A NEW GENERATION OF PV MONITORING SYSTEM WITH HIGH-GRADE REMOTE DIAGNOSTICS BASED ON MODULE LEVEL MONITORING AND INTEGRATED YIELD SIMULATION

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ABSTRACT: The significant enlargement of the functionalities of the SunSniffer® PV monitoring system is the objective of a German joint research project. The SunSniffer® technology has already realized the approach of a module based PV monitoring. Essential project targets are the integration of a PV yield simulation engine, the significant enhancement of the error detection sensitivity via continuous nominal-actural value comparisons, an automated fault analysis, automated recommendations for action (swapping of modules, module cleaning etc.) based on ROI considerations, and the automated prediction of an imminent PV plant performance deterioration. The previous project work was focused on the integration of the simulation engine, the development of the automated error detection, and the development of the automated fault analysis. First the accuracy of the selected PV yield simulation engine was investigated. It was demonstrated that the simulation accuracy can attain values down to 0.4 %. Concerning the automated fault analysis the approach was to develop an algorithm that continuously analyzes the measured module voltage und string current data by means of pattern matching. As example a feasible approach to distinguish between PID and partial shadowing was shown.
Keywords: Monitoring, Plant Control, Reliability, Stability, System Performance

1 INTRODUCTION

The market for sustainable, renewable energies is growing fast and, in recent years, great progress in terms of the overall efficiency of PV systems has been made. In order to follow the constantly growing PV market it is necessary to develop more sophisticated monitoring tools which are capable of finding a fault or failure in the PV system as soon as possible. The ability to predict failures by monitoring changes in system parameters offers plant owners the possibility to increase profitability by decreasing downtime.

In a recently published study performed by the International Energy Agency it was found that PV plants are performing at a satisfactory level within given parameters but could achieve higher levels of output [1]. "Task 13", a research project set up by the Photovoltaic Power System Programme (PVPS), a cooperation platform within the IEA, set out to investigate module errors, analytical monitoring methods and long-term performance analyses. Its findings can be summarized thus:

a) Faults and defects reduce PV plant efficiency.
b) Fault finding and troubleshooting must be carried out in greater depth.
c) IEA recommendation: measurements should be taken directly at the junction box.

The Performance Ratio (PR) of PV plants has increased by up to 20 % today when compared to 35 years ago, with some plants running at as much as 90 %. Others, however, can only point to a value of 70 %. Investor confidence would be greatly boosted by increasing the PR to a higher, sustained level, resulting in higher bankability, lower capital costs and hence lower production costs. The way to achieving this is through rapid, exact fault finding. As things stand at the moment, profit-reducing faults remain, in some cases, undetected. If detected, a more exact analysis of the problem can be prohibitively complicated and expensive. It is true to say that it is less than clear as to which methods are best at finding which faults. Defective bypass diodes are a case in point. Although they pose a danger to safety, no great effort has been made to find a reliable way with which to detect them.

The answer to these problems is module-specific monitoring. The IEA recommends that "For more advanced monitoring the power or current on the junction box level or the string currents should be measured." [1]. It is impossible to say whether a reduction in performance is due to a system error or merely lower irradiation, when monitoring is conducted only at the power collection point. In the event of a PV plant producing less energy than expected, junction box or string based monitoring significantly reduces the amount of time and money for detecting the failure. Monitoring at the junction box level is, therefore, strongly recommended.

The approach of a module based PV monitoring is the base of the biennial joint research project InSeMo funded by the BMWi-E (German Federal Ministry of Economics and Energy), that started in December 2014. Partner of NEXT ENERGY in that project is STORM Energy GmbH that started with the planning, installation, and operation of PV plants in 2002. In parallel to that STORM Energy started to develop the SunSniffer® technology, a novel module based monitoring system that was brought onto the market in 2009. Objective of the biennial BMWi-E joint research project is to enlarge significantly the functionalities of the SunSniffer® PV monitoring system.

In this paper, we will present the current status of that joint research project including the attained results until now. Up to now, the SunSniffer® PV monitoring system is based on the tracking of actual values (module operating voltage, string operating current, ambient temperature in the junction box). In the frame of the joint research project a PV simulation engine enabling a high-quality simulation suitability will be integrated into the SunSniffer® internet platform. Additional to that also an irradiatiance sensor will be integrated in the SunSniffer® PV monitoring system so that the set of actual values now also includes solar irradiation values. Thus, the essential innovation realized by the joint research project is the feasibility to create nominal values concerning the PV yield (by conducting simulations after feeding them with solar irradiations values and specification data of the PV plant). This enables to identify performing problems of a PV plant by comparisons between actual values and corresponding nominal values. Based on these comparisons it is the essential project aim to developed an intelligent algorithm that

a) clearly can determine performance problems of a PV plant,
b) can locate which modules cause yield losses,
c) can identify the source of yield losses,
d) can suggest the PV plant owner how to react (swapping of modules, module cleaning etc.).

