VERIFICATION OF MEASURED PV ENERGY YIELD VERSUS FORECAST AND LOSS ANALYSIS

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ABSTRACT: Yield forecasting of the commercial design tool PVsyst (v5.6) is compared to the performance measurements of multi crystalline modules in Dietikon, Zurich, during 2011. The total measured horizontal irradiance was 1146 kWh/m^2 in 2011. This pyranometer measurement covers 91.5% of the total annual irradiance (determined using IDAWEB data with 100% uptime for Affoltern). The historical irradiance data averaged over decades are about 11.4% (Meteonorm) or 13.6% (PVGIS) lower than the IDAWEB data in 2011. The standard deviation between 2001 and 2011 is about 4.9% with respect to IDAWEB. The measured DC performance ratio (PR_{DC}) is 0.937 with a measurement uncertainty of ±0.031 (k=2). Simulations with manufacturer and optimised parameters showed a deviation to the measurement between 4% and 8%. A second analysis considers shading losses for different shading angles. Calculated losses are about 2% lower than simulated losses with PVsyst using a model of partial shading for a shading angle of 20°. Interesting results could be achieved by determining the loss upon limiting the inverter output power. There is only 4.4% annual loss when the inverter output power is set to a limit of 70 % for the location Dietikon in 2011.
Keywords: Performance, Yield Forecast, Shading, Inverter

1 INTRODUCTION

The prices of solar cells decreased rapidly during the last years. Notwithstanding the economic performance of the PV plant is still very important [1]. The trustability of the predicted energy yield is one of the most essential parameters with respect to economic efficiency and financing. But it is also one of the most uncertain factors during the installation and planning phase. To improve the quality of design of a PV plant, it is necessary to use PV software planning tools which deliver realistic forecasts. Last year, a study was undertaken to evaluate four PV modelling software tools [2]. The study compared the predicted energy with the measured energy in Spain. The current paper is focused on comparison of high quality outdoor performance measurements with simulations performed by PVsyst (v5.6). Furthermore, losses due to mutual shading and inverter limiting are also analysed. The used data are measured at the EKZ reference PV power plant in Dietikon, Zurich, CH. The analysis is part of a multiple year joint research project, whose team includes an electric utility (EKZ), a provider of thin film photovoltaic production solutions (TEL Solar) and a university (ZHAW).

2 APPROACH

This paper is focused on the multi crystalline silicon PV modules. Therefore, the results are only valid for this technology. Since December 2009, multi crystalline modules from Sunways have been installed on the roof of a building in Dietikon. There is a grid connected string and one reference module whose IV characteristics are measured every minute. The electricity generated by the string is fed into the grid and is monitored precisely on the DC and AC side of the inverter. Pyranometers (CMP 21 Kipp & Zonen), filtered and non-filtered mono crystalline silicon reference (ISE HOQ (unfiltered), and KG3 and KG5) cells are mounted horizontally (pyranometer, ISE HOQ) and in the PV module plain (all) in order to measure the irradiance [3,4].

The analyses presented in this paper are based on the measurements from 1st January to 31th December 2011. The measurements are minutely mean values except DC power measurements. These measurements are logged at the beginning of each minute (minutely momentary). The used data sets, their uncertainties and uptimes are shown in table I. The downtimes are due to software updates, monthly sensor cleaning, yearly flasher measurements, measurement software errors, and computer and server maintenance. The low uptime of the DC power measurement is caused by an inactive measurement device during the night time.

Table I: Comparison of different sensors installed in Dietikon with their uncertainty values (k=2) and uptimes. All sensors are logged as minutely mean values except the DC power measurements which are logged as minutely momentary values. The DC power measurement does not work during the night (low uptime).

