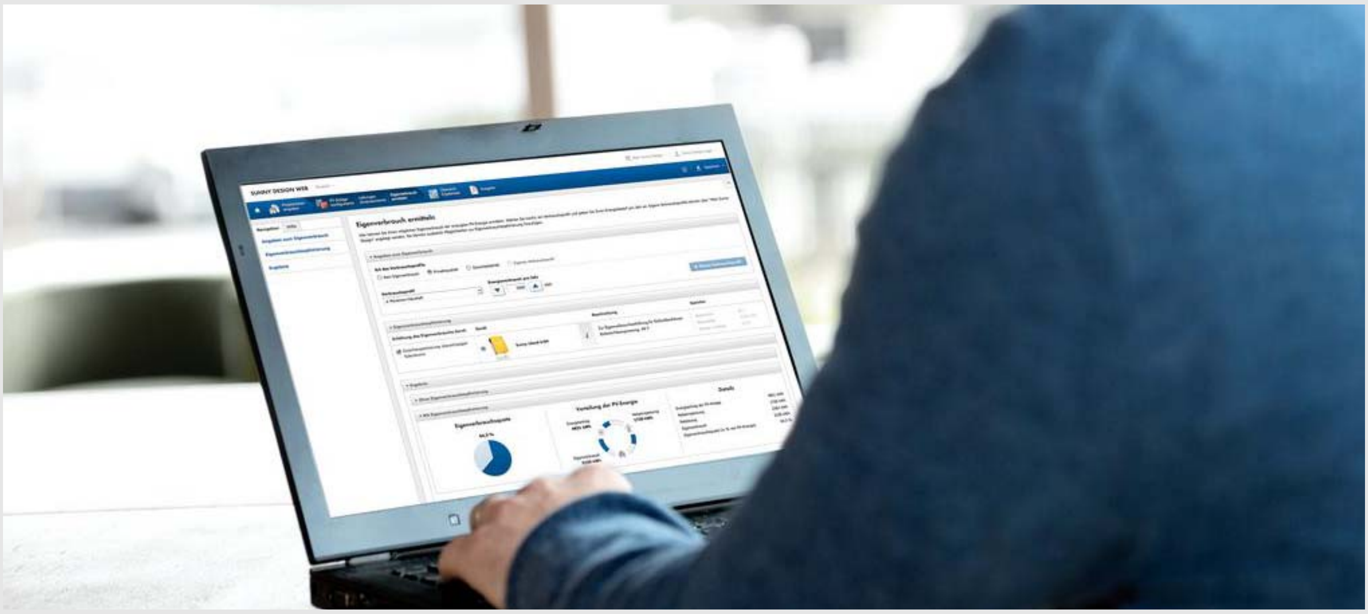
Technical Information

Designing PV Plants Optimised for Economic Efficiency



Content

The most efficient PV plant design is usually not far from the operating limits, for example, the minimum input voltage of the inverter. Knowing how the PV plant behaves at these limits makes it possible for the professional planner to increase the competitiveness of his or her designs. The following pages contain a description of what happens when the current MPP (Maximum Power Point) voltage of the PV array falls outside of the MPP range of the inverter and what effects such a situation can have on energy yield. This information creates the foundation for the informed application of the parameter "economic viability", which help Sunny Design Web users to specifically plan the ideal design.

1 Introduction

These days, planners are usually able to draw on comprehensive experience gained through their own projects when designing PV plants. A typical PV plant is thus designed quickly with the useful support of many tools (for example, the design software Sunny Design). When designing complex projects or projects outside of the usual dimensioning range, it is common to look at several different plant variations and their yield simulations to come up with the configuration most economically advantageous.

Inverter efficiency is first and foremost a decisive factor influencing the effectiveness of the PV plant. In addition, the degree of correlation in the PV array and inverter operating ranges also has a significant but often overestimated influence on energy yield. An inverter which cannot reach the current MPP in all insolation conditions but continues to work at an extremely high degree of efficiency is able to produce a higher yield than a similar device which operates continually within the MPP of the PV array but at a lower degree of efficiency. Unfortunately, alternatives like these are usually not compared, seeing as normal design regulations are based on the assumption that the modules always operate within their MPP. To begin with, it should then be determined which losses in yield can be expected if operations are carried out outside of the MPP. In this way, the area which must be analysed in determining the optimal design can be established.

