Modeling and simulation of a solar simulator with multi-wavelength high-power LEDs

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INTRODUCTION

The goal of this work is to propose a design for a solar simulator module with an optical spectrum closely matching the Air Mass 1.5 reference solar spectral irradiance. The work[1] in the reference proposes a similar design that uses a large array of dysprosium sunlight lamps to create a high-power simulator; however, the dysprosium lamps are an approximation of sunlight. The work[2] describes similar issues with other common light sources such as the xenon arc lamp, which has a similar spectrum to sunlight, but has sharp transitional peaks. As discussed in the work[3, 4], the straight peaks of each LED's color spectrum make it difficult to create pure white light, and often single colors can stick out. The proposed design will use high-power LEDs combined at varying intensities to match the spectrum and will work to minimize such peaks and ensure a smooth and accurate light source.

A solar simulator is a light source which can be used for measuring performance of PV cells or panels indoors. The IEC60904-9 standard[5] defines classifications of solar simulators. According to the standard, the simulators are classified as Class A, B, or C based on criteria of three parameters: i) spectral distribution match, ii) non-uniformity of irradiance, and iii) temporal instability of irradiance. In this study, we focus on the development of a solar simulator with LEDs for a spectral distribution match to meet Class A criterion. Figure 1 shows the reference solar spectral irradiance [7].

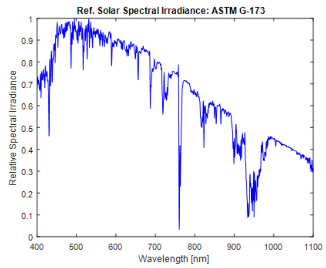

Fig. 1 Reference solar spectral irradiance

METHODS

To model these LEDs, we started by modeling the system in MatLab. Essentially, each LED has a short wavelength spectrum, and by adjusting a scaling factor, each LEDs' spectrum can be combined in such a way to make a spectrum the same length as the sun's. This spectrum was then compared to the sun's, and using that comparison, we tweaked the values of the scaling factor until the spectrum of the LEDs was close to the sun's. Once we had the optimal spectrum, we modeled the simulator part using a tool called LightTools. This involved moving model LEDs around a space the size of the part we are planning to make, adjusting the positions and intensities to match the spectrum found in MatLab. We then did color measurements and analysis to see how closely our part would match color-wise to the sun.

RESULTS

Table 1 and Figure 2 show the first results of the simulation. The relative intensity of each LED was calculated with respect to the base warm white LED so that the addition of each LEDs spectral region adjusted for its relative intensity matched the spectral distribution of sunlight as closely as possible. Based on the error percentage calculated (last column in Table 1), the simulated solar simulator meets Class A (±25%).

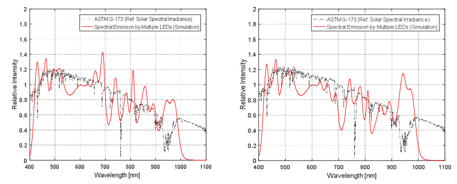

Fig. 3 and 4 Relative spectral emission

Table 2 and Figure 3 show the second results of the simulation. In this case, the relative intensity of each LED was set to minimize the error of the simulation's spectral irradiance when compared to sunlight's, while not compromising the average error in the spectral distribution.

RESULTS

Table 1 Simulation results based on the error percentage

Wavelength Range [nm]	Average of % error of the absolute difference [%]	Percentage of irradiance calculated [%]	Percentage of total irradiance [%] (Specification)	Error [%]
400 - 500	24.0882	18.8963	18.4	2.6975
500 - 600	13.4081	19.4602	19.9	2.2101
600 - 700	13.2972	20.9621	18.4	13.9242
700 - 800	29.5562	13.8699	14.9	6.9132
800 - 900	19.1485	14.8487	12.5	18.7896
900 - 1100	100.681	11.9628	15.9	24.7624

Table 2 Simulation results based on the error percentage

Wavelength Range [nm]	Average of % error of the absolute difference [%]	Percentage of irradiance calculated [%]	Percentage of total irradiance [%] (Specification)	Error [%]
400 - 500	24.9324	18.5529	18.4	0.8311
500 - 600	14.4563	19.7610	19.9	0.6985
600 - 700	12.2772	18.5375	18.4	0.7471
700 - 800	37.9049	14.7789	14.9	0.8127
800 - 900	19.4828	12.5226	12.5	0.1805
900 - 1100	123.780	15.8471	15.9	0.3324

From LightTools, we profiled the color of the simulator, finding the spectral distribution, the temperature, the CRI and CQS score, as well as the Color Chart and Luminance views. The temperature was found to be 5699.3 K, the CRI score to be 95.03, and the CQS score to be 95.707. Figure 5 and 6 show the Color Chart and Luminance views.

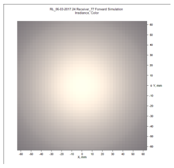

Fig. 5 Color Chart View

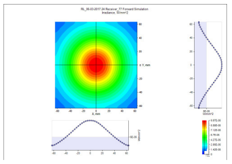

Fig. 6 Luminance View

CONCLUSIONS

Using a MATLAB simulation to find the optimal intensities of each LED and a model by LightTools to measure some important properties of the simulated sunlight, a solar simulator module with a Class A designation from the standard[5] for spectrum distribution match was successfully designed. This module not only matches the spectrum well, but also has impressive color quality. These results can be improved as LED technology continues to develop, creating LEDs to fit the dips in the simulated spectrum and powerful LEDs with long wavelengths.

REFERENCES

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