Incidence Angle and Diffuse Radiation Adaptation of Soiling Measurements

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INTRODUCTION

- PV soiling ratio measurements are recommended for power plants and in resource assessment
- Soiling ratio for PV cells, ξ_{cell}, decreases with growing angle of incidence (AOI) [1]
- Considerable shares of energy production are generated at large AOI: At CIEMAT's Plataforma Solar de Almeria (PSA), 33% of the GTI is received at AOI from 40° -70°, 17% from 50°-70°.
- Soiling losses increase with AOI up to about 75°
- Active soiling sensors like DustIQ or MARS are not able to measure the AOI effect on soiling losses as they don't use the sun as light source
- We present a method for data of active soiling sensors to match the AOI dependency of PV cells

MEASUREMENT SET-UP

- Temperature corrected irradiance measurements with 4 PV reference cells (PVRC) give soiling ratios for cells with float glass and standard PV textured cover glasses
- DustIQ installed alongside PVRCs in 45° tilt, South orientation, see Fig. 1
- PVRC depends on AOI; DustIQ soiling ratio after calibration does not, see Fig. 2

Fig. 1: Measurement set-up at CIEMAT's Plataforma Solar de Almería.

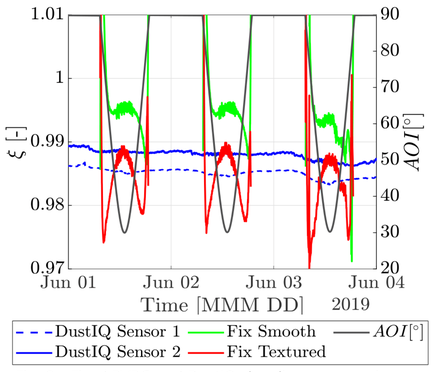


Fig. 2: Fixed PVRC and DustIQ cleanliness comparison after local dust calibration (three example days)

DEVELOPMENT OF ADAPTATION METHOD

1. Normalize soiling ratio ξ_{cell} with each day's average over reference AOI-interval, $\bar{\xi}_{\mathrm{cell},AOI_{\mathrm{ref}}}$ (Fig. 3)
2. AOI-effect only affects beam portion. Linke turbidity T_L is a measure for the attenuation of direct irradiance. Separate sunny from shady instants with Linke turbidity based cloud-filter algorithm[2]
3. Fit polynomials for different soiling ratio bins and sunny conditions to find $f(AOI)$. Cut at 70° AOI to avoid noisy data (Fig. 3).
   - AOI effect increases with increased soiling ratio (color bar Fig. 3)
4. Introduction of T_L-exponent to reproduce behavior at high T_L as shown in Fig. 4.

$$\xi_{\mathrm{DIQ,corr}} = \xi_{\mathrm{DIQ}} \cdot c_{\mathrm{calib,DIQ}} \cdot f(AOI)^{\frac{1}{T_L - T_{L,\mathrm{ref}} + 1}}$$

Raw DustIQ cleanliness — Local dust slope calibration constant — Sunny adaptation function from polynomial regression — exponent describes the effect of clouds masking the sun

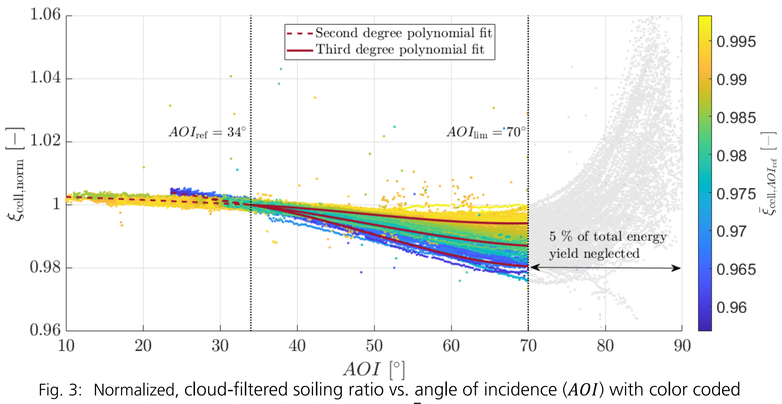


Fig. 3: Normalized, cloud-filtered soiling ratio vs. angle of incidence (AOI) with color coded daily mean soiling ratio. Exemplary fits through $\bar{\xi}_{\mathrm{cell},AOI_{\mathrm{ref}}}$ -bins are shown.