Sensor	Uncertainty [k =2]	Uptime
Pyranometer CMP 21 horiz.	1.2%	97.5%
Pyranometer CMP 21 tilt 30°	1.2%	97.7%
ISE cell HOQ (unfilt.) horiz.	2.4%	96.0%
ISE cell HOQ (unfilt.) tilt 30°	2.4%	96.0%
DC power (Agilent N3303A)	0.6%	46.6%
AC power (Sineax A320s)	0.8%	98.2%

In the chapter yield forecast verification, more than one data set are being used. Therefore, all utilised data sets are synchronised to achieve comparability. The resulted synchronised data set covers 91.5% of the total annual energy yield and has an uptime of 40.1%. This analysis is described in the next chapter.

The calculated performance ratio is based on minutely mean (pyranometer) and minutely momentary (DC energy) data because the DC power is only available as momentary value. Calculations based on minutely momentary data for pyranometer and DC energy provide only a 0.1% lower PR.

The investigation is focused on the yield forecast verification, the shading losses, the yield dependency on the angle of incidence (AOI), and the losses due to AC power limiting.

3 YIELD FORECAST VERIFICATION

PV power plant planners use commercial PV design tools in the planning process. Often there are no detailed indications about uncertainty of the predicted energy yield available. But the yield is one of the major quantities that indicate the economic performance such as return on investment.

The commercial PV design tool PVsyst is used to verify the yield simulation with annual yield measurements of the multi crystalline reference module. In the simulation irradiance planning data from JRC PVGIS Classic [6] and Meteonorm [7] as well as pyranometer measurements are applied.

The top five data sets of table I with different uptimes are used for the verification. In order to compare the data, a synchronisation is needed. Additionally, only irradiation measurement values greater than 10 W/m^2 are taken into account while eliminating offset errors during the night. The energy content of these sets can be determined using irradiance data (2011) from IDAweb (data portal MeteoSwiss) [5] with an uptime of 100%. As MeteoSwiss doesn't measure the global irradiation in Dietikon (385 m above the sea), the global irradiation in Zurich (Affoltern, 443 m above the sea level) has been taken. The distance to the analysed location is 8 km. PVGIS and Meteonorm predict 1.2% and 1.8% higher annual irradiance for Affoltern than for Dietikon.

The IDAweb data has a resolution of ten minutes and an uptime of 100%. The total measured irradiation is 1248.3kWh/m^2 in 2011. The data was converted to a resolution of one minute using the approach of constant value during ten minutes. After that, the synchronisation was done. Finally, the resulted synchronised data sets with an uptime of 40.1% cover 91.5% of the total annual energy yield (see table II) with respect to IDAweb (sync).

Table II shows the annual horizontal irradiation measured by the pyranometer and the unfiltered ISE (Fraunhofer Institute for Solar Energy Systems) reference cell (not temperature corrected). Spectral behaviour and angle dependency are the main differences of the applied sensor technologies. The deviation between pyranometer and reference cell measurements is 4.8% (horizontal) and 3.4% (30° tilted). For the sake of completeness, the historical data and the IDAweb data are also illustrated in Table II.

Table II: Comparison of different irradiance data in kWh/m^2. The measurements in Dietikon and the IDAweb (Affoltern) data from 2011 as well as historical data of JRC's PVGIS Classic [6] and Meteonorm [7] are shown. PVGIS and Meteonorm data for Dietikon are interpolated. The top three irradiance data are synchronised.

Data [kWh/m^2]	0°	30°	year	uptime
Pyranometer CMP 21	1146	1324.6	2011	40.1%
ISE cell HOQ (unfilt)	1090.9	1285.7	2011	40.1%
IDAweb (sync.)	1142.8		2011	40.1%
IDAweb	1248.3	-	2011	100%
JRC PVGIS	1078.1	-	1981-1990	100%
Meteonorm I	1103.7	-	1981-1990	100%
Meteonorm II	1108.7	-	1986-2005	100%

