IMPROVING THE ENERGY YIELD OF PV POWER PLANTS THROUGH INTERNET BASED SIMULATION, MONITORING AND VISUALISATION

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ABSTRACT:
In this paper, a new method is demonstrated for online remote simulation of photovoltaic systems. The required communication technology for the data exchange is introduced and the methods of PV generator parameter extraction for the simulation models are analysed. The method shown for parameter extraction from the manufacturer data is especially useful for the commissioning procedure, where the measured installed power is transferred to standard test conditions using the simulation model and can then be easily compared with the design power. At a simulation accuracy of 2% using the software environment INSEL® any problems with the PV generator can reliably be detected.
Online simulation of a grid connected PV generator is then carried out during the operation of the photovoltaic plant. The visualisation includes both the monitored and the simulated online data sets, so that a very efficient fault detection scheme is available. The method is implemented and validated on several grid connected photovoltaic power plants in Germany. It is excellently suited to provide automatic and real time fault detection and significantly improve the commissioning procedure for photovoltaic plants of all sizes.

Keywords: online simulation, software, plant commissioning, fault detection

1 INTRODUCTION

The economic performance of grid connected photovoltaic plants critically depends on the electricity yield, which is a function of meteorological conditions, but also of the real installed power and functionality of the whole system.

Most commercially available data acquisition and analysis systems only visualise the data either locally or by transferring the data through the Internet to Web servers, where they can be easily accessed. If data from PV plants are just visualised, only very significant faults or power reductions can be detected by the plant manager. During commissioning with varying meteorological boundary conditions it is hardly possible to find out deviations from manufacturer data as large as 10-20% of the installed power, unless the current-voltage characteristics are measured under known meteorological conditions. This is an expensive procedure, which only gives a result for the time of commissioning. Deterioration of plant performance during its lifetime is not known using this method.

High performance photovoltaic simulation tools such as INSEL [1], which is used in this work, provide a cheap and reliable alternative to detect faults or power losses in photovoltaic plants. The online simulation provides performance results with less than 2% error.

Simulation tools are mostly used during the design phase to predict the yield of the PV plant, only one concept of satellite based meteorological data uses a full simulation model also based on INSEL to calculate the theoretical yield of the plant once per month. As the error of satellite based hourly irradiance measurements is over 20%, deviations of system yield from the potentially possible yield can only be detected above this error range [2].

In this paper, a new methodology is demonstrated for online remote simulation of photovoltaic systems. After describing the required communication technology for the data exchange, the methods of PV generator parameter extraction for the simulation models are analysed. Online simulation of a grid connected PV generator is carried out. The deviations between simulation results based on manufacturer data and real time monitoring results can be clearly attributed to the faulty parameter sets. The new method is excellently suited to provide automatic and real time fault detection for photovoltaic plants of all sizes.

2 COMMUNICATION STRATEGIES FOR SIMULATION BASED REMOTE MONITORING

To allow precise system simulation for a PV power plant, monitoring data for the meteorological boundary conditions such as irradiance and ambient temperature have to be available. Irradiance data should best be available in the module plane, or can be calculated from horizontal data with about 1% error on average.

To detect faults in the power plant, DC voltage and current and AC power should be monitored. If possible the module temperature should be measured, but can also be calculated from ambient temperature and more precisely from temperature and wind speed.

All the data need to be transferred from the datalogging equipment to a server, from which clients can access the data, visualize it and simulate performance.

There are different server technologies with varying degree of response time: ftp servers only transfer complete data files on request, which are produced at a set time interval, for example every hour. Alternatively, a web server can transfer HTML pages with included XML data, which are actualized in a given time interval.

For real time access to the measured data, socket servers such as data socket from National Instruments writes the data to the computer memory, where they are continuously actualized. Other protocols such as OPC provide the same functionality. The simulation environment INSEL with its graphical interface VEE already includes data socket server and client blocks,

where monitored data can be easily written to the memory (server) and read from the server for the simulation process (client or simulation agent).
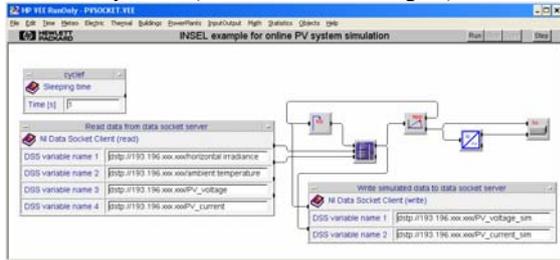

Figure 1: INSEL block diagram for a grid connected PV system in the graphical editor, where measured data are read from a data socket server and simulated data are written back.

To avoid data losses in case of communication problems with the socket connection using computers on different sites it is advisable to run a local client on the server computer, which just writes hourly or daily data files.

If VEE is used for the data acquisition software, all tasks such as data logging, visualisation, communication and simulation are combined within the same simulation environment INSEL. If other software packages such as LabVIEW are employed for monitoring purposes, all INSEL blocks for simulation and communication can be easily integrated as functions from dynamic link libraries.

