Design of PV Plants in Polystring Operation
– Optimization of Self-Consumption vs. Mismatch Loss –

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Introduction

Not least due to the amendment of the (German) Renewable Energy Sources Act (EEG) and falling investment costs, even PV plants with modules which are not optimally aligned are now becoming an economically attractive proposition. The typical specific energy yields of such plants are, of course, lower than those attained by optimally aligned plants. However, in the analysis of economic viability, there are other factors which also play a decisive role. Apart from the self-consumption of the generated solar energy, an increasingly important aspect is also the sizing of the inverter. With non-uniformly aligned module surfaces, less inverter power is required and hence the corresponding share of plant costs is reduced. Furthermore, in the case of such module alignments, we need to ask whether it is always necessary to install separate MPP tracking, or whether the module strings can alternatively be switched in parallel? Studies carried out on existing east/west-aligned plants in this kind of "polystring" operation suggest that only minimal yield losses result [1.3].

The partially counteractive aspects of plant design in question cannot be assessed without an individual simulation of the energy fed in and self-consumed. This paper will depict what possibilities we have for the design of plants with non-uniformly aligned module strings using the resources available to us today. In particular, we will be taking a look at the influence of module alignment on inverter sizing, yield, self-consumption, and also on the rate of return of the plant.

The information presented is of general interest for planners and operators of PV plants, and can make a positive contribution to analyzing the economic viability of such plants.

Inverter Sizing

The ratio of the maximum DC power of the inverter to the connected peak power of the PV array can be taken as the measure for sizing the inverters in a PV plant. This measure will be referred to in the following as the nominal power ratio = (NPR).

In the past, it has been shown that undersizing the inverter actually makes economic sense. However, the investment costs saved in the process need to be higher than the resulting yield loss. For Central Europe, a maximum yield loss of 0.2%, which corresponds to an NPR of 90%, has proved to be the optimum value [2]. However, this value is only valid for PV plants with ideal (south) module alignment. In the case of PV arrays which are not optimally aligned, e.g. installed on facades or east/west-aligned plants, their maximum power is reduced and therefore it may make sense to undersize the inverters to a far greater extent.

However, to carry out the plant-specific calculation of the lower limit for NPR, we need information on the specific energy distribution of the output power of the PV array. This is the only way to determine the maximum DC power of the inverter at which yield loss corresponds to 0.2%. It can be achieved on the basis of a time-step simulation of the generator power, which takes into account both the individual orientation of the PV array(s) and the climatic conditions of the location.