The regulations stemming from this process take into account PV module and location properties as well as the inverter properties and, therefore, depart from the previously established standards at the operating limits for well-founded reasons. They form the foundation for the Sunny Design Web design suggestions (starting with version 3.01) and thus contain more proposed solutions than the previous versions. Detailed information on the yield of each design and the use of practical assistance functions make it simple and straight forward to come up with a plant configuration optimised for profitability. The target-aimed procedure for future plant planning will be depicted in an example at the end of this document.

2 Falling Below the Minimum Input Voltage

The lowest PV array operating voltage arises at the highest PV cell temperature. The decisive factor here is the temperature of the cells embedded in the module, which is usually high above the ambient temperature and also depends on how effective heat dissipation is. This means, for example, that an in-roof module, which is integrated into the roof cladding, is poor at releasing the solar energy absorbed and transformed into heat into the environment than a ground mounted. It, therefore, heats up much more than a rear-ventilated PV module and produces less power. Table 1 displays the different mounting types supported by the design software Sunny Design as well as the resulting cell temperatures and energy losses which can be expected in plants with monocrystalline cells in Munich.

Type of mounting		Cell temperature with respect to environment*	Energy yield with respect to ground-mounted installation*
	Ground-mounted installation	+20°C	0.0%
	On-roof, good back ventilation	+30°C	–1.8%
	On facade, poor back ventilation	+35°C	–2.7%
	Integration into roof or facade, no back ventilation	+45°C	–4.5%

* Monocrystalline cells, Munich

Table 1: Warming of PV cells in different mounting types with respect to the environment

The minimum input voltage is linked to the current grid voltage in many inverter topologies. If the input voltage is too low, the (transformed) input voltage (for inverters with low-frequency transformers) will no longer surpass the grid voltage, compromising the guarantee of a sinus-shaped current feed-in. A secure design must take into account the fact that feed-in is still possible, even with the lowest permitted input voltage in an electricity grid with the highest permitted grid voltage (for example, 230 V +10%).

If a PV array's MPP voltage is lower than the minimum input voltage of the inverter, the installation will cease to operate within the MPP and will operate at the lowest possible inverter input voltage (see Figure 1).
As described above, there are two main reasons for this situation arising:

- The MPP voltage decreased due to high cell temperature.
- The grid voltage is higher than that which was assumed during planning, and the minimum input voltage linked to it (V_{DCmin}) has also increased as a result.

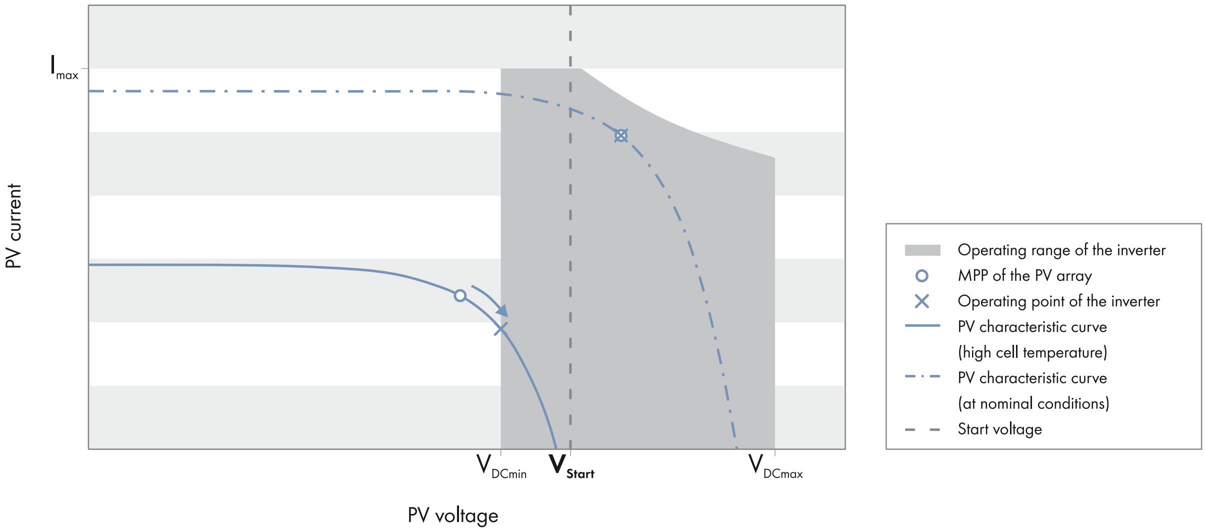


Figure 1: The PV array works with the lowest possible inverter input voltage should its MPP voltage be lower

