PV Module Angles

Richard Perez and Sam Coleman

Photovoltaic (PV) modules work by converting sunshine directly into electricity. Sunlight is *the* essential ingredient. PV modules work best when their cells are perpendicular to the Sun's incoming rays. Adjustment of static mounted PV modules can result in from 10% to 40% more power output yearly. Here's the angle.

Getting Perpendicular

Keeping the module perpendicular to the incoming sunlight means that the module intercepts the maximum amount of sunlight. If you have trouble visualizing this concept, take this magazine outside and hold it up to the sun while observing its shadow. If the magazine (or module) is edge on to the sunlight, then it casts a small shadow. If the magazine's cover (or module's face) is perpendicular to the sunlight, then the shadow is as big as it will ever be. The size of the shadow shows us exactly how much sunlight is being intercepted. In the case of a PV module, maximum shadow means maximum power.

The problem is that the Sun constantly moves in relation to the stationary PV module. Actually, the apparent motion of the Sun is due to the Earth's motion, but for our purpose here this celestial fact is mere trivia. Even if we place a module so that is perpendicular to the Sun at solar noon, it is not even close to perpendicular in the morning and evening. This daily east to west solar motion is called solar azimuth. Also consider that the Sun's apparent height in the sky changes from winter to summer. This yearly north to south solar motion is called solar declination. And you thought solar power was simple. Well, it really is…

Actually you can face a PV module south, tilt it so the included angle between its face and the ground is your latitude, and you're done. It will work and it will work well. What we are talking about here is squeezing anywhere from 10% to 40% more power from PV modules by keeping them as perpendicular as possible to the incoming sunlight.

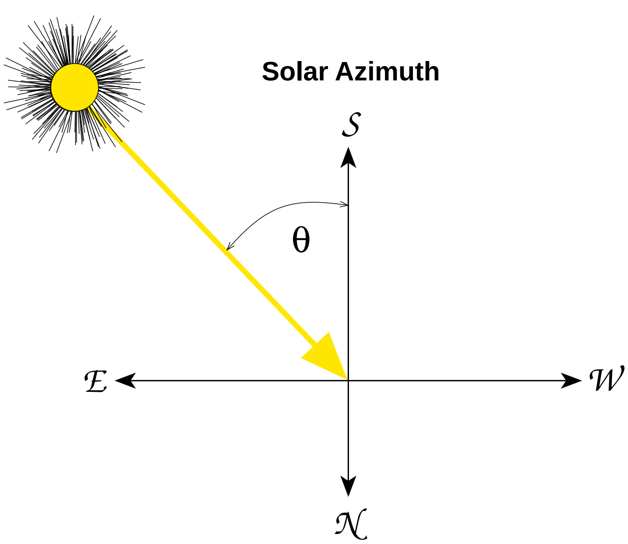
An Angular Matter

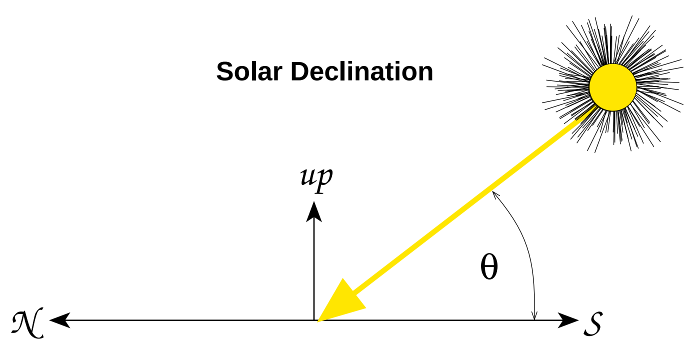
It's matter of angles. If the module is to be kept perpendicular to the sun's daily east to west motion (azimuth), then a device called a tracker is used. A tracker follows the sun's daily motion and provides anywhere from 25% to 35% more power from the PVs hitchhiking on its back.

If you keep up with the sun's seasonal north to south migration, then manual adjustment boosts PV power production by up to 10%. The chart on the next page has all the data necessary to accomplish this seasonal, north/south, adjustment.

