

# SURVEILLANCE OF PHOTOVOLTAIC SOLAR ENERGY SYSTEMS USING METEOSAT DERIVED IRRADIANCES

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## ABSTRACT

In this paper, we describe a surveillance procedure for grid connected photovoltaic (PV) systems. The site specific solar irradiation data will be derived from satellite images rather than from ground based measurements. No additional hardware installation will be necessary on site. On the basis of hourly irradiance time series, monthly values of PV system yield will be calculated and distributed automatically towards the system operators. He or she may then compare the estimated power production to the real production meter reading. First tests reveal an overall accuracy of about 10 % for that period of a year offering 90 % of the annual solar irradiation.

## 1 INTRODUCTION

Photovoltaic (PV) Systems generate electricity from sunlight. In grid- connected systems, a fraction (or all) of the generated power is fed to the local utility network. A large number these systems is in operation in Europe today, and a strong increase is expected for the near future. Today, the installed PV power of small systems increases with remarkable rates in some countries, e. g. with some 10 MW<sub>p</sub> per year in Germany. Generally, these PV systems in a power range from 1 to some 10 kW<sub>p</sub> do not include any long term surveillance mechanism. As most system operators are no PV specialists, system faults (component failures) or decreasing performance (e. g. due to increasing shading by growing vegetation) will not be recognized. At least two negative effects would be related to a bad performance of numerous PV systems: the overall energy production

(and thus the saving of CO<sub>2</sub> emissions) would be reduced, and the individual plant operator will see financial losses. Regarding the increasing pay-back rates for PV energy (0.99 DM/kWh in Germany from spring 2000 onwards, similar initiatives are foreseen in other European countries), the last point becomes more and more important both for the plant operator as well as for the PV industry.

Therefore, there is a need for methods which allow for a cheap and reliable check of the power production of grid connected PV systems. These checks are done by calculating the estimated output of the PV system with a simulation-model. The model needs information about the installed components and a site specific irradiation time series as model input. While suitable simulation tools are available, the generation of site specific irradiance time series is crucial, especially as this is the most important factor determining the accuracy of a yield check. Hardware solutions (small irradiance sensors, intelligent monitoring devices) are available, nevertheless, extra devices will cause extra costs and require additional maintenance effort.

The EU JOULE III project PVSAT will set up a remote performance check for grid connected PV systems. No additional hardware installation will be necessary on site. The site specific solar irradiation data will be derived from satellite images rather than from ground based measurements. A target yield will be estimated for each individual PV system on a monthly basis. It will be reported to the system operators to allow for a comparison of targeted and real yield values.

## 2 HOW DOES PVSAT WORK?

The PVSAT procedure is based on three main components:

- A data base of PV system configuration data
- A satellite image processor
- A generic PV system model

The interaction between these components is depicted in figure 1 and will be explained in the following.

A PC data base contains geographical, component and operator related data for each individual system.

The entries in the data base cover the following details:

- Addresses of PV system site and of operator
- Geographic coordinates of the site
- Orientation and tilt angle of PV system
- Horizon obstruction at the site
- Manufacturer and type of PV modules
- Size and wiring scheme of PV generator
- Mounting technique of PV generator
- Manufacturer and type of inverter

These data are to be collected once for each participating system. For new systems, the system supplier might aid the data acquisition process, as he will be acquainted with all technical details of the system at the moment of its installation. Nevertheless, also systems already running for a long time may participate in PVSAT.

The continuous reception and processing of METEOSAT images (done at Oldenburg University) allows for the production of site specific time series of solar irradiance data for each of the locations. Global horizontal irradiance is estimated from the visible channel data using the concept of the HELIOSAT method [1]. The HELIOSAT-method is a semi-empirical method in which a cloud index is calculated from satellite images which is then correlated to the clearsky index. This method has been recently modified [2], and the SATELLIGHT team [3] made further improvements to it. The PVSAT server continuously receives the METEOSAT images and converts them to cloud index images. These images are stored for on demand generation of site specific hourly irradiance times series. Hourly values are made by a weighted average of the three images received within the hour. While single irradiance values (in 30-minutes steps) show deviations up to 25% from corresponding ground measurements, the statistics of local irradiation climates are reproduced well by the satellite derived data. In consecutive steps, global horizontal irradiance is converted to the tilted plane by the Klucher-model [4]. A local horizon obstruction is taken into account, by defining a horizon line in steps of 30° at the plant site.