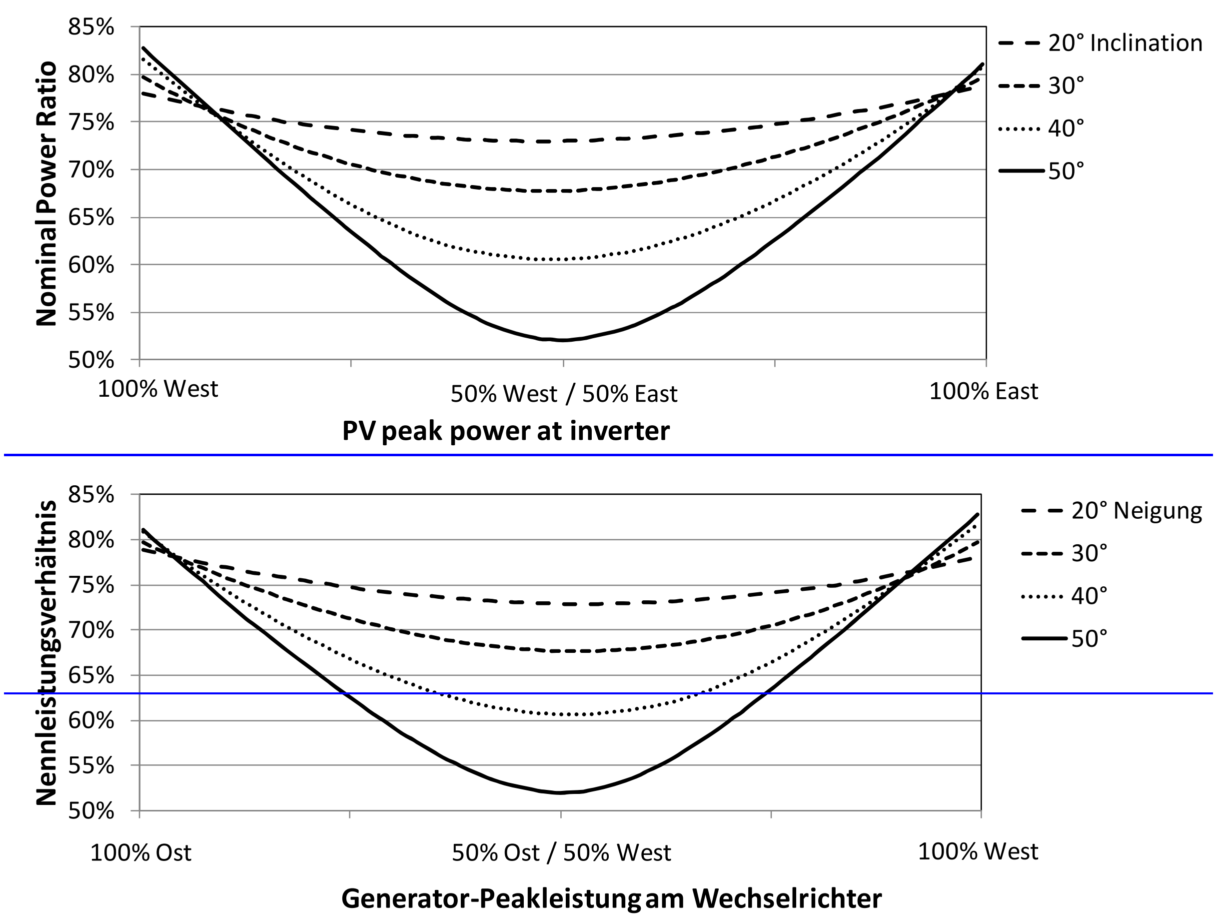


Figure 1: Plant-specific lower limit of the nominal power ratio for different mix ratios of substrings with east/west orientation at the inverter. The curves correspond to differing roof inclinations. A yield loss of 0.2% has been taken into account in the calculation.

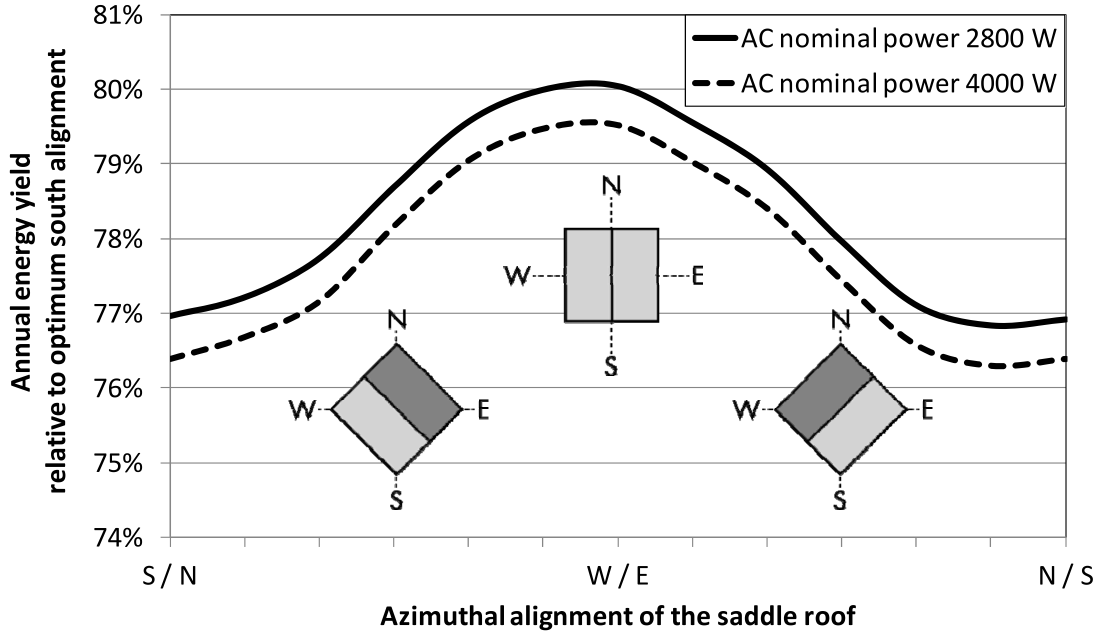
Figure 1 shows the result of simulations on a PV plant in Kassel with two substrings, one facing east and one west. The curves represent various roof inclinations.

