Calculating Inter-Row Spacing

The inter-row spacing calculations that I am doing manually do not match the results of our shadow studies in AutoCAD. Which results are accurate? What is the correct way to manually calculate inter-row spacing for a ground mounted PV array layout?

Computer software that permits shadow studies is an excellent design tool for large scale, ground mounted PV arrays. These programs model complex geometries with great accuracy and speed. Assuming that the CAD data entry is correct, these inter-row spacing results are correct. In all likelihood, your manual calculations are correct as well—just incomplete.

Historically many photovoltaic systems arranged in rows were designed using only an altitude angle calculation. This is the approach detailed, for example, in the American Technical Publishers' textbook, *Photovoltaic Systems*. The formula given there for calculating minimum inter-row shading is:

$d = h \div \tan \alpha$

According to the editors, *d* is the minimum distance between rows; *h* is the height differential between the top of one row and the bottom of the row to the north; and *α* is the solar altitude angle.

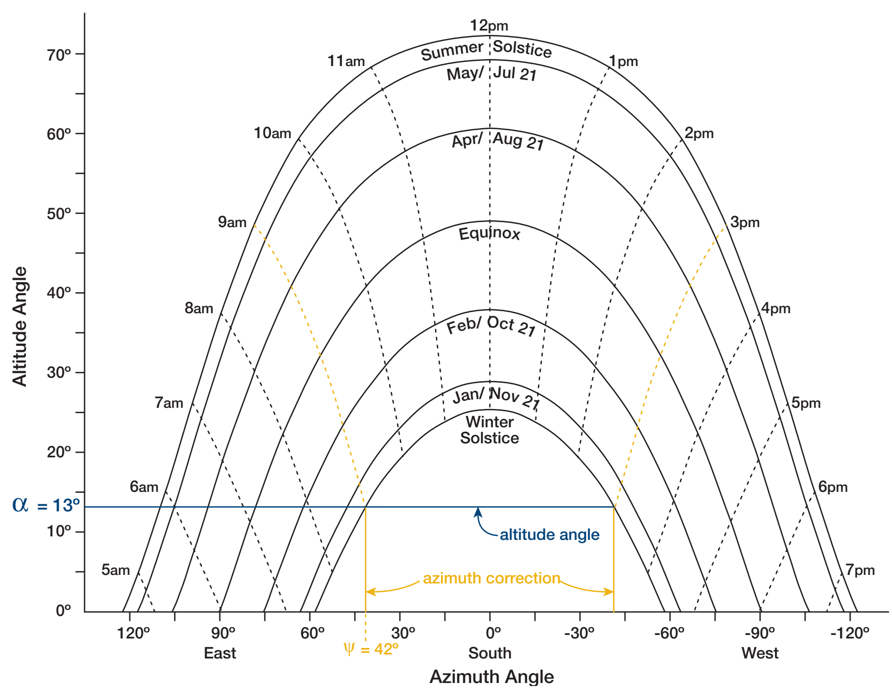
It is more accurate to say that this formula determines the *shadow distance* between rows. But because this shadow falls perpendicular to a south-facing array only when the sun is located at true south in the sky, solar noon is the only time when the length of the shadow cast between rows would be equal to the minimum inter-row distance. If your design calculations call for a shade-free solar window of 9am to 3pm on December 21, for example, then an azimuth angle correction is required.

The first step for doing manual inter-row spacing calculations is to generate a sun path chart for the site, as shown in Illustration 1. The University of Oregon's Solar Radiation Monitoring Laboratory (SRML) provides an online program for this purpose (solardat.uoregon.edu/SoftwareTools.html). For best results, enter the site's specific latitude and longitude. These are easy to obtain using the free version of Google Earth (earth.google.com). Simply point to the specific site, and latitude and longitude are provided to the nearest 100th of a second in the lower left hand corner of the program screen. Convert the latitude and longitude provided in Google Earth to decimal degrees. Also, make sure to enter south latitude and west longitude as negative numbers. Following these steps for Ogden, Utah, results in a 41.21° latitude and a -111.97° longitude.

Use the sun path chart in Illustration 1 to determine the sun's altitude angle at 9am and 3pm solar time on December 21, the shortest day of the year. Referring to the chart for Ogden, Utah, the sun's altitude angle for design purposes is about 13°. Illustration 2 (p. 18) indicates that *h* equals 10 feet. We can now solve for the shadow length (d_shadow) using the referenced formula:

d_shadow = h ÷ tan α°
d_shadow = 10 ft. ÷ tan 13°
d_shadow = 10 ft. ÷ 0.231
d_shadow = 43.3 ft.

CONTINUED ON PAGE 18



Data courtesy solardat.uoregon.edu

Illustration 1 When the latitude and longitude for Ogden, UT, are specified, the SRML sun path chart program plots the path of the sun across the sky at that location.

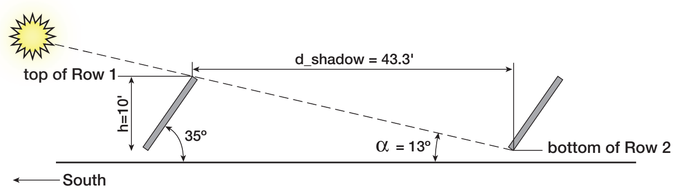
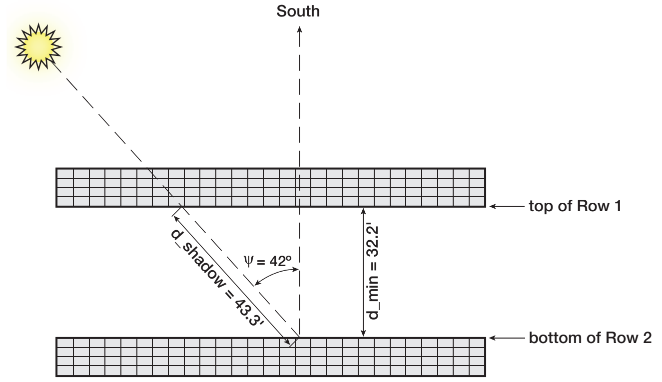


Illustration 2 Side view of inter-row shadow length at 9am and 3pm on the winter solstice.



mollyohalloran.com (2)

Illustration 3 Plan view at 9am.

Once shadow length is determined, it is time to apply the azimuth angle correction. Referring again to the sun path chart for Ogden, Utah, the sun's azimuth is approximately 42° east of true south at 9am and 42° west at 3pm on the winter solstice. As Illustration 3 indicates, knowing both the shadow length and the azimuth (Ψ) correction angle allows us to solve for minimum inter-row spacing (d_min):

$d\_min = d\_shadow \times \cos \Psi$
$d\_min = 43.3 \text{ ft.} \times \cos 42°$
$d\_min = 43.3 \text{ ft.} \times 0.743$
$d\_min = 32.2 \text{ ft.}$

The azimuth angle correction detailed here is very significant for PV system designers, integrators and their customers. Inter-row spacing is reduced by 25% in this example. This could mean 25% less site grading or a 25% larger array for the client. Improving power density in this manner can increase PV plant size, energy harvest, revenue, profit or all of the above.

—Ken Gardner / Gardner Engineering Alternative Energy Services / Ogden, UT / gardnerengineering.net