EVALUATION OF LONG TERM PERFORMANCE MEASUREMENTS OF PV MODULES WITH DIFFERENT TECHNOLOGIES

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ABSTRACT: PV modules of six different technologies (m-Si, mc-Si, EFG, CIS, CdTe, a-Si) have been monitored concerning the performance under external conditions for a period of more than 2 years. In addition to the standard solar radiation measurements with pyranometer solar sensors with corresponding cell technology have been used to supplement the measurements. This allows in principle to consider spectral effects. The solar radiation measured with the sensor and the pyranometer is analysed on monthly basis. The effect of using spectrally weighted solar radiation data on the performance ratio of PV modules is shown.
Keywords: Qualification and Testing, PV Module, Monitoring, Performance

1 INTRODUCTION

More than the name plate rating it is the energy production of PV modules under external conditions which is an indicator for the performance of a PV module. The draft IEC 82/254/NP "Performance testing and energy rating of terrestrial photovoltaic (PV) modules" provides a guideline to assess the energy production under standardised conditions. Regarding the prediction of the energy yield at a particular site suited meteorological data must be available. Especially amorphous material shows a strong dependence on the spectral distribution of the solar irradiance. Field tests may supplement laboratory investigations of e.g. spectral and temperature dependency of solar cell material. Field tests of PV modules performed at ISET aim at the investigation and verification of various factors influencing the performance of PV-modules. Also seasonal and long term performance as well as reliability can be analysed.

In this study we consider modules with 6 different technologies (m-Si, mc-Si, EFG, CIS, CdTe, a-Si). For each technology a solar sensor Sensol® with a cell of corresponding technology is used to record the solar irradiance. By using solar sensors which are spectrally matched to the solar modules the fraction of solar irradiance useful for the module can be measured directly. The measurements are completed with standard meteorological measurements of global irradiance, ambient temperature and wind speed.

In this work we take data from two consecutive years (2002 and 2003). First radiation data measured with the Sensol®'s are analysed. Afterwards the monthly performance ratio for the PV modules is determined by using pyranometer or alternatively Sensolâ measurements. The analysis shown here continues the work first presented in [1] on a larger data basis.

2 MONITORING DETAILS

2.1 PV Modules

ISET's test site is located in the town of Kassel, Germany at Latitude 5° North and Longitude 9° East. PV modules from different manufacturers and with different technologies are continuously monitored under external operating conditions. For this study we consider modules with the following cell technologies:

- crystalline Si technologies: c-Si, c-Si (EFG type), mc-Si
- thin film technologies: a-Si, CIS, CdTe

The modules are mounted on a fixed rack, facing South at a tilt angle of 30°. A custom electronic load is used to operate the modules continuously under MPP conditions. Voltage and current are measured at the DC side of the module, module temperature is measured at the backside of each module with a standard PT100 sensor. Fig. 1 gives an impression of the setup.

Figure 1: Setup for the long term monitoring of PV modules on a rack with fixed position. Solar radiation is measured with pyranometers and with Sensol®. For each module technology a Sensol® with corresponding cell technology is available (see detail).

2.2 Supplementary Measurements

The measurements are complemented by standard meteorological measurements of global irradiance (horizontal and in-plane of the modules), ambient temperature and wind speed. Further measurements of global irradiance in the UV-A channel (310 - 400 nm) and measurements of global radiation by pyranometers equipped with coloured glass domes are performed. There are three coloured pyranometers which measure in the wavelength range up to 3000nm starting at 530nm, 630nm and 695 nm.

2.3 Sensol®

Sensol® is a sensor for solar radiation measurements which is available with solar cells of different material [2]. The short circuit current of the sensing cell is measured via a shunt resistor, a temperature signal from a PT 1000 sensor is available for compensation purpose. For the measurements a total of 12 Sensol®'s has been used equipped with the 6 cell technologies mentioned above. The spectral sensitivity curves of the sensors are depicted in Fig. 2 .

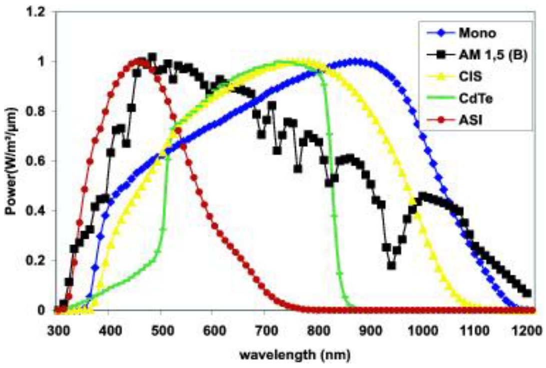

Figure 2: Spectral sensitivity curves of solar sensors Sensol®.

An example of the different spectral sensitivity of the used sensors is shown in Fig. 3. It shows the variation of the Sensol® signal as a function of the airmass (AM) for clear sky (clearness index k_t^*> 0.8) and for overcast conditions (clearness index k_t^*< 0.4). Shown are curves fitted to one minute average values for a period of one year (2003). Only values with incidence angle < 60° have been considered to avoid angle of incidence effects. The a-Si Sensol® shows a strong variation with respect to air mass and clear sky index. In contrast the c-Si Sensol® shows only small sensitivity against variation of clear sky index and air mass.

