APPLICATION OF SOLAR SIMULATORS IN PV TECHNOLOGIES

Dragoljub Mirjanić [1], Darko Divnić [1], Tomislav Pavlović [2], Ivana Radonjić [2], Esad Jakupović [1],

[1]Academy of Sciences and Arts of the Republic of Srpska, Banja Luka, Republic of Srpska, B&H

[2]Faculty of Sciences and Mathematics, University of Niš, Niš, Serbia

Abstract: Solar cells and solar modules made of monocrystalline, polycrystalline and amorphous silicon on glass or plastic basis, GaAs, CdTe, CIS, organic, solar cells with concentrators, etc. are used in the world today to convert solar radiation into electricity.

For the physical characterization of solar cells and solar modules, solar simulators with xenon, halogen and LED lamps are used as light sources. Determination of energy efficiency of solar cells and solar modules using solar simulators is performed under the following standard conditions: temperature of 25°C, solar spectrum AM1.5 and solar radiation intensity of 1000 W /m 2.

The paper will provide an overview of solar radiation simulators used today in the world to determine the energy efficiency of solar cells and solar modules obtained using various photovoltaic technologies, as well as the characteristics of the solar radiation simulators themselves.

Keywords: solar cells, solar modules, solar radiation simulators, energy efficiency.

INTRODUCTION

Photovoltaic solar cells convert the energy of the sun into electricity at constantly improving eciencies. Mainstream technologies exhibit close to 20% eciencies whereas record eciencies have exceeded 40% showing the potential for further technological advancement and increase in eciency. high quality characterisation of photovoltaic modules for accurate power rating and energy yield prediction measurements is critical and more essential than ever. Most manufacturers oer a 20-25 year warranty for their panels. However, if the characterisation of the modules is not precise and their quality does not meet the promised levels, the lost revenue of an investment can be large. Therefore, advanced characterisation methods need to be applied. There are various characterisation methods, either outdoors or indoors.Indoor characterisation methods are easier to be used in production lines as they are faster and weather independent. At the heart of production control is a solar simulator.

Solar simulators are being broadly used for the characterisation of dierent photovoltaic technologies. Dierent types of light sources, such as xenon or halogen lamps, have been used in various installations. LED solar simulators are the new trend for the characterisation of photovoltaic devices as they promise to be more reliable and accurate due to the many advantages of the LEDs used as light sources.

SOLAR SIMULATOR PERFORMANCE REQUIREMENTS

All solar simulators need to meet certain standard specications to be considered reliable. They can measure the I-V characteristic of PV devices under any conditions but the eciency data should be measured under standard test conditions (STC) at a 25°C device temperature, an AM1.5G solar spectrum, 1000 W/m2 irradiance and normal incidence. Their classication is based on the values of spectral match to the AM1.5 solar spectrum, the non uniformity of light and the temporal stability.

The classication is considered AAA if the spectral mismatch to the solar spectrum from 400 to 1100nm in 5 bands of 100nm and one band of 200nm is less than 25%, the non-uniformity is less than 2%, the short term instability is less than 0.5% and the long term instability is less than 2%. However, due to limitations, STC cannot always be met resulting in measurement errors. Corrections are applied to deal with deviations between the required conditions and those delivered by the solar simulators. An estimation of the measurement uncertainty is necessary. In characterisation systems the main sources of measurement uncertainty are the spectral match, the non-uniformity of light and the reference cell. The two former sources of uncertainty are related to the solar simulators and their performance. Spectralnon-uniformity uncertainty, which is not accounted for by the standards, will also be considered. In order to minimize these uncertainty factors the spectral match and uniformity of the solar simulators need to be further improved.