3 VISUALISATION OF PV SYSTEM PERFOR-MANCE

The graphical interface VEE is used in the INSEL environment to freely construct simulation models using the available blocks within the Menu structure. The VEE software package from the Agilent company provides in addition powerful visualization tools. As an example the large photovoltaic generator of the main railway station Lehrter Bahnhof in Berlin is monitored and visualized within the VEE environment [3].
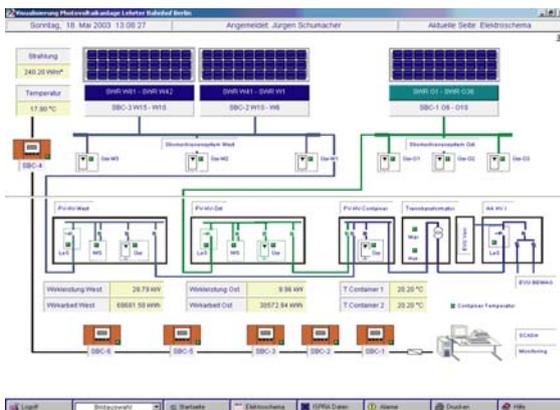
Figure 2: Overview of the photovoltaic generator at the main railway station in Berlin using the graphical editor VEE.

The visualization scheme can easily integrate the simulated values from the online remote simulation and even cause alarms if significant deviations are detected between simulation and measurement.


Figure 3: Detailed view of the west side generator of the main railway station project in Berlin with operating indicators for each individual inverter and visualisation of power and energy of each roof row.

4 PHOTOVOLTAIC SYSTEM SIMULATION

The best available physical model for photovoltaic modules is the two diode equation, which requires six fit parameters to describe the two exponential functions for the Shockley and recombination diodes and the photocurrent. To accurately determine the fit parameters, IV curves at different irradiance and temperature levels are required, which are not available for the majority of market available modules. INSEL provides a block for the determination of these parameters, if measured IV curves are given.

As an alternative, a new method was developed by the authors to obtain analytically six parameters for the one diode equation from the manufacturers data sheet. The new feature in the implemented algebraic equations is that the assumption of an infinite shunt resistance is no longer required [4]. INSEL now contains the one diode parameters for more than thousand PV modules.

The PV generator is operated with an MPP tracker and the inverter is modeled using the Schmidt/Sauer equation requiring only three partial load efficiencies for the model parameter extraction [5]. Parameters for five hundred inverters are provided in the INSEL data base.
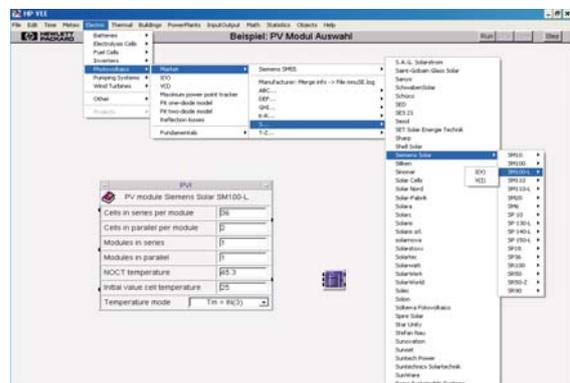
Figure 4: Selecting PV module parameters from the INSEL database of more than 1000 modules.

5 EXPERIMENTAL SET-UP FOR REMOTE PV SYSTEM SIMULATION

To test and demonstrate the method, a small grid connected photovoltaic power plant at the University of Applied Sciences Offenburg was monitored and remotely simulated at the University of Applied Sciences Stuttgart. The PV generator consists of eight $90W_p$ modules from Photowatt at a tilt angle of 25° with a $650W_{AC}$ Würth Solergy inverter.

All measured data were written to a data socket server in Offenburg from a LabVIEW visualisation. The Stuttgart data socket client accessed the real time data each second, performed a complete system simulation for the given meteorological boundary conditions and wrote back the simulated results to the data socket server – all within a millisecond.

Figure 5: PV installation at the University of Applied Sciences Offenburg.

6 RESULTS

6.1 PV module characteristics

In the first step, six one diode model parameters and the inverter characteristics had to be determined for the Photowatt PW 1000 module and the Würth Solergy WE 500 NWR inverter data sheets. The model parameters are required for the one diode equation shown below.

$$j = j_{ph}\left(c_{ph1}, c_{ph2}\right) - j_s\left(c_s\right)\left(\exp\left(\frac{q\left(V + jr_s\right)}{n_s kT}\right) - 1\right) - \frac{V + jr_s}{r_p}$$

The manufacturer data for the PW 1000 module are given below.

Manufacturer data	Value
Open circuit voltage / V	43.0
Short circuit current / A	2.8
MPP voltage / V	33.6
MPP current /A	2.7
MPP power / W	90.7
Temperature coefficient voltage / mV K^{-1}	-0.156
Temperature coefficient current / mA K^{-1}	0.93

Table 1: Manufacturer data.

The INSEL block pvdet1 was used to calculate the one diode parameters from the manufacturer data. Using the extracted parameters for the simulation model, the performance of the PV system was calculated, written to the server and visualized using the LabVIEW environment.