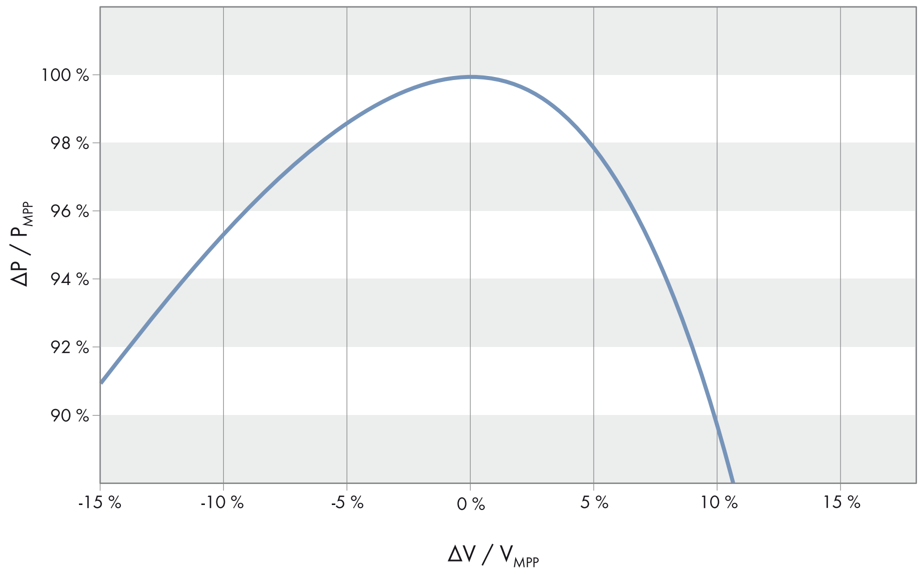


Figure 2: As long as the operating point remains close to the MPP, the majority of PV power will be used (PV module: monocrystalline Si, SolarWorld SW 175)

These operating conditions do not cause any problem for the inverter, but they do, however, lead to losses in PV array yield. Figure 2 demonstrates an example of the associated power losses by presenting power as loss with respect to the current MPP power as a function of the distance of the operating voltage from the current MPP voltage. The actual operating point will be located in the right half of the diagram if a limit is imposed due to minimum input voltage. Theoretically, a PV module functions quite well under these circumstances: If the MPP voltage is less than 1% below the minimum input voltage of the inverter (for example, at 564 V compared to 570 V), 99.9% of the MPP power can still be used. Even with what appears to be a dramatic variation in voltage of 5% (for example, 543 V compared to 570 V), the PV array power, which is a mere 2% below the MPP power, can still be used. These numbers apply to conventional PV modules with crystalline Si cells; and losses are even lower with many thin-film PV cells.

However, the situation is much more critical if the open-circuit voltage of the PV array no longer reaches the inverter start voltage $V_{PVStart}$. In the case of a feed-in interruption, the PV plant may possibly not be able to continue operation immediately after the disturbance is fixed which may have an appreciable influence on the plant yield on the day of the occurrence. The plant must be designed to ensure that the open-circuit voltage of the PV array is always higher than the start voltage of the inverter.

3 Exceeding the Maximum MPP Voltage

Another factor to be considered in the design of a PV plant is the array's MPP voltage at the cells' minimum operating temperature. Although the inverter can be damaged if the maximum input voltage is exceeded, exceeding the maximum MPP voltage is, by contrast, nonhazardous. Similar to the case of the minimum input voltage not being reached, the operating point of the PV array shifts itself in relation to the MPP, resulting in a lower loss in yield. In contrast to the maximum array voltage consisting of the open-circuit voltage at minimum cell temperature, it makes little sense to orient the design according to the MPP voltage at the lowest outside temperature. The warming of the PV cells with regard to their environment should also be considered in this case to allow for the assumption of, for example, a maximum MPP voltage at a cell temperature of +15 °C (– 10 °C outside temperature + cell warming of +25 °C) for PV plants in Germany.

