Energy Yields of PV Systems
- Comparison of Simulation and Reality

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ABSTRACT: Simulation of PV systems is an important feature to predict mainly the yield but also the operational behaviour. How accurate are the simulation results? Thus the purpose of the work is to demonstrate the differences between simulation and reality. In a first step, three 1 kW_P PV systems coming from the solar promotion "Sun at School" have been investigated. Measured yields were available for many years. The software tools PVSYST and PVSOL have been applied to simulate the systems. In a second step, the yields of the 1016 kW_P PV system on the New Trade Fair Centre in Munich – which went in operation in 1997 - has been simulated using the block oriented simulation system INSEL. Simulation of two cases on the basis of measured irradiance data in the generator plane and ambient temperature data are leading to best simulation results. The total annual deviation between simulation and measurement is +5,2 % in case of the fit with measured module data and -1,4% for the data sheet case. Of course, this does not mean that the data sheet approach is more accurate since cable losses, mismatch losses etc. have not been considered at all.

Keywords: Software, Solar Radiation, Grid-Connected

1. GENERAL

Nowadays simulation is a common feature to make a prognosis about the expected yield and the operational behaviour of mostly grid connected PV systems. To demonstrate the reliability of the simulation results, the following steps will be carried out:

- In a first step, three small 1 kW_P PV systems have been investigated. Values of real yields were available for many years. The software tools PVSYST and PVSOL have been applied to simulate the systems. Meteorological data have been provided by the aid of the software Meteonorm 6.0 using hourly mean values. Simulation and real results for these small systems will be compared.
- Second , the yields of the 1016 kW_P PV rooftop system on the New Trade Fair Centre in Munich – which went in operation in 1997 - has been simulated using the block oriented simulation system INSEL. Excellent monitoring data from 1999 up to the year 2006 were available in hourly time resolution. Some of the modules have been certified at different times so that measured IV curves can be used to fit the two diode model to the module characteristics with very high accuracy. Here, simulation and real results will be compared again.

2. THREE SMALL SYSTEMS

These three systems were selected out of the photovoltaic promotion "Sun at School", where more than 900 schools in Germany received PV systems to teach the pupils. The components (Modules Siemens M55 and inverters SPN 1000) have been in operation for more than 10 years. The systems were built up due to the same principles with the same components. Only the location, the tilt and azimuth angle and the length of the cables vary. It should also be noted, that the PV systems were well maintained by the teachers; thus they were in a good state.

2.1 Basic Data

Table 1 indicates the basic data of the systems located in the area of Upper Bavaria. System A has variable tilt angles: 30° in summer, 45° in winter.

Table 1: Basic data of the systems investigated

Sys.	Location	Rated power	Azimuth	Tilt	Start-Up
A	Munich	1,1 kW_P	190°	30°/ 45°	1996
B	70 km south of Munich	1,1 kW_P	160°	60°	24.06. 1996
C	20 km east of Munich	1,1 kW_P	180°	60°	19.12. 1995

2.2 Long Term Yield

For PV systems A and C yield data are continuously available from the year 1996 to 2006, for B they only for 1996 and from 2002 to 2006. **Figure 1** indicates the yields obtained and shows the appropriate operational behaviour. Low values in the year 2003 can be seen for System B. The reason is that system B had experienced several outages of the inverter due to construction works at school. Additionally inverter B has been switched off frequently by pupils. With the exception of 2007 A showed to highest yields. The trend of the yields of A and C is the same; the level of C is lower. The reason is probably the 60° tilt angle of system C.

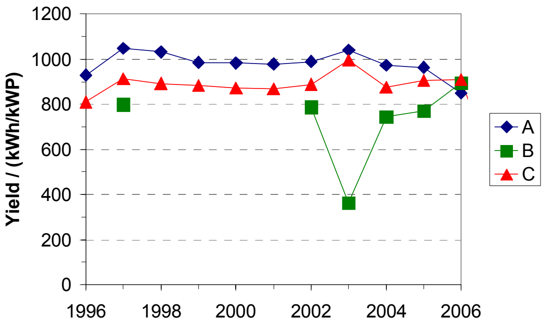

Figure 1: Yields from 1996 - 2006

The users of the PV systems were asked about their operation experiences. Actually, the systems are running well, there are no damages. No cleaning of the modules is foreseen.

