SOLAR SIMULATOR FOR MODULE

# Learning Working Mode

Photo by Siliken

*Class AAA long pulse simulator, manufactured by Siliken Automation*

*José Vicente Lamparero*

The maximum operating point of solar Photovoltaic (PV) panels changes with environmental conditions. Simulator is born to locate the maximum power point and outline the module characteristic curve. Several simulator types exist and are classified depending on their working mode, but with the same purpose, characterize module with maximum accuracy.

BY JOSÉ VICENTE LAMPARERO

**New Concept for Solar Simulator**

For the last four decades, renewable energy utilization has considerably been increased. When transporing electrical current to remote places, photovoltaic systems are more advisable. In general, electricity provided from solar modules is more expensive than the one from the utility grid. For that reason, it is necessary to study carefully the photovoltaic system efficiency.

To characterize photovoltaic modules needs solar exposure, but unfortunately rays are not always available, or characterization requirements are not simply enough to characterize the module correctly.

When taking module measurements, homogeneous and constant light focus is required. Solar light focus becomes dependent during photovoltaic modules manufacture. Indeed, humidity, temperature are great influent factors in solar radiation.

New concept is born! Solar simulator has been created to obtain a homogeneous light focus whichever instant during the day in. This machine is capable to play solar light with precision enough to be considered as a natural solar light.

**Solar Simulator Types**

Simulators working mode is basically similar, however, depending on the specific purpose they are compound by different systems.

Differences are noticed on the generating light focus mode, although they could also present differences on the capture data system. Simulators can capture data in parallel or switching a single-channel. Single channel switching is less accurate, but cheaper on final price, for uses it just only one channel versus a three channel capture in parallel mode.

Simulators are classified into types depending on radiation generation mode, they are divided into two different groups:

Steady-state simulator generates a continuous focus light. It gets great homogeneity on light-focused plane, but consume a large amount of energy. Measure acquisition is also deficient as temperature module increases while data capturing and becomes detrimental.

Pulsed simulator generates short duration pulses (values, from 1 ms to 100 ms). Measurements are faster than steady-state simulators, but more complex and expensive. It is due to a shorter period exposure and in consequence, the temperature increase is invaluable while data recording.

Two different groups appear when talking about pulsed light simulators caused by different characteristic curve outlined.

Short pulse or multiple pulse simulator type, facing the module against different resistance magnitudes (from short circuit R=0 to open circuit R=inf), one pulse by step is required, to define the characteristic curve. Reduce investment, but on the other hand, they take more time and have lower precision to characterize the module.

Long pulse or single pulse system is single-shooted, connects the module with a variable resistance in time and, electronic load is recommended. In this way, a curve is outlined with only one shoot and a great resolution between different points depending on the simulator acquisition velocity.

Depending on pulse form, two classes are differed:

- Plane pulse, stepped pulse shooted and

prefixed radiation value, capturing while radiation is constant and steady.

- Decaying pulse, generates a ramp pulsed shoot, and capture data while the desired average value takes place. These simulators easily measure with different irradiation levels and could be used to gauge the module serial resistance.

**General Simulator Operation and Normative**

Despite its differences, every simulator has the same working method, this could be represented with a basic schedule compounded by: light focus (pulsed or continuous) filtered to get the desired power, and the light spectrum necessary and finally a data acquisition system. See Figure 1.

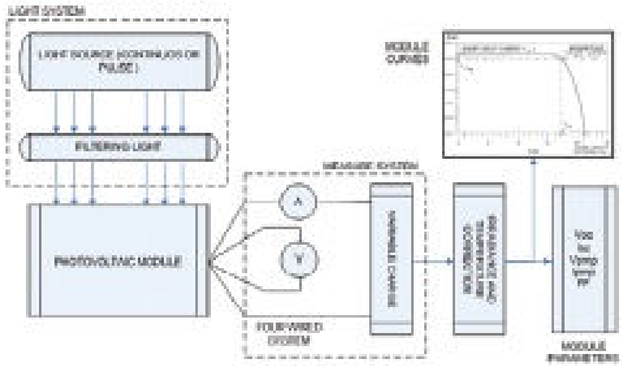


*Figure 1. Schematic illustrating a typical process* (Source: Silken)

During the measurement, module is swept from short circuit to open circuit, during this time simulator captures a raw data points for current, voltage and irradiance. From these data I-V and I-P curves are outlined.

These curves are the ones photovoltaic manufacturer presents to characterize their modules. VI curve represents current variance vs. voltage required by module connected charge. This curve represents real power generated by module. PI graph represents real power generated vs. current.