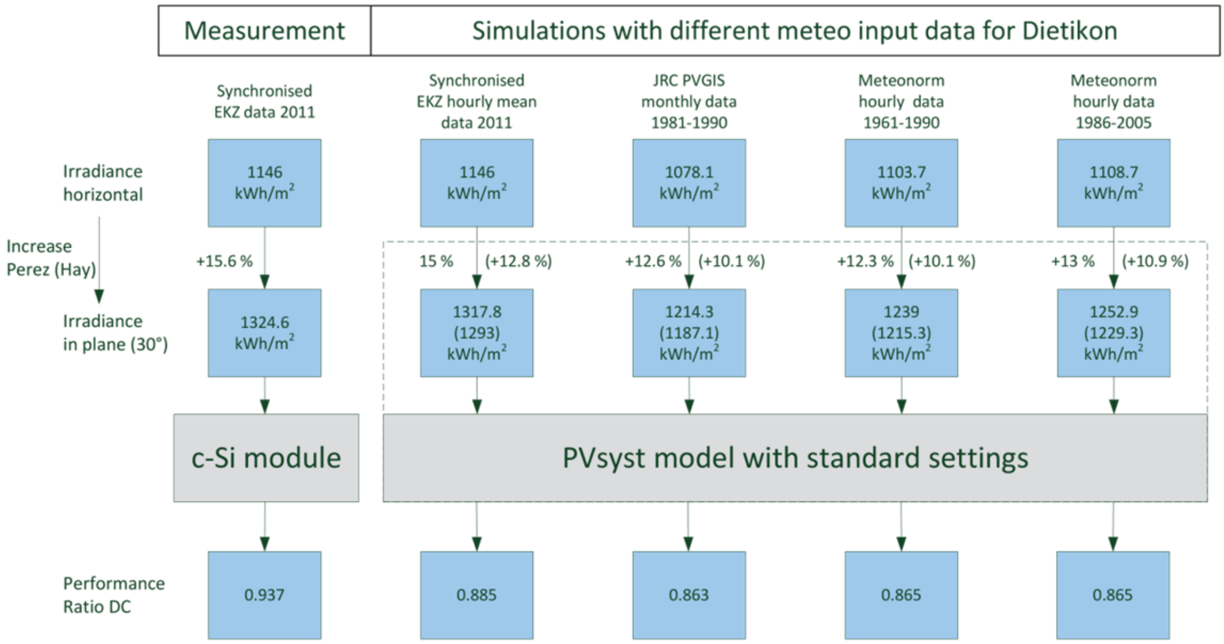

Figure 1: Horizontal and in plane (30 °) pyranometer measured solar irradiance in 2011 in the left column versus PV planning data from JRC PVGIS (monthly data), Meteonorm (hourly data) and own hourly data calculated from minutely measured EKZ data. The differences of the measured DC yield and PR of multi crystalline technology are found using the different meteo input data. The transformation from horizontal meteo data to in plane meteo data is based on the Perez model (Hay model in brackets).

The new PVGIS CM-SAF database is available [6]. Therefore, the horizontal irradiation is only 2.7% lower than the horizontal irradiation determined by IDAWEB.

The installed reference module (SM210U) and the simulated module (SM210U) [8] from Sunways have a nominal power of 230Wp. The first simulation is done using the standard settings with PVsyst and different meteo data. Simulations with historical average data require a horizon so that they can be compared with the measurements. The reason for this is that the pyranometer measurements are affected from the horizon compared to historical averaged data (satellite measurements or horizon corrected radiation). Ohmic wire losses and array mismatch can be disregarded due to four terminal sensing and the single module measurement. The measurements and simulations are shown in figure 1.

The annually measured horizontal solar irradiance by pyranometer is 1146 kWh/m^2. The in-plane measurements are 15.6% higher. It should be noted that these values cover 91.5% of the annual irradiance with respect to the IDAweb data. The three historical average planning data are 11-14% lower than the IDAweb data in 2011. The calculated increase from horizontal to in-plane irradiance is 10-13% using the Hay model and historical irradiance data.

The measured PR of the reference module in 2011 is 0.937 ±3.3% (k=2). It is calculated using flasher measurements (227.4W) and the pyranometer irradiation. The simulated PR (referred to label) done with historical meteo data differs by up to nearly 8%. The best modelled PR is reached by using measured meteo data and is still 5.6% lower than the measured PR.