2.3 Simulation

Simulation of the technical system – here carried out with software PVSOL and PVSYST - requires meteorological data for the location such as the ambient temperatures and the irradiances.

2.3.1 Meteorological Data

There are many data sources for monthly meteorological data. For reasons of comparability all data sets have been generated by METEONORM 6.0. They contain global and diffuse irradiation on a horizontal plane, ambient temperature and wind speed in an hourly resolution. These values serve as input data for the simulation software PVSOL and PVSYST.

2.3.2 Transformation of the Irradiation

The transformation of the irradiance on the tilted plane can either be done by application of the model of Hay and Davis or the model of Perez. PVSOL only uses the Perez method. PVSYST permits the selection of one of the two models.

Figure 2 illustrates the comparison of the two methods with PVSYST for the three systems A, B and C. In most of the months of the year the results due to the model of Perez are a few percent higher than those from Hay and Davis. However from September on they become lower. But in December – with low irradiations – the Perez results are 7 % higher.

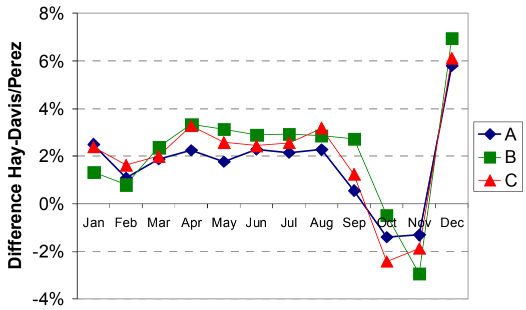

Figure 2: Deviation of monthly accuracy between the models of Hay - Davis and Perez

For the whole year the Perez transformation gives the higher irradiation values (~2 – 3%) on the tilted plane.

Comparing PVSOL and PVSYST - only with the Perez model - a maximum deviation of 1 % in a year can be seen. In summer the results are nearly identical, with a deviation of up to 0,3 %.

2.3.3 Computation of Module Temperature

When computing the module temperature out of the ambient temperature and the irradiation on the tilted plane, there are great differences between the two models. Especially in winter from November to March there are deviations up to 9 %. The Perez model always gives the higher values, as it does with the irradiations. In the rest of the year module temperatures are nearly identical.

The comparison of PVSOL and PVSYST (only Hay and Davis) indicates considerably higher deviations (for all three systems A, B and C) between the two software tools. PVSOL e.g. computed a mean module temperature of 14,0 °C, PVSYST a value of 20°C. The maximum monthly deviation appeared in January with 2,0° C from PVSOL and 7,0 °C with PVSYST.

2.3.4 Input of Technical Parameters - Simulation

The module data of the PV module Siemens M55 are available in the database of PVSYST. To take degradation into account, nominal power had been decreased for the rough value 10 %. The input data required by PVSOL were taken out of the data sheet, also taking degradation into account. The inverter data were not available, they had to be entered.

As the components were more than 10 years old, some of the input data (efficiency values of the inverter depending on the load, part load behaviour of the modules) had to be estimated. The data of the wiring could easily be entered into the software, only the length of the cables had to be varied. As the modules were clean, no decrease due to dust on the modules was assumed. Mismatch was taken into account with 2 %.

The simulation could easily be carried out. Both PVSOL and PVYST apply hourly steps.

2.3.5 Comparison Simulation Results versus Reality

A comparison of the real and simulated yield can be seen in **Figure 3**. The real yield is equivalent to the mean value of the measured yields in Figure 1.

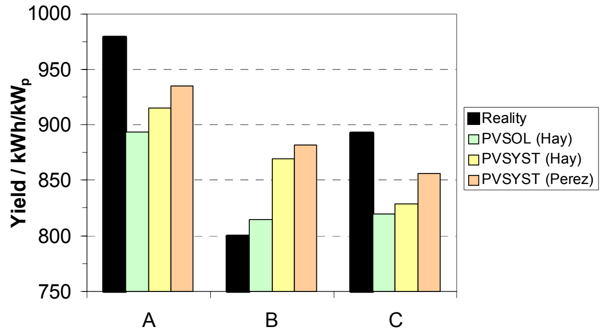

Figure 3: Comparison of real and simulated data

For PV systems A and C the real yields are higher than the simulation. Compared to the mean yield of the simulation the reality of A is 7,1 % higher, B is 6,5 % lower, and C is 7,0 % higher. It should also be noted, the Perez model is nearer to reality for A and C. The reasons for these deviations may be the following:

- A high degradation of 10 % had been assumed; obviously this was too much considering A and C.
- PV system B had experienced several outages of the inverter due to construction works at school and in one year inverter B has been switched off frequently by pupils.