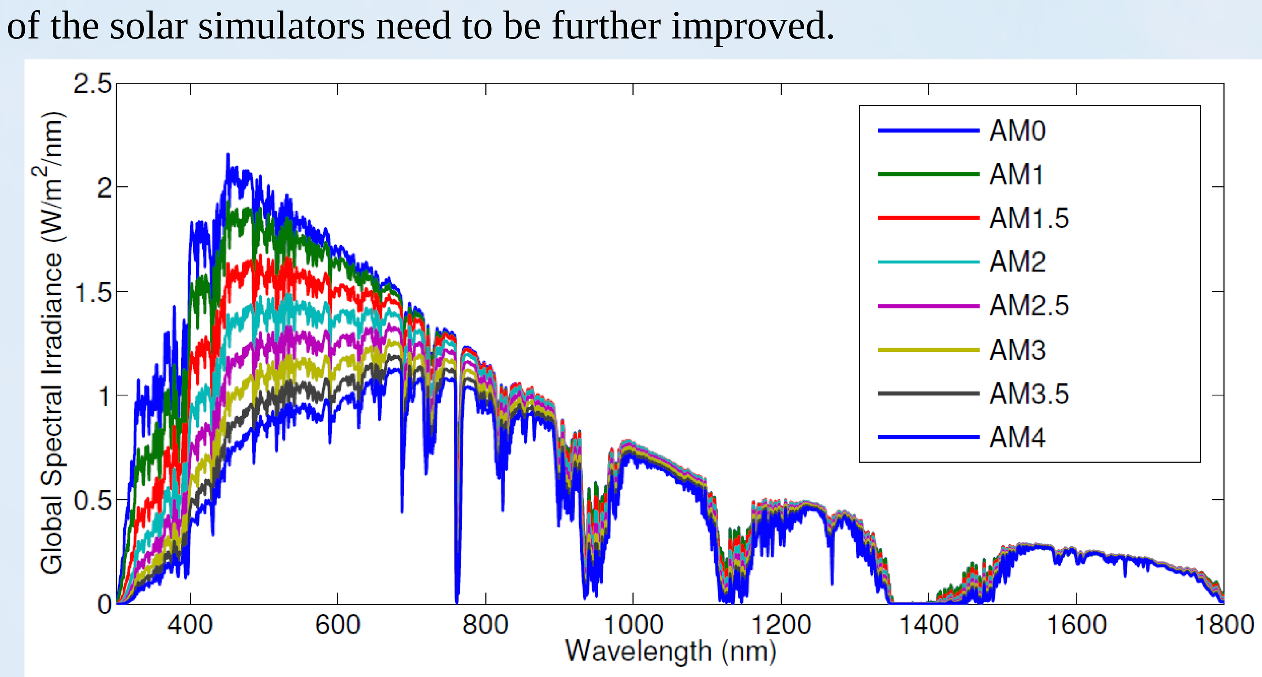

Figure 1. Modelled global spectral irradiance for dierent Air Mass

According to the IEC60904-9 standards, a solar simulator needs to be of a specic classication in order to accurately characterise photovoltaic devices indoors.

Spectral match, non-uniformity of irradiance and temporal instability are taken into account both for steady state and pulsed solar simulators in order to determine their classication. Letters A,B and C are used to specify which class each one of the above characteristics belongs to. The spectrum used as a reference is the one matching AM1.5G. Any dierence between the solar simulator's spectrum and the reference spectrum determines the spectral mismatch of a solar simulator. Table 1 shows the global reference solar spectral irradiance distribution given in IEC60904-9, and Table 2. shows IEC60904-9 requirementsfor each classication

	Wavelength range (nm)	Percentage of total irradiance in the wavelength range 400nm-1100nm
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	900-1100	15.9%

Table 1. Global reference solar spectral irradiance distribution given in IEC60904-9

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 2. EC60904-9 requirements for each classication

I-V CHARACTERISTIC CALIBRATION

The I-V characteristic can be measured by a solar simulator under any conditions.

Manufacturers are selling their products providing eciency values under Standard Test Conditions (STC). Both outdoor and indoor systems can be used for the extraction of an I-V curve and the power rating of a device under STC, for power rating measurements under different conditions and for energy yield prediction measurements.

