CdTe PV Module Spectral Shift Effects

Atmospheric spectral changes have a significant impact on energy yield. Different atmospheric constituents absorb and/or reflect irradiance at different wavelengths, which results in changes in atmospheric spectrum. Significant constituents include precipitable water (P_{wat}) and air mass (AM). Of these factors CdTe module performance is most sensitive to P_{wat}, whereas crystalline silicon (c-Si) PV modules are more sensitive to Air Mass[1-2].

First Solar has extensively researched the effects of spectrum on PV performance. This research, which has been published in academic journals and conference proceedings[1-4], reaffirms the need for spectral corrections in PV performance modeling. Seasonal and short-term weather related changes in solar spectrum cause a shift in the performance of PV systems as large as 5% from nameplate[2]. Spectral shift (M) is a metric used to indicate variation in PV performance from nameplate due to deviations from ASTM G173 spectrum (AM1.5), and can be predicted using the SMARTS model[1-4]. SMARTS model results can be parameterized into simple functional forms that can easily be implemented into PV simulation software. Analysis of PV performance data from a variety of climates, over all seasons, illustrate that both the SMARTS model, and parameterizations thereof, match measured data[1,3-4].

Spectral shift effects vary with PV technology due to the range of spectral responsivity of the module. Historically, the most commonly used spectral correction method was an air mass modifier proposed by Sandia National Labs[5]. The model was intended to be applicable to all PV technologies. However, this air mass function requires module testing outdoors under clear skies. Moreover, follow-up work has suggested that use of the air mass modifiers yielded errors larger than when no corrections were applied. The subsequent research hypothesized that precipitable water caused the seasonal and geographic disparities in the modifier value[6-7].

Given that P_{wat} is the primary driver of spectral effects on CdTe PV technology, First Solar first proposed an empirical correlation for CdTe technology that was a function of precipitable water only[3,4]. Water vapor absorbs irradiant light in the wavelengths outside the CdTe QE (above 900nm)[4], therefore module performance increases relative to a broadband irradiance measurement when P_{wat} is high. Hot humid climates such as the South Eastern United States and most of India indicate expected energy gains of 3%-5% over nameplate with First Solar Series 4V2 and Series 4V3 modules due to the high P_{wat} content[2].

More recently, First Solar improved upon the model by adding terms to account for secondary *AM* affects[1]. For CdTe, the new two parameter spectral model produces results comparable to the earlier P_{wat} only model; however, it has the added advantage of also being applicable to c-Si technologies. Other recent publications by a c-Si manufacturer[8] and a national lab[9] have suggested correlations that also include both precipitable water and air mass, with other considerations of aerosols and clearness index.

The inclusion of spectral variation into energy models has the potential to improve prediction accuracy which will lower the risk of projects failing performance commitments, making projects more bankable and financing easier.

In addition to the First Solar internal publications, a considerable number of external documents support the sensitivity of PV performance to spectrum.

- Higher band-gap PV technologies display a large seasonal dependence over multiple locations. Low AM values and high P_{wat} positively impact the performance of CdTe technology[10].
- One spectrum can result in spectral gains for one technology, but also spectral losses for another one[11].
- CdTe and a-Si based samples indicate advantages for blue shifts of the solar spectral irradiance[12].
- Technologies with a narrow range of wavelengths are more sensitive to P_{wat} amounts, which a single AM correction factor does not address[13].
- It is reasonable to expect that the solar spectral content can vary apart from broadband irradiance and air mass; for example, due to water vapor content or atmospheric turbidity[6].

  CdTe technology exhibits a greater spectral sensitivity than CIGS and c-Si due to its narrow spectral response. CdTe shows a net gain in current density during the summer months when the days are longer and higher electrical demand during peak times [14].
- Sensitivity to spectral irradiance can be predicted by determining spectral irradiance variation as a function of input atmospheric conditions [15].
- The difference between the incident spectral distribution and the reference spectrum assumed by broadband instruments is found to result in daily energy yield predictions that are incorrect by as much as 15%.[16]

First Solar introduced PlantPredict, a cloud-based web application that allows users to develop solar energy estimates for utility scale PV applications[17]. PlantPredict has the spectral correction method proposed by Lee and Panchula natively included[1]. First Solar recognizes that *PVsyst*, a commonly used commercial software for performing energy predictions does not contain a relative humidity parameter which is essential to calculating spectral shift for PV modules. Therefore an adjustment to monthly soiling factors external to PVsyst is required to accurately model spectral shift. Until such time as *PVsyst* permits the application of a mismatch loss due to spectral shift, please see PD-5-423 and PD-5-423EX for instructions and sample calculations.

