INTELLIGENT PERFORMANCE CHECK OF PV SYSTEM OPERATION BASED ON SATELLITE DATA

A. Drews[*], J. Betcke, E. Lorenz, D. Heinemann; Energy and Semiconductor Research Laboratory, Carl von Ossietzky University, Oldenburg, Germany
P. Toggweiler, S. Stettler, J. Rasmussen; Enecolo AG, Moenchaltdorf, Switzerland
W. van Sark; Dept. of Science, Technology, and Society, Utrecht University; Netherlands
G. Heilscher, M. Schneider; Meteocontrol GmbH, Augsburg, Germany
E. Wiemken, W. Heydenreich; Fraunhofer Institute for Solar Energy Systems, Freiburg, Germany
H.G. Beyer; Dept. of Electrical Engineering, FH Magdeburg-Stendal, Magdeburg, Germany

The PVSAT-2 project, supported by the European Union (EU), aims at the assembling of a fully automated service for performance check and error detection for photovoltaic (PV) systems.
This procedure will reduce the operators running costs by helping optimizing energy yields and system maintenance by daily surveillance.
Malfunctions of a grid-connected PV system, e.g. drop out of single module strings, shading by surrounding objects, or inverter errors lead to energy losses that can be high and costly if they remain undetected for a longer period of time.
PVSAT-2 provides a user-friendly, accurate, and reliable method to avoid unnecessary energy losses and therefore prevents operators from decisive financial losses.
PVSAT-2 is the successor of the EU project PVSAT that already helps PV system operators to detect system faults by providing monthly a system specific reference yield calculated from satellite measured irradiance data and a PV system simulation. PVSAT-2 takes up here with newly added components like error detection, further improvement of the irradiance calculation and PV simulation, and the fully automation of the whole procedure:

- A local hardware device will automate yield measurements and will communicate daily with a central server.
- Software on this server will analyse the performance of the PV system on a daily basis and automatically detect system failures and their causes.
- Combining satellite data with ground data of irradiance will improve the accuracy of the horizontal global irradiance.
- An enhanced model for diffuse radiation will improve the accuracy of the array plane irradiance.
- The PV system model that carries out the PV simulation will be improved to allow the simulation of non c-Si modules.

This paper will present the overall structure of the PVSAT-2 performance check and and some first results. The main focus will be on the error detection routine and its central footprint algorithm. The improvements made at the irradiance calculation scheme and its relevance for the error detection will be touched. Further details on the irradiance calculation will be presented in detail in a separate paper as well as the enhanced PV system model.

