulator for module production with extended spectrum, using 22 different LED types.

The LED light source and the spectrum was measured and certified by TÜV Rheinland.

Due to the scalability of the system our standard products go up to a measurement area of 1400 x 2750 mm, other setups can be provided on request.

Find out more about MBJ Solutions LED Sun Simulator on our website.

About the company

Headquartered in Ahrensburg, Germany.

MBJ Solutions GmbH specialises in the development and sales of test and measurement systems for the photovoltaic industry.

MBJ offers sun simulators, electroluminescence test systems and test systems for insulation and grounding tests for the solar module production as well as for mobile measurement systems for the on-site testing of solar modules.

The company was founded in 2009 and has since sold more than 500 test systems worldwide.

We develop and produce all our products in Germany. Since many of our customers are based in Asia, we also have a service office in Taiwan.

Innovative solutions and customer orientation are a matter of course for us. Our customers include well-known institutes and manufacturers of the PV industry.

Our many years of experience and a motivated team make us the perfect partner for your PV projects.