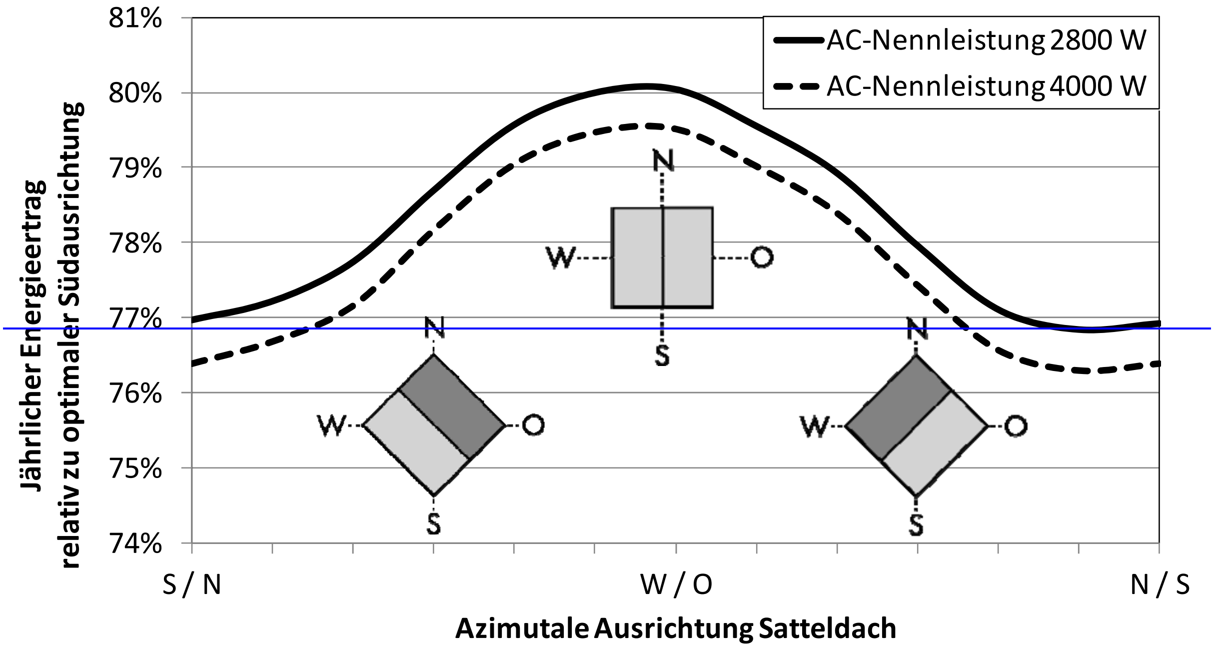
If the east and west-facing generators are each operated with a separate inverter (100% east, left, and 100% west, right), the NPR is approximately 80%, depending on the roof pitch. As expected, these values are lower than that achieved with an optimum south orientation (90%). A clearer sizing advantage is achieved if the PV arrays are operated jointly with one inverter. In this case, and assuming symmetric configuration (50% east, 50% west) and a roof inclinations of 40°, the lower limit for NPR is around 61%. This is due to the fact that the maximum power points of the east and west-facing arrays are reached at different times. Hence, over the course of the day the distribution of the energy supply evens out, and in total this results in a lower maximum power input at the inverter.

Yield Simulation

As we have just shown, inverter sizing is a factor which can provide significant cost benefits, particularly when operating east/west-oriented plants. However, such advantages are offset by the reduction in yield resulting from the non-optimal module alignment. What this actually means in quantitative terms will be investigated in the following.

The simulations presented here originate from a PV plant in Kassel with two module fields of identical power output, installed on opposite sides of a saddle roof. The inclination of the module surfaces is 40° from the horizontal. The simulations were carried out with varying azimuthal alignments of the roof surfaces. As point of reference, a PV plant of identical peak power[1], but with optimum south orientation, was also calculated (roof pitch 30°). The yield simulations were carried out with the design software Sunny Design 2.20 by SMA Solar Technology AG[2].





[1] PV array with 20 or 2*10 polycrystalline PV modules and 230 Wp nominal power each (STC)
[2] Free download at http://www.SMA.de/SunnyDesign

Figure 2: Annual energy yield of the saddle-roof mounted plants (roof pitch 40°) for various azimuthal alignments relative to a reference plant with optimum south alignment.
The energy yield of the larger inverter is slightly lower due to frequent operation at partial load

The inverters used in this study were one Sunny Boy 4000TL-21 by SMA Solar Technology AG (AC nominal power 4000 W, NPR 91%) and one inverter with identical electrical properties but with reduced power (nominal AC power 2800 W, NPR 64%). The inverters are equipped with 2 MPP trackers each and configured for multi-string operation. The results are shown in Figure 2.