[*] corresponding author: anja.drews@uni-oldenburg.de

Overview of the future PVSAT-2 service

Figure 1 shows the structure of the strived PVSAT-2 service with its main components. The operator of the PV system supplies a technical description of the PV system once to the PVSAT-2 service. This description contains the major information on orientation, inclination and configuration of the modules, type of inverter used, and a horizon line needed for the PV simulation. Furthermore, a so called weblog, a local hardware device, which records hourly the energy yield of the PV system has to be installed. This local hardware device sends via Internet automatically every day its record to a central decision support system (to be explained later in this text) hosted by a central server.
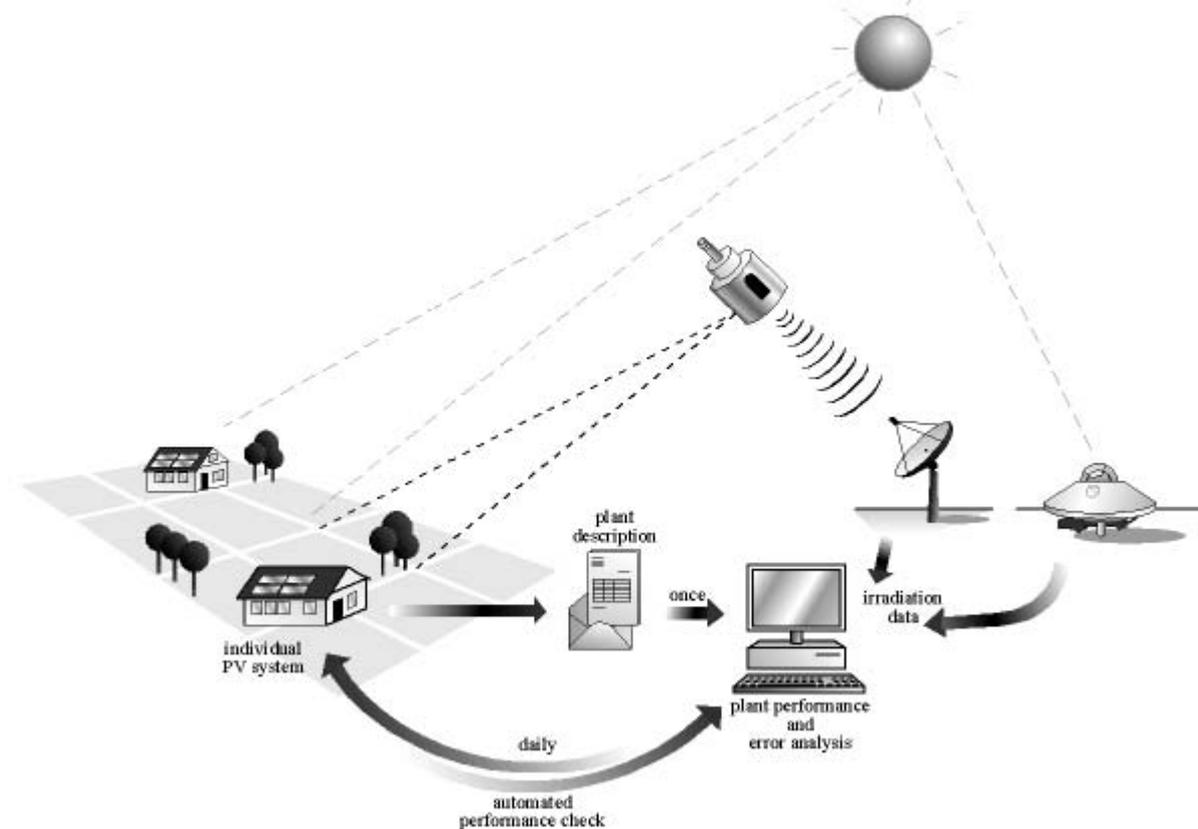

Figure 1: Schematic overview of the elements of the PVSAT-2 procedure.

To determine the expected energy yield of a PV system, satellite data and ground based irradiance measurements give information about the solar resource at the site of the PV system. These data are used because local measurements by pyranometers are costly for operators and need periodic maintenance.

First, surface irradiance is derived from METEOSAT-7 images (later METEOSAT-8) with the Heliosat method (Hammer, 1999). Satellite images have a very good spatial and temporal resolution what makes them very suitable for PV applications. To achieve a higher accuracy the satellite measurements are combined with ground measurements by the geostatistical method kriging-of-the-differences (Betcke and Beyer, 2004). These irradiance values are input for a PV simulation (Beyer et al, 2004). According to the submitted plant description, in the second step a PV simulation will determine the expected energy yield of the day.

Here, the central decision support tool carries out the daily performance check. It compares the expected and recorded energy yields on the daily and hourly basis individually for each PV system. It decides on the occurrence of a failure. The detectability of a malfunction depends on the analysis of hourly values (e.g. shading) or is detectable by evaluation of daily values over a longer period of time. In case an error occurred, the

footprint algorithm, part of the error detection routine, determines its cause. This whole procedure of error detection is hardly influenced by the accuracy of the input data.

If the malfunction is found, the operator of the PV system will be informed automatically as part of the automated procedure.

Improved irradiance calculation

The incoming radiation at the site of the PV system has to be known to simulate the expected energy yield. This information is derived currently by measurements of the geostationary weather satellite Meteosat-7 (It will be changed to Meteosat-8 in the future.). These data have a high temporal resolution and a better spatial coverage than meteorological ground stations. The Meteosat images are received half-hourly operational at the University of Oldenburg. The Heliosat method (Hammer, 1999) is used to determine ground irradiance for a pixel with a resolution of 3 km x 5 km above the site of a PV system. Validations with ground stations showed that the error of this method can reach up to 30% for hourly values and lies between 5 and 10 % for monthly irradiance values (Hammer, 1999). These errors are strongly dependent on the weather situation (i.e. variability) and on the sun elevation angle. Under cloudy sky conditions the error increases while only small errors occur on days with clear skies. Larger errors also occur for low solar elevation angles and result in more deviations during wintertime. The quality assessment on these derived irradiance data and its dependencies is rather complex. Further details and explanations on the quality assessment will be published soon.

One further development to improve the irradiance calculation and to reduce the error is the introduction of a new model to calculate diffuse irradiance (Mueller et al, 2004). Another way for improving the accuracy is the combination of the satellite data with ground measurements of irradiance with the geostatistical method kriging-of-the-differences. The error can be reduced this way to 3-4% for monthly values and also for hourly data (Betcke and Beyer, 2004).

