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DESIGNING PROCEDURE OF LED-HALOGEN HYBRID SOLAR SIMULATOR TO SMALL SIZE SOLAR CELL TESTING

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Abstract

During the experimental investigation of solar cells, the quality of the illumination is essential. In the case of solar simulators, the main goal is the accurate reproduction of sunlight. The designing procedure of a halogen LED hybrid solar simulator is described in this article. One of the main goals is the compliance with the relevant standard (ASTM E972).

Keywords: *solar cell, solar simulator, LED, halogen.*

1. Introduction

The first-generation solar simulators are based on halogen, xenon or simple tungsten light sources and on their combinations **[1]**. Due to the development of semiconductor technology, new types of solar simulators can be created which are based on high power LED units. These devices are energy efficient and well controlled, the solar spectrum can be reproduced well by the combination of different color LED units. One main disadvantage of LED solar simulators is as follows: 1000 W/m^2 light intensity is required for standard measurements and it is difficult to assure it by using LED units only **[2]**. Combination of LED and first-generation illumination (e.g. halogen) can solve this problem **[3]**.

2. Designing

American Standard for Materials (ASTM) E972 describes the standard specifications of solar simulation for photovoltaic testing **[4]**. Our goal is to design a C-class solar simulator according to the mentioned standard. Adequate illumination of small size (max. 150 mm x 150 mm) solar cells can be solved by the planned device. The construction is based on a combination of high power LED units with different colors and halogen lamps. During the design procedure, the optimal supply currents of LED color groups, the optimal position and the quantity of halogen lamps are defined, with the respect to the standard spectral distribution and homogeneous light intensity distribution.

2.1. Spectral match

The absolute spectrum distribution of each light source is determined indirectly. In case of each LED color, the radiation wavelength range and the wavelength of the radiation peak are known. According to measurements, the average light intensity of LED units is determined for various supply currents. With the help of these data, spectral distribution of LEDs are well approached by Gaussian curves. The spectral distribution of the halogen lamp is estimated according to the blackbody spectrum at 3200 K color temperature. Superposition of the spectrum curves of each light source gives the spectral distribution of the solar simulator for the given parameters. Spectral match in wavelength intervals can be calculated by Equation (1).

$$SE(\lambda_a - \lambda_f) = \frac{\int_{\lambda_a}^{\lambda_f} E_{NSz}(\lambda) d\lambda}{\int_{\lambda_a}^{\lambda_f} E_{AM1,5}(\lambda) d\lambda} , \qquad (1)$$

where:

$SE(\lambda_a\text{-}\lambda_f)$ is the spectral match in the actual wavelength range [-];

λ_a lower limit of wavelength range [nm];

λ_f upper limit of wavelength range [nm];

E_{NSz} intensity of the solar simulator spectrum [W/m²/nm];

$E_{AM1,5}$ intensity of the AM1.5 spectrum [W/m²/nm].

During spectral optimization we need to determine the supply currents of the LED color groups (within the allowed limits), which leads in standard C-class spectral match in wavelength intervals. In case of 625 current combination the described method is calculated by a MATLAB code and in each case, the spectral match in the wavelength ranges are determined. **Figure 1.** shows the spectral distribution of sunlight (global AM 1.5) and spectral distribution of each light source and solar simulator in the case of the best spectral match.

2.2. Light intensity distribution

The design method of the correct light intensity distribution is based on preliminary measurements. In the case of the LED units, the measurement results of the spectral analysis are used. Light intensity distribution in the case of 625 current combinations are determined by a MATLAB code. For the halogen lamps, the variables are the position and the number of the bulbs. The spots of lamps are fixed (corners and sides of the LED matrix), but the angle with the horizontal, the number of lamps (4 or 8), the distance from the test plane and the LED matrix are variables. This time, 27 combinations are tested. For each combination, the program calculates the superposition of the light intensity distributions and determines the non uniformity of the actual light intensity distribution based on Equation (2).

$$T_{EGy} = \frac{E_{\max} - E_{\min}}{E_{\max} + E_{\min}}, \qquad (2)$$

where:

T_{Egy} is the non-uniformity of light intensity distribution [-];

E_{max} is the maximum light intensity [W/m²];

E_{min} is the minimum light intensity [W/m²].

