Comments on paper draft shade3D by Martin @ Valentin Software, 13. January 2017

First of all we would like to thank you for this very interesting draft and for integrating PV*SOL in your analysis. The results are quite interesting to us and we think this topic will find the interest of a broader public. Below you will find comments on the different parts of your draft of which we hope you will find them to be constructive.

1 Method

1.1 Comparing to SunEye

All simulation programs are compared to the results of SunEye, which unfortunately is not calculating the impact of shading on the PV output very accurately. In our opinion, it should not be used as a reference for a proper shading analysis.

If using SunEye results as reference, the aim and scope (and title) of the paper should be rewritten accordingly, e.g. “Which software is the best at reproducing SunEye results” or the like. As we understand you are aware of this restriction, as you point out in the end of section 3 in your draft. Perhaps it could be helpful to point out more clearly what the differences in the simulation procedures are in order to enable the reader to understand the meaning of the differences in the results.

We would suggest to use real world data from PV plants or test stands. Otherwise the conclusion that can be drawn out of such an analysis is very limited.

1.2 “Loss”

In the abstract and in most other parts of the draft you speak of “losses” where it is unclear what kind of losses are talked about. On a closer read the definition becomes clear (e.g. that “sky diffuse loss” is referring to the obstructed portion of the sky dome, see next comment), but most of the people only read the title, the abstract, some figures and the conclusion of papers. And in this context the usage of the word “loss” in our opinion gives the impression that we speak of energetic irradiation losses or even electrical losses.

1.3 Sky diffuse loss

See our data for sky diffuse loss in section 3.

Table 2: The data shown here (labeled as “sky diffuse loss”) is more a geometric figure that indicates which part of the sky is not visible to the module. It is not a loss in energetic means, not for diffuse irradiation and most of all not for electric losses. The loss of diffuse irradiation (as energy in Ws/m²) due to a partially obstructed sky (either instantaneously or over a given period) depends on the distribution of the diffuse irradiance over the sky (as power in W/m²). You go for an isotropic distribution there, which admittedly is correct when geometrically talking about the portion of the sky that is obstructed.

And, more importantly, the loss of the total irradiation incident on the module due to a partially obstructed sky depends additionally on the diffuse fraction at the time step in question. And lastly, the real loss for the module would be the loss of electric energy, which cannot directly be derived from the loss of the total irradiation on the module surface.

For example, if a module is tilted at 45°, with no other obstructions existing, the geometric proportion of the sky not visible to the module would be 25%. For the loss of the diffuse irradiation on the module however it would be very important to take into account where the module is oriented at and where the sun is at this moment. If the module faces south and the sun is also standing in the south, the loss of diffuse irradiation will be a lot lower than 25%, say 20%. If the diffuse fraction at that time would be 40%, the loss of total irradiation would only be 8%. Finally, given that there is no additional shading of the direct light, the electrical loss would depend on the low light characteristics of the module and would probably be around 4%.

Displaying the “sky diffuse loss” like done in the draft suggests, in our opinion, that it is the loss of diffuse irradiation on the module, and thus an important output of the program. But actually, for us it is only a very basic geometric figure that stands at the beginning of a long modelling chain that leads to more important results: the loss of diffuse irradiation seen by the module (over the year for example), the loss of total irradiation, and of course the loss of electric energy due to the shading.

We would suggest to display a more meaningful parameter than “sky diffuse loss” in order to be able to estimate the quality of the simulation results. For example, the loss of diffuse irradiation over the diffuse fraction:

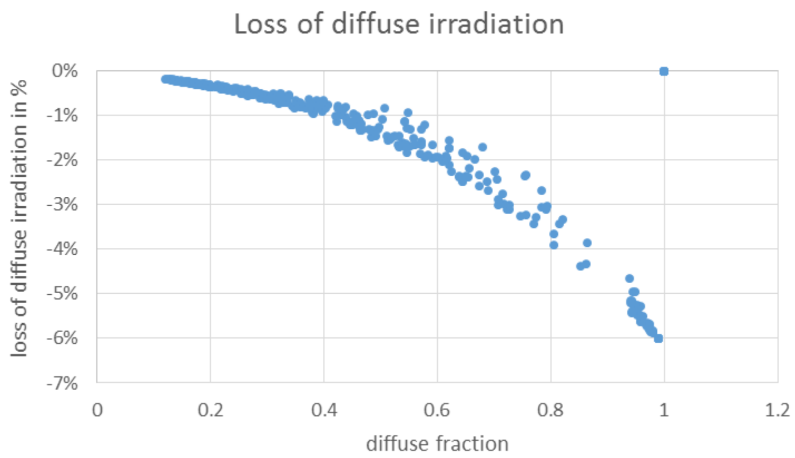


Figure 1: The loss of diffuse irradiation over the diffuse fraction for the first thousand simulation hours for Basic Test 1 (Denver)