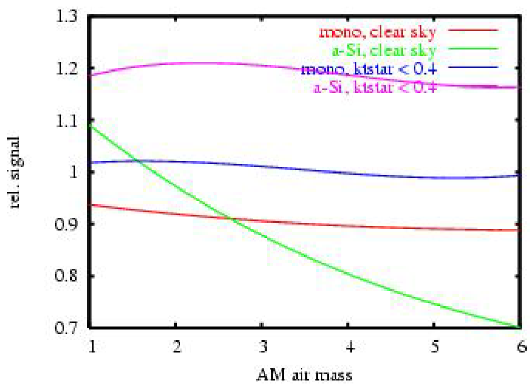

Figure 3: Variation of Sensol® signal relative to pyranometer as function of air mass AM for clear sky conditions (k_t^*> 0.8) and overcast conditions (k_t^*< 0.4)

3 SOLAR RADIATION DATA

As previously mentioned data from the years 2002 and 2003 have been taken for this evaluation. Fig. 4 shows the monthly solar energy (wh/m^2) for the two years measured with a pyranometer and with Sensol®. The second year (2003) has significantly more solar energy compared to the previous year. Also the ambient temperature is higher on average (see Fig. 9).

The relative deviation of the Sensol® signals compared to the pyranometer signal is shown in Fig. 5.

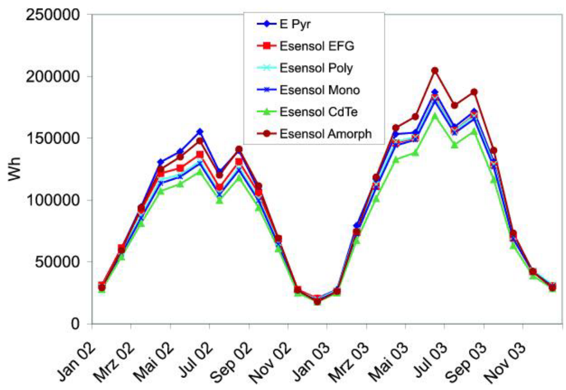

Figure 4: Monthly solar energy measured in-plane of the solar modules for the years 2002 and 2003. The solar irradiance was measured with a standard pyranometer and with Sensol® with different cell technologies.

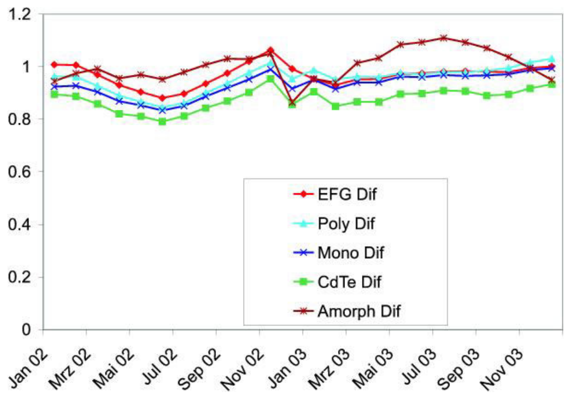

Figure 5: Signal of Sensol® relative to Pyranometer.

3.1 Crystalline sensors

The Sensol® equipped with crystalline sensors (EFG, mc-Si, c-Si) measures less radiation compared to the pyranometer signal during summer 2002. Further differences in 2002 between the crystalline sensors can be observed. In 2003 these differences disappear. Further in 2003 the Sensol® signal is close to the pyranometer even during summer.

3.2 Thin film sensors

The CdTe-Sensol® behaves similar like the crystalline sensors: It is low during summer 2002, which can not be observed during 2003. It is the CdTe- Sensol® which shows the lowest signal of all Sensol®. In contrast the a-Si-Sensol® shows the highest signal. In 2002 it is close to the pyranometer while in 2003 it significantly exceeds the pyranometer. Due to the unstable nature of the a-Si cell material this Sensol® type may not be suited as a measuring sensor.

3.3 Spectral band measurements with Pyranometers

Fig. 6 shows the contribution of selected spectral bands to the global signal. These data are from a pyranometer for the UV-A channel and pyranometer equipped with filters. A increase of the UV-range (300-410nm) during the summer month can be observed. The variation of the other channels does not follow a simple pattern and provides no easy explanation for the variation of the Sensol® signals.

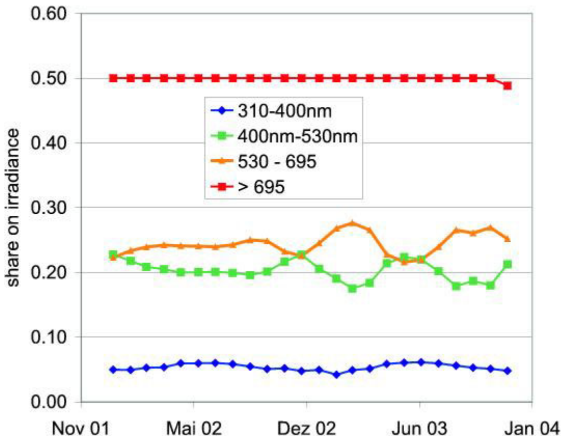

Figure 6: Share of selected spectral bands to the monthly solar radiation. Data are measured with pyranometer equipped with filter and a UV-A pyranometer.

