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Intercomparison of Pyranometers for Distributed Measurement System

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Abstract

Irradiance is one of the most important parameter measured by PV monitoring systems. Its value is needed to estimate reference yield ($Y_R$) and after then performance ratio index (PR). Uncertainty convolved with irradiance measurements has a strong influence on final monitoring quality. This paper presents intercomparison test of ten CMP11 pyranometers which will then be used for the measurement of PV systems distributed across two continents and four countries. Measurements were taken under different installation conditions (horizontal, in-plane). Ten CV2 ventilation units were used as a part of system improvements. Finally pyranometers data were combined with EKO MS700 spectral measurements to evaluate spectral variations.

Introduction

Irradiance measurements are probably the most important and also the most complicated part of PV monitoring systems. Accurate irradiance measurements are needed to calculate sums of available energy and to ensure intercomparability of sites. They can also be used for automated control and fault detection. It is required to achieve high accuracy in the irradiance values based on instantaneous measurements. Appropriate irradiance measurements techniques are an important part of successful PV monitoring systems. Uncertainty of the irradiance measurements depend on the sensor and its:

- technology
- calibration
- offset
- response time

Beside sensor parameters also environmental condition can make a difference to the taken measurements [1]. This paper concentrates on pyranometers, as these are the most commonly used global irradiance sensors. Measurements are based on the heating of thermopiles covered with black absorber. Each pyranometers creates a voltage which then is scaled with the sensitivity coefficient specified in calibration certificate. Authors assumed that most probable (reference) value of irradiance is created as the mean from all of taken and scaled measurements. It would allow to figure out differences between reference and measured value and then to calculate corrected sensitivity coefficient. Heat-sensitive part of the sensor is protected against external world with a double dome. If the temperature difference between inner dome and temperature sensitive surface will occur, infrared radiative flow will take place. This is the so called thermal offset. Temperature difference between body and heated surface create a voltage which is almost proportional to that difference. It can have both positive and negative value. Thermal offset will be studied further in this paper. Pyranometers have almost the same sensitivity across the entire spectral range. As the PV modules sensitivity and quantum efficiency is wavelength dependent, thus that differences may be the source of the serious errors.

Experimental Setup

All the measurements were taken at Loughborough (52°46'N, 1°12W) between 22/10/2008 and 16/01/2009. Basic layout of the system configuration has been presented in figures Fig.1, Fig2 and Fig3.

![Fig.1 System setup](image-url)
Ten Kipp&Zonen CMP11 pyranometers were connected up to the Campbell Scientific AM16 multiplexer. Output from multiplexer was controlled to Campbell Scientific CR1000 datalogger. Signal selected by AM16 was measured with 50Hz filtering. Filtering was applied by 25ms integration time. To avoid zero offset error of the datalogger, measurements were taken in input-reverse mode. Sampling intervals were specified as one second. Measurements data were then stored in the CR1000 internal memory and successively downloaded into the database structure. Initially, the pyranometers were mounted in-plane of the PV measurement system (i.e. 45 degree inclination). At the same time seven horizontally mounted EKO MS-700 spectroradiometers were collecting spectral data. After two weeks of measurements configuration of the pyranometers were changed to the horizontal mounting. Pyranometers were installed inside CV2 ventilation units. The next week’s measurements were taken with CV2 completely disconnected. After that five CV2 were powered in regime: fan+ 5W heating. Then CV2 powering configuration was swapped and another week of the measurement was taken. Finally five of CV2 were powered with 10W heating and fan.

### Analysis

At the very first data filtering procedure was applied. For daytime analysis only data with values greater than 10W/m² were taken. For the offset analysis only data below 0W/m² were taken.

Calibration coefficients

To check how the calibration coefficients affect accuracy of irradiance measurements, all of the measurements taken during non-cloudiness days with irradiance over 700W/m² were used. Then the mean value was calculated from all of ten pyranometers. The mean value was assumed to be the most probable, and was used as reference. The dependence between the mean value and each single measurement for specified pyranometers are presented in figure Fig.4. Basing on irradiance measurements taken under standard conditions (>800W; AM=1,5) corrected value of sensitivity coefficients were calculated. Equation which was used to calculate new coefficient was shown in formula1.

