FAILURE DETECTION ROUTINE FOR GRID CONNECTED PV SYSTEMS AS PART OF THE PVSAT-2 PROJECT

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ABSTRACT: Identification of energy losses in PV systems up to now needed time intensive analyses. The Failure Detection Routine (FDR) relieves this by daily automatically analysing the performance of PV systems and, in case of a malfunction, determining possible causes. As input data the FDR needs the hourly energy yield (kWh) of the PV system and reference values of the energy yield. The reference values are calculated with the help of irradiance data provided by a satellite and with specific information about the PV system. If the actual energy yield is significantly lower than the reference energy yield, the FDR analyses the pattern of energy loss (height, duration, etc.). This pattern is automatically compared with predefined patterns of frequently occurring failures (as e.g. shading or string defect). The accordance of the actual pattern of energy loss with the predefined failure patterns is used to define which failures are most probable in the actual case and which ones can be excluded. First results show that the FDR is able to detect energy losses within one day. It is very capable in deciding which failures are impossible in the actual case and gives a helpful choice of possible failures.
Keywords: Plant Control, Performance, Monitoring

1 INTRODUCTION

Especially minor energy losses of PV systems often are not recognised by the operator and even in case of major energy losses, a time intensive analysis of the PV system is needed to identify the failure. The Failure Detection Routine relieves the operator of this burden by analysing daily and automatically the performance of the PV systems and, in case of a malfunction, determining its cause. A broad spectrum of different failures, e.g. shading, string or module failure, part time outages, snow cover, soiling and wrong inverter control may be detected. Due to the detailed information given by the Failure Detection Routine, the maintenance effort of PV systems is reduced und system outage time is minimised. The Failure Detection Routine is developed in the scope of the project PVSAT-2 [1], which is part of the EU programme „energy, environment and sustainable development“ and is assisted in Switzerland by BBW. The project started in November 2002 und will last until October 2005. The commercial application will start in 2005.

2 PVSAT PROCEDURE

The Failure Detection Routine is an integral part of the EU project PVSAT-2 [1]. The goal of this project is the satellite based monitoring of grid connected PV systems to reduce outage time and maintenance effort. The functional principle of the PVSAT procedure is described in several publications [2, 3, 4]:

- The hourly energy production of the PV systems is electronically registered and forwarded daily to a central server with a low cost hardware device.
- The reference energy yield of the PV system is calculated hourly with values of the global irradiation derived from satellite and ground measured data and with technical information about the properties of the PV system [3, 4, 5].
- Daily the Failure Detection Routine runs on the central server. It compares the effective and the theoretical energy production and searches for failures in the PV system.
- In case of a severe malfunction, the operator of the PV system is instantly informed per email or sms. All information about the performance of the PV system and the results of the Failure Detection Routine are permanently available on the internet for registered users.

3 FAILURE DETECTION ROUTINE

3.1 Functional Principle

As a starting basis the Failure Detection Routine (FDR) compares the simulated and monitored energy yield of the actual day. Because the accuracy of the simulated energy yield rises if longer time intervals are considered [4] , also the last 7 and the last 30 days are analysed. A failure has occurred, if the monitored energy yield is significantly lower than the simulated energy yield. Therefore the FDR doesn't only detect technical problems as e.g. string defects, but also external factors as shading or soiling. If the FDR detects a failure, in consequence it analyses the pattern of the energy loss and thus creates a profile of the actual failure. This profile is then compared with predefined profiles of several frequently occurring failures as e.g. string defect, shading etc. Depending on the degree of coincidence between the actual failure profile and the predefined profiles, the FDR decides about the likelihood of different failures (see Fig. 1).

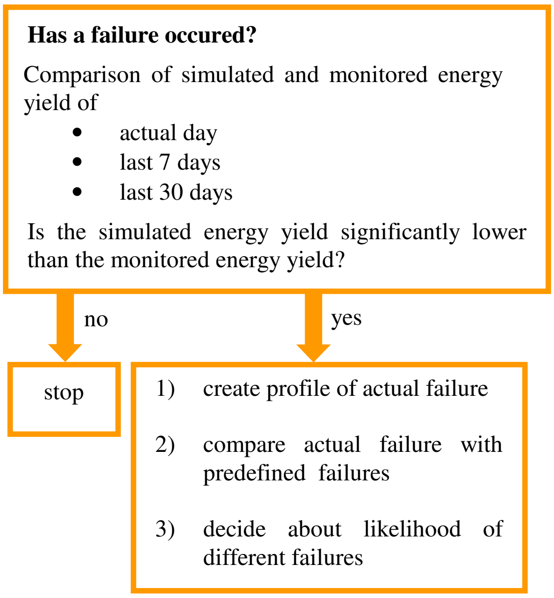

Figure 1: Functional Principle of the Failure Detection Routine

3.2 Analysis of Failure Patterns

If the performance of the PV system is unsufficient, the FDR analyses the pattern of the energy loss. Thereby not only the short and long term behaviour of the energy loss is investigated, but also the air temperature and the behaviour of neighbouring PV systems (see Fig. 2).