Improvement will be achieved with a second PVsyst simulation with optimized parameter settings described below.

- First, the transformation of horizontal irradiance into the module plain is done by the Hay model (increase of 10-13%) in PVsyst. The use of the Perez model (instead of Hay's) results in an increase of irradiation by 12-15% referring to the horizontal irradiation (see figure 1). The measurements show an increase of 15.6%. This improvement doesn't affect the PR significantly.
- Second, flasher measurements done in April 2011 [3] replace the manufactures nominal STC values given for all the modules in this class. These measurements are done with the Swiss mobile flasher bus (SMFB) [9,10] and have an uncertainty of ±3% (k=2). The module efficiency loss factor in PVsyst is set to 0.0% (standard value 1.5%)
- Next, the P_{MPP} temperature coefficient (TC) of -0.45%/K analysed from the outdoor measurements in 2011 [3] has been entered. The manufacturer data sheet value is -0.43%/K. In addition, the Normal Operating Cell Temperature (NOCT) for this technology was determined (manufacturer value 45°C). The measured module temperature values were selected for the meteo condition 800W/m^2 ±50 W/m^2 irradiation, 20°C ±2°C ambient temperature and 1m/s ±0.3m/s wind velocity. This selection (about 1000 data points) results in an average module temperature of 43.5°C. This measured NOCT value for the mounting condition in Dietikon (figure 2 in [9]) was used as an input parameter for the PVsyst simulation.
- Finally, there is a limited way to implement low light behaviour. In 2011, a comparison between the SMFB and stationary calibration laboratories was made [10]. JRC in Ispra made advanced performance analyses of the multi crystalline module (uncertainty: ±2.1% k=2). It was found that the efficiency at the irradiance of 200W/m^2 is 5.3% lower than STC. PVsyst modelled a reduction of 9.5% relative to STC. But adjusting this behaviour in PVsyst is not possible by a simple parameter without affecting the measured STC values.

The simulated PR from measured irradiation data could be improved from 0.885 to 0.9 using the optimized parameter settings. This is still 4% lower than the measured value. The determination of the nominal power with the SMFB gives the largest uncertainty (3% at k=2) [9]. Therefore, it is a dominating factor of the uncertainty of the measured PR. It should be noted that the direct comparison of measured crystalline modules between SFMB, JRC and ISE showed a difference for the measured values of about 1% [10]. The 4% exceeds this uncertainty. The suggested reason for that is mainly attributed to the limiting modelling of the low light behaviour and angle of incidence (AOI) behaviour. Improvements in PVsyst model for low light behaviour are expected in the next version [11].

4 ENERGY MAPPING, ANGLE OF INCIDENCE AND SHADING LOSSES

This chapter discusses the influence of shading losses. But first, a particular kind of yield representation will be introduced. Shading losses can be calculated, based on the yield mapping and compared to literature and simulation. In this analysis, the measurements of the multi crystalline reference module are used again. This module is located at the front and it finds no mutual shading.

4.1 Energy mapping and angle of incidence

A grid with a mapping interval of 2.5° for elevation and 5° for azimuth is built and the yield in each raster element is calculated. The limits are 68° and 308° for azimuth angle and 1° and 68.5° for elevation angle, respectively. Additionally, the shading limit (red curve) is drawn for a shading angle of 20° (see figure 2).

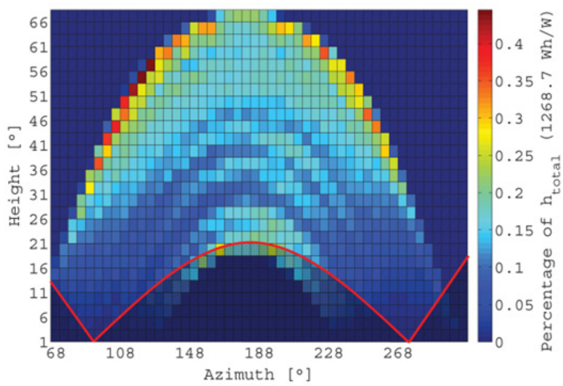

Figure 2: Mapping of 2011 annual PV electricity production of a 30° tilted south oriented multi crystalline silicon reference module depending on the direction of the direct sun beam (location Dietikon, Zurich). Shading limit due to shading angle of 20° is shown in red.