The numbers quoted here are, however, not universally valid, and individual module mounting types and the ambient temperature of the location should, of course, be considered in the design.

4 Plant Yield at Operating Limits

The above mentioned observations of performance in the MPP area still, however, do not reveal how often such situations come up and how they influence the energy-related annual yield of the PV plant. How high the loss in yield is and if it is acceptable or not, depends not only on the module used but also on mounting type of the PV modules (cell temperature) as well as on other factors and must be assessed or simulated individually. Figure 3 depicts, in a specific example (location: Munich, south orientation, 30° tilt, PV module with monocrystalline cells), the loss in annual energy yield should the inverter place a high (V_{MPPmax} in the low cell temperature range) or low (V_{MPPmin} in the high cell temperature range) limit on the PV array MPP voltage range. Referring to cell temperature makes the application of the results to any module or string length of the PV array easier. The limits of the normal design range are also marked at cell temperatures of +70°C and −10°C for orientation.

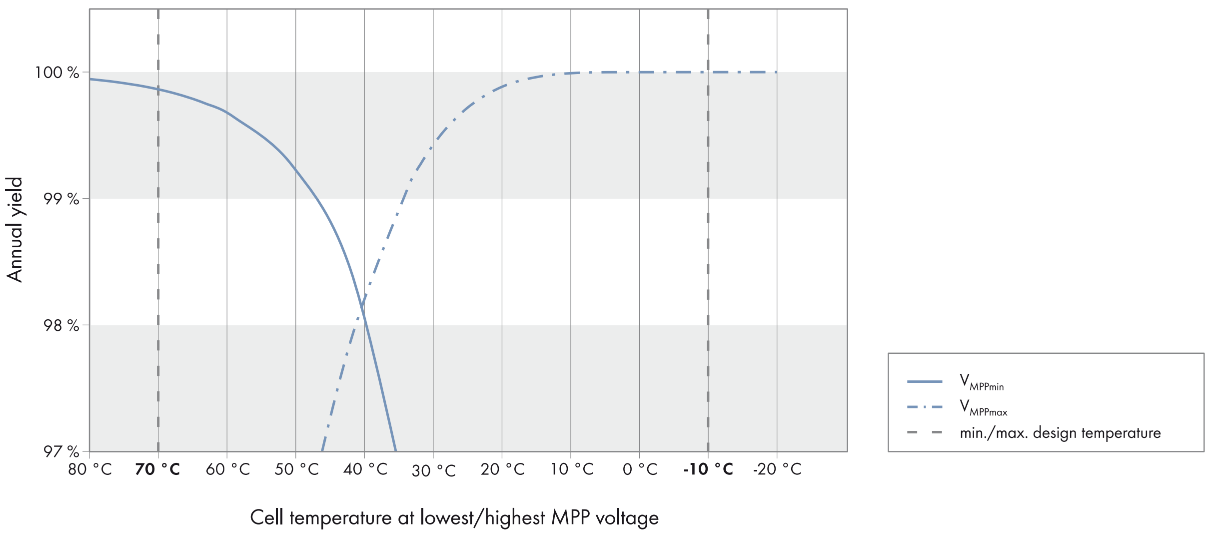


Figure 3: Energy-related annual yield of a PV plant with limited PV voltage (simulation with one-minute timing for a PV plant in Munich, on-roof mounting, 30° tilt, south orientation, module with monocrystalline Si cells)

5 Design Regulations for PV Plants

This assessment can now be used to establish under which circumstances the higher inverter efficiency is balanced out by correspondingly high mismatch losses. Here, two inverters with the same power, but with different topologies, are observed:

- STP 15000TL with a European weighted efficiency of 97.8% and a minimum MPP voltage of 360 V.
- STP 15000TLEE with a European weighted efficiency of 98.3% and a minimum MPP voltage of 570 V.