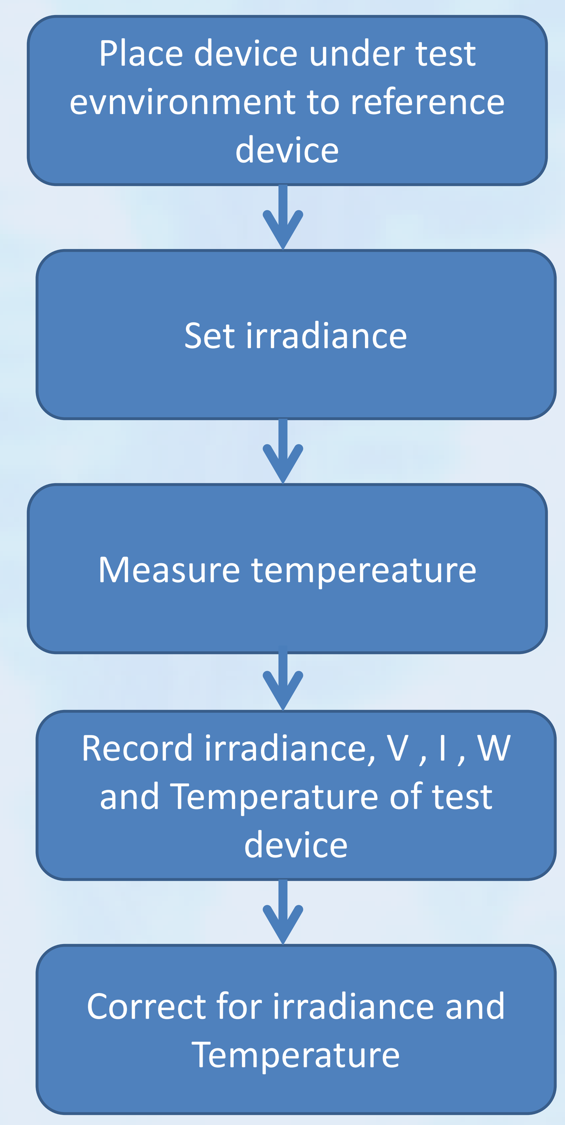

Figure 3. Flowchart of I-V characteristic calibration process under simulated sunlight

The measurement of a photovoltaic I-V characteristic follows the procedure described in Figure 3. The principle of the measurement is similar both under natural and simulated sunlight although dierences apply due to the varying nature of the two set-ups. The main dierence is the use of a solar simulator for the illumination of the solar panels in the indoor environment and the adjustment of the irradiance that it involves. The focus here is on the I-V characteristic calibration under simulated sunlight. A flowchart of the method is given in Figure 3. Firstly, the reference device is placed in the illuminated area and used to adjust the irradiance to the desired levels. A PV reference device is a specially calibrated solar device that is used to measure irradiance or to set the irradiance of a solar simulator. A reference device should have similar properties to the device under test. The spectral response, optical characteristics, dimensions, packaging and electricalcircuitry should be identical. The irradiance is set to the value that results in the short-circuit current or maximum power of the reference device at the desired level. For STC irradiance should be equal to 1000 W/m2. The calibration procedure followed depends on the dimensions of the reference device in relation to the device under test. If the devices have identical dimensions and electrical properties they should both be placed at the same position in the illuminated area, where the eective irradiance is measured. The eective irradiance is averaged across a panel's active area in case of non-uniform irradiance. Then, the device under test needs to be positioned in the illuminated area and connected to the measurement set-up as appropriate. Depending on the set-up the reference device might need to be removed. Usually they are placed next to each other. The temperature of the devices needs to be stabilised within 1oC of the ambient temperature. The I-V characteristic and the device under test temperature are recorded. The I-V curve is corrected to the desired temperature and irradiance if the temperature of the device under test is dierent to the desired. The correction is performed under STC is needed.

OVERVIEW OF EXISTING SOLAR SIMULATORS

The main dierences between dierent types of solar simulators are the light source(s) employed and the mode in which they operate. The main light source categories used both by commercial solar simulators and solar simulators in research laboratories are fillament lamps, arc lamps and LEDs.

The main types of filament lamps are the tungsten halogen lamps which are only used in the steady state solar simulators. The main types of arc lamps are the xenon high pressure arc lamps which can be used both in steady state and ash solar simulators. Other light sources such as metal halide and sodium lamps have also been used. The best spectral output is covered by the xenon lamp, Figure 4.

Solar simulators can be operated in steady state or flash mode. Steady state solar simulators operate continuously and perform I-V curve measurements accurately with a long time constant. Flash solar simulators can be separated in single and multiflash. Multiflash solar simulators use multiple flashes (about 200 to 250) instead of 1 to produce an I-V curve to prevent the device measured from heating up. The measurement takes longer to complete compared to single ash measurements. Flash solar simulators introduce less heat on the devices and use less power due to their non-continuous operation which increases their lifetime and reduces the operation and maintenance costs. LEDs can be used both as flash and steady state solar simulators because they can be regulated quickly and remain stable for a long time respectively. They are available in many colours.

