

## AN APPROACH TO THE IMPACT OF SNOW ON THE YIELD OF GRID CONNECTED PV SYSTEMS

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**ABSTRACT:** Although most of the yield of grid-connected systems will occur in summer, snowfall may decrease the yield considerably. The impacts of snow depend on many parameters such as the height of snow, its weight or the tilt angle of the modules. The analysis of the reference plant shows that the reduction of the annual yield in the Degrees of latitude of South Germany is perceptibly. This is an important information for instance for the construction of plants or the issue of yield prognosis.

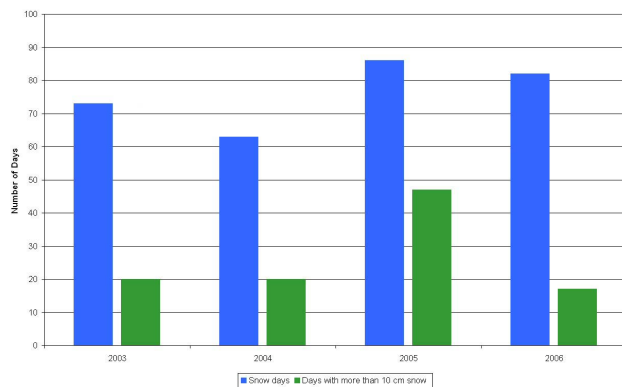
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### 1 INTRODUCTION

The heavy winter 2005-2006 in Germany had impact on the yield of grid-connected PV systems. The analysis of long-term data sets from PV-plants in south-east Germany illustrates that this impact is perceptibly throughout all PV-plants investigated. It is the goal of this work to describe the operational performance under snow conditions and to quantify this impact. Further steps for the investigation of this topic are in preparation. There are many parameters on which the decrease of yield due to snow depends, i.e.

- Type of snow, i.e. fresh-fallen snow or old snow
- Global radiation
- Ambient temperature and module temperature
- Atmospheric humidity (microclimate)
- Tilt angle of the modules
- Type of mounting system (specific characteristics)
- Set-up of the modules
- Distance of the modules to the ground

Figure 1 is based upon weather data of Germany's National Meteorological Service (DWD) and gives a general impression about the snow situation for Munich (Germany) in the years 2003 to 2006.



**Figure 1:** The blue (left) bars show the number of days with snow, the green (right) ones represent days with snow heights > 10 cm. Source is (1).

It is the aim of this paper to demonstrate the effects of the snow by the aid several PV systems in the greater Munich area. The reference plant is a rooftop system with about 1 MW<sub>p</sub>.

### 2 THE REFERENCE PLANT: 1 MW<sub>p</sub> ROOFTOP SYSTEM (NEW MUNICH TRADE FAIR CENTRE)

The photovoltaic rooftop plant – see Figures 2 and 3 – is mounted on the roofs surfaces of the six northern halls of the New Munich Trade Fair Centre is one of the worlds largest. The PV generator consists of 7812 frameless solar modules with an output of 130 watt which is equivalent to 1016 kW<sub>p</sub> in total. There is a total roof surface of 66.000 m<sup>2</sup> on the six halls available. Solar modules are mounted on 38.100 m<sup>2</sup> of this area. It was connected to the grid in November 1997.



**Figure 2 and 3:** Modules of the 1 MW<sub>p</sub> system in summer and winter

The PV-modules (SM130-L, Siemens solar) are aligned to the south, have a tilted angle of 28° and are interconnected on three inverters with 330 kVA nominal power, which work in the Master Slave Slave operation mode.



**Figure 4:** Sensor arrangements of the reference plant

The PV-plant is equipped with a substantial measuring technique. A total of 468 measured values are acquired as minutely instantaneous values. Among other values - with a Pyranometer the horizontal irradiation, the ambient temperature and with two reference modules the irradiances on module level as well as the module temperature are recorded. Additionally very detailed measured values of the plant are available. The measured values are stored with the software WINCC and were then written into a MySQL data base.

The MySQL data base being developed and still cultivated has an extent of 3.2 Giga Byte. The data base is continuously maintained and will be constantly extended. Also the inquiries of the data base will run through further development. The data base to the reference PV-plant has thereby over 3.6 million lines with meteorological and operation performance data measured values in over 200 columns.

