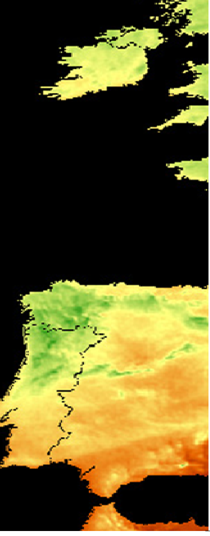

P V S A T - 2

An automated performance check for photovoltaic systems based on solar irradiance information from satellite data

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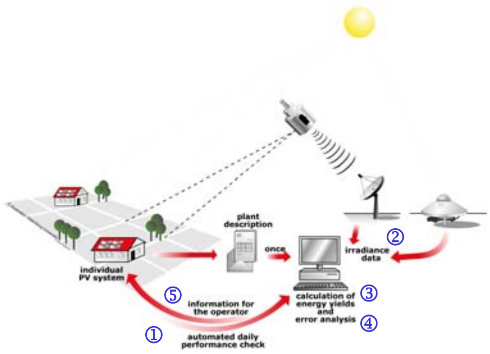
Introduction

Within the EU project PVSAT-2, a fully automated performance check for grid-connected photovoltaic (PV) systems has been developed to assure maximum energy yields and to optimize system maintainance. Aim is the early detection of system faults and therefore, the prevention from energy and lastly from financial losses. System failures can be hard to detect; solar irradiance information are necessary to calculate reference values of the expected energy yield.

Solar radiation derived from data of the METEOSAT satellites play a major role in PV system surveillance. They are a cost-effective alternative for small PV systems (up to 5kW) compared to expensive on-site measurements.

The PVSAT-2 procedure



① The **actual power output** of a PV system is automatically recorded on-site and transfered daily to a central server.

② **Solar irradiance** is determined from **METEOSAT images** on an hourly basis and refined by combination with **ground measurements** from weather stations by kriging-of-differences.

③ Based on the derived irradiance values, an **individual yield calculation** for the PV system is performed **daily** by a **PV simulation**.

④ To detect system failures, the central system compares daily the actual and the simulated yield. The fully **automated failure detection routine** searches for causes of occured malfunctions.

⑤ **Information** about the performance, detected system failures, and the probable causes for the malfunction are submitted to the operator.

Irradiance data from satellite measurements

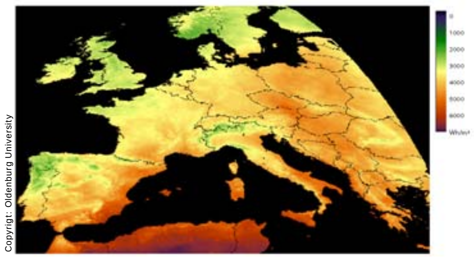
• Satellite Data:

	METEOSAT -7	MSG-1
Channel:	VIS (0.45-1.0 µm)	HRV (0.6–0.9 µm)
Temporal Res.	30 minutes	15 minutes
Spatial Res.	2.5 x 2.5 km (sub-satellitepoint)	1.0 x 1.0 km (sub-satellitepoint)

• Method:

The solar irradiance for Europe at ground level is derived by the HELIOSAT-Method.

(- Hammer, A. et al. (2003): 'Solar Energy Assessment Using Remote Sensing Technologies', *Remote Sensing of Environment*, 86, 423 – 432.
- Müller et al. (2004): 'Rethinking satellite based solar irradiance modelling – The SOLIS clear sky module', *Remote Sensing of the Environment*, 91, 160 - 174)

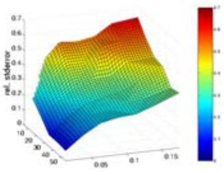


Example: monthly mean daily sums for April, 2001 derived from Meteosat-7 data

• Accuracy:

Overall accuracy of the satellite data (Meteosat-7) compared to ground measurements of 20 DWD stations for the year 2000.

RMSE, monthly	4.7 %
RMSE, daily	9.9 %
RMSE, hourly	21.3 %
MBE	0.6 %



Stderr for hourly values in dependence of sun elevation and variability of cloud cover.

• Weather-dependend accuracy:

The accuracy of the satellite-derived irradiance data is strongly dependent of sun elevation and the predominant weather situation. Errors decrease with higher irradiance.

• Kriging-of-differences: The accuracy can be improved significantly for cloudy sky situations.

Simulating PV power output and automated failure detection

• PV simulation:

The irradiance data and a technical specification of the PV system are the basic input for the daily estimation of the expected power output.

The quality of the PV simulation output depends highly on the accuracy of the irradiance data. Under clear sky conditions with low errors system faults can be detected fast.

• Automated failure detection routine:

List of detectable malfunctions

Module/ cable related failures	String defect
	Module defect
Power limitation of inverter	MPP tracking
	Part load behaviour
Shutdown; total blackout	Defect control devices
	Defect inverter
	Grid outage
Failures related to ambient conditions	Shading
	High temperature
	Snow cover

Principles of the failure detection routine

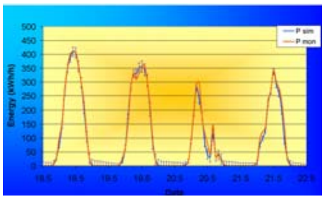
If the monitored energy yield is significantly lower than the simulated yield, the failure detection routine will search for the most possible cause of the system‘s malfunction.

To reduce the uncertainties of the simulated power output by averaging, the system‘s performance is evaluated for different periods (1 day,7 days, 30 days). The characteristics of the fault for each period are explored and a failure pattern is extracted. This is compared to the predefined failure patterns of the above listed malfunctions.

Finally, the likelihood of possible system faults are determined.

Results and conclusion

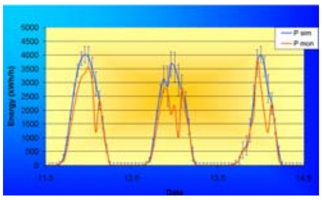
During a one-year test phase the functionality and applicability of the developed PVSAT-2 procedure is evaluated and improvements are introduced.



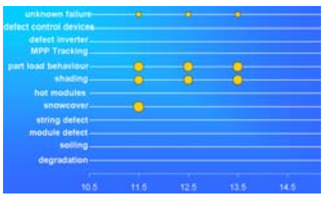
Results of a well working system:

The simulated PV output is within the error margins of the measured values.

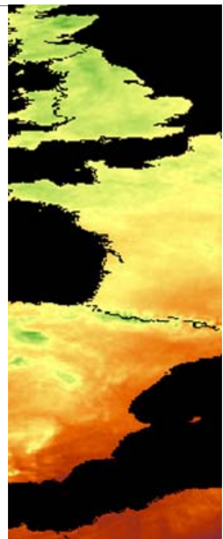
System with partial energy loss:



Different possible failures are extracted –their probability is indicated by the size of the bubbles. Certain failures can be excluded while the probability of other malfunctions rises with time.



The first results prove the usability of satellite-derived solar irradiance data for the surveillance of PV systems.
Malfunctions of a system as well as their most probable causes can be identified fast.
PVSAT-2 will provide a cost-effective and user-friendly service.



PVSAT

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