(1)  \[ \text{Corrected coef} = \frac{\sum_t V_{\text{CMP}11} - x}{\sum_t G_{\text{mean}}} \]

![Figure 4: Measured irradiance as a function of reference irradiance](image)

To check how the calibration coefficients affect accuracy of irradiation measurements, all measurements with value greater than 10W were taken under consideration. Energy sums differences from mean, integrated during measurement campaign, were presented in figure Fig.5.

<table>
<thead>
<tr>
<th>CMP11 no</th>
<th>Initial coefficient</th>
<th>Corrected coefficient</th>
<th>correction %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.900</td>
<td>8.857</td>
<td>-0.48</td>
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<tr>
<td>2</td>
<td>8.730</td>
<td>8.741</td>
<td>0.13</td>
</tr>
<tr>
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<tr>
<td>4</td>
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<tr>
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<td>9</td>
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<tr>
<td>10</td>
<td>9.100</td>
<td>9.041</td>
<td>-0.65</td>
</tr>
</tbody>
</table>

**Table1: Sensitivity coefficients**
Standard deviation of energy sums for all of the pyranometers before recalibration was equal to 0.48%. Standard deviation of energy sums for all of the pyranometers with corrected coefficient was equal to 0.16%.

Thermal offset

During measurements campaign wide range of the weather condition occurred. Clear and cold nights were observed. Under that specific conditions thermal offset occurred. Figure 6 present value of the offset during the early morning for horizontally installed sensors with and without CV2 ventilation units.

Dynamic response

Pyranometers have relatively large time constant. Typical value is equal to 5s [4] to get a 95% response. Irradiance can change in seconds by hundreds of W/m². To estimate the order of magnitude of changes that can be measured by CMP11 pyranometers, the values of differences of the irradiance in one second intervals were evaluated. Calculations follow the formula (2) and (3).

\[ (2) \Delta_{\text{max}} = \max \left( G(t_i) - G(t_{i+1}) \right) [W/m^2/s] \]
\[ (3) \Delta_{\text{min}} = \min \left( G(t_i) - G(t_{i+1}) \right) [W/m^2/s] \]

Value of \( \Delta \) can be treated as the estimator of dynamic properties of the sensor. Figure 8 present \( \Delta \) calculated for all ten pyranometers.

Mean values for maximal positive changes of irradiance was equal to 201.9 [W/m²/s] with SD=7.84 [W/m²/s]. Mean values for maximal negative changes of irradiance was equal to 193.6 [W/m²/s] with SD=6.66 [W/m²/s].
Spectral response

Spectrum of the sunlight may be changed by the aerosol pollution, clouds diffusion, and air mass factor. Measurements taken with pyranometers estimate values of the irradiance through wide bandwidth (310-2800 [nm]). Spectral sensitivity and quantum efficiency of the photovoltaic modules is changing strongly with wavelength. Seven MS-700 were used to estimate sunlight spectral irradiance. Basing on all the measurements mean value of was calculated. Figure 9 shows evolution of the spectrum through the daytime.

Measurements taken by the spectroradiometers were compared with standard AM 1.5 sunlight spectrum.

Conclusion

Intercomparison of the sensors has shown that standard deviation of the irradiation measured by non calibrated sensors was equal 0.48% for the intercomparison period. Basing on measurements taken under STC new coefficients were calculated for each of the pyranometers. After recalibration, new coefficients were tested with different set of data. The value of standard deviation was decreased to 0.16%, which is one third of the initial value. Pyranometers taken during the measuring campaign were new, recently calibrated and from the same manufacturers’ series. It allows explaining low value of the initial irradiation deviation. Comparing to the 4.5% deviation stated in [1] measured 0.48% seems to be negligible. It is highly probable that this value will change with a time. However for accurate measurements it is better to take similar sensors. During the measurement campaign thermal offset occurred. As it was shown in Fig.6 significant influence of the ventilation unit was observed. Heating ventilation unit with 5W has reduced thermal offset, but did not completely eliminate it. Dynamic properties of the sensors were inspected by investigating the highest changes of the irradiance through 1 second interval. Both positive and negative changes of the irradiance have around 200 [W/m²]. Finally spectral measurements taken during campaign were presented. Fig.9 show differences between standard AM 1.5 spectrum and measured spectrum. Knowing the exact sunlight spectral distribution allow to predict available energy for different modules technology with higher accuracy. Further investigation of the usage of spectral measurements is carried by the authors and will be published soon.

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References