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Monitoring and remote failure detection of grid-connected PV systems based on satellite observations

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Abstract

Small grid-connected photovoltaic systems up to 5 kW_p are often not monitored because advanced surveillance systems are not economical. Hence, some system failures which lead to partial energy losses stay unnoticed for a long time. Even a failure that results in a larger energy deficit can be difficult to detect by PV laymen due to the fluctuating energy yields.

Within the EU project PVSAT-2, a fully automated performance check has been developed to assure maximum energy yields and to optimize system maintenance for small grid-connected PV systems. The aim is the early detection of system malfunctions and changing operating conditions to prevent energy and subsequent financial losses for the operator. The developed procedure is based on satellite-derived solar irradiance information that replaces on-site measurements. In conjunction with a simulation model the expected energy yield of a PV system is calculated. In case of the occurrence of a defined difference between the simulated and actual energy yield, an automated failure detection routine searches for the most probable failure sources and notifies the operator.

This paper describes the individual components of the developed procedure—the satellite-derived irradiance, the used PV simulation model, and the principles of the automated failure detection routine. Moreover, it presents results of an 8-months test phase with 100 PV systems in three European countries.

Keywords: Performance check; Satellite-derived irradiance; Automatic failure detection

1. Introduction

The number of grid-connected photovoltaic (PV) systems operating in Europe has increased enormously in the last years. About 403 MW_p has been newly installed (~360 MW_p in Germany) in 2004 (EurObserv'ER, 2005). Most of these systems range in power rating between 1 and 10 kW_p. Regular performance checks on the functioning of grid-connected systems are necessary for a reliable use and successful integration of PV into the daily energy supply. System surveillance for larger systems is usually performed by using additional hardware such as radiation sensors (pyranometers or reference cells), data loggers, or other intelligent monitoring devices. This can be expensive

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Nomenclature

G	global irradiance on the horizontal plane (W/m^2)
D	diffuse irradiance on the horizontal plane (W/m^2)
G_t	global irradiance on the tilted plane (W/m^2)
d	diffuse fraction (W/m^2)
P_{AC}	PV power output (W or kW)
ΔG, Δd, ΔG_t, ΔP_{AC}	expression of uncertainty for the named quantities (W/m^2, W)
η_{MPP}	efficiency at maximum power point
T_M	module temperature (°C)
T_A	ambient temperature (°C)
α	temperature coefficient (°C)
a_1, a_2, a_3	device specific parameters
c	coefficient for different kinds of PV system assembly
h	hour
t	time
P_{sim}	simulated PV power output (W or kW)
P_{mon}	monitored PV power output (W or kW)
P_{inst}	installed PV power output (W or kW)
P^*	specially weighted and sampled power output
P_x	power output at one point in time

and requires intensive maintenance that is only economical for larger systems. Therefore, small grid-connected PV systems up to 5 kW_p are often not checked on a regular basis. Furthermore, due to the fluctuating yield of a system resulting from the intermittent character of solar irradiance, partial system faults or decreasing performance are difficult to recognize for most operators of small systems as they usually are not PV specialists. Small as well as larger system failures that lead to partial energy loss can remain unnoticed for a long time. Besides the ecological benefits in reducing CO_2 emissions, the economic perspective for these small systems is of importance. An easy and safe-to-handle long-term service to check system performance is needed to prevent from the loss of energy for the operator, and, especially in case of granted feed-in tariffs, from severe financial losses. The feed-in tariffs in Germany, 0.406 €/kW h up to 0.568 €/kW h depending on the system type and installation (EEG, 2004), or in Spain, 0.4 €/kW h for systems smaller than 100 kW (RD, 2004), provide profits to operators and the PV industry. To secure these economical profits for small systems, cost-effective methods that detect system failures as quickly as possible are of paramount importance to increase the operating efficiency of a PV system.

Within the PVSAT-2 project such a low-cost and reliable performance check on a daily basis has been developed. The expected energy yield of a PV system is determined using irradiance data derived from the meteorological satellite Meteosat-8 replacing on-site measurements with a reference cell or a pyranometer. Required hardware, directly connected to the PV system, is reduced to a low-priced hardware device which combines a data logger and a modem in one. It records the actual energy yields at pre-defined time intervals and sends these data automatically to a central server where an automated data analysis is carried out. Moreover, the PVSAT-2 scheme provides a fully automated failure detection routine which evaluates the expected and actual energy yield in order to detect the occurrence of a malfunction and to identify the most likely failure source. The operator of a system is automatically informed and has fast Internet access to the performance data of the PV system. The strength of the developed scheme lies in the inexpensive use of satellite data that avoids costly and error-prone on-site measurements. Furthermore, surveillance algorithms provide a fast overview on the performance of a system and possible faults by automatic notification.

In this paper, the entire PVSAT-2 procedure is described. Furthermore, results from tests with historical data and an 8-months field test in Germany, The Netherlands, and Switzerland with 100 systems of voluntarily participating test users are presented. It shows the applicability in a real environment and the readiness for marketing of the developed PVSAT-2 routine. Practical experiences, benefits, as well as limitations are discussed.

2. PVSAT-2 procedure

The PVSAT-2 procedure is illustrated in its basic structure in Fig. 1. The solar irradiance is derived on an hourly basis from the data of the meteorological satellite Meteosat-8 by applying an enhanced version of the Heliosat method (Hammer, 2000; Hammer et al., 2003; Lorenz, 2004). Based only on satellite-derived irradiance data, the expected yield of a PV system is calculated using a PV simulation model as described in (Beyer et al., 2004). For the calculation of the PV system's energy yield, simulation specific technical information about the system is needed which is to be supplied once by the operator of the system. This comprises information on the major system components, manufacturer, type and number of modules, inverter as well as their technical data. Other required information are the geographic location, a description on the system's assembly (e.g., roof-integrated or free-standing), orientation, inclination, and configuration (e.g., how many substrings) (Section 3.2).

The actual energy yield of a PV system is recorded for every hour by a data logger that transmits these data every night via a telephone line to a central server. There, the achieved energy yield and the simulated values are