

Modules Spacing and Mutual Shading

In this video we are going to learn how to calculate the inter-row spacing for tilted or ground-mounted PV systems in order to avoid potential self-shading issues.

The main topics that will be discussed are the calculation of the shade-free time window, the row spacing and the ground cover ratio.

You have to imagine that in a solar plant there is the possibility that some modules cast a shadow on other modules placed behind and this can happen in different moments of the day and of the year. In this video we will look at this problem and give you some design guidelines.

These two representations are an example of the same PV system composed by two rows of identical modules with identical tilting angle and position.

The only difference is that they were obtained by simulating the sun position in two different and opposite periods of the year, winter and summer. In winter, on the left-hand side, the position of the sun is low on the horizon and thus the shadow casted is much longer compared to a typical day of summer as the one simulated on the right-hand side.

So the length of the shadow is different during the year. This aspect has to be taken into account during the design of the PV system because it may happen that during winter rows get mutually shaded, lowering the yield of the system. Therefore an optimization is needed to avoid accidental shading among the modules, which leads to an under-performing system, but also to avoid over compensation, which increases the land or roof usage.

Since the length of the shadow is the longest when the sun is lowest on the horizon, reaching its minimum on the 21st of December, it is common practice for installation companies to design and optimize the PV system for a shade-free time window on this date.

Normally this shade-free interval of time is an input from the customer, which needs for example the maximum power achievable by the system from 10 AM to 2 PM.

Then, based on this input, the engineer calculates what should be the inter row spacing. Let's see how to do it.

First we have to determine what the sun elevation angle is going to be and we will use this graph with the solar azimuth versus elevation at certain location on earth, for example in Delft, in the Netherlands.

The 21st of December, which is the solstice of winter, is represented by this blue line on the bottom, while the top curve is the solstice of summer, falling on the 21st of June. We can also identify the analemmas for every hour of every day.

Note that analemmas are here reported as continuous single lines. At this point, we select the shade-free time window between 10 AM and 2 PM and we want to ensure that rows are

not mutually shaded on the solstice of winter. Starting from this window highlighted in the chart, we can draw an horizontal line out to the left of the chart that points to the solar elevation angle at those specific moments.

In our case it is estimated a 10° angle which will be used next to determine the module row spacing.

Let's now look at the trigonometric system here. We are going to derive the equation of the row spacing starting from this simple trigonometric relation, where d is the row spacing and it is obtained by adding the vertical projection of the module, where l is the length of the module and θ_m is the tilt angle of the PV module. The second term is also called d_{shadow} , obtained by the vertical projection of z , which in turn is the distance between the top edge of the module and the end of the shadow on the ground. We can rearrange this equation and write z as function of the height h of the module. Then, sinus divided by cosine can be written as the tangent of the sun altitude and finally h can be also expressed as a function of the module length and the tilt angle.

To summarize, there are different ways to express row spacing d as function of length of the module, tilting of the module and altitude of the sun and all these equations are mathematical equivalent.

The next step in the design is to account for the azimuth angle and thus we will use again this figure to draw two vertical reference arrows down from each time reference. The azimuth values are 152 when it's 10 AM and 208 degrees at 2 PM and we will use these data in the following formula to determine the minimum module row spacing.

Here you can see the final equation with the azimuth correction, highlighted in red. Once you plug all the information required you will know the value of d for example at 10 AM and at 2 PM and then you just have to pick the biggest distance among them and that will be the distance among each row of PV modules. However, for a first quick estimation, one can use the rule of thumb that the distance between two rows of modules should be at least three times the length of the module. It is important to note that module spacing plays an important role also in determining the surface area required for the installation. Indeed, in the last slide we introduce a parameter to measure the land occupation.

Such a parameter is called Ground Cover Ratio and it is defined as the ratio between the area of the PV array divided by the total ground area, which could be the area of the roof or of a field. GCR is strictly related to the tilt angle because an increase in tilt angle requires row spacing to increase to avoid inter-row shading. So, lower GCR values will keep modules spaced far apart, which maximizes their individual energy yield, but will result in a smaller-sized system installed capacity. On the other hand, higher Ground Cover Ratio values will increase the system size but will also reduce the energy yield from higher mutual shading. The role of an engineer is to find the optimal tilt and GCR combination for maximizing the output of a system or, in other words, to find the trade-off between the system size and its energy yield.

In summary, in this video you learned how to graphically locate the solar azimuth and elevation for a specific shade-free time window. Then, with these data we derived the trigonometric formula to obtain the inter row spacing d_{shadow} and, lastly, we defined the ground cover ratio parameter to evaluate our PV system design. In the next lecture we will deal with the different grounding options and with the related mounting issues.