In the current project status the evaluation is made by MySQL data base inquiries using MatLab. Several criteria and algorithms were developed to identify and to monitor certain weather and plant conditions and to derive correlations. For this analysis a multiplicity of functions in MATLAB for the two and three-dimensional presentation of numeric data was applied.

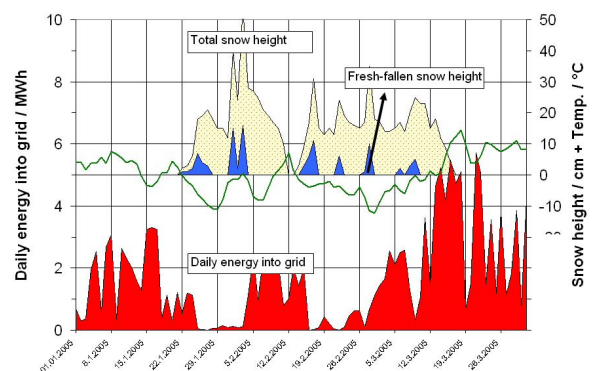
Figure 4 shows the actual arrangement of some of the sensors which caused difficulties in analysing the snow situation and its influence upon the correlation between the energy meteorological status and the operational performance of the plant. Therefore the data coherences were examined very accurately and special data base inquiries were developed.

In the data base the minutely mean values (calculated from secondly instantaneous values) of the years 1998 to 2006 are provided, whereof the following parameters for the analysis were regarded: horizontal irradiation, ambient temperature, irradiation on reference cell, temperature of the reference cell, DC performance of the entire plant and DC performance of partial generators.

### 3 ANALYSIS OF THE DATA BASE AND DERIVATION OF FIRST RESULTS

With these measured values of the data base and the snow heights of the DWD, the influence of the snow on the yield of the plant was examined.

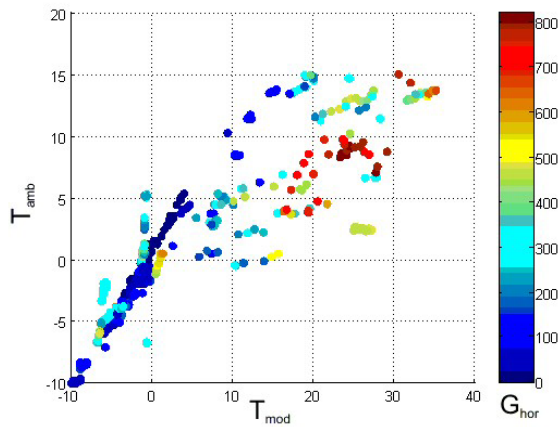
Basically it must be distinguished between the old snow and the fresh-fallen snow. On days when fresh snow arises, the irradiation also is very small, i.e. the influence on the yield is negligible. The situation is different if it snowed over a longer period and if the modules have a remaining snow cover. If sunny and cool days follow after such a period, then the plant can only convert a fraction of the irradiation available.



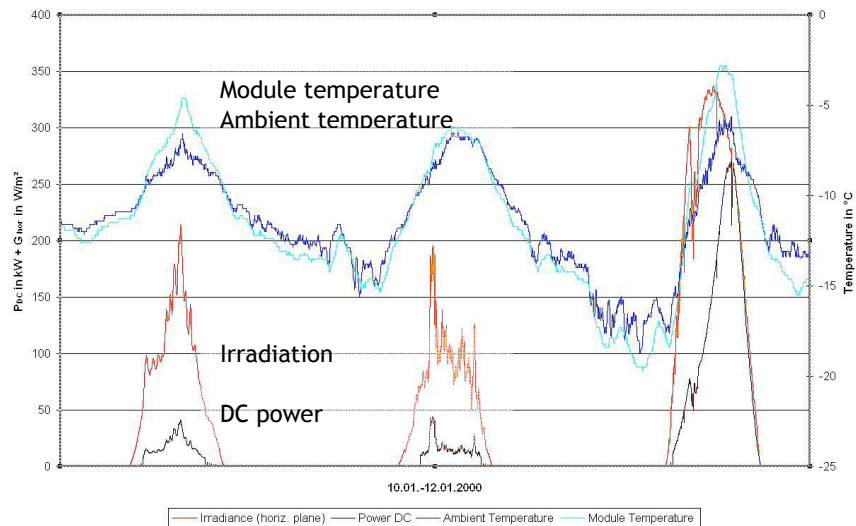
**Figure 5:** Influence of fresh fallen snow and total snow height on then energy yield (1)