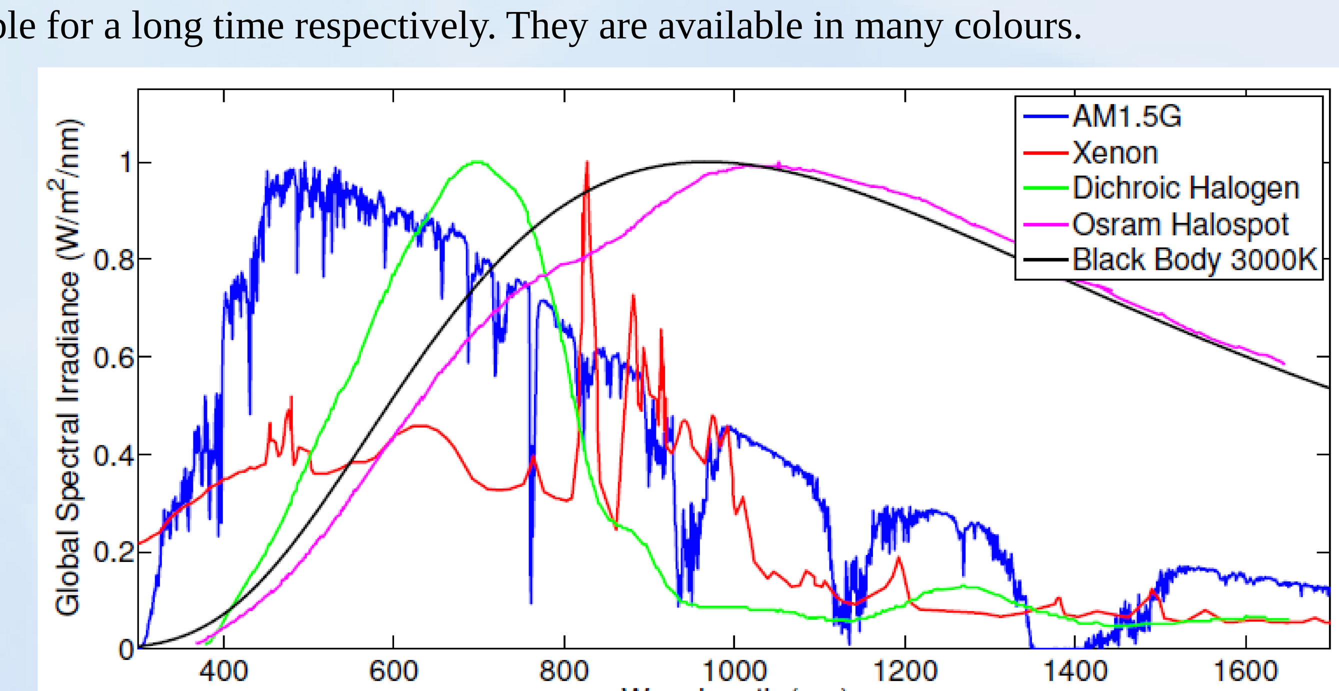

Figure 4. Spectra of dierent types of lamps compared to the AM1.5G

CONCLUSION

Solar simulators mainly consist of one or multiple light sources, some optics for the lamps or lters to shape the lamp's spectrum further, if needed, monitoring equipment to record irradiance and temperature, a cooling system for the lamps and the devices, if overheating is observed, and all the control and power electronics. Also, many solar simulators have been built using a combination of two or more of those light sources to improve the spectral match and extend the spectrum, which is needed for the measurement of particular technologies such as multi-junction solar cells.

LED solar simulators are the new trend in the characterisation of photovoltaic devices.

LEDs have the potential of achieving a light intensity of 1000 W/m2 as well as other intensities. Their intensity can be easily adjusted without changing the spectrum, compared to other light sources for which this is not straightforward. They have much longer lifetimes in comparison to other light sources, thus maintenance costs are expected to be reduced signicantly and calibration accuracy is increased over time. LEDs exhibit higher conversion eciencies from electricity to light, they are more stable, provided a stable current source and a good temperature control, more cost eective and more energy effiecient. The main disadvantage of LEDs is their quick degradation after exposure to high temperatures. The use of a cooling system is of great importance due to the fact that temperature rises signicantly during their operation.