Irradiance measure should be taken through a reference photovoltaic device, according to standard IEC 60904-6 or a pyranometer. Temperature measurements should be accurated with ±1 ℃ precision, voltage and current with ±0.2% precision. For this purpose four-wire system measure should be used.

Solar cells provide quite enough amount of current, a standard cell approximately provides $I_{sc}$=8 A. Accurate measure for voltage module is reached by using a four-wire measure technique. By using this technique, voltage drop is avoided in parasite resistances, annulling measure errors.

Values are influenced and varied with the module temperature and irradiance. In this order measures should be corrected to standard testing values conditions (25 ℃, 1000 W/m² and AM1.5G spectrum). In Figure 2, outlined curve shapes and its influences respect those parameters are shown.

Solar cell simulators and precision module simulators are also corrected by spectrum. Spectrum has less influence on characteristics than other variables such as temperature and irradiance level. But this influence could become appreciable in single solar cell measurements.

Notice irradiance difference variations do affect module current (current generated by a single-cell is proportional to the irradiance received), voltage is not affected as much, over 800 W/m² voltage generated

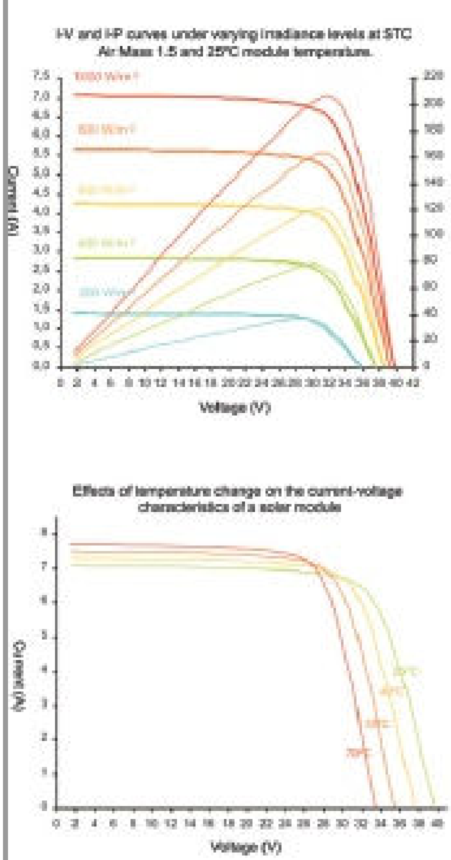


*Figure 2. Temperature and irradiance influence on IV and IP curves* (Source: Silken)

is practically constant.

Temperature variations are just opposite. In this case, voltage is the most affected, the higher the temperature the less voltage the cell generates.

To correct captured curves, it is necessary to know with accuracy the temperature as well as irradiance on capturing moment. With this purpose, simulators should be equipped with a higher precision system which measures the irradiance on plane and the module temperature.

The Standard IEC 60891 describes irradiance and temperature correction procedures. Corrections are implemented through the expressions (see Expression 1):

V1, I1, Irnr, T1 are actual measured voltage, current, irradiance and temperature.

V2, I2, Isr, T2 are the corrected characteristics.

$\alpha$ and $\beta$, are temperature coefficients for current and voltage.

Rs is the series resistance.

K is the curve correction factor.

The capturing $\alpha$ and $\beta$, and serial resistance procedure is established in standard IEC 60891. It basically consists of performing different captures to different temperatures to find $\alpha$ and $\beta$. And emitting different pulses varying radiation to plot how the maximum power plots vary with radiation and identify Rs.

## Indeed, humidity, temperature are great influent factors in solar radiation.

After correcting measurements, characterization module parameters are determined (Voc, Isc, Ppmp,Vpmp, Ipmp). Voc is the open circuit voltage; it consists of maximum voltage across the output terminals of module when the charge is infinite. Isc is the short circuit current, represents the maximum current provided when the charge is zero.

Pmp is the point on the current-voltage (I-V) curve of a solar module under illumination, where the product of current and voltage is maximum (measured in watts). The points on the I and V scales which describe this curve point are named Imp (current at maximum power) and Vmp (voltage at maximum power).