The goal is to find the optimal combination, which ensures the smallest light intensity non uniformity. Most homogeneous light intensity distribution in the test plane is shown in **Figure 2.**

3. Results

3.1. Designed construction

The planned solar simulator construction is based on the combination of 36 high power LEDs (5 W electric power per piece), 8 halogen lamps (50 W electric power per piece) and the subunits,

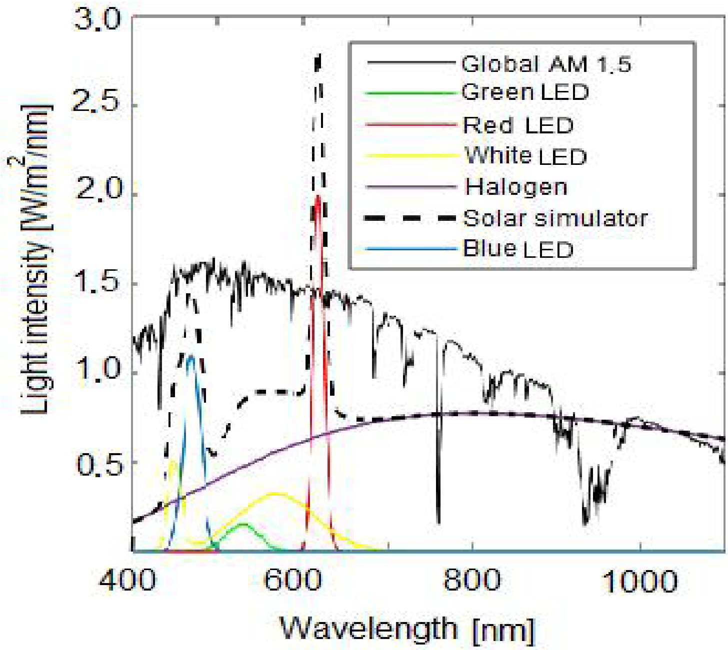

Figure 1. *Optimal spectral distribution*

which are required for the operation (power supply, controll unit, heat sink, fan and frame). Table 1 shows the applicable supply currents in case of each LED color group. The position of the halogen lamps is described in Table 2.

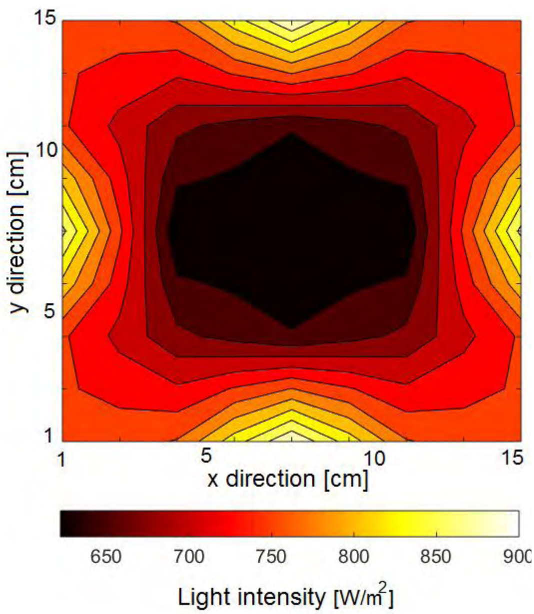

Figure 2. *Most homogeneous light intensity distribution in the test plane*

Table 1. *Supply current and voltage values of different colored LEDs*

Color	I [mA]	U [V]
Red	710	2.5
Blue	710	3.4
Green	670	3.2
White	680	4.0

Table 2. *Position of halogen lamps*

Horizontal distance from the LED matrix	Corner: 30 mm	Side: 34 mm
Angle with the horizontal	Corner: 30°	Side: 45°
Vertical distance from the test range	Corner: 75 mm	Side: 60 mm

3.2. Solar simulator compliance to standard

The mentioned standard classifies the solar simulators according to three criteria. In the case of C class the criteria and the values of these criteria are the following: (i) spectral match between the illumination and sunlight: 40 200 %; (ii) spatial non-uniformity of illumination: ≤ 10 %; (iii) temporal non uniformity of illumination: ≤ 10 %. Furthermore, each standard device needs to able to create 1000 W/m2 average light intensity (AM 1.5).

Based on the calculations, the average light intensity value of our solar simulator is 910 W/m2 and the spatial non-uniformity is 12%. Spectral match is shown in Table 3.

4. Conclusions

During this work, our main goal was to design a C class standard solar simulator, which can be used for the testing of small size solar cells. Based on the results, we can see that the intensity and homogeneity of illumination is slightly poorer than the criteria set out in the standard. Probably this problem can be solved by the help of the additional optimization of the halogen lamps position. In terms of spectral match, the spectral distribution of light sources meets the C-class criteria in each wavelength interval, except for 400 nm 500 nm. This result indicates the necessity for a new LED color unit installation, one which is dominant in low wavelengths (ultraviolet). In summary we can say that, with the help of halogen-LED hybrid illumination, standard solar simulator can be fabricated in a relatively cost-effective way. In our case, additional research is needed to be done in order to reach this goal.

Table 3. *Calculated spectral match in the examined wavelength ranges*

Wavelength range [μm]	Spectral match [%]
0.4-0.5	12.8
0.5-0.6	67.0
0.6-0.7	82.3
0.7-0.8	67.9
0.8-0.9	81.5
0.9-1.1	115.3

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