These errors within the derived irradiance data have to be considered in the error detection routine. The exact knowledge of these errors and its dependencies is an absolutely necessary prerequisite for a variable definition of allowed differences between the expected and the real energy yield and therefore, for the exact determination of the occured malfunction.

Decision Support System

The so called decision support system unites the error detection routine that decides about the occurrence of a malfunction in a PV system, the footprint algorithm that detects causes for a system failure, data bases that store long-term surveillance data of a PV system, and the notification system that informs the operator. It is the central system that manages all information. Its central element is the footprint algorithm developed at the Fraunhofer Institute of Solar Energy Systems that will be described here in more detail.

Development of the footprint algorithm

For the development of the footprint algorithm monitored data of several PV systems have been analysed for the occurrence of system malfunction periods. The aim of this analysis is to identify typical error patterns.

From the database of the German 1000-roofs programme hourly mean values have been extracted. The analysis concentrated on two monitored signals, the irradiance and the produced AC power.

Displaying scatter diagrams (Figure 2) and using a normalised presentation of the produced AC power allowed in a first try the detection of the following errors:

- String error (four of the eight strings of the PV system were disconnected for a few days). The number of strings disconnected could be derived successfully.
- MPP tracking error. Within a three-days period, an excursion of the MPP-tracking system of the inverter could be detected in one of the days. The analysis of the power production pattern on hourly base is a pre-condition for detecting this error source.
- Snow coverage. Difficult to detect within one day. A snow cover may disappear within days, causing the AC power production continuously approaching from nearly zero to the expected values over days.
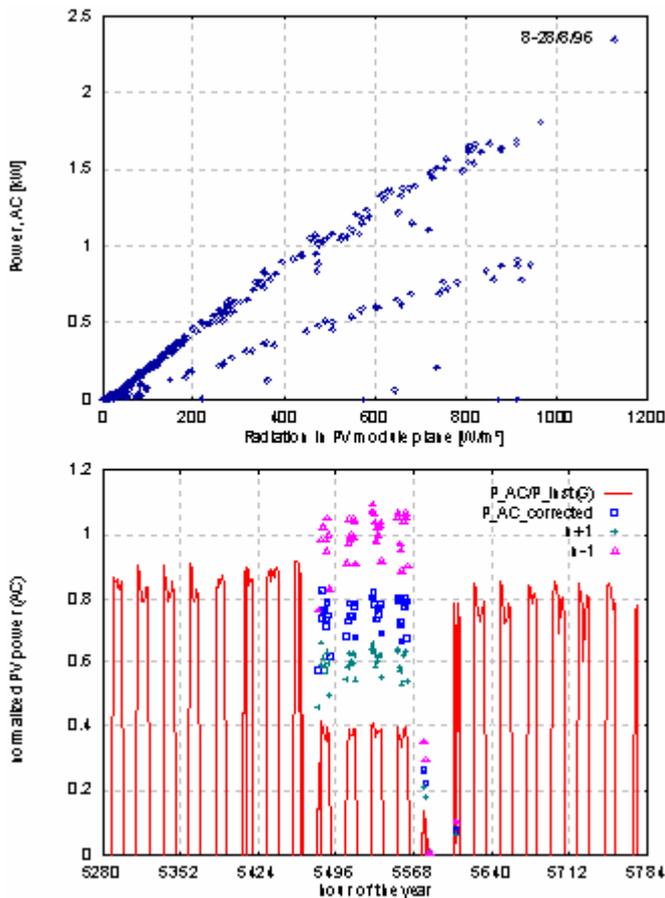

Figure 2: Example: String error in a system from the D-1000 data base. The scatter diagram above indicates the occurrence of the failure; the figure below shows the decrease in power production (normalised) on the time axis. With the correct assumption of 50% of disconnected strings, the 'virtual' correction of the data (blue boxes) is more close to the average production profile than with the assumption of one string more or less disconnected (n+1, n-1).

This analysis has shown so far that for the allocation of different error sources hourly values of irradiation and AC power are necessary. Daily mean values are not sufficient. Furthermore, the uncertainties of satellite-derived irradiance values demand more effort in averaging processes in the footprint method to reduce the expected errors.

The footprint algorithm

The footprint method is divided into two steps. The first step contains a pre-sorting algorithm that prepares the calculated and the monitored yields to take the errors from the satellite data into account. The second step is the identification of the error source.

