Spectral irradiance effect on photovoltaic modules of different technologies: modelling and experimental results

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PV modules are rated according to their power at Standard Test Conditions, however, photovoltaic panels rarely operate under these conditions. Due to each technology having its own spectral response as seen in Figure 1 - which differs from that of irradiance sensors - they may respond differently under the same spectral conditions. This spectral mismatch factor (M) measures the impact on the photovoltaic production due to the deviation from the standard solar spectrum ASTM G-173 [1]. It can be multiplied by the short-circuit current of a PV device to correct the bias, could vary from site to site and is caused by changes in the solar position and atmospheric content.

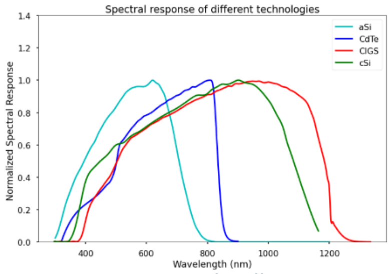

Figure 1 Spectral responses for different technologies normalized to their maximum value. Measured by CalLab PV Modules at Fraunhofer ISE.

In Palaiseau, France a study was conducted to assess the impact different spectral irradiance distributions have on c-Si, a-Si, CdTe, and CIS photovoltaic panels. One way to determine whether a spectrum has shifted towards longer or shorter wavelengths is by analyzing the average photon energy (APE), which is affected by air mass (AM), precipitable water (P_{wat}), and aerosols present in the atmosphere since they will increase or decrease the atmosphere's scattering and absorption capacity which are spectral dependent. The spectral mismatch factor was calculated using different models that consider parameters such as short-circuit irradiance, precipitable water, relative humidity, solar irradiance, spectral response, and air mass [2,3].

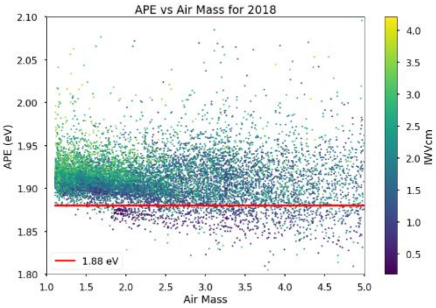

Figure 2 Average photon energy vs air mass and integrated water vapor on-site measurements for 2018

From Figure 1 we can say that thin-film technologies are more sensitive to blue-rich spectra whereas c-Si and CIGS are more sensitive to red-rich spectra. A shift of the spectrum towards shorter wavelengths can be caused due to the presence of P_{wat} in the atmosphere since most of the absorption bands of H_2O are located in the near-infrared wavelengths. In Figure 2 it is noticeable how as the presence of water increases the APE also increases, reaching values higher than 1.88 eV (which corresponds to an ASTM G-173 spectrum). Since shorter wavelengths have more energy, a value above 1.88 eV indicates a blue-rich spectrum that would be more favorable for thin-film technologies.

In Figures 3 and 4, we see the tendency and distribution of M versus APE values for crystalline and amorphous silicon technology based on solar spectral measurements of 2018. These figures illustrate how APE values greater than 1.88 eV lead to M values greater than one for a-Si and lower than one for c-Si. This means their output could be higher or lower when compared to the ASTM G-173 spectrum.

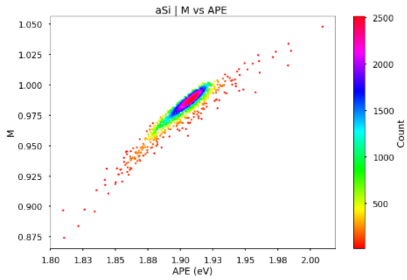

Figure 3 M values corresponding to a-Si technology versus average photon energy and count of events.

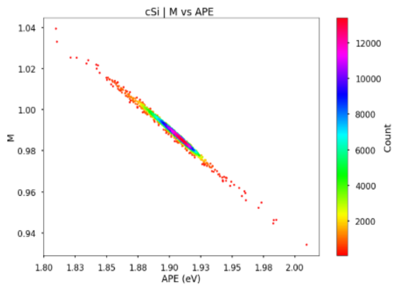

Figure 4 M values corresponding to c-Si technology versus average photon energy and count of events.

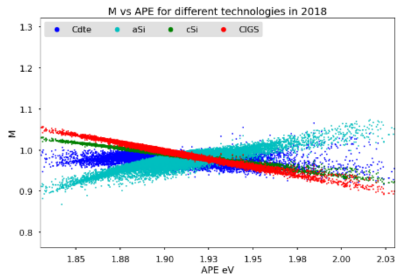

Figure 5 APE vs M values for CdTe, aSi, cSi, and CIS technologies with spectral measurements from 2018

To further study the correlation between APE and M, in Figure 5 we can see the tendency of the spectral mismatch factor to increase or decrease according to the APE for all technologies. From Figure 1 it can be argued that as APE increases, the M values for thin-film technologies will tend to increase whereas those for crystalline silicon will tend to decrease due to their differing spectral responses. Moreover, in Figure 4 it may be seen how the CdTe's M values do not vary as much as those of the other technologies. This could be explained due to less sensitivity to shifts in the spectrum towards shorter or longer wavelengths as its maximum spectral response lies between those of amorphous and crystalline silicon.

Additionally, the effect that an increase or decrease of the tilt angle of the irradiance sensor - with respect to the one used to model the reference spectrum (37 °) - can have on the spectral irradiance distribution was explored although the results are not shown in the present work.

[1] *Reference Air Mass 1.5 Spectra*. (n.d.). Retrieved September 4, 2020, from https://www.nrel.gov/grid/solar-resource/spectra-am1.5.html
[2] Dirnberger, D., Balckburn, G., Muller, B., & Reise, C. (2015). On the impact of solar spectral irradiance on the yield of different PV technologies. *Solar Energy Materials & Solar Cells*, *132*, 431–442. https://doi.org/10.1016/j.solmat.2014.09.034
[3] Lee, M., & Panchula, A. (2016, June). *Spectral Correction for Photovoltaic Module Performance Based on Air Mass and Precipitable Water*. IEEE 43rd Photovoltaic Specialists Conference (PVSC), Portland,OR,USA. https://doi.org/10.1109/PVSC.2016.7749836