At due east/west alignment, the substrings attain a peak which is equivalent to approx. 80% of the yield with optimum south alignment. It is striking that with a lower-sized inverter (nominal AC power 2800 W) the energy yield is somewhat higher. This can be explained by the more favorable exploitation of partial-load efficiencies.

As an alternative to using a multi-string inverter, it is also feasible to operate both PV arrays on just one MPP tracker. As earlier investigations on existing PV plants with east/west-aligned generators have shown, in certain cases polystring operation only displays minimal mismatching losses, with the result that yield losses are significantly lower than one percent [1, 3]. The currents from the PV modules may vary significantly in the substrings over the course of the day, as the module surfaces are subject to varying intensities of irradiation. However, the voltage at the MPP is practically identical. The precondition for polystring operation is that the substrings have an identical arrangement, i.e., they have the same number of PV modules of the same type.

Simulations we have performed confirm the results of the above investigations: With east/west alignment of the substrings, a yield loss of 0.25% is found in polystring operation as against multi-string operation.

Self-Consumption

When the alignment of the PV modules deviates from the optimum, the annual energy yield of the plant goes down, but how does this affect the proportion of the PV energy generated that is used for self-consumption?

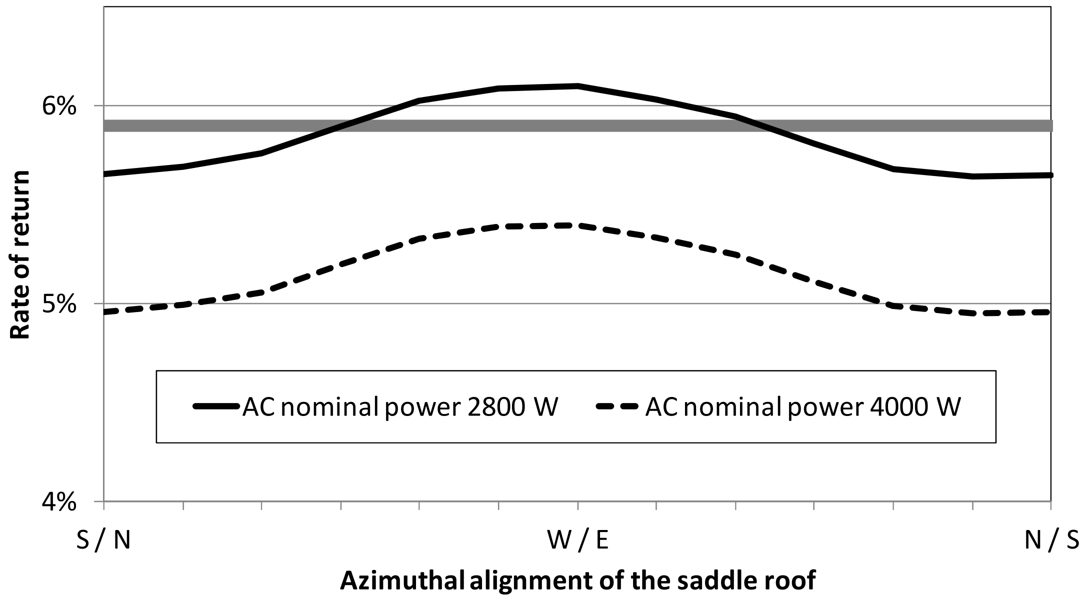
Again, the calculations are based on time-step simulations for various roof alignments (roof pitch 40°) as well as for a reference plant with identical peak power but with optimum south alignment. In order to calculate the potential self-consumption, the time series of a typical load profile for a private household was used. The annual energy demand of the household was assumed to be 4,200 kWh.

While the yield of the 4.6 kWp saddle-roof plant decreases in relation to the reference plant by around 1000 kWh p.a., self-consumption is only reduced by around 100 kWh p.a. This means that the self-consumption rate is increased. In the case of the east/west-aligned plant, this rate is 40.8% and hence around 6% higher than that achieved with optimum south alignment. Inverter sizing only has a negligible effect on the self-consumption rate.

A Consideration of Economic Viability

Finally, we would like to consider the economic viability of the depicted plant scenarios with regard to inverter sizing, energy yield and self-consumption.

The internal rate of return of a private PV plant over a period of 20 years is essentially determined by the PV system price, the generated energy and the feed-in compensation according to the EEG. Further factors, such as the power degradation of the PV modules, the availability of the PV plant, the service and running costs, or the taxation of earnings, have either no, or only very little influence. For the sake of simplicity, costs for loan capital were neglected in the context of a small, private PV plant.