Figure 2: Duration, height and changes in energy loss, behaviour of neighbouring PV systems and temperature are important aspects considered in the FDR to determine the possibility of different failures

The following aspects are analysed:

- **Daily energy loss**: amount of the daily energy loss?
- **Hourly energy loss**: amount of the maximum hourly energy loss for that day?
- **Temperature**: average temperature during the last 3 days?
- **Spatial dimension**: did neighbouring PV systems as well suffer from energy losses that day?
- **Changes**: is the energy loss constant in time?
- **Duration**: for how long did the energy loss occur?
- **Correlation with sun elevation and irradiance**: does the energy loss correlate with irradiance or sun elevation [2]? This so called footprint method was developed at the Fraunhofer Institute and doesn't only analyse the actual day but also considers the behaviour of the PV system in the last 30 days.

3.3 Predefined Failures

Once the pattern of the actual failure is analysed (see Table I), a failure profile is created which can be compared with predefined profiles of frequently occurring failures (see Table II).

	height	duration	...
actual failure pattern	100%	3 hours	...

Table I: Extract of an analysed failure pattern: height and duration of the energy loss have been investigated

	height	max. duration	...
degradation	0 – 20%	>30 days	...
shading	0 – 35%	5 hours	…
defect inverter	100%	>30 days	…
grid outage	0 – 100%	5 hours	…
…	…	…	…

Table II: Extract of the patterns of predefined failures: the amount of energy loss and the maximum duration of energy loss are listed for several predefined failures

Up to now, failure profiles of 12 failures have been defined on the basis of practical experience from PV experts and literature [6, 7]:

- **Degradation / module over rating**: reduction of the cell efficiency after some time of operation / lower module power at STC than quoted in the technical data specifications
- **Soiling**: especially dust and bird-dung can pollute the solar modules and thus diminish the energy yield.
- **Module defect**: any defect in a solar module as e.g. broken cells or destructed module junction box.
- **String defect**: breakdown of one or several strings leads to constantly lower energy output.
- **Snow cover**: snow cover impedes energy production and piling up of snow and ice can cause glass breakage of the modules.
- **Hot modules**: cell efficiency reduces with increasing temperatures.
- **Shading**: solar cells can be shaded by trees, other buildings or protruding parts of the same building. In special cases, partial shading by upper rows of the PV system is possible.
- **Part load behaviour**: some inverters show unsufficient efficiencies at low power output.
- **MPP tracking**: some inverters have problems in following the MPP at changing weather conditions.
- **Grid outage**: for safety as well as for self-protection purposes the inverter is programmed to disconnect from the utility during out-of-spec conditions. The

PV system will isolate itself should the utility voltage drop below a certain level. Some PV systems are programmed with tolerances that are too tight, which produces unnecessary shutdowns of the photovoltaic system.

- **Defect inverter**: means a total breakdown of the inverter
- **Defect control devices**: DC main switch as well as the AC mains connection can be pulled off, thus preventing energy production. Also registration and signalization of the operating data can fail.

3.4 Likelihood of Failures

The profiles of the predefined failures describe the same aspects as are investigated to create the profile of the actual failure (ranges of daily and hourly energy loss, temperature range, effect on neighbouring PV systems etc., see Table II). Thus every aspect of the actual failure profile is compared with the same aspect of the predefined failures. Based on this, scores are distributed to every predefined failure which are a measure of the coincidence between the observed and the predefined pattern. If a predefined failure contrasts in one or even more aspects with the actual failure pattern, this failure is considered impossible. For all other predefined failures the scores for all aspects are summed up to give a hint on the probability of the failure (see Table III).

Every predefined failure is also characterized with its frequency of occurrence according to literature studies [6, 7]. By setting higher scores to failures which occur more frequently, this value is also considered when the FDR decides which failures are the most probable ones.

	height	max. duration	result
degradation	0	4	0
shading	0	2	0
defect inverter	4	4	8
grid outage	4	2	6
…	…	…	…

Table III: Extract of a table where the actual failure pattern is compared for the aspects "height of energy loss" and "maximum duration of energy loss" with the predefined failure patterns. 0 / 2 / 4 denote no match / match / high match between the actual failure pattern and the predefined failure. Summing up the scores for the different aspects (using 0 as exclusion criteria), the most probable failures are the ones with the highest result.

4 TEST PHASE

From January to September 2005 a test phase for the PVSAT project is running with 100 PV systems distributed over Holland, Germany and Switzerland. In this test phase the hourly energy yield of the PV plants is monitored and the reference yield is calculated with the help of satellite data (see Fig. 3). Additionally the FDR is tested with historic data of PV systems.

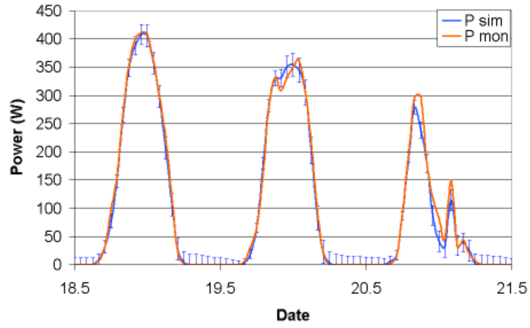

Figure 3: Monitored and simulated power of a well working PV system in the test phase. The standard deviation of the simulated power is indicated with error bars.