Figure 3 illustrates the situation: A level of efficiency which is 0.5% higher and is also represented in a correspondingly higher annual yield will only be made up for through a significant limitation on the MPP range. Only when MPP tracking continues to work solely for cell temperatures below 55 °C, does the annual energy yield decrease by 0.5% to 99.5%, and the inverter with the higher level of efficiency will most likely no longer produce the highest yield.

For common dimensioning, this means that the maximum design temperature of the PV cells can be reduced from 70 °C to at least 55 °C if the inverter displays a 0.5% higher level of efficiency compared to a similar device. Figure 4 displays the parameters for the entire plant efficiency, the performance ratio PR, of both observed inverters in a direct comparison as a function over the array voltage at a cell temperature of 70 °C. The absolute PR values are, in addition, also dependant on the location and mounting type of the PV modules. However, the trends displayed in both graphs clearly show the difference between both inverters: the PR of the STP 15000TL primarily follows the voltage dependency of the efficiency in exactly the same way as the PR of the STP 15000TLEE at a high array voltage. Below minimum input voltage of the STP 15000TLEE (at 570 V), the effect of the voltage limitation stands out, and the PR plummets dramatically with very low array voltages. In this design range (< 500 V), a general recommendation for inverter selection is no longer possible. In fact, this can only be done based on yield simulations of both plant variations using concrete project data.

Plant Yield Comparison

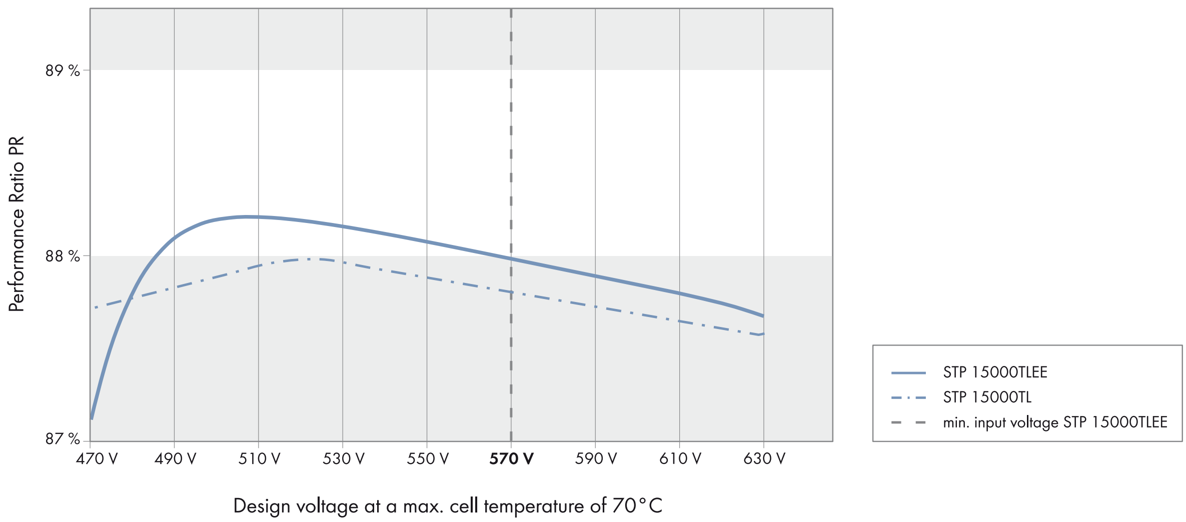


Figure 4: Comparison of the performance ratio of two inverters (simulation with one-minute timing for a PV plant in Munich, on-roof mounting, 30° tilt, south orientation, module with monocrystalline Si cells)

6 Design Strategy in Sunny Design Web

The design software Sunny Design Web also takes the loss in yield into account through a limited input voltage range just like the insolation and climate data on location. The automatic design thus considers all configurations which have the potential to present the most efficient variant for each individual case. A rough yield simulation is created for each configuration and the results are ranked in a list.

A comparison of different inverters, similar to the one carried out above, can be tailored to the current project and easily performed by the planner. The following screen shots are meant to show how Sunny Design Web supports the planning of the example project discussed above.