The simulated performance was in general 15% higher than the measured performance! This means that the manufacturer data cannot have been correct.

As a consequence, IV curve measurements were carried out on the generator. A Stella field tester was used at high irradiance levels of about 900 W m^{-2}. A two diode curve fit routine implemented as a block in INSEL (pvfit2) was then applied to all three measured curves to extract the module parameters of the two diode equation. This equation was then used to calculate STC conditions for the module.

Using the new STC curve, the one diode model parameters were again calculated. Using these parameters, online simulation was carried out again and an excellent agreement between measured and simulated IV curve was obtained.

| Parameters for one diode model	Value
Photocurrent coefficient c_{ph1} / V^{-1}	0.1557
Temperature coefficient photocurrent c_{ph2} / V^{-1} K^{-1}	0.000394
Diode current parameter c_s / A m^{-2}	16689
Diode quality factor n_s / -	1.0232
Series resistance r_s / Ω m^2	0.0003619
Shunt resistance r_p / Ω m^2	0.04887

Table 1: Six one diode parameters obtained from the calculated STC conditions.
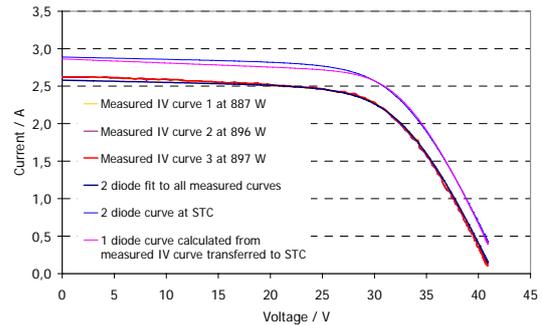
Figure 6: Measured IV curves, 2 diode model fit to the IV curves, transformation of 2 diode curve to STC, calculation of 1 diode parameters from STC conditions.

6.2 Online system simulations

Using the extracted module parameters and the inverter characteristic values, the whole system was then simulated online using the irradiance on the tilted plane and module temperature only as an input. As the process of data transfer and simulation only takes milliseconds, simulations were first carried out on a second basis. However, the deviation between measurement and simulation was rather high, as the measured irradiance information from the pyranometer has a slow time constant of about 20 seconds.
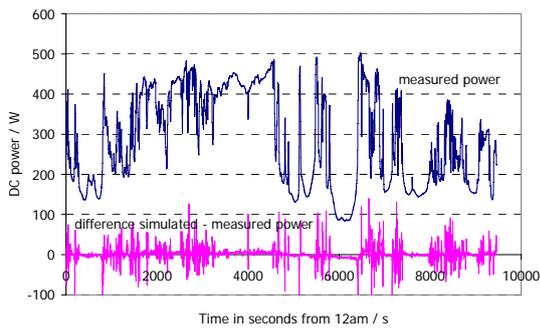
Figure 7: Measured and simulated DC power of the MPP tracked PV generator at a measurement time interval of 1 second on the 6.4.2005.

If the monitored data are averaged over a 1 minute interval, the difference between simulation and measurement greatly decreases.
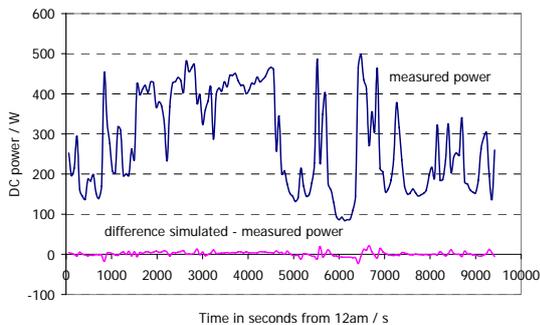
Figure 8: Measured and simulated DC power of the MPP tracked PV generator at a measurement averaging time interval of 1 minute on the 6.4.2005.

The simulation data now fit the measured power data excellently even on a day with extremely fluctuating meteorological conditions. The difference in energy output over the three hour measurement period is 0.5%. The mean arithmetic error between measurement and simulation is 2%.

7 CONCLUSIONS

In the work, a methodology was proposed and demonstrated to simulate grid connected photovoltaic power plants not only in the planning stage, but also online using Internet communication. The simulation models used are physically accurate models of the photovoltaic modules, the MPP tracker and the inverter and reproduce measured data with 1% error only. All physical models together with the parameter sets for over 1000 modules and 300 inverters are implemented with the required communication blocks in the simulation environment INSEL.

Real time access to monitored data is possible using a range of protocols such as socket communication. The online simulation of a small PV power plant revealed that the real installed power is 15% lower than given by the manufacturer. Using curve fitting algorithms to measured IV curves, new parameter sets for the generator could be determined, which were then used for online simulation.

At a time averaging interval of 1 minute, a mean arithmetic error of 2% could be achieved for online simulation. This allows very precise fault detection for the plant operation.

The method allows to derive the nominal power of photovoltaic generators for any given meteorological condition and is thus excellently suited for the commissioning procedure. With the parameter sets calculated, fault detection during the lifetime operation is possible within a few percent error range.

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