The total yield in 2011 corresponds to 1268.7Wh/Wp. The produced yield around the summer solstice (two month are taken into account) is 23% of the total yield. 6% of the total yield accounts for the winter time (also two month). Longer sun paths located in figure 2 with less electricity production are not based on data outage but rather on cloudy days.

Another view regarding the yield distribution is done in figure 3. For each pair of elevation and azimuth angle there is a corresponding angle of incidence. The operation is not bijective because different sun positions have the same AOI. The black bars in figure 3 show the frequency of occurrence of AOI for one year. The used interval is 5°. Red and cyan bars illustrate the yield for one AOI interval and represent pyranometer and multi crystalline silicon module technology, respectively. Most of the electricity is produced at an AOI lower than 45°. The frequency of occurrence (AOI < 45°) amounts to 43.2%. The resulting percentage of the total yield for an angle lower than 45° is 69.1% for the pyranometer and 68.6% for the multi crystalline silicon module, respectively. The angular behaviour with respect to AOI below 35° is better for the pyranometer. This behaviour changes between 35° and 65° in favour of the multi crystalline silicon technology. The pyranometer technology has again a better behaviour over 65°. The measured data according to figure 3 clearly shows very small deviations in energy density per AOI between pyranometer and multi crystalline technology. Due to physical principles, higher optical reflection for the crystalline module is expected at higher values of AOI compared to pyranometer. This ends up in a lower yield for the crystalline module. The measurement evidence doesn't show this behaviour in yield. It is expected that a lower module temperature at higher AOI values compensates this effect. For more detailed analysis, the change of spectrum at higher AOI has also to be taken into account.

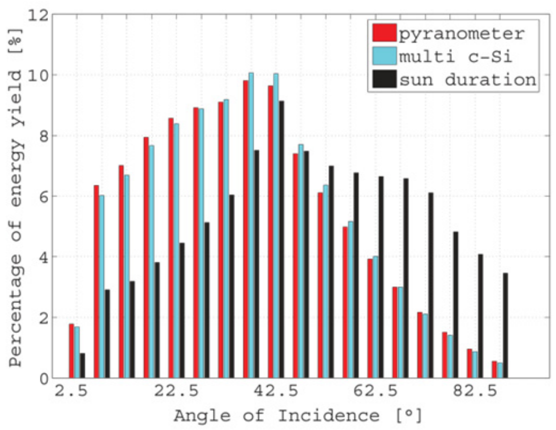

Figure 3: Yield depending on angle of incidence (5° resolution) for 30° tilted south oriented pyranometer (red) and multi crystalline silicon (cyan) technology in Dietikon, Zurich (2011). Black bars show the frequency of occurrence of angle of incidence for one year.

4.2 Shading losses

The same mapping as in figure 2 was also done with a grid of 1° for azimuth and height. This grid, with a better resolution, is needed to reduce the systematic error of the discretisation. The measured module is not affected by shadow of another module. Consequently the shading losses for different shading angles could be calculated using different models. The shading impact is calculated for each grid element. In the model A, the total yield is lost if the shadow hits the reference module. That means that the partial shading has the same effect as the full shading. This ends up with an overestimation of the losses. The model B delivers different yield losses depending on the sector where the shadow occurs. There are three sectors according to the by-pass diodes. If the shadow line is located in the lower third the losses are 1/3 of the yield. The losses are 2/3 in the middle third and 3/3 in upper third. This loss classification into three areas is also used in the model C. For shadow in the lower third, the losses are still 1/3. In all remaining cases, the yield is reduced to 10% assuming that 10% of the global irradiation is diffuse irradiation. This situation is more realistic due to the limited voltage range of each inverter. The inverter cannot operate at one third of the voltage. It will rather operate at higher voltage and therefore, the current is limited by the diffuse irradiation. The results are compared in figure 4 with reference [12] and PVsyst (v5.6) simulations. PVsyst will improve the shading calculations in the next version [11]. Additionally, the shading losses at shading angles of 10°, 15°, 20°, 25° and 30° are listed in table III.