Fill Factor (FF) is the relation between theorical and real maximum power the module is capable to provide. (See Figure 3)

$$Non-uniformity\quad(\%)=\left[\frac{\max irradiance-\min irradiance}{\max irradiance+\min irradiance}\right]\times 100\,\%$$

*Expression 1. Temperature and irradiance correction formula* (Source: Silken)

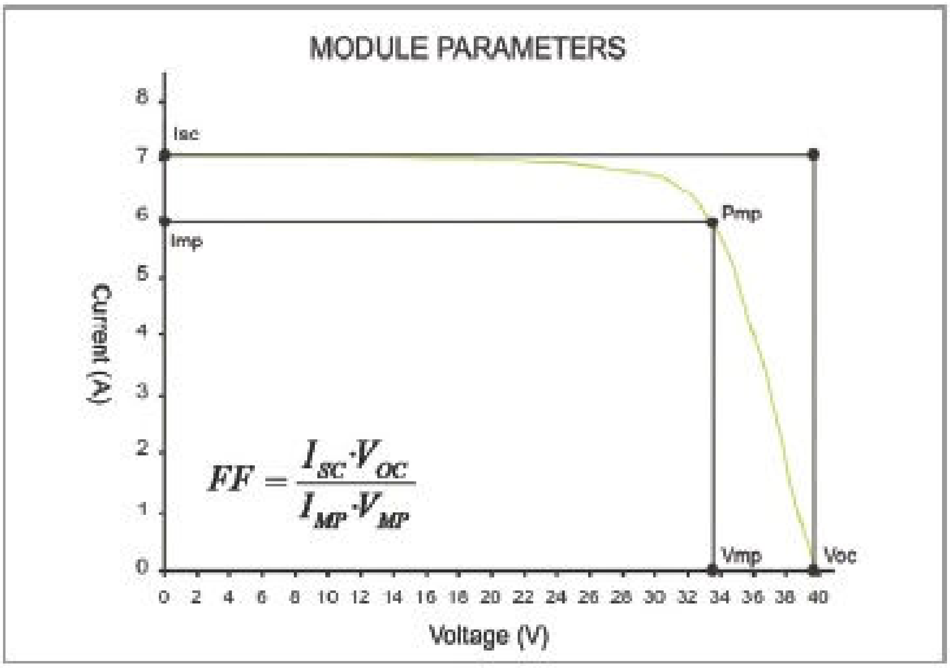


*Figure 3. Typical module parameters graphic representation and expression for fill factor* (Source: Silken)

$$Non-uniformity\quad(\%)=\left[\frac{\max irradiance-\min irradiance}{\max irradiance+\min irradiance}\right]\times 100\,\%$$

*Expression 2. Non-uniformity* (Source: Silken)

### Standard Classification

Standard IEC 60904-9 describes minimum requirements for simulator used in a manufacture process. The objective simulators are classified depending on:

- Non-uniformity for the light plane.
- Spectral match for light
- The long-term instability and short-term instability

Solar simulators can be either used for endurance irradiation tests or performance measurements of PV devices.

The standard 60904-9 says, *"Solar simulators for irradiance exposure should at least fulfil class CCC requirements where the third letter is related to long-term instability. In the case of use for PV performance measurements, classification CBA is demanded where the third letter is related to the short-term instability."*

In brief, restrictions will become wider for photovoltaic performance measurements classification being required AAA classification; Table 1 represents simulator classification limits according to standard.

The non-uniformity refers to maximum irradiance difference between maximum and minimum point on measurement plane, and it is calculated with an expression:

Getting a good uniformity in actual simulators is reached by using optical kits. These optical kits are compounded by diffuser lens and homogenizer elements. It is also worked with basic light concepts, the further the light focus is settled the better light uniformity on plane. This is the reason because some simulators on the market reach over 6 meters.

The non-uniformity increase on measurement plane affects IV curve, if non-uniformity is high, position and module orientation in simulator affect measured results. As each solar cell on module receives different radiation and, cells produce a different current value.

The spectral match refers to the similarity between the solar spectrum and the lamp spectrum. The range in study is from 400 nm to 1,100 nm. According to the IEC 60904-9, every sub-range must have a determined percent of the total irradiance to get a Class A spectrum.

For that purpose, frequently Xenon flash lamps are used and combined with the appropriate filters in order to reduce the excess of specific wavelengths (see Figure 4).

Once you have done the measurements with a calibrated spectrometer, due to the non-linearity of the device, it is necessary to interpolate the data into equidistant wavelengths. Then, getting percent in all sub-ranges you can get the classification for your simulator, see Table 2.

**Nowadays, getting a proper characterization as for cells as photovoltaic modules becomes extremely necessary to maximize installation efficiency.**

Final classification will be the worst sub-range classification obtained.

The LTI is related to the irradiance change of measured data sets during the time of data acquisition.

While characteristic curve capturing process, radiation should be as constant as possible. In order to this a variability limited range is set to be considered as acceptable. This characteristic is most critical in decaying pulse simulator, these simulators work with a irradiance ramp, therefore, the measuring period should be limited, to avoid differences between maximum and minimum and be higher than 2%. On the Steady-State simulators and plane step simulator, this variation is not critical.