2 EXPERIMENTAL SETUP

Base of the SunSniffer® technology is a low cost sensor that is installed in the junction box of PV modules and that is tracking the module operating voltage and the ambient temperature (Figure 1). The measurement data of all modules of a PV plant are subsequently broadcasted via power line technology to the SunSniffer® String Reader that collects and averages the measured values in 5 minutes resolution. These data are transmitted to the SunSniffer® Gateway, afterwards the data of each module (voltage, power, yield, junction box temperature) are online available in 15 minutes resolution. All collected data are put into graphs and can be observed by PV plant owners by the SunSniffer® Internet Platform (Figure 2). Thus, the essential feature of the previous SunSniffer® technology is that the approach of a module based PV monitoring has been already implemented including the continuous yield record of each individual module of a PV plant.

Figure 1: SunSniffer® Sensor, String Reader (left) and Gateway (right).

As PV yield simulation engine the software insel® was selected that enables to simulate the operation of any kind of PV system. To model of PV system, insel® offers an extensive data base for solar modules. Alternatively solar module models can also be developed by the integration of flasher data at varying irradiance and cell temperature.

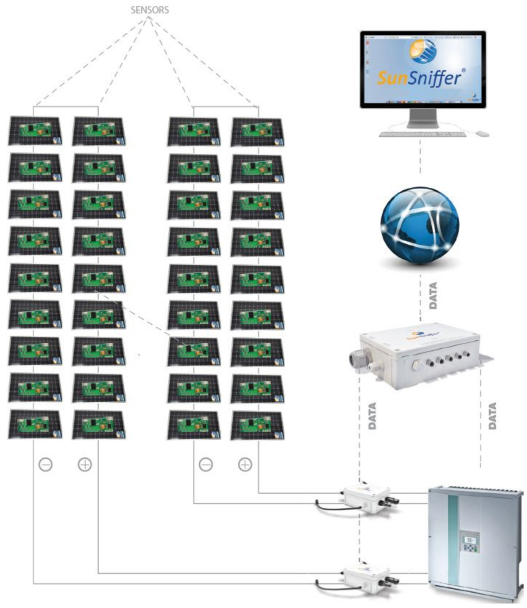

Figure 2: Setup and communication structure of the SunSniffer® PV monitoring system.

In frame of the BMWi-E joint research project the data of PV systems were investigated so far. The first PV system referred as "PV system A" is located on the roof of the NEXT ENERGY institute building in Oldenburg, Germany. 12 SCHOTT Solar a-Si modules are serial connected (1.14 kWp total power) and a small string inverter realizes the grid connection. The irradiance at the ambience of the a-Si modules was measured by a SMA sunny sensor based on an a-Si solar cell (accuracy of 8 %). The sensor also measured the temperature at the backside of one a-Si module.

The second PV system referred as "PV system B" is a commercial PV plant of STORM Energy located on the roof of a large building in Nuremberg, Germany. The total power is 54.7 kWp and all c-Si modules are SunSniffer® equipped. The irradiance at the ambience of the c-Si modules was measured by a Mencke & Tegtmeyer GmbH sensor based on a c-Si solar cell (accuracy of 10 %).

3 RESULTS AND DISCUSSION

3.1 Simulation accuracy

One intended essential innovation of the BMWi-E joint research project InSeMo is the feasibility to generate nominal values concerning the PV energy yield by simulations. One prerequisite for the successful identification of PV plant performing problems on the basis of comparisons between actual values and corresponding nominal values is a sufficient simulation accuracy. The accuracy of the insel® simulation engine was evaluated by several investigations.

Primarily the PV system A was modelled and simulated on the basis of the measured solar irradiance and temperature data of the year 2012. Since SCHOTT Solar a-Si thin-film modules were not available in the insel® solar module data base, an own module simulation model was designed based on the manufacturer data sheet in combination with measured module IV-curves at varying solar irradiance and cell temperature. Figure 3 shows the measured monthly PV energy yields ($yield_{measured}$) and the correspondding simulation results ($yield_{simulated}$). Except for the months February and April a good accordance can be noticed. Concerning the mentioned two months the deviation can be attributed to a sensor malfunction, in large part no daily solar irradiance values were measured.