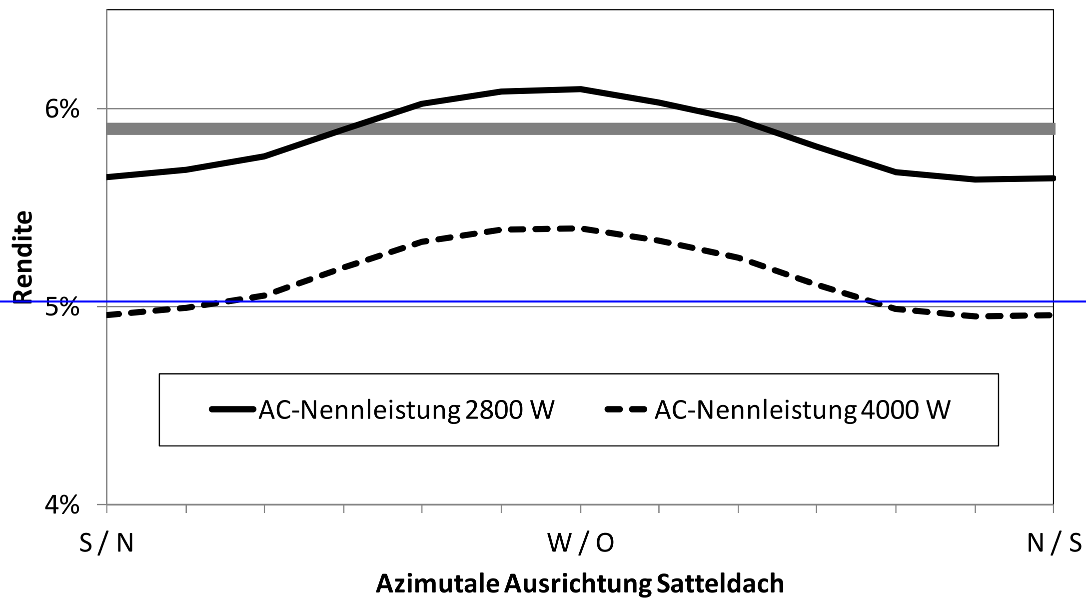


Figure 3: **Calculated rate of return on the plant scenarios tested investigated for various azimuthal alignments of the saddle roof with self-consumption (4.6 kWp). The gray line indicates the rate of return of a south-aligned plant without self-consumption.**

The compensation for grid feed-in and self-consumption, applicable from January 1, 2012 according to the EEG 2012, was taken as a basis for the comparison of the plant concepts, with an assumed annual electricity price increase of 3%.

In Figure 3, the rates of return of saddle-roof plants with self-consumption and different sized inverters are shown. The highest rate of return of 6.1% is achieved by a saddle-roof plant in east/west alignment and a small-sized inverter (nominal AC power 2800 W). Due to the choice of inverter, the rate of return was increased by 0.7 percentage points compared to a plant configuration using an inverter with nominal AC power of 4000 W. The saddle-roof plants have a rate of return which is approx. 2% to 3% lower than that of a south-facing plant *with* self-consumption. On the other hand, the rate of return of the east/west-aligned plant with smaller-sized inverter is comparable to that of a plant with optimum alignment *without* self-consumption (gray line).

Summary

The use of suitable software enables the economic viability of plants with differently aligned module strings to be analyzed and optimized. Thus, the partially counteractive effects of inverter sizing, plant yield and self-consumption rate can be quantified. Based on the scenarios investigated, it was possible to demonstrate that the economic viability of an east/west-aligned plant using self-consumption can actually be equivalent to that of an optimally aligned south-facing plant without self-consumption.

Clearly, the attractiveness of east/west-oriented plants results on the one hand from the higher (by comparison with south-facing PV arrays) proportion of self-consumed energy as a ratio of the total PV energy generated. In PV systems of the future which are no longer subsidized, this additional self-consumption may come to play an important role. On the other hand, for photovoltaics to be successful, the system costs and hence also the cost of the inverters will need to decrease further. A decisive contribution in this direction can be made by optimizing the size of the inverter for each specific plant. The east/west-aligned roof will therefore present an interesting option to plant planners of the future.

Literature

[1] Andreas Wagner, Joachim Laschinski: "Matchverluste bei Ost-West-Generatoren mit nur einem Wechselrichter", 20th PV Symposium Bad Staffelstein, March 2005.

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[3] Dietmar Staudacher, Thomas Mühlberger, Roland Prötsch: "Matchverluste bei Ost-West-Generatoren mit nur einem Wechselrichter", 25th PV Symposium Bad Staffelstein, March 2010