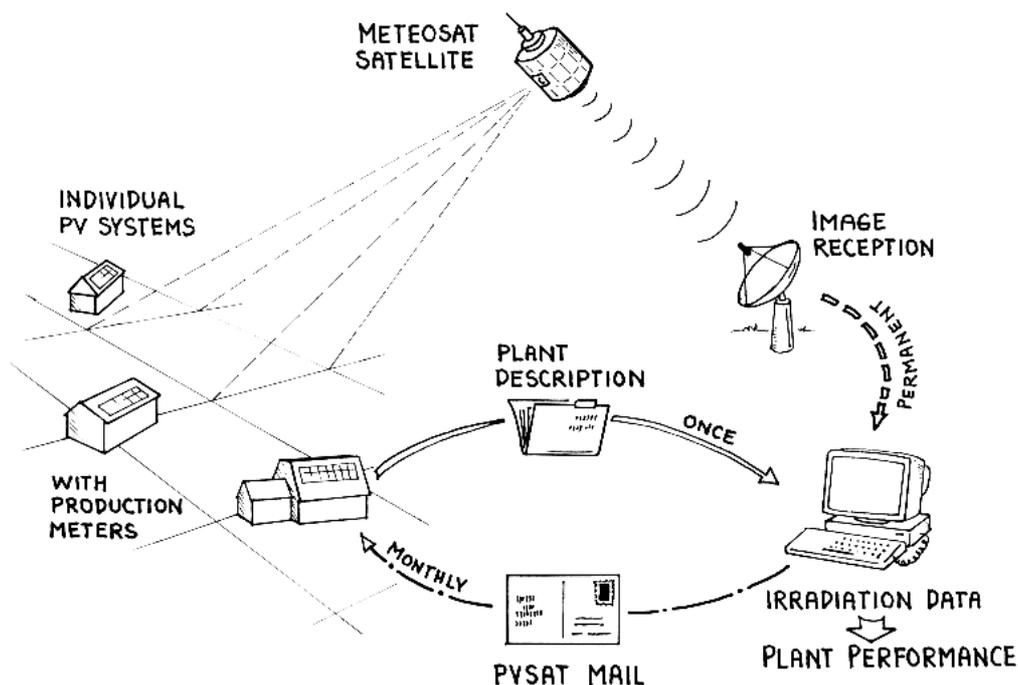


Figure 1: Overview on the PVSAT procedure. For each individual PV system participating in PVSAT, geographical, component and operator related data are entered in a configuration data base. The continuous reception of METEOSAT images allows for the production of site specific time series of solar irradiance for each of the locations. At the end of a given period, individual yield values are calculated for all PV systems using a PV system model and the irradiance time series. The results are transferred to the operator for a comparison of the estimated production to the energy actually produced.

At the end of each month, individual yield values are calculated for all PV systems. For this purpose, a generic system model is fed with the configuration data and according irradiance time series. The model has been set up using the simulation system INSEL [5] which has been used widely for system simulation and evaluation purposes [6]. The accuracy of the simulation tool has been tested with data from the German 1000 roofs programme using meteorological input data measured on site. The results indicate that under these conditions the monthly performance ratio can be modelled within an error range of  $\sim 2\%$  rmse.

The interface between the data base (running on MS-Windows) and the system model (running, as the satellite image processor, on Linux machines) is based on e-mail. Therefore, several distributed data bases may access the PVSAT server without interference. The results of the model calculation are transferred back to the data base, from where they are distributed (mailed, faxed or e-mailed) to the individual system operator. He or she may then compare the estimated production to the real production meter reading.

### 3 ACCURACY OF THE PROCEDURE

A main task of the project work programme has been concerned with the assessment of the accuracy of the PVSAT routine, both for the image processing and for the system modelling section. Basis of the investigations are PV system operation data acquired within the German 1000-Roofs-Programme [7]. Irradiation data on horizontal and tilted planes are available as well as system performance data, both with a time resolution of 5 minutes.

A major problem with the production of site specific irradiation data is the correct estimation of radiation

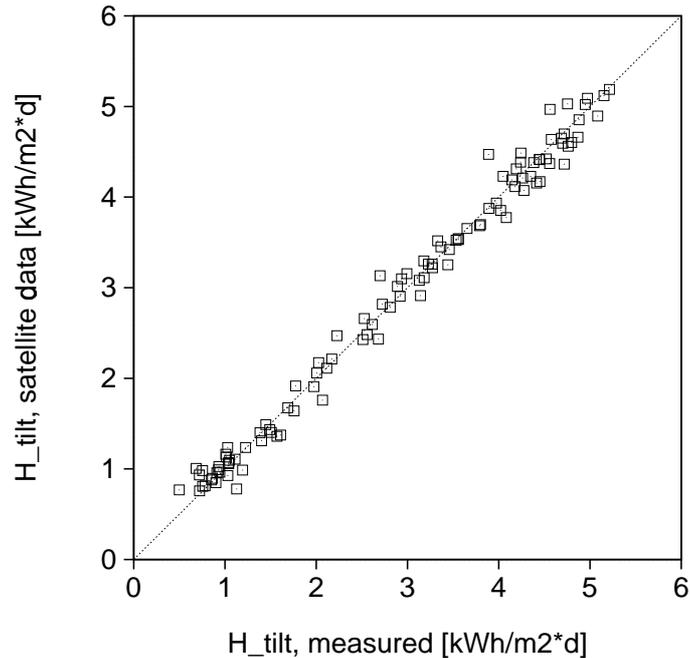


Figure 2: Comparison of satellite derived to ground measured irradiation data in the plane of the PV arrays including horizon effects. Each dot represents a monthly mean value of daily irradiation sums, the plot comprises one year of data for 9 PV system sites in Germany.

losses due to a local horizon obstruction. Satellite derived irradiances compare quite well on a monthly basis to data as measured by the German Weather Service at unobstructed sites. For the individual PV system sites individual horizon lines have to be taken into account. The accuracy of the calculated irradiance on the converter plane strongly depends on the quality of these horizon data. Figure 2 gives a comparison of satellite derived data including horizon effects and the plane-of-array data measured at the specific sites. The RMSE for this sample of monthly mean values amounts to 5.7 %. This fits quite well to general statements concerning monthly satellite data RMSE values, which range from 5 % to 10 %.