Observed PV Array

PV arrays

Name	Manufacturers/PV module	Number of PV modules/Peak power	Orientation/Mounting type
1 PV-Generator 1	IBC IBC MonoSol 245 ET (01/12)	63 PV modules 15.44 kWp	0° 30°

Automatic Design Suggestion List

Design suggestions

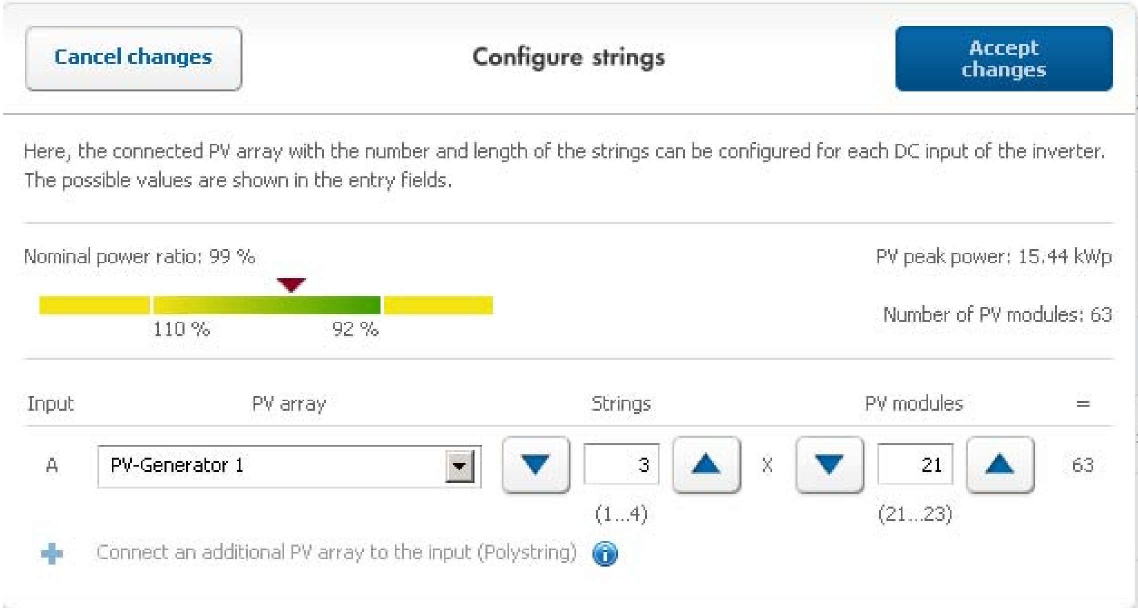
Sorting: Economic viability

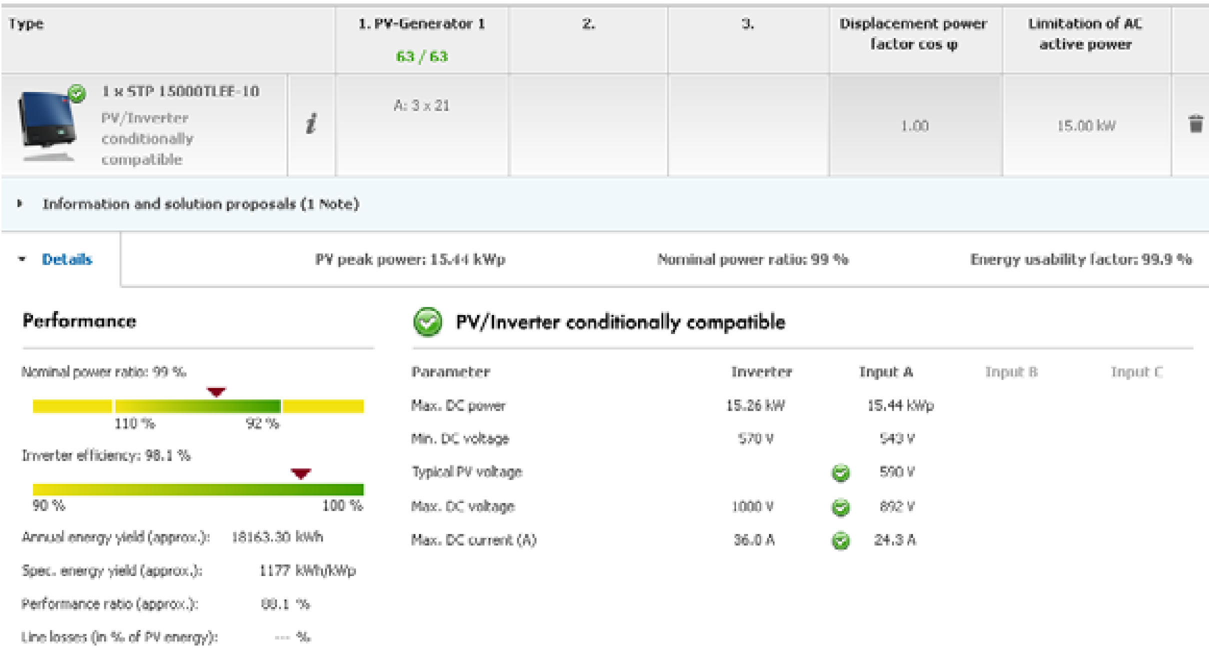
Selection	Number of inverters	Nominal power ratio	Energy yield/Rating	Economic viability	Nominal AC power
☐	1 x STP 15000TLEE-10	99 %	100 %		15.00 kW
☐	1 x STP 15000TL-10	99 %	99.7 | 0.3 %		15.00 kW
☐	1 x STP 12000TL-10 1 x SB 1600TL-10	91 % 87 %	99.1 | 0.9 %		13.60 kW
☐	1 x STP 12000TL-10 1 x SB 2100TL	93 % 100 %	99 | 1 %		13.95 kW
☐	1 x STP 12000TL-10 1 x SB 1700	91 % 94 %	98.7 | 1.3 %		13.55 kW
☐	1 x STP 12000TL-10 1 x SB 2500TLST-21	98 % 90 %	99.1 | 0.9 %		14.50 kW
	1 x STP 10000TL-10	93 %			