If you decide to stick to the geometric sky diffuse loss, an important information would be from which point of the module the sky is looked at. Since you have very close shading objects, the results will be different when looking from the center of the module or, say, the upper right corner. See also our data for the “sky diffuse loss” in section 3 below. More on the comparison of the near shading objects in section 4.

1.4 Beam irradiance shading loss

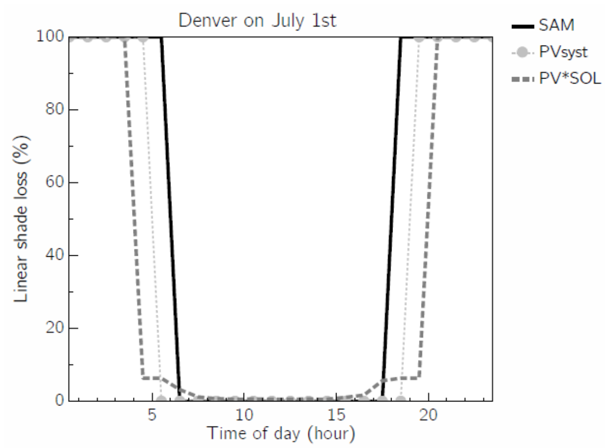
As pointed out in the draft, the beam irradiance loss is also a geometric figure. Here, nearly the same arguments apply as for the “sky diffuse loss”. But more importantly, SAM and PVsyst seem to calculate the geometric irradiance losses, whereas the output of PV*SOL is the electrical loss due to shading of the direct portion of the irradiation. This is an important difference (as you also mention in the text), since even a small geometric beam irradiance loss can lead to significant electrical losses. It is mentioned in the draft that you try to calculate the geometric irradiance losses from the DC power loss. But for the type of module you investigate (with 3 substrings), the electric losses are not proportional to the geometric irradiance loss, so comparing these results to the outputs of SAM or PVsyst cannot produce a meaningful conclusion.

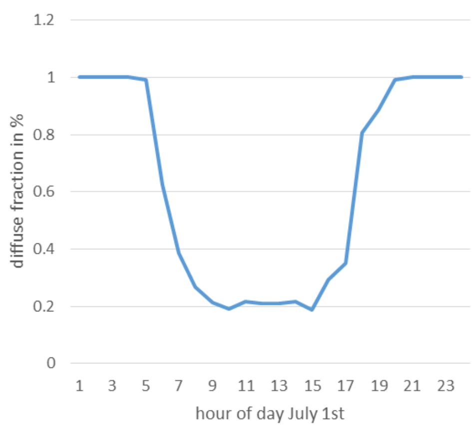
For example, if you have only a small fraction of direct shadow on the module, SAM and PVsyst would output a small geometric loss of beam irradiation. PV*SOL would detect where exactly the shadow is located and calculate the corresponding loss using the superposition of the three resulting IV characteristics.

- If the shadow is only on one of the three substrings (compare to case 2 in the Appendix at the end), there would be two strings with characteristics produced by the total irradiation and one string with a characteristic produced by diffuse irradiation only. So the loss would be approx. 1/3 of the total power (point A) or equal to the direct fraction of the irradiation (point B), depending on which local MPP the tracker would choose (and further depending on other factors like low light behavior and module temperature and so on).
- If the shadow (of the same size) would be on all three strings at the same time (case 4), we would have three diffuse characteristics, resulting in a loss of about the amount of the direct fraction. Here is another example about shadows on interconnected modules (but the same applies for the substrings in a module).