Cosine Stuff

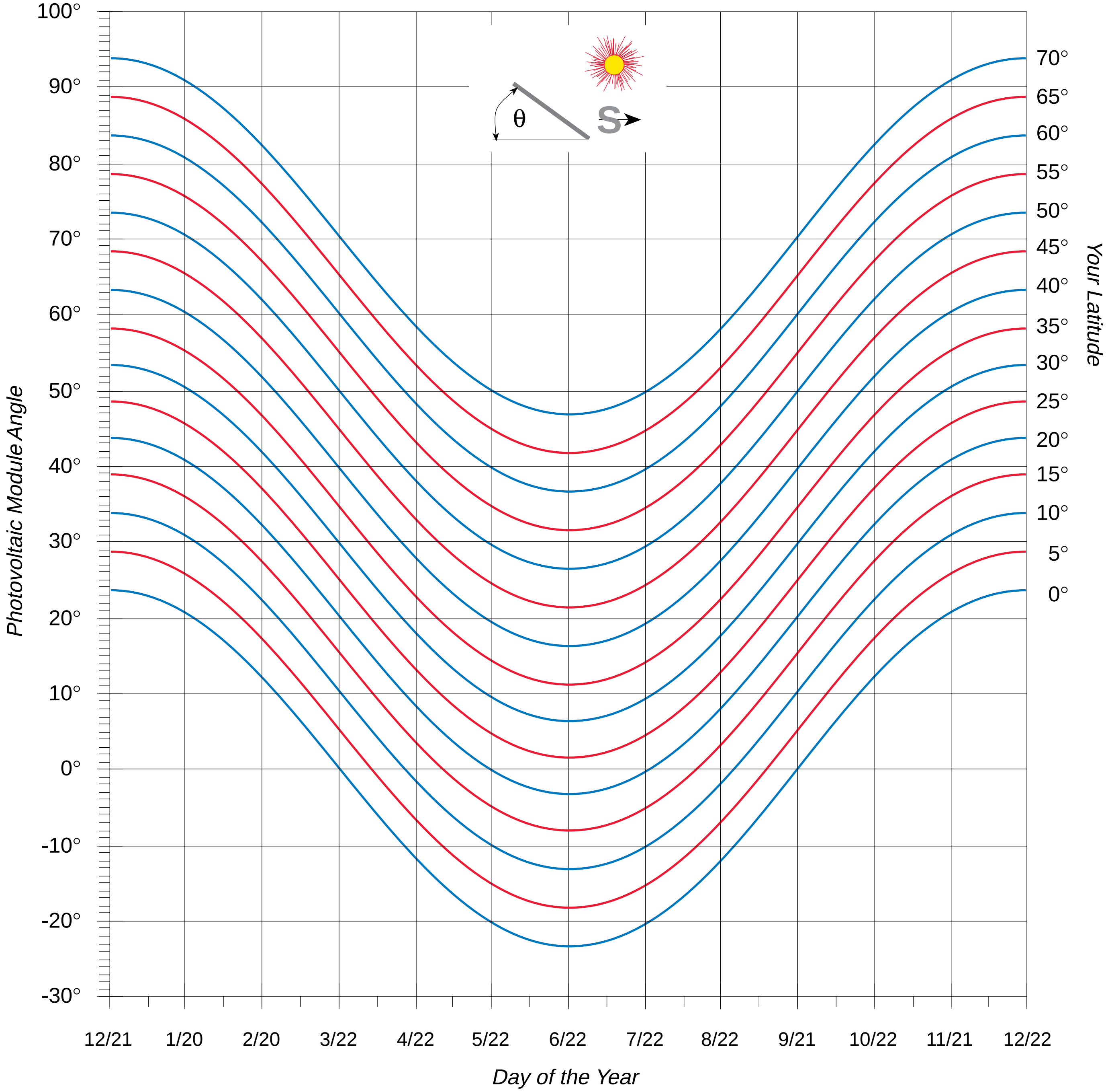
While using PV modules is very simple, the mathematics describing their angular relationship to the sun are very difficult. I sought help from Sam Coleman who is adept at ritual trigonometry. After covering





Left: a bird's eye view of solar azimuth, the sun's apparent east to west daily motion.
Above: a ground level view of solar declination, the sun's seasonal north to south motion.