3. LARGE SYSTEM

The system selected for the comparison of reality to simulation is the PV generator on the roofs of the six northern halls of the New Munich Trade Fair Centre with a peak power of 1016 kW_P. This generator has 7812 frameless solar 130 watt modules SM130-L with 84 monocrystalline silicon solar cells made by Siemens Solar. The system consists of 12 generators. Two generators on each roof are asymmetric and consist of 30 and 32 strings in parallel, respectively. Each string has 21 modules in series.

The Simulation software INSEL [1] has been applied to carry out the following simulations.

3.1 Module Data

Measured module IV curves have been used to fit the two diode model parameters. Twelve modules have been measured; the data of the one who was closest to the name plate normal power were selected for simulation. For comparison the parameters have also be calculated only on the basis of the data sheet information.

Figure 4 indicates measured and simulated voltage current characteristics and DC power output of the module selected. The measured data (red curves) are almost completely covered by the two diode model fit (green curves). The parameter determination from data sheet values (blue curves) shows a poorer performance in the mid-voltage range.

The simulation model is based on the time series of the measured global radiation in the module plane and the hourly values of measured ambient temperature data. No loss mechanisms like imperfections of the maximum power point trackers, mismatch losses, reflection losses, cable and connection losses have been considered in this calculation.

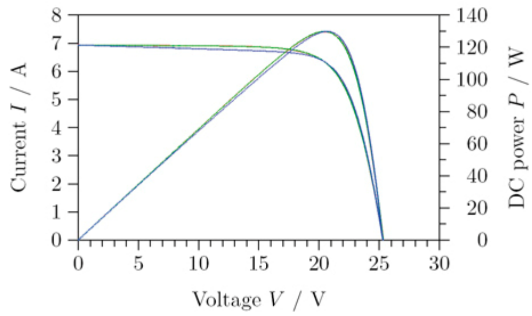

Figure 4: Measured and simulated IV characteristic and DC power output of the module selected

3.2 Simulation

Simulations of the two cases on the basis of measured irradiance data in the generator plane and ambient temperature data lead to the result in **Figure 5**. It shows real measured DC energy yields in 2004 and the simulation results; on the base of data sheet and measured data. The total annual deviation between simulation and measurement is +5,2 % in case of the fit with measured data and -1,4% for the data sheet case. Of course, this does not mean that the data sheet approach is more accurate since cable losses, mismatch losses have not been considered.

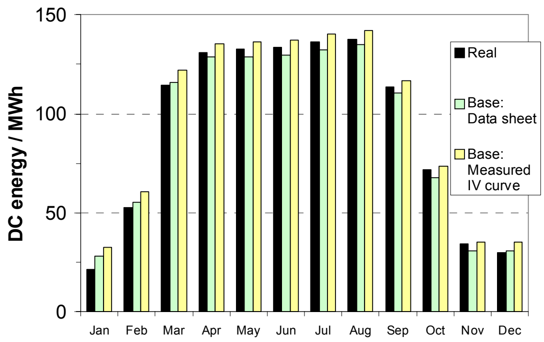

Figure 5: Real measured DC energy, simulation results on the base of data sheet and measured IV curves

4. CONCLUSION

The simulation of the small systems with two software tools shows that the results are not too far away from reality. Great influences on the simulation results are coming from the adjustable parameters such as degradation. A very important factor is the selection of the model for the transformation of the irradiation on the tilted plane.

For the large system it has been demonstrated that ideal information about meteorological data, measured voltage current characteristics and the application of the two diode model of INSEL leads to accurate results.

5. REFERENCES

[1] Luther, J., Schumacher, J., INSEL – A simulation system for renewable electrical energy supply systems. Proceedings 10th. European Photovoltaic Solar Energy Conference (475-470), *Lisbon*, Portugal, April 1991