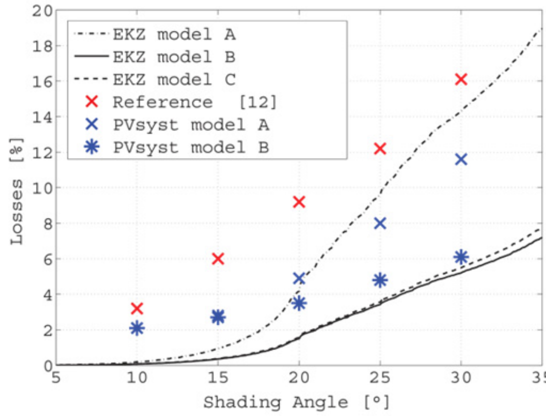

Figure 4: Shading losses calculated from the 1° mapping for different shading angles versus predicted shading losses by the commercial PV software PVsyst v5.6 and reference data [12]. Three models are used for EKZ and two for PVsyst. Model B and C consider partial shading.

Table III: Calculated shading losses in % sorted for different shading angles and different sources (see also figure 4). The location is always Dietikon except the reference [12] (Berlin). The top three are based on the same model (partial shading = full shading). The lower three consider partial shading in different ways.

Data source	Losses at diff. shading angles in %				
	10°	15°	20°	25°	30°
EKZ model A	0.2	0.9	4.2	9.6	14.3
PVsyst model A (simulated)	2.1	2.8	4.9	8	11.6
Reference [12] (Berlin)	3.2	6	9.2	12.2	16.1
EKZ model B	0.1	0.4	1.5	3.4	5.2
PVsyst model B (simulated)	2.1	2.7	3.5	4.8	6.1
EKZ model C	0.1	0.4	1.6	3.6	5.5

In PVsyst, two models are verified. The model A considers no partial shading. For model B, three strings (each with 2 x 15.6cm width) are set up and the electrical effect for the mutual shadings is used for the simulations.

There are great deviations of the shading losses with respect to the same angles. The losses for the used standard angle of 20° vary between 1.5% and 4.9%. The losses according to EKZ A, PVsyst A and reference [12] are based on the same model. It is important to know that the literature data are published in 1998 for the location in Berlin. PVsyst B and EKZ B are regarding the partial shading (as described above).

The PVsyst calculations for model A and B show the same losses for shading angles of 10° and 15°. Above these angles, the more accurate model has smaller losses. The losses calculated with the measured data (EKZ A) are lower than the losses of PVsyst A with respect of angles of 10°-20°. Using model B shows that the losses at EKZ B are always lower than the losses of PVsyst B. The EKZ C and the EKZ B show the same results. The losses according to the reference [12] data are the highest. It is difficult to make a comparison with the other results because of the different location.

5 INVERTER OUTPUT POWER LIMITING

Until now, only undesired losses based on physical behaviour were discussed in this paper. But there could also be desired losses during sizing and planning of a PV plant. A future problem will be the peak installed PV power (STC). On one hand there is a problem when the produced solar electricity exceeds the demand. On the other hand electric utilities have to provide a larger grid connection if the installed PV plant capacity is larger than that of the power connection. Storage, East-West oriented plants, lower tilt angles and inverter output power limiting are only a few of the possibilities to solve or mitigate these issues. Since May, Germany has subsidized battery storage systems for PV power plants of up to 30kW. Owners of such battery system will receive 30% of the applicable costs of the battery system. But the maximal power fed into the grid must not exceed 60% of the installed capacity [13]. That is a new approach of funding PV energy and reducing feed-in capacity. This chapter discusses the losses as a result of limiting the inverter power without battery storage.