4.1 First Results

Although most PV systems seem to work well most of the time, there have already been detected some failures during the test phase. One PV system in Basel (Switzerland) regularly showed breakdowns in power in the late afternoon at clear days (see Fig. 4).

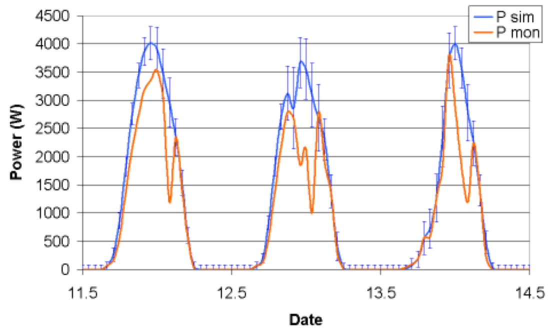

Figure 4: Monitored and simulated power of a badly working PV system in the test phase. The standard deviation of the simulated power is indicated with error bars.

The FDR recognized the energy loss and suggested grid outage, part load behaviour or shading as possible failures. At several cold days it also suggested snow cover (see Fig. 5).

A deeper (manual) analysis revealed that the reason for the energy loss was an overheated inverter. The inverter was situated in a small room beneath the roof without air ventilation. As this failure is not included in the list of predefined failures yet, it could not have been detected. To improve the FDR therefore the failure "hot inverter" will be added to the list of predefined failures.

Snow cover was considered possible at certain cold days, although in Basel snowfall in May is absolutely rare. To prevent the FDR from detecting snow cover too often, thus the aspect "temperature" in the predefined failure pattern of snow cover will be lowered from 10°C to 6°C.

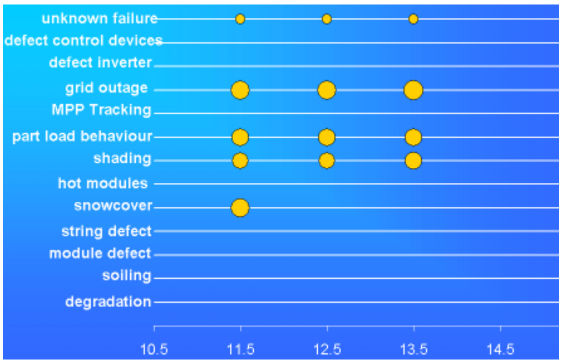

Figure 5: Result of the FDR for the PV system in Fig. 4: bubbles indicate matches between the actual failure pattern and the predefined failures. Bigger bubbles represent better matches.

In one of the PV systems the data logger couldn't read out the energy meter and thus constantly monitored 0 W (see Fig. 6). As a result, the FDR alarmed that either the inverter or the control devices were defect (see Fig. 7).

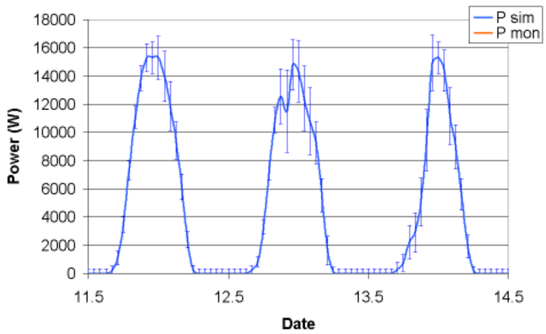

Figure 6: monitored and simulated power of a PV system in the test phase. The standard deviation of the simulated power is indicated with error bars.

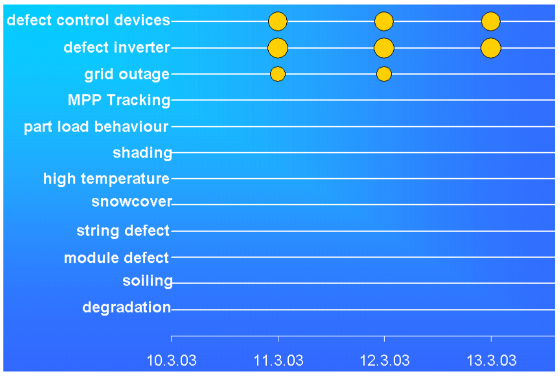

Figure 7: result of the FDR for the PV system in Fig. 6: bubbles indicate matches between the actual failure pattern and the predefined failures. Bigger bubbles represent better matches.

5 CONCLUSIONS

The first results show that it's possible to detect failures with the FDR and that the routine is good at finding out which failures are absolutely impossible. But it will be necessary to do fine tuning of the predefined failure patterns during the test phase and it will also be necessary to include new predefined failures in the routine. But already the actual status quo of the FDR is able to decide about the functioning of a PV system and to give hints on possible failures which otherwise only could be detected with time intensive analyses. In October 2005 the PVSAT procedure (inclusive FDR) will be commercially available on www.spyce.de [8].

It is anticipated that this tool will become a standard for the automated surveillance of grid connected PV systems.

6 ACKNOWLEDGEMENTS

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