Also, if you take the results from PV*SOL (calculated as you did) you still have the influence of the diffuse fraction in your figures. If you have 100% shading of the direct light, but no direct light (diffuse fraction of 1), there will be no loss. So what you display in your figures is not really the geometric beam irradiation loss as the draft suggests – at least for PV*SOL. And apparently, this is also the case for PVsyst in some cases.

We think, these two factors explain a lot of the differences in your plots Fig. 4 – 14. For example the plot for Denver on July 1st:





So, in summary, we don't think that the different outputs of SAM, PVsyst and PV*SOL are comparable in the way you suggest nor are they a good indicator for the quality of the shading analyses.

We would suggest to compare the DC output of the test plants. We think the best and most meaningful result would be the difference between the unshaded and the shaded test case, calculated with each software and compared by timelines, like you did.

1.5 Monthly solar access

It would be helpful to clarify how the solar access is calculated in this section.

2 Various comments

- It would be helpful to list the version of the programs that were used
- As mentioned above, the differences in the approaches of the 3 tools should be listed:
  - From which point of the module the sky dome obstruction is measured (center of the module in PV*SOL)
  - Are trees opaque, semi-opaque or do they change their opaqueness during the year (like in PV*SOL)
  - With which time resolution occurs the simulation of the 3D geometry? (averaged 10min in PV*SOL)

3 Sky diffuse loss

If you decide to stick to the sky diffuse loss as comparative figure, we'd like to add our numbers as they are now available in the latest version of PV*SOL (2017 R6).

In addition, a very interesting add-on to these tables would be a geometric calculation of the minimum portion of the sky dome that is not visible to the modules (last column). If the module is tilted, it cuts out a part of the sky dome behind it, something like a potato wedge. It is illustrated in the Appendix in the second picture of the sky domes.

The area for the wedge is

$$A = \frac{\gamma}{360^\circ} \cdot 4\pi r^2 = \frac{\gamma}{90^\circ} \cdot \pi r^2$$

So, the portion of the sky that is not visible to the module because of its inclination γ would be

$$\frac{A_{wedge}}{A_{dome}} = \frac{\gamma}{180^\circ}$$

The fraction obtained by the software tools should in no case be lower than this value. If there are no other objects nearby, the "sky diffuse loss" should equal this value. If there are other objects, this "wedge fraction" can be considered a handy minimum to check against.

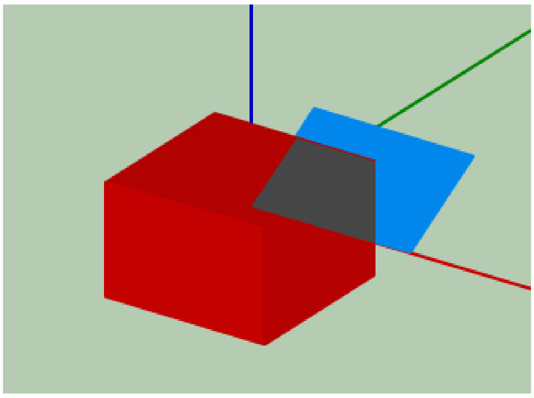
Scene	SAM	PVsyst	PV*SOL	Inclination	Minimum (Digon/full sky dome)
Denver	8.80	18.50	22.3	30	16.7%
Quito	16.80	18.10	15.4	10	5.6%
Perth	8.10	8.60	18.1	20	11.1%

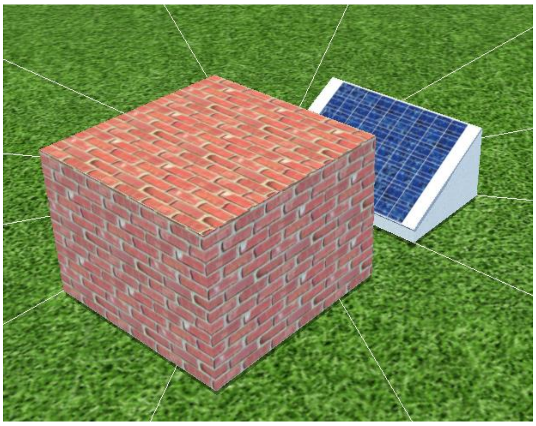
Scene	SAM	PVsyst	PV*SOL	Inclination	Minimum (Digon/full sky dome)
Ivanhoe	17.7	20.7	30.8	15	8.3%
Babbitt	9.3	7.3	22.0	22	12.2%
Halsted	9.7	11.1	32.2	38	21.1%
Paradise I	12.4	12.1	25.1	29	16.1%
Paradise II			32.4	42	23.3%

Also, we were wondering how you calculate on figure for the “sky diffuse loss” in the project “Paradise”, if there are actually two module areas with different inclination and orientation. So we provided two numbers for this project.