Compare selection | Add selection as an alternative | Adopt design

Detailed Design of the STP 15000TLEE

A prerequisite for detailed design is the classification of the inverter as "conditionally compatible". This classification shows the planner that the design is located within the normal design regulations. The result is, however, only correct if the planning regulations (temperatures, location, grounding system, grid voltage,...) are adhered to. If differing operating conditions are present at the installation site (for example, mains voltage 10% above the nominal value), the design should be carried out using the corresponding unfavourable values.





Comparison of Design Variants

Compare suggested designs

	Alternative 1	Alternative 2
Inverter	1 x STP 15000TLEE-10	1 x STP 15000TL-10
Status	✓	✓
PV modules	63 x IBC IBC MonoSol 245 ET (01/12)	63 x IBC IBC MonoSol 245 ET (01/12)
Total number of PV modules	63	63
PV peak power	15.44 kWp	15.44 kWp
Number of inverters	1	1
Nominal AC power	15.00 kW	15.00 kW
AC active power	15.00 kW	15.00 kW
Active power ratio	97.2 %	97.2 %
Annual energy yield (approx.)	18163.30 kWh	18117.50 kWh
Energy usability factor	99.9 %	100 %
Performance ratio (approx.)	88.1 %	87.9 %
Spec. energy yield (approx.)	1177 kWh/kWp	1174 kWh/kWp

7 Tips for Working with Sunny Design Web

If only the voltage limits are used in the assessment, as was common up until now in Sunny Design and all other design and simulation programs, the assessed plant designs presented here will contradict them in part at the operating limits. This is no need for alarm, as the reasons for this are known and were explained in the present document.

The planner should proceed as follows in order to attain the most attractive design with regards to efficiency with the help of Sunny Design Web (starting at version 3.01):

1. Careful input of location settings for the planned PV plant (location, orientation, mounting type, etc. are all decisive factors in the energy yield over the course of the year)
2. Temperatures should be based on ambient temperatures (see temperature settings)
3. Compile design suggestions
4. Sort design suggestions by economic viability (economic viability takes the specific cost of the inverter into account as well as the energy yield)
5. Critical testing of the designs ranked at the top of the list of suggestions for possible individual issues (see comments on detailed design above)
6. Testing of the top-ranked suggestions on the list and comparison with actual costs

The process described here makes a list of the most profitable plant designs very quick to compile. It should be noted that the ranking in the suggestion list should never be viewed as absolutely accurate. Seeing as the unique cost structure of the PV plant plays an important role in the economic viability, the best configurations still need to be balanced with the actual costs.