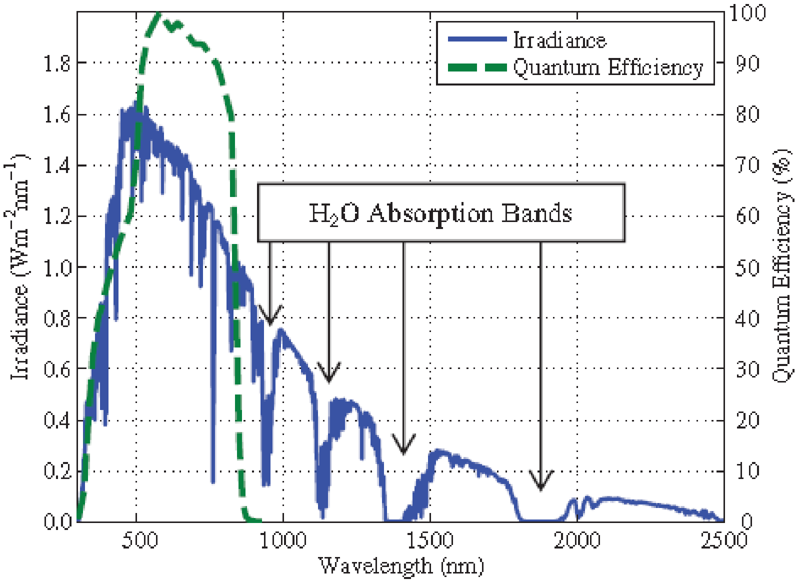

Figure 1. Global irradiance spectrum defined by ASTM G173 and an example QE curve normalized to 100% for a CdTe PV cell[3]

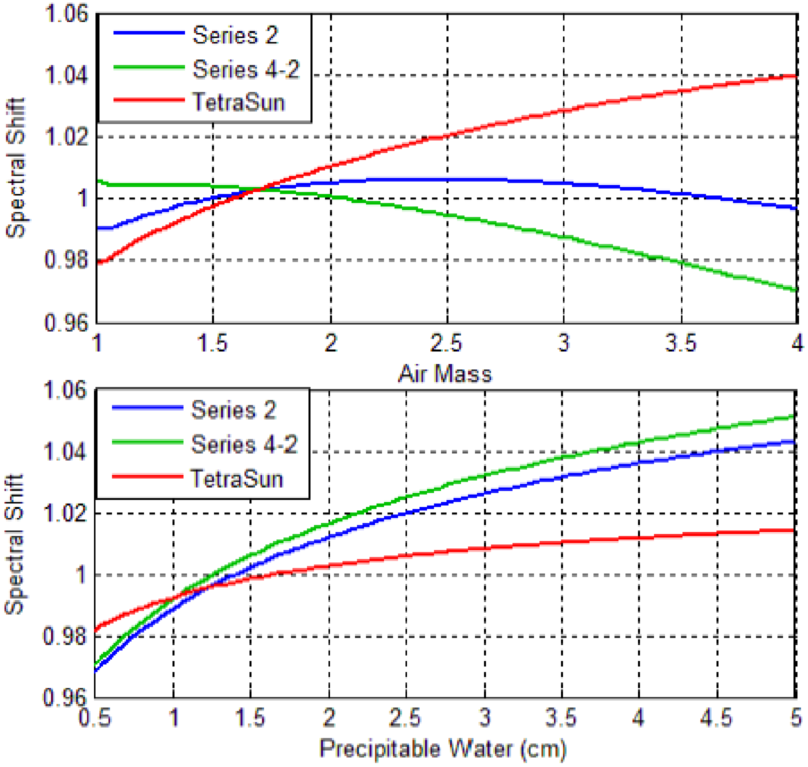

Figure 2. Sensitivity of Series 2 and Series 4V2/4V3 CdTe modules and Tetrasun mono-Si modules to P_{wat} and AM_a.[2]

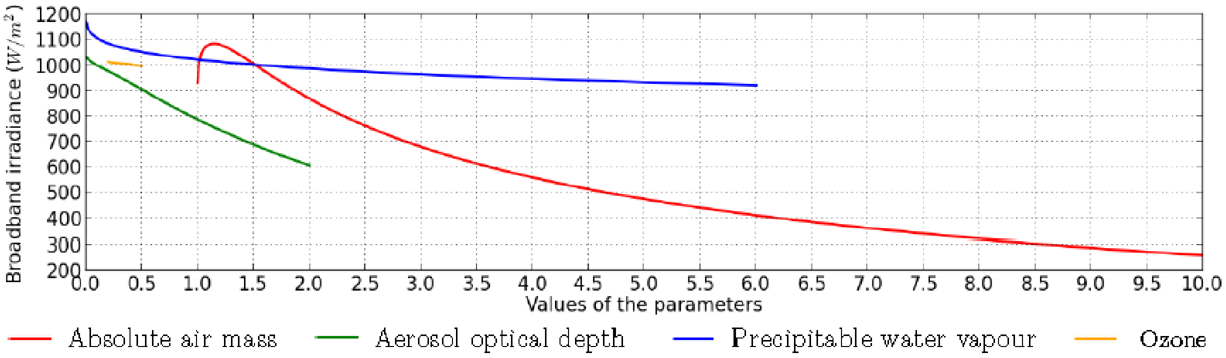

Figure 3. Effect of influencing parameters on the broadband irradiance[11]