4 3D scenes

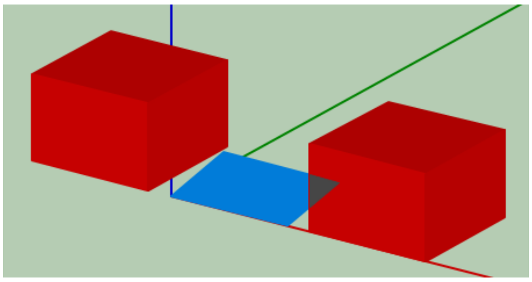
4.1 Basic Test 1 (Denver)

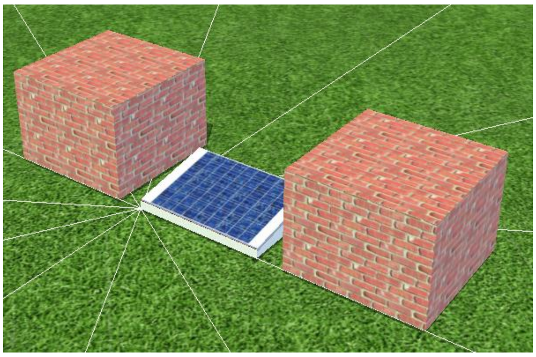




The module is not touching the ground.

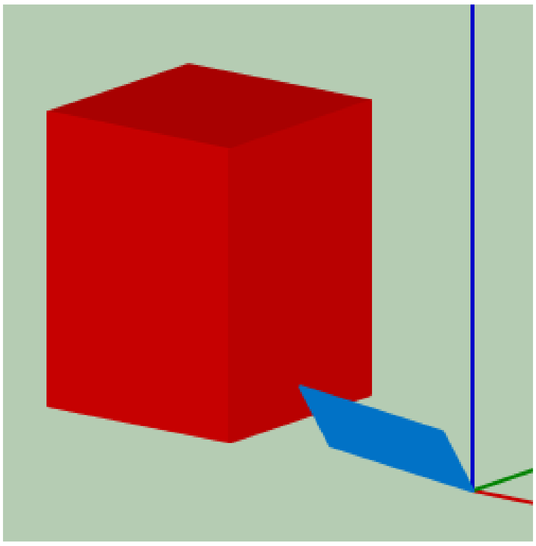
4.2 Basic Test 2 (Quito)

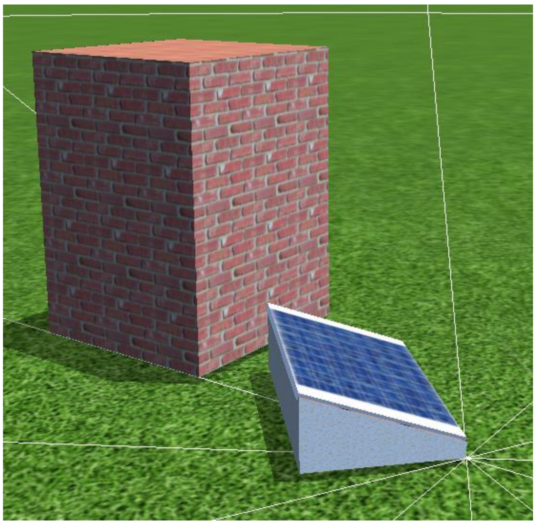




The module is not touching the ground.

