Low-Cost Multiparameter Sensor for Solar Resource Applications

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Abstract

- Low-cost, multiparameter sensing and measurement devices enable cost-effective solar resource applications for solar energy projects.
- The National Renewable Research Laboratory (NREL) Solar Radiation Research Laboratory (SRRL), in collaboration with Arable Labs, Inc., deployed Arable Lab's Mark multiparameter sensor system.
- The device measures the downwelling and upwelling shortwave solar resource and longwave radiation, humidity, air temperature, and ground temperature.
- The system is also equipped with six downward- and upward-facing narrowband spectrometer channels that measure spectral radiation and surface spectral reflectance.
- This study describes the shortwave calibration, characterization, and validation of measurement accuracy of this instrument by comparison with existing instruments that are part of the NREL SRRL Baseline Measurement System [1].

Method

Fig. 1. Arable's Mark low-cost multiparameter system at the NREL SRRL

- Calibration used the NREL SRRL outdoor calibration methodology [2] – [4].
- The calibration was carried out using the NREL SRRL reference direct normal irradiance and diffuse horizontal irradiance radiometers.
- Optimum calibration of the solar zenith angle of 37.5° was selected, and the calibration factor was derived using:

$$R = \frac{V}{GHI_{ref}}$$

where R is the instrument's responsivity, in μV/(W m^-2), and V is the instrument's sensor output voltage (μV).

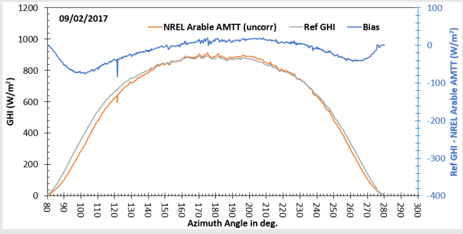

Fig. 2. Measured irradiance from the reference data set and the UUT as well as directional bias. The data from 09/02/2017 are used to calibrate the UUT using Eq. 1.

Some directional dependency of the shortwave sensor was noticed (Fig. 2). One of these directional dependencies is because of the azimuthal orientation of the detector with respect to the incoming solar radiation.

Results

A. Shortwave Data Analysis

To correct for directional dependency, a correction was applied as a function of solar azimuth (using the bias line in Fig. 2.), as follows:

$$E_{cor} = E_{raw} - \sum_0^6 a_i\, A^i$$

where E_{cor} is the corrected irradiance for the unit under test (UUT), E_{raw} is the uncorrected (raw) irradiance, A^i is the solar azimuth, and a_i are numerical coefficients obtained by least-squares fitting.

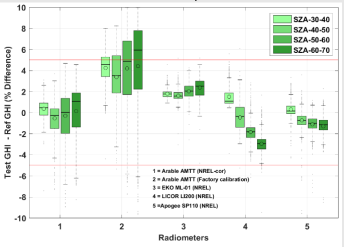

Fig. 3. Irradiance comparison of photodiode sensors relative to the reference data (1-min data set from 8/18/2017 to 11/28/2017)

The NREL correction method shows ±2% bias compared to 2%–8% when using only the factory methodology. Further, the NREL-corrected UUT shows a comparable or better result, with average bias of less than ±1% compared to the three conventional photodiode sensors.

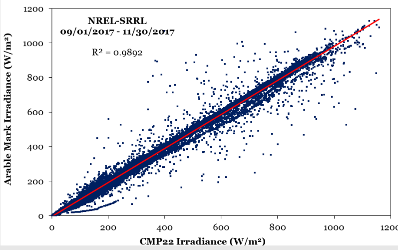

Fig. 4. One-minute GHI comparison between Arable Mark and a reference CMP22 thermopile pyranometer

A long-term analysis included an all-sky comparison at 1-minute temporal resolution during a 3-month period (8/18/2017 to 11/28/2017). The results show good agreement with an R-square value of ~0.99 compared with the reference CMP22 instrument.

B. Spectral Data Analysis

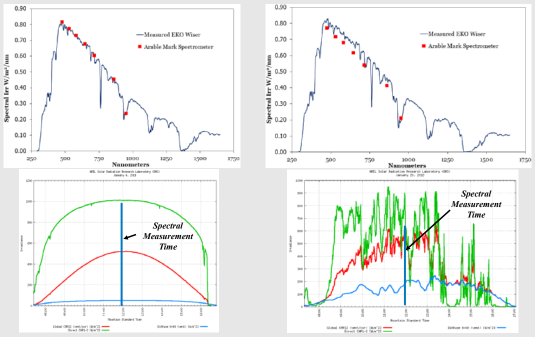

Fig 5. (Top) Spectral comparison between the WISER and Arable Mark for 01/04/2018 @ 12:00 LST; (bottom) broadband direct (green), global (red), and diffuse (blue) irradiance measured with thermopile radiometers for that clear day (left) and the same but for partly cloudy skies for 01/20/2018 @ 12:00 LST (right)

- A similar least-squares fitting function as the shortwave is used to correct the error. After correction, the Mark and WISER instruments show good agreement under clear-sky conditions (Fig. 5, left).
- Under partly cloudy skies, the difference is significant. This can be partly attributed to the difference in scan rate because the WISER scans every 5 minutes, whereas the spectrometer scans each minute. Sky conditions and atmospheric transmittance can change rapidly under cloudy situations, hence triggering rapid variations in the solar spectrum (Fig. 5, right).

Conclusions and Future Work

- The comparison of the Arable Mark device demonstrated good agreement with the existing photodiode pyranometers, such as the LI-200 sensor from LICOR (with an average bias of less than ±1%).
- The calibration and characterization methodologies employed by NREL result in ±2% bias compared to the reference global horizontal irradiance (GHI) data obtained with a thermopile pyranometer during a 3-month period.
- The spectral capabilities of the Mark instrument were found satisfying compared to a reference spectroradiometer, at least under clear-sky conditions.
- Future work will characterize shortwave and spectral data from the Mark device on fixed-tilt, one-axis, and dual-axis tracking.

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