For this reason the measured and simulated PV energy yields were compared again. This time the daily measured PV energy yields were suppressed on days with maximum measured solar irradiance values < 2 W/m², hereby days with sensor malfunction were automatically filtered. A comparison between the filtered measurement ($yield_{filtered}$) and the simulated PV energy yields of February and April showed now also for these two months an excellent accordance. Related to the annual energy yield of the PV system A in 2012 the deviation between measured and simulated value was after the filter implementation decreased down to 0.4 % indicating a high suitability of the selected simulation engine.

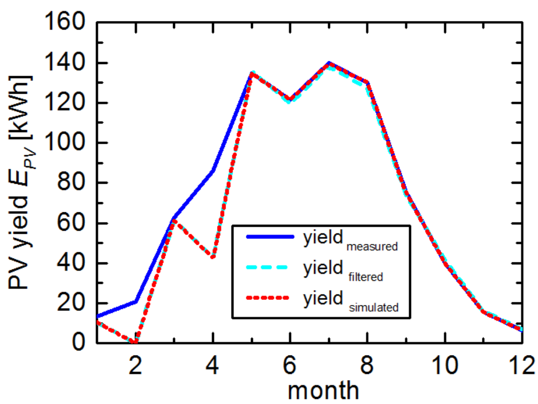

Figure 3: Measured and simulated monthly energy yields of PV system A in the year 2012. The measured monthly PV energy yields are shown without ($yield_{measured}$) and with filtering days ($yield_{filtered}$) that had maximum measured solar irradiance data < 2 W/m² including days with senor malfunction.

After the investigation of monthly and yearly scales the insel® simulation accuracy was also evaluated for 15 minutes periods. Figure 4 shows the measured and simulated voltage curve of a solar module of PV system B during a sunny in August (14 August 2013) as well as the corresponding measured solar irradiance. It can be observed that the simulation accuracy is affected by the low light performance of the installed solar irradiance sensor. The increase of the solar irradiance measuring error can be attributed to the issue that during sunrise and sunset sunlight enters the reference c-Si cell of the sensor at a small incidence [2]. Moreover, for very small solar irradiance values additional rounding errors in the simulation calculations arise. Figure 4 shows that for solar irradiance values > 400 W/m^2 the influence of these errors disappears and the deviation between the measured and simulated module voltage decreases to values ≤ 1.6 %.

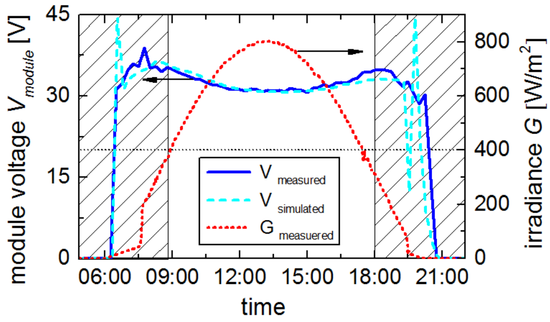

Figure 4: Measured and simulated voltage of a solar module of PV system B and the corresponding measured solar irradiance for 14 August 2013.

3.2 Automated error detection via nominal-actual value comparison

First milestone of the the BMWi-E joint research project InSeMo was to integrate the selected simulation engine into the SunSniffer® Internet Platform in order to implement the ability to generate nominal PV energy yield values. After the successful realization of that the base of the development of an automated error detection via nominal-actual value comparison was established.

The following task was to detect an appropriate threshold for Δ in order to maximize the strike accuracy.

$$\begin{aligned}\Delta &= E_{PV,actual} - E_{PV,nominal} \\ &= E_{PV,meas} - E_{PV,sim} \qquad (1)\end{aligned}$$

Criteria for avoiding a too small threshold were error calculation considerations. In addition to the remaining simulation inaccuracy also measuring inaccuracies were taken in account. In this context the corresponding data of the SunSniffer® Sensor were 1 % (module voltage and string current) and ±1°C concerning the measured ambient temperature in the junction box with 30 s time resolution. Based on these error calculation considerations a threshold of Δ_{thres} = 2 % was determined. In a later project stage long-term field test concerning the developped automated error detection via nominal-actual value comparison will be performed in order to evaluate the reliability of the selected threshold Δ_{thres}.

3.3 Automated fault analysis

The next intended extension of the functionalities of the SunSniffer® PV monitoring system was to realize an automated fault analysis. The approach was to develop an algorithm that continuously analyzes the measured module voltage und string current data by means of pattern matching. It is well known that there is a large number of physical effects that cause PV energy yield losses. In frame of the BMWi-E joint research project InSeMo pattern matchings first are developed for well-known and highly practice relevant effects. Examples are soiling, shadowing, potential induced degradation (PID), wire insulation issues, defect bypass diodes, and cell cracks.