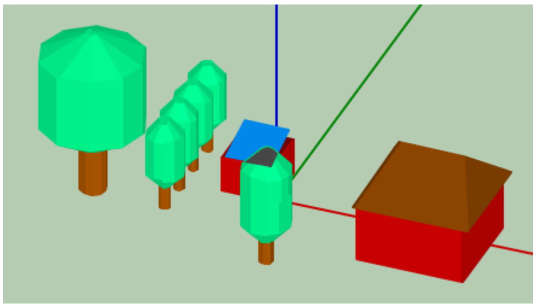
4.3 Basic Test 3 (Perth)

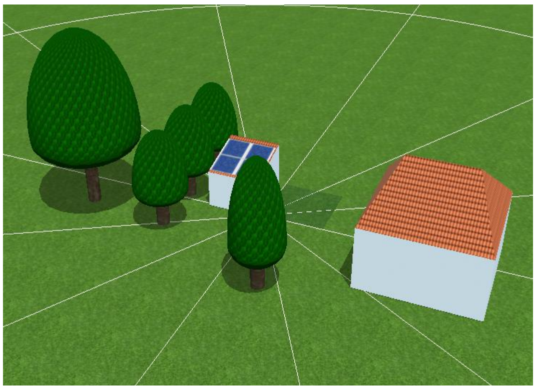




The module is not touching the ground. I am not sure, if I am getting the angle correctly in the SAM scene, but it seems that the long and the short sides of the module are different?

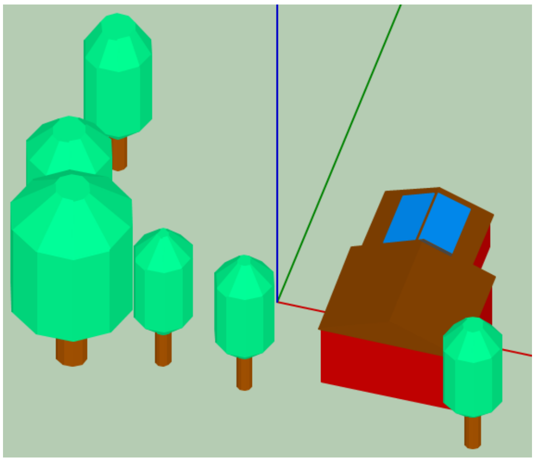
4.4 Ivanhoe

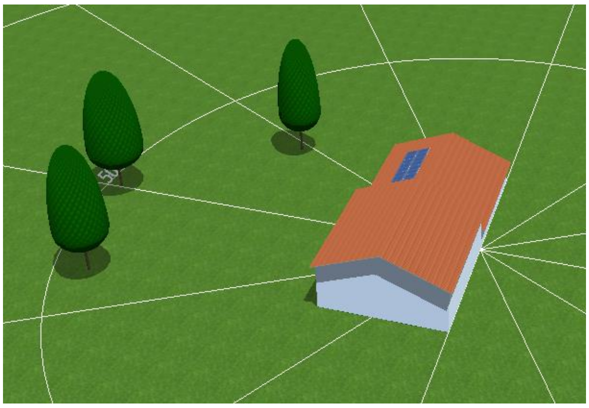




There are only three small trees, not four. The first small tree is not in line with the big tree (in the SAM scene, the stems seem to be in one line with the red axis)