In general, normalised signals will be considered: P_sim / P_mon = simulated power / monitored power; P_mon / P_inst = monitored power / installed power.

Since the individual calculated yield values with hourly time resolution are expected to be provided with large errors, the approach in the pre-sorting of data is as follows:

The signals P_sim / P_mon will be sorted in intervals with an interval average value P*. The interval average P* shows in general a smaller variance than the variances of the individual signals. Thus, P* exhibits more stability and allows an improved detection of errors.

The intervals are defined in two nearly independent domains: The signals are sorted into a capacity domain and into a time domain. In the capacity domain, the intervals are fractions of P_mon / P_inst, and the time domain consists of hourly intervals. For both domains, the interval averages are determined. The different spatial distribution of the interval averages in both domains is a pre-condition to detect the error source in the subsequent footprint algorithm. Figure 3 illustrates the sorting into intervals in the capacity domain.

Three averaging periods are considered: One day (the past day), the last seven days and the last 30 days. Thus, for each interval in both domains, there will be three interval averages calculated according to the considered periods. An increase in accuracy of the signal pattern is expected with this approach.
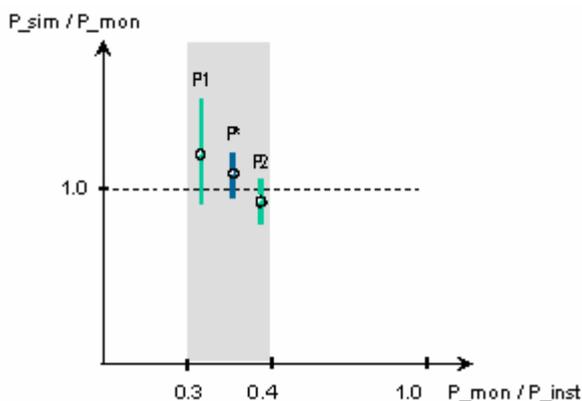

Figure 3: Signal sorting in the capacity domain.

First tests of this approach were made using monitored data from:
a) A grid-connected PV system installed at Oldenburg University. For this system, monitored and simulated yield values including the standard deviations due to the irradiation uncertainties have been submitted.
b) A grid-connected PV system installed at a secondary school building in Freiburg. For this system, the simulated yields were determined with a simple model and standard deviations of the signals were estimated.

For both systems, trouble-free operation periods were used for the first test of the approach. Figure 4 shows the interval averages in both domains for the 30 days period from data of the system at Oldenburg University.
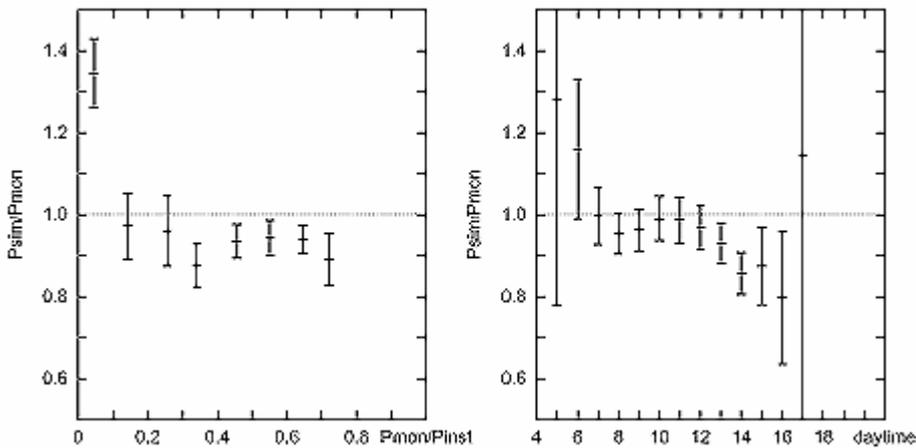
Figure 4: Interval averages from the 30-days period of the test system at Oldenburg University. For this period, a slight systematic lower production than expected in the upper power range, mainly in the afternoon hours, can be detected.