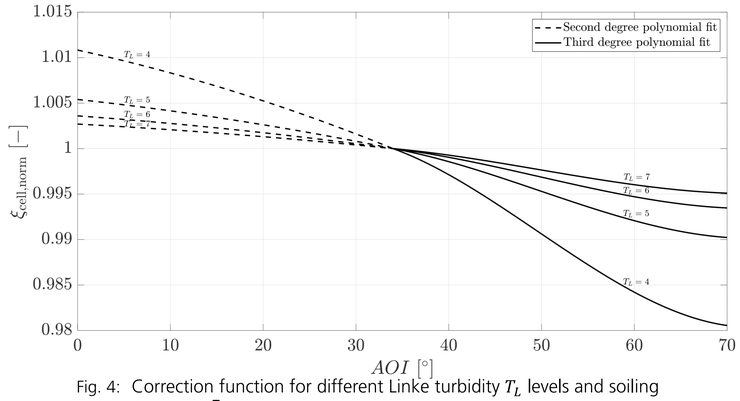


Fig. 4: Correction function for different Linke turbidity T_L levels and soiling ratios of $0.96 < \bar{\xi}_{\mathrm{cell},AOI_{\mathrm{ref}}} < 0.97$. AOI-dependence on low T_L and increased soiling levels is more expressed and approximates unity for large T_L.

VALIDATION

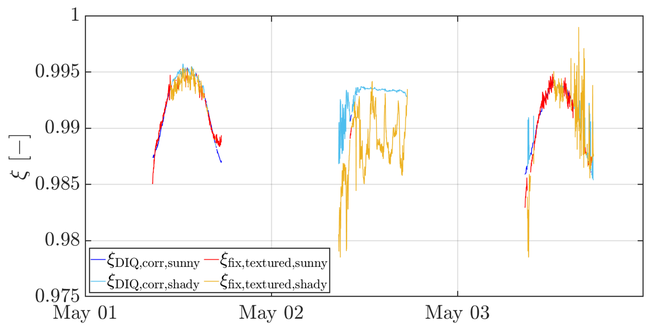
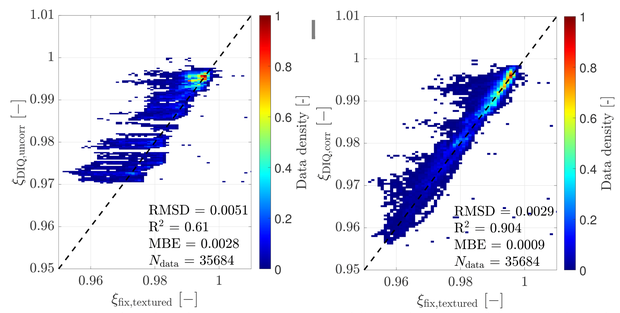


Fig. 5: Corrected DustIQ signal for sunny and shady conditions. PVRC reference soiling ratio shown in red and yellow.

- corrected DustIQ signal better reproduces PVRD daily AOI – characteristic for sunny conditions (dark blue line)
- Episodes of high T_L where correction function approximates unity (light blue) can deviate more from reference.



- Remaining deviation from bisector is due to uncertainties in cleanliness measurement and calibration. Partly cloudy sky conditions cause noise, see Fig. 6

Fig. 6: Density plots between uncorrected (l.) and corrected (r.) DustIQ and fix textured PVRC soiling ratio for three months (12.03.2019 - 12.06.2019).

CONCLUSION

- Presented AOI and diffuse irradiance adaptation method applicable for active soiling sensors, that do not include the AOI effect on the soiling losses in their output signal
- Widely applicable as correction depends only on AOI and the Linke Turbidity T_L that can be derived from irradiance measurements
- The method increases the accuracy of PV yield analysis that includes active soiling sensors

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References:

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2 Hanrieder, Natalie, et al. "Modeling beam attenuation in solar tower plants using common DNI measurements." *Solar Energy* 129 (2016): 244-255.