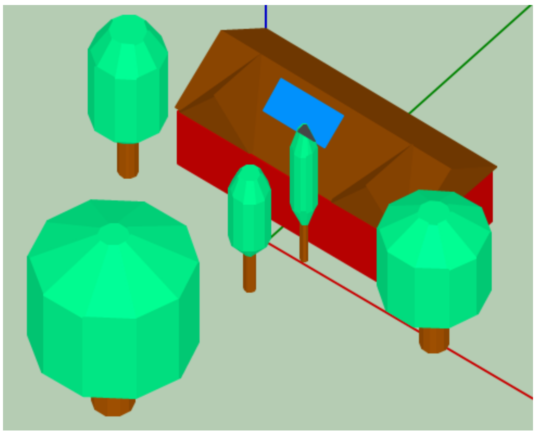
4.5 Babbitt

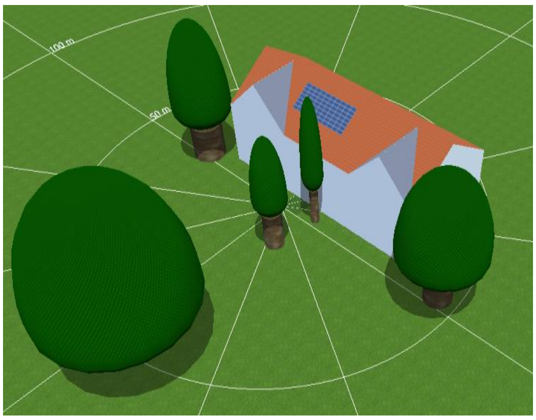




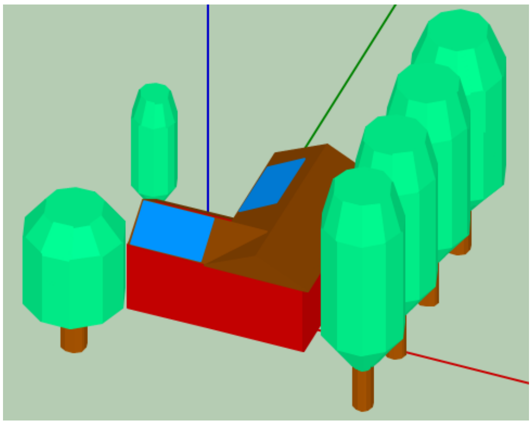
There is one module area missing. Also the geometry of the house seems to be different. The amount and placement of the trees as well.

4.6 Halsted

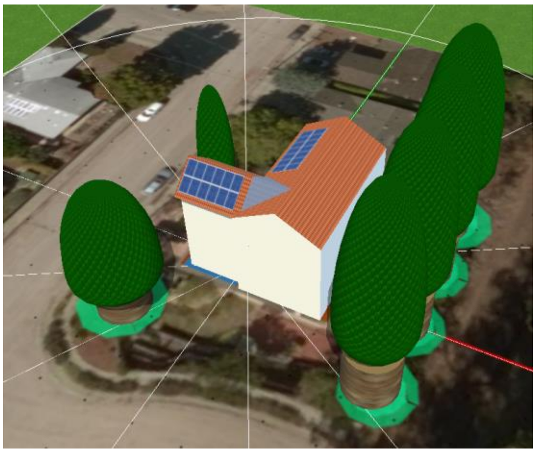




4.7 Paradise



The placement of the two small trees near the house seems to be closer to the PV system.



The right part of the house is not in line with the left part. In general, the proportions seem to be a bit off, e.g. the ratio of the width to the height of the front façade.

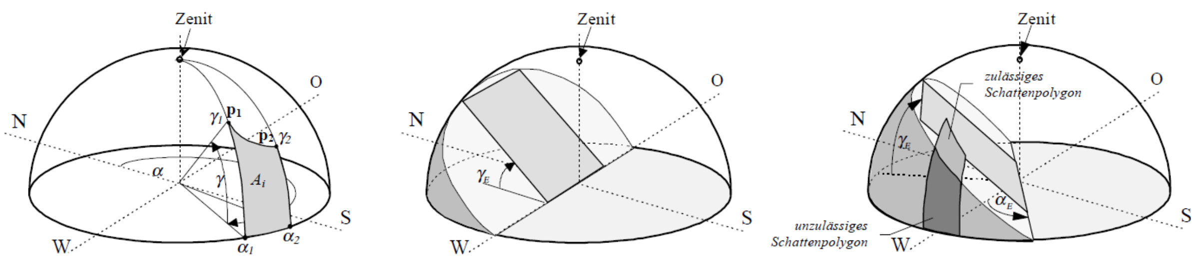
5 Appendix: Shading Calculation in PV*SOL

The Diffuse shading and direct shading and their influence on the yield of a PV module are calculated in PV * SOL in different ways. I would like to explain it briefly here.

5.1 Diffuse shading (isotropic fraction)

For each module a separate horizon line is determined. The horizon line is a combination of

- farther horizon line,
- nearby objects and
- for the module not visible part of the sky hemisphere



Translations: *zulässiges Schattenpolygon* = permissible shadow polygon, *unzulässiges Schattenpolygon* = impermissible shadow polygon

Surface of the horizon line (on the spherical surface) is calculated.