With the described preparation of the signals it is possible to reduce the system behaviour to more simple error pattern, as shown in Figure 5. These error pattern may then be compared with pre-defined error pattern for specific system malfunctions.
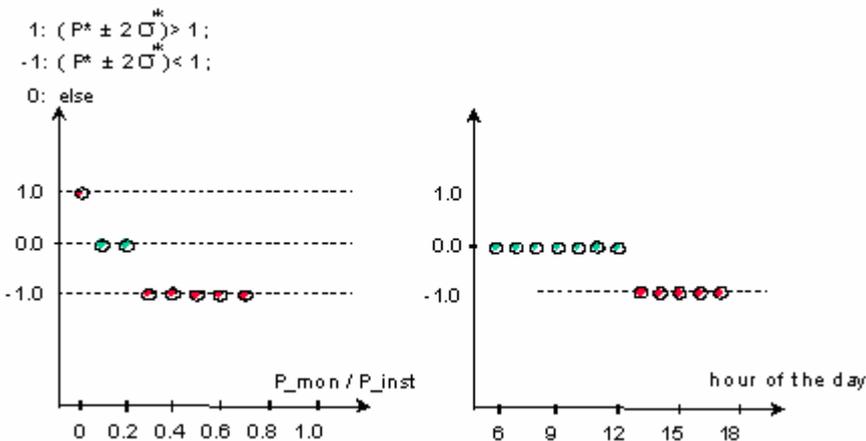

Figure 5: Error pattern for the 30-days test period of the Oldenburg University PV system (extracted from interval averages as shown in figure 3).

An example for a pre-defined error pattern for shading is given in Figure 6. Probability weights are distributed according to the expected appearance of the error. The probability for this error increases as the real system behaviour follows this specific error pattern.. The method may use additional input values (e.g. clear sky index, sun position).

A promising approach was developed to detect system errors on the one hand and to distinguish between system errors on base of pre-defined footprint tables on the other hand. An advantage of the method is that decisions will be made preferably on base of interval averages instead of unstable individual signals. In addition, a lack of individual signals for short periods due to server, network or other problems will not affect the procedure seriously (Wiemken and Heydenreich, 2004).
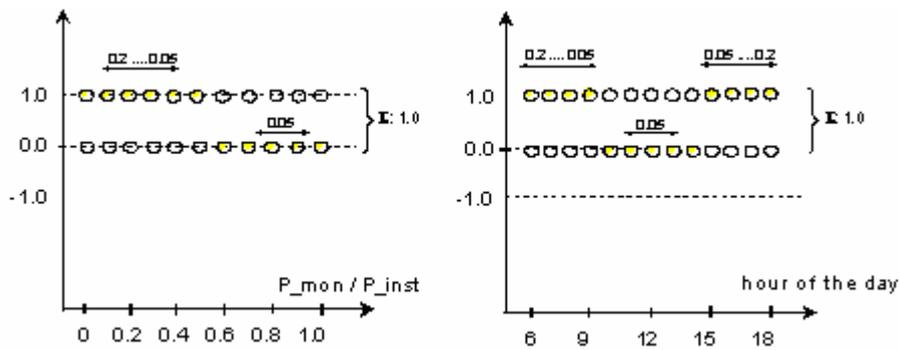
Figure 6: Example: Pre-defined error profile (footprint-table) for shading. Probabilities are distributed to the yellow marked circles; the blank circles contain probabilities of zero.

Summary

In the different parts of the PVSAT-2 project good progress has been made in developing a comfortable PV system surveillance.

The development of the footprint method so far has been a successful effort in error detection. The part of the method described in this paper gives a first view on the functionality. The entire error detection routine and also the footprint algorithm will be able to consider more errors than described here.

The PVSAT-2 procedure will be validated in a one year field test in Germany, the Netherlands, and Switzerland.

Acknowledgements

References

Betcke, J. and Beyer, H.G. (2004): Accuracy improvement by combining ground and satellite measurements. Elsewhere in these proceedings.

Beyer, H.G., Heilscher and G., Bofinger, S. (2004): A robust model fort he MPP performance of different types of PV modules applied for the performance check of grid-connected systems. Elsewhere in these proceedings.

Hammer, A. (1999): Anwendungsspezifische Solarstrahlungsdaten aus Meteosat-Daten, Ph.D. Thesis, Carl von Ossietzky University Oldenburg, Institute of Physics.

Mueller, R.W., Dagestad, K.F., Ineichen, P., Schroedter-Homscheidt, M., Cros, S., Dumortier, D., Kuhlemann, R., Olseth, J.A., Piernavieja, G., Reise, C., Wald, L. and Heinemann, D. (2004): Rethinking satellite based irradiance modelling – The SOLIS clear-sky module, accepted for publication by Remote *Sensing of the Environment.*

Wiemken, E. and Heydenreich, W. (2004): Development of a Footprint Method for Automated Error Detection, In: PVSAT-2 Internal Annual Progress Report for the EU.