4 MODULE PERFORMANCE

The module performance for the two considered years was evaluated. Fig. 7 and 8 show the monthly performance ratio for PV modules with crystalline and thin film technologies. For each module the performance ratio was calculated on two ways: First based on irradiance data measured with pyranometer, secondly with irradiance data measured with Sensol®.

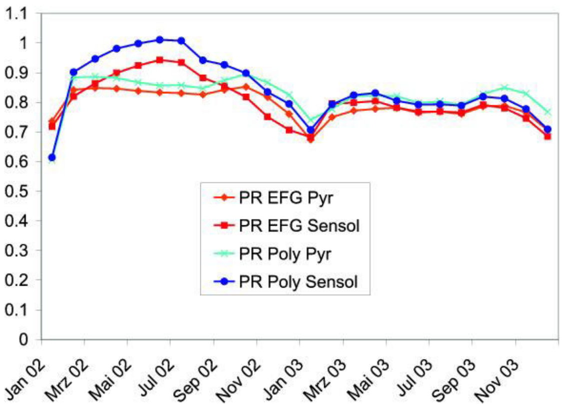

Figure 7: Monthly performance ratio PR for PV modules with crystalline cells. The performance ratio was evaluated withradiation data measured with either pyranometer or with Sensol® with corresponding cell technology.

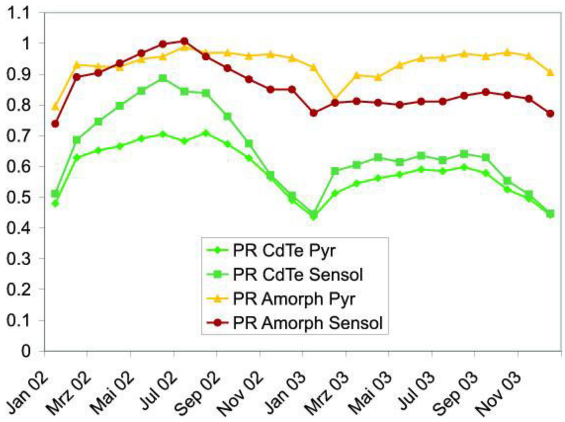

Figure 8: Monthly performance ratio PR for PV modules with thin film technology. The performance ratio was evaluated with radiation data measured with either pyranometer or with Sensol® with corresponding cell technology.

4.1 PV modules with crystalline technology

In 2002 the performance ratio evaluated with pyranometer is below the values derived with Sensol® data. This difference is most significant during summer. However in 2003 these differences disappear and no significant difference can be observed. This is in agreement with Fig. 5 which shows that the difference between crystalline Sensol® and pyranometer decreases significantly in 2003. The generally lower performance ratio in 2003 may be explained by the higher average ambient temperature in 2003 (see Fig. 9).

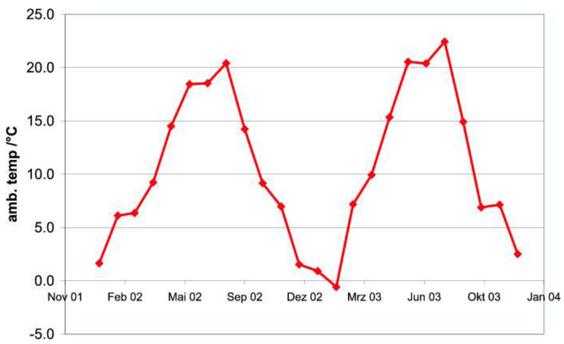

Figure 9: Monthly average ambient temperature.

4.2 PV modules with thin film technology

For the a-Si module a determination of the performance ratio with the a-Si Sensol® leads to a decrease of the performance ratio in 2003 due to the increased Sensol® signal.

The CdTe behaves like the crystalline modules: The difference in performance ratio calculated either with pyranometer or with Sensol® which is observed in 2002 decreases significantly in 2003. Further the CdTe module shows like the crystalline modules a decrease in performance ratio in 2003. This is not the case for the a-Si module if rated with the pyranometers

5 CONCLUSIONS

In our work we have shown the difference of the performance ratio if calculated with pyranometer measured solar radiation or with solar radiation measured with solar cells. The evaluation of the results must also consider the accuracy of the solar radiation measurement. For the measurements with the Sensol® a measurement accuracy of 4 - 5 % can be assumed.

During the summer month of the first year significant differences in the calculated monthly performance ratio have been found. However this trend does not continue in the second year. It should be mentioned that 2003 was a year with favourable solar conditions in Germany. The measurements are being continued in order to increase the available data basis. The data for 2004 will show whether the trend of the year 2003 continues or not.

The approach to measure the solar radiation with a device matched to the module material offers the principle advantage to differ between spectral and temperature effects on module performance. This is a problem reported e.g. by Ransome et.al.[3][4].

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