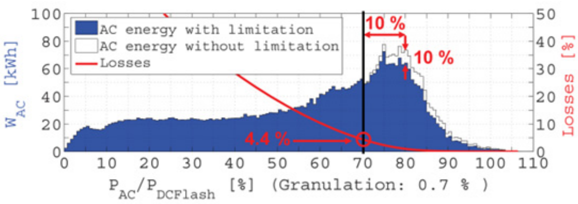

Figure 5: AC string energy distribution without inverter limitation (white, $W_{ACTotal}$ = 4103kWh) and output power distribution with inverter limitation at 70% (blue). The data are minutely mean measurements. The red curve shows the losses at different limitations (see table IV). A limit of 70% of nominal PV generator power results in 4.4% losses. 10.4% losses correspond to a limit of AC power of 60%.

Table IV: Losses according to the inverter limitation ($P_{AC}/P_{DCFlash}$) between 50% and 100%. These values originate from figure 5 (red curve)

Limitation [%]	50	55	60	65	70
Losses [%]	18.5	14.1	10.4	7.0	4.4
Limitation [%]	75	80	85	90	95
Losses [%]	2.3	1.0	0.3	0.1	<0.1

The multi crystalline modules (total 3.38 kWp based on flasher values) are connected to the Sunway NT4000 inverter (Euro-Efficiency 97.1%). The AC performance is measured minutely (mean) and therefore, the energy distribution in 2011 is shown in figure 5. The inverter limitation is marked at 70% (a solid black line). Therefore performance which exceeds this limit causes losses in yield. These losses are subtracted and drawn in the same plot. Annual losses for a limitation at 70% correspond to the integral of the difference of these two curves and amounts to 4.4% of the total annual energy (4103kWh). That is much less than intuitively assumed. Losses for other limitations are drawn with a red curve. Inverter output power limitations over 60% induce losses of 10.4% (see table IV). Figure 6 shows the yield (referred to flasher value) for each performance. The calculated losses depend on the used data resolution. Measurements with a resolution of 10s showed an increase in losses (0.5%) compared to the minutely averaged data (formed by averaging 10s data) [14].

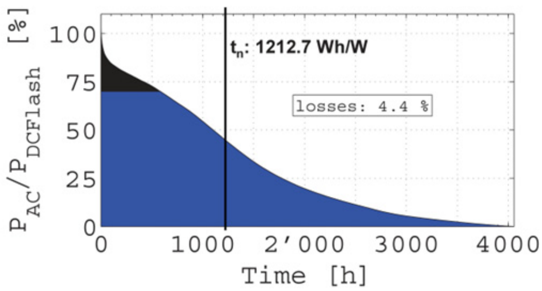

Figure 6: Reduction of the inverter output power relative to nominal power (determined by flasher measurements) by limiting the inverter's maximum AC output power to 70%. Annual AC yield is 1212.7Wh/W (without limiting) for the installed string power of 3.38kWp (Location Dietikon, Zurich).

Similar analyses have been done for PV plants with 1kW, 1MW and 2MW installed power, respectively [15]. It was concluded that the losses of the 1MW and 2MW plant, due to power limitation, are lower than the losses of the 1kW plant. Another conclusion was that larger PV plants are less susceptible to irradiation peaks. The reason for this fact is that irradiation peaks within the larger plant are damped). Losses of 2% (limitation of 77%) for the 2MW (multi crystalline) plant was simulated.

What is the advantage of this limitation? The owner loses 4.4% of yield every year when the inverter output power is set to a limit of 70%. Another possibility is to use an undersized inverter. Therefore the size will be reduced as well as its price. But the performance characteristics will also change. This fact cannot be neglected and the calculated losses will no longer be the same. Another fact in future is that peaks at noon cannot be fed into the grid due to oversupply. Electric utilities will also limit actual inverters power in certain markets (e.g. Germany) anyway. Thus, a system with undersized inverter is economically disadvantageous compared to a system with only output power limiting. Another problem exists from the perspective of the electric utility. The size of the grid connection has to be increased when maximum PV power exceeds the installed limit. Thus inverter power limitation could be an option to decrease the grid connection limit. The electric utility saves more money than the revenue that the losses would bring in. This comes at the cost of the PV owner. But maybe, the utility can pay them.