The proportion of this surface on the entire surface of the hemisphere gives diffuse shading degree

Isotropic fraction of irradiance is reduced by this factor

$$E_{\text{I, Modul}} = \frac{A_{\text{Schatten}}}{A_{\text{Halbkugel}}} E_{\text{I}}$$

Schatten=shadow Halbkugel= hemisphere

$E_{1,\text{Modul}}$ is the isotropic shading factor. It remains constant throughout the year for each module. Isotropic does not equal to diffuse depending on the model used for the distribution of the diffuse irradiation over the sky dome. In PV*SOL, the model by Hay&Davies is used (takes in horizon and circumsolar brightening)

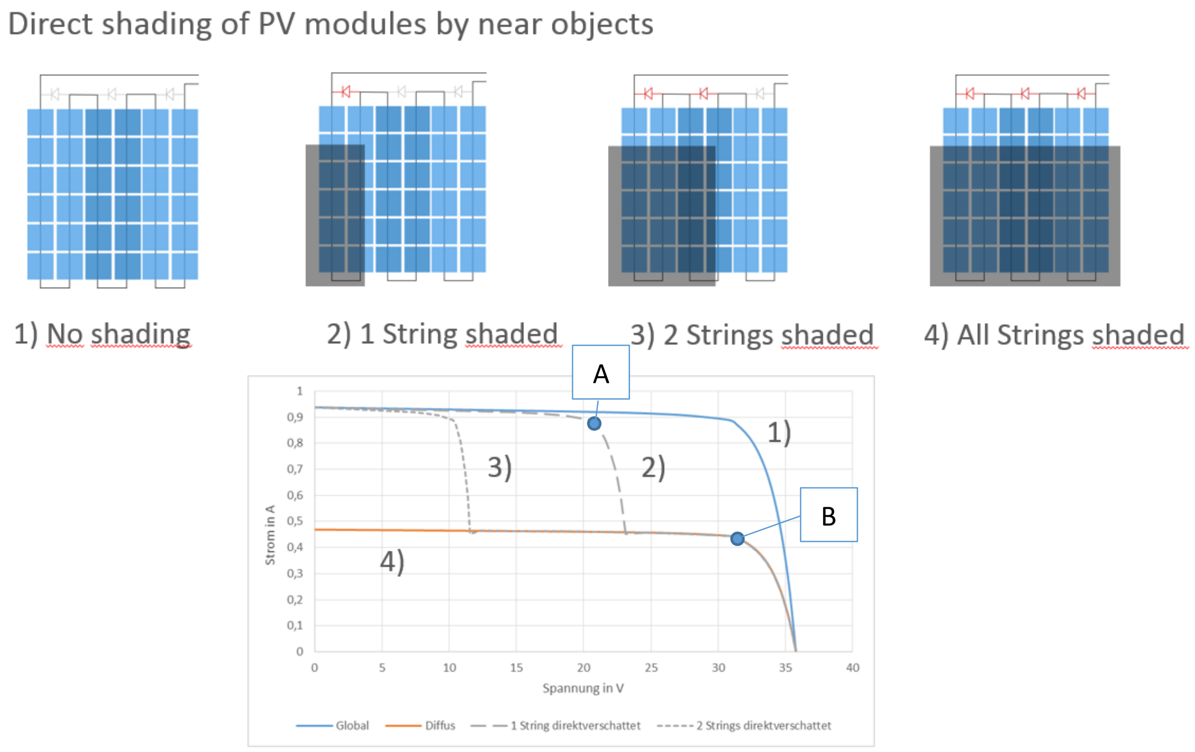
With this, the factor „Shading of diffuse radiation by horizon“ is calculated in PV*SOL.

5.2 Direct shading (anisotropic)

From the 3D visualization of PV * SOL the exact shading situation of each PV module is known for each time step.

In the yield calculation each module is divided into substrings according to the number of bypass diodes, depending on cell connection horizontally or vertically. It is now checked for any substring in each time step if there is shading. If there is shading, the bypass diode can be active, otherwise not. If the bypass diode is active, the diode losses are calculated.

PV*SOL assumes from this that the shaded strips are never completely shaded, but that there is always diffused radiation on the shaded parts. There is therefore a VI characteristic curve with lower current for these cells as well. If the resultant MPP current is less than the short circuit current for the shaded cells, the bypass diode is not active and the complete module works with low current and high voltages.



Yield decrease due to direct shading is not dependent on the shaded area, but only on how many cell strings are affected by the shading.

Yield decreases due to direct shading is considered in the result values “Module-specific Partial Shading” and “Low-light performance” in PV*SOL.