In Figure 5 it can clearly be seen that the most important factor on the daily output energy is the fresh fallen snow. In the time around the end of January 2005 there are two periods of fresh fallen snow. The daily output energy goes to zero. Additionally in this period there is a total snow height of more than 40 cm which drops the yield as well. However in the first decade of March total snow heights of 20 cm occur with not so much fresh fallen snow. The energy yields do not decrease as much as in January. A correlation between the incidence of fresh fallen snow and decrease of yield is obvious.

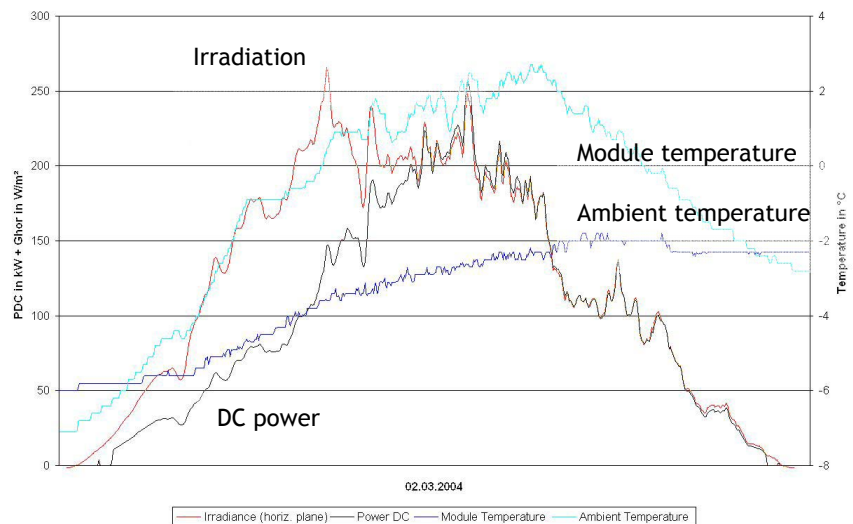
Very interesting is also the observation of the slipping procedures of snow mantles upon the PV-modules. The slipping sequence of snow is caused by diverse parameters (irradiation, ambient temperature and module temperature). As pictured in figure 6 already at small irradiation values of less than 100 W/m<sup>2</sup> and module and ambient temperature values less than 0°C the snow on the modules could begin to slip. These events also occur even at -10 °C ambient temperature, at -10 °C module temperature and relatively low irradiation values. The run of the curve in Figure 6 has a relatively slow increasing gradient. This leads to some interesting conclusions. Within the recording period the slipping procedure of snow constantly started with an ambient temperature of less than 15 °C. Also interesting is that warm modules do not lead by any means to a slipping procedure of snow. This speaks against theories to operate PV-modules over a short time-period as load to get the PV-modules free of snow.



**Figure 6:** Site conditions (irradiation, ambient temperature and module temperature) at that time when a slipping procedure on the solar modules was recorded. These slipping procedures of snow are also reflected through other diagrams showing the operation performance.