6 CONCLUSION

The annual irradiance measured with pyranometer in Dietikon correlates with IDAweb measurements after using synchronised data sets within 0.3%. The forecasted PR (PVsyst 5.6) for Dietikon is higher after using the optimized parameter settings. But it is still 4% lower compared to high quality outdoor performance measurements. This exceeds the uncertainty (±3.3% k=2) of the measured PR. It is expected that an improvement of low light behaviour adjustment will result in a PR within the measurement uncertainty. But the modelling of low light behaviour in PVsyst (v5.6) is very difficult if not impossible. The simulation tools are not directly able to implement module measurements based on international standards (IEC61853-1).

Three models are used for calculating shading losses. It is not accurate enough to use the approach that partial shading is equal to full shading. The deviations above shading angle of 20° are between 2.7% and 9.1%. The modelling of partial shading leads to lower losses. That is true for PVsyst simulations and calculations based on measurements in Dietikon.

Inverter output power limiting is a helpful instrument to reduce high power peaks in the grid without storage. The resulting losses for a limit of 60% or 70% are with 10.4% and 4.4% much lower than intuitively assumed. This method is financially interesting for PV plant owners (only if it is undersized from the beginning) and for electric utilities. Furthermore, it is one of the cheapest ancillary services for grid stabilization.

REFERENCES

[1] Arnulf Jäger-Waldau; PV Status Report 2012; JRC Scientific and Policy Reports, Ispra 2012

[2] D. Gonzàlez Peña et al.; Photovoltaic Prediction Software and their Evaluation with real Data in Spain; 27th EU PVSEC, Frankfurt 2012

[3] N. Allet et al.; Evaluation of PV System Performance of five different PV Module Technologies; 26th EU PVSEC, Hamburg 2011

[4] J. Sutterlueti et al.; Detailed Outdoor Performance Analysis of Thin Film and Crystalline Silicon Based Reference PV Power Plants in Switzerland; 3rd Int. Conference of Thin-Film Photovoltaics, Munich 2011

[5] MeteoSwiss IDAweb; http://www.meteoschweiz.admin.ch/web/en/services/data_portal/idaweb.html

[6] JRC Photovoltaic Geographical Information System Interactive Maps; re.jrc.ec.europa.eu/pvgis/app4/pvest.php

[7] Meteonorm; METEOTEST Genossenschaft; Bern http://meteonorm.com/products/meteonorm-*software*/

[8] Photon Solar Module-Database; http://www.photon.info

[9] T. Achtnich et al.; Swiss mobile flasher bus: Progress and new measurement features; 25th EU PVSEC, Valencia 2010

[10] F. P. Baumgartner et al.; Intercomparison of Pulsed Solar Simulator Measurements between the Mobile Flasher Bus and Stationary Calibration Laboratories; 26th EU PVSEC, Hamburg 2011

[11] PVsyst SA; Satigny Switzerland; http://www.pvsyst.com/en/software/software-development

[12] Volker Quaschning et al.; Increased energy yield of 50% at flat roof and field installations with optimized module structures; 2nd World Conference and Exhibition on PVSEC, Vienna 1998

[13] Sandra Enkhardt; Germany: PV storage subsidies expected in May; http://www.pv-magazine.com/news/details/beitrag/germany--pv-storage-subsidies-expected-in-may_100010135/#axzz2SdkS6tNu; PV Magazine 08. February 2013

[14] Bruno Burger et al.; Inverter sizing of grid-connected photovoltaic systems in the light of local solar resource distribution characteristics and temperature; www.sciencedirect.com; Science Direct Elsevier, October 2005

[15] Bodo Giesler et al.; Influence of Limitation on the MPP-Range from PV; 27th EU PVSEC, Frankfurt 2012