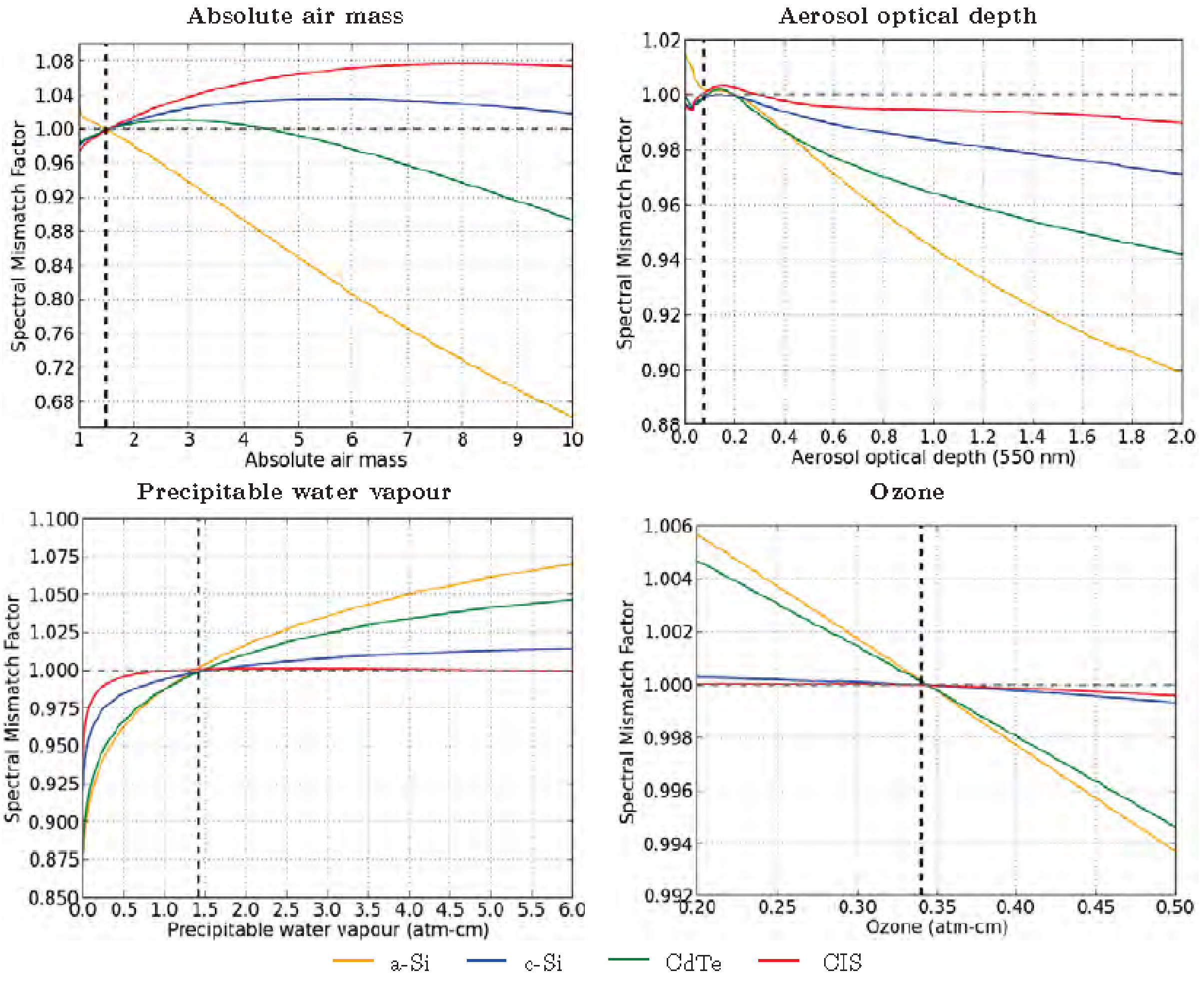

Figure 4. Effect of multiple influencing parameters on spectral mismatch[11]

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