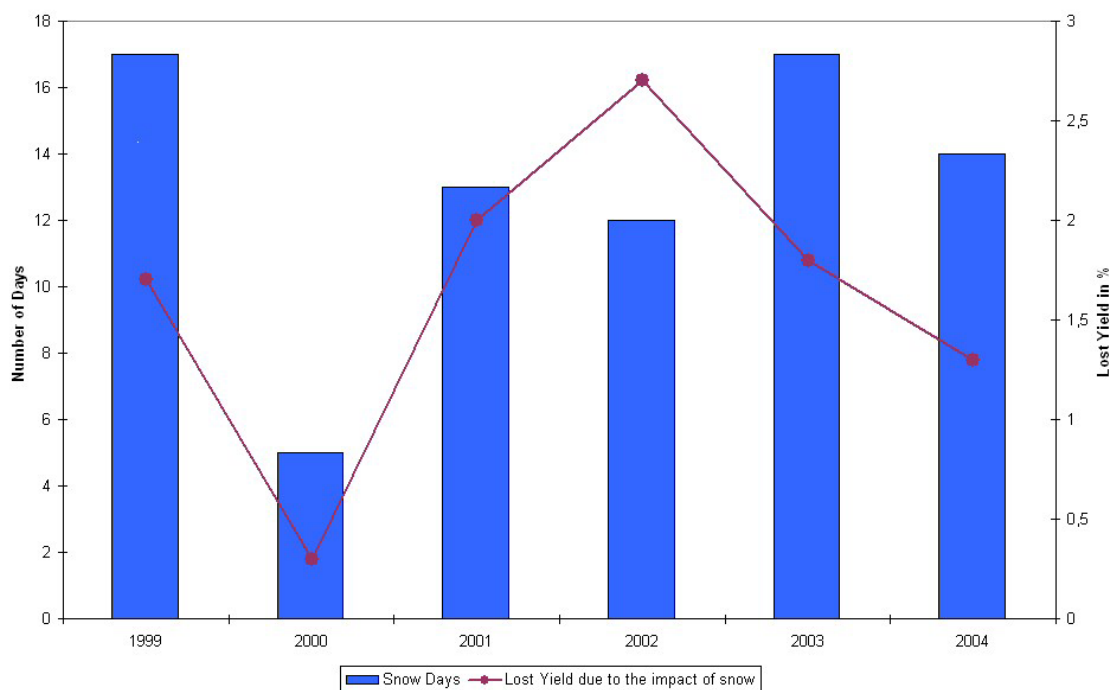
**Figure 7:** Operational performance of the reference PV-plant over a three day time-period. The upper dark blue curve marks the ambient temperature, the light blue curve is the module temperature, the red graph shows the irradiation and the brown curve displays the developing of the DC power.



**Figure 8:** Operational performance of the reference PV-plant for one single day (2. March 2004; same colours used as in figure 7). The effect of the slipping procedure of snow on the plant performance can clearly be seen.

The operational performance of the reference PV-plant over a three day time-period showing a slipping sequence of snow is displayed in Figure 7. The ambient temperature and the module temperature move between -3 and -20 °C. The irradiation remains under 200 W/m<sup>2</sup> and remains on the third day under 350 W/m<sup>2</sup>. On the first two days the plant is nearly completely snow-covered. The plant starts only briefly and only a fraction of the irradiated energy could be used by the PV-system. Interesting is also the beginning slipping procedure of snow at temperatures of -10 °C. Figure 8 displays the gradual slipping procedure of snow until at noon the system is working without limitations.

A rough estimation of the yearly yield reduction by snow is very interesting. The purple curve figure 9 gives an estimation of yearly lost yield by snow covered modules. The values for the proportional annual yield decrease by snow lie between 0.3 and 2.7%. This value is confirmed by operational experiences of other plants.



**Figure 9:** The blue bars show the number of days at which the reference PV-system was covered with snow. The purple curve gives a percentage estimation of yearly lost yield by snow covered modules.

#### 4. CONCLUSIONS

The present work shows interesting points, but for universally valid results more detailed measuring campaigns are required. In the future following steps are planned to be taken:

- A) Improvement from the measurement equipment
  - Usage of heated pyranometers
  - Installation of more webcams to verify the slipping procedure of snow
  - Usage of a thermography camera
- B) Usage of remote sensing technology to determinate the snow coverage from satellite pictures
- C) Data sets from more PV-plants
  - Detailed monitoring from three different grid connected PV-Plants on the University of Applied Sciences Munich
  - Installation of a special test equipment to mechanically adjust the moduls in different angles

With this results it will be tried to find a additional simulation parameter for PV-simulation-programs to consider the average impact of snow on the yield.

#### 5. REFERENCES

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- (2) Becker G., Giesler B., Kumerle G., Rehm W., Schiebelsberger B., Weber W.; More Than 6 Years of Operation Experience With A 1 MW Photovoltaic Power Plant - Highlights and Weak Points -; 19th EPVSEC, Paris