Figure 5 and 6 exemplarily show feasible approaches for a PID and partial shadowing pattern matchings. Conductance G values were calculated based on the equation (2) given below and plotted vs. V_{module}.

$$G = \frac{I_{string}}{V_{module}} \qquad (2)$$

Figure 5 shows the variation of G-V-curve in the case of increasing PID at c-Si modules. The raw data of that PID study were taken from Schuetz et al. [3] and were measured under standard test conditions (STC).

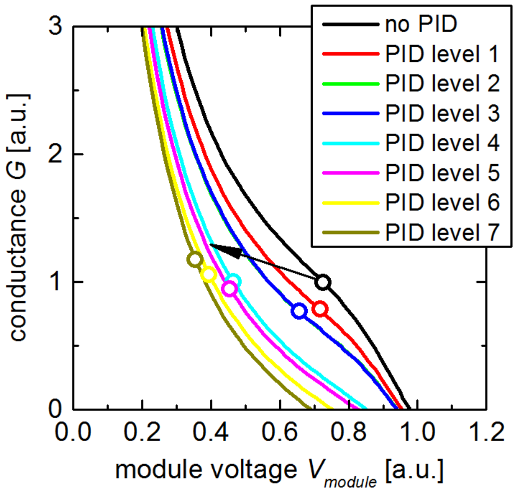

Figure 5: Variation of the conductance vs. c-Si module voltage curve under increasing potential induced degradation (PID). The corresponding maximum power point (MPP) position is marked at each curve. Raw data were taken from Schuetz et al. [3].

As comparison Figure 6 shows the variation of the G-V-curve under increasing partial shadowing. The c-Si module is equipped with 5 bypass diodes that are successively activated. Raw data were taken from Koirala et al. [4]. A comparison of both figures shows that the maximum power point (MPP) moving characteristics could serve as criterion to distinguish between potential induced degradation (PID) and partial shadowing induced PV energy yield losses.

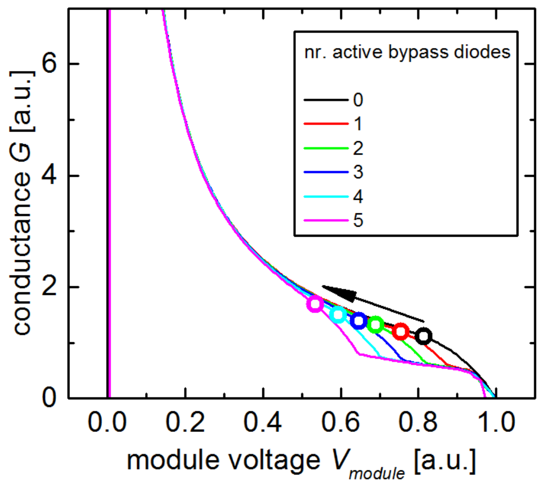

Figure 6: Variation of the conductance vs. c-Si module voltage curve under increasing partial shadowing and as function of the number of active bypass diodes. The corresponding maximum power point (MPP) position is marked at each curve. Raw data were taken from Koirala et al. [4].

4 CONCLUSION AND OUTLOOK

The presented work shows the current status of the BMWi-E joint research project InSeMo. First the accuracy of the selected PV yield simulation engine was investigated. Measured and simulated annual yields were compared and it was demonstrated that the simulation accuracy can attain values down to 0.4 %. The simulation accuracy was also evaluated for 15 minutes periods showing inaccuracies of the selected solar irradiance sensor under low light conditions. After the integration of the selected simulation engine into the SunSniffer® Internet Platform an automated error detection via nominal-actural value comparison was developed and implemented. An important task was to detect an appropriate threshold for the tolerable deviation between measured and simulated PV yield. Error calculation considerations lead to a threshold value of 2 %. Finally first results of the further project aim of an automated fault analysis were presented. The approach was to develop an algorithm that continuously analyzes the measured module voltage and string current data by means of pattern matching. A feasible approach to distinguish between PID and partial shadowing was specified.

Further work will be spent on the development of further new functionalities like automated recommendations for action (swapping of modules, module cleaning etc.) based on ROI considerations, or the automated predicttion of an imminent PV plant performance deterioration resulting in yield losses. In order to ensure a high reliability of the new functionalities of the SunSniffer® PV monitoring system, further key activities in frame of the BMWi-E joint research project InSeMo will be the execution of a long-term field test.

5 ACKNOWLEDGEMENT

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