STI is referred to delay in same signal continuous samples. Simulators with an independent channel for irradiance, voltage and current are not very much affected by this restriction, as STI only depends on data recording velocity. However, simulator switch only has a single-channel capture and works switching signals onto the same channel, and should ensure time between two sequential points is not higher than limits represented in Table 1.

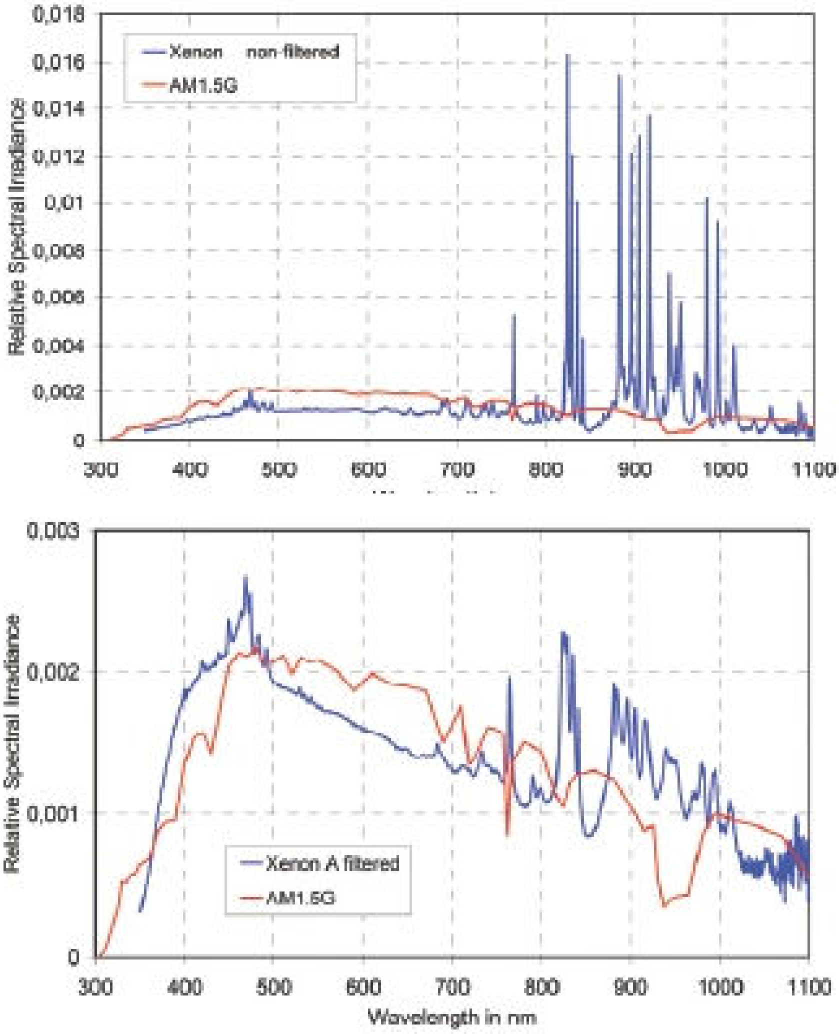


*Figure 4. On the left, spectral irradiance distribution of a pulsed solar simulator using a non filtered Xenon lamp/On the right, spectral irradiance using a filtered A Xenon lamp* (Source: Siliken)

## For Maximum Efficiency

Nowadays, getting a proper characterization as for cells as photovoltaic modules becomes extremely necessary to maximize installation efficiency. Therefore, simulators have become a clue to market manufacturers and their development is constantly increasing to get accuracy in measurement. Nowadays most simulators used in production are long pulse simulator class with a filtered xenon lamp.

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| Classifications | Spectral match to all intervals | Non-uniformity of irradiance | Temporal instability | |
|---|---|---|---|---|
| | | | Short term instability of irradiance STI | Long term instability of irradiance LTI |
| A | 0,75 – 1,25 | 2 % | 0,5% | 2 % |
| B | 0,6 – 1,4 | 5 % | 2 % | 5 % |
| C | 0,4 – 2,0 | 10 % | 10 % | 10 % |

*Table 1. Standard IEC 60904-9 solar simulator classification* (Source: Siliken)

| | Wavelength range nm | Percentage of total irradiance in the wavelength range 400 nm – 1 100 nm |
|---|---|---|
| 1 | 400 – 500 | 18,4 % |
| 2 | 500 – 600 | 19,9 % |
| 3 | 600 – 700 | 18,4 % |
| 4 | 700 – 800 | 14,9 % |
| 5 | 800 – 900 | 12,5 % |
| 6 | 900 – 1 100 | 15,9 % |

*Table 2. Global reference solar spectral irradiance distribution given in IEC 60904-3* (Source: Siliken)