The next quantity needed for an accurate system modelling is the PV module temperature during operation. For arbitrary systems within the PVSAT procedure, neither the module temperature nor the ambient temperature is known. Therefore, a separate model generates ambient and module temperatures from monthly mean values of temperature and the according irradiation data. Using these values instead of measured values adds an inaccuracy of 1 - 2 % of the monthly energy production.

Any remaining input parameters may be derived from the component data sheets. Thus, they strongly depend on the quality of these data sheets and, in some cases, on the approximation of the manufacturer data by the PVSAT simulation models. Figure 3 shows the overall results for 9 PV systems and a test period of one year. For nearly all months with an average daily irradiation of more than 1.5 kWh/m<sup>2</sup>, the differences between estimated and real PV production are smaller than 10 %. About 90 % of the annual energy production is related to these months.

For the remaining time (3 or 4 months during the winter period), the accuracy still needs some improvement. The main reasons for the large deviations during the winter period are:

- Increasing errors in the irradiation calculation from satellite images during winter (especially in case of snow covered ground)
- Inaccurate horizon lines which show a stronger effect at lower solar elevation angles
- Poor knowledge of component behaviour under low part-load conditions

The first item may be improved after the transition to MSG in 2001. The last item is subject to further efforts of the PVSAT team, while a solution for the second problem is still under discussion.

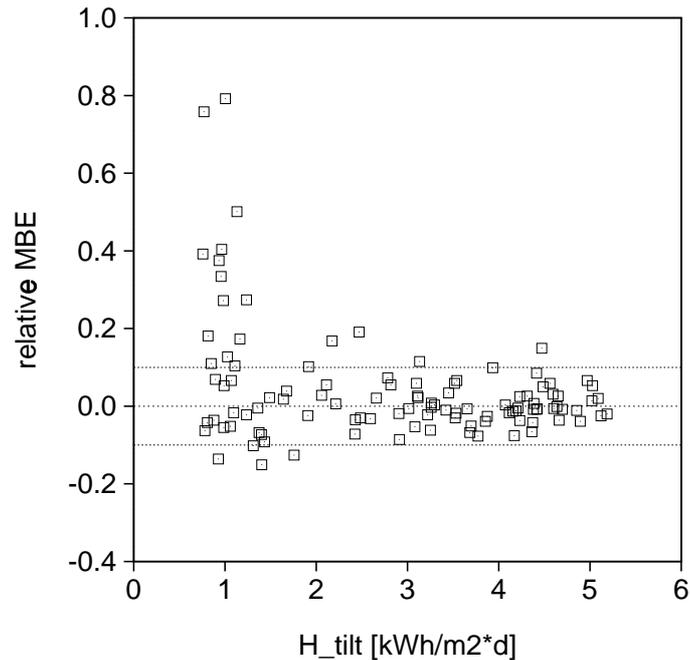


Figure 3: Relative error of estimated monthly PV power production ( $(\text{estimation} - \text{observation}) / \text{observation}$ ) versus the mean daily irradiation for each month. The plot comprises one year of data for the same 9 PV systems as in figure 2.

## 4 TEST PERIOD

A semi-public test period of PVSAT has been started in May 2000 and will last for one year. This test phase is supported by associations of solar energy users and of system suppliers. It will provide information on several questions:

- o What is the real-world accuracy of the procedure as a whole?
- o Does the automated communication between the data bases and the PVSAT server work properly?
- o What kind of information and aid do the PV system operators need?
- o How do system suppliers interact with PVSAT?
- o How would future service models look like?

After the test phase and its evaluation, PVSAT will be available to the public. The concepts of operation (by system suppliers, associations or neutral institutions) is currently under discussion.

## 5 CONCLUSION

Up to now, the results of the prototype PVSAT procedure are encouraging. The probability of calculating the monthly yield with a deviation less than 10 % is greater than 90 % for all months with an average irradiation of more than 1.5 kWh/m<sup>2</sup>d.

Considering this accuracy, PVSAT is not directly suitable for a concept of “guaranteed results”, which could establish legal aspects between the system supplier and the owner or operator. Nevertheless, the goal of PVSAT is the early detection of partial system faults, and this goal will be achieved for all standard systems.

While PVSAT is designed for the estimation of monthly yield values (in order to support an early fault detection), the overall accuracy on an annual basis is considerably higher and reaches values of about 5 %.

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