Solar Panel Angles for Various Latitudes



several pages with arcane formulæ, he arrived on the equations that generated the chart on this page. See the sidebar for the gory trigonometric details on the next page.

What Angle to Adjust to?

This chart assumes that the module is facing true south (true north for those in the southern hemisphere). On the y-axis (vertical) of the chart are the degrees of included angle between the PV's face and ground. On the x-axis (horizontal) are the days of the year. There are fifteen curves, each for 5° degrees of latitude.

First find the curve that most nearly corresponds to your latitude (right side of chart). Follow that curve until it intersects the current date on the x-axis. The corresponding angle read on the y-axis is the included angle between the PV module's face and the ground. This angle will result in the PV module being perpendicular to the sun's rays at noon on that date.

Calculation of Panel Angle

Sam Coleman

The calculation of the panel angle (A) is based on the supposition that the panel will be perpendicular to the sun's rays at solar noon. Solar noon is the time when the sun is highest in the sky. This is when the angle between the plane of the horizon and a line drawn from the site to the sun is greatest.

This calculation involves two parameters, These are the latitude of the site (L) and the declination of the sun (D). The declination of the sun is the latitude at which the sun is directly overhead at solar noon. This varies from 23.5° north latitude on the summer solstice (June 21) to 23.5° south latitude on the winter solstice (December 21). These latitudes are known as the Tropic of Cancer and the Tropic of Capricorn. On the equinoxes (March 21 and September 21) the declination of the sun is 0°, so that it is directly over the equator at solar noon. The equation for calculating the declination(D) for any day is:

$$D = 23.5° \sin((T / 365.25) * 360°)$$

where T is the number of days to the day in question as measured from the spring equinox (March 21).

The panel angle (A), the angle between the panel and the horizontal plane, is then calculated from the equation:

$$A = L - D$$

How Often to Adjust

Most folks who do it, do it at least four times a year. The best dates are up to you , but most prefer mid February, mid April, mid August and mid October. A quick glance at the chart will show that these periods are when the sun's declination is most rapidly changing. The chart gives the proper angle for a specific day.

Now here is where some strategy comes in. Adjust the PV modules so that they are perpendicular on a day midway between today's date and the date when you next plan to adjust the angle. This gives best performance during the period between adjustments. The more adjustments you make yearly, the more power the PVs will produce.

Building Adjustable Mounts

PV mounting structures can be built from a variety of materials and in a variety of styles. Almost all designs can be made to be seasonally adjustable. Virtually all commercially produced PV racks are seasonally adjustable because they are made to work at a wide range of latitudes. For the specifics of PV mounting structures see HP 22, pg. 41. What counts is that the mounting structure be seasonally adjustable and that you actually adjust mounting structure at least four times yearly. Otherwise, just mount the PV module at your latitude and forget it. I wish to emphasize that we are talking fine tuning here. Seasonal adjustment will yield a yearly boon of about 10%.

Buying Adjustable Mounts

When it comes to following the sun's daily east to west motion, you can't beat a commercially made tracker. I compared the cost of modules, vs. the cost of the tracker, vs. the power output of both using either the tracker or buying more modules. I found that it is cost effective to track eight or more PV modules. Both Zomeworks and Wattsun make effective and reliable trackers that will increase PV power production by 25% to 45% yearly. Even experienced fabricators have trouble homebrewing a reliable tracker for less money than a factory job. Considering the cost of the modules riding along, the tracker is just not the place to save a few bucks.

The tracker site must have unrestricted solar access in order to make tracking effective. This means dawn to dusk sun with few or no obstructions that shadow the modules. Using a solar site evaluator, like the Solar Pathfinder, is essential for determining a site's tracker suitability.

Getting Angular

Whether you adjust your PV modules quarterly, or never, or have a tracker to do it all for you, understanding the sun's apparent motion is a basic solar skill. At Home Power, we have used static mounts with seasonal north/south adjustments since 1985. We adjust them about four times yearly. Many of our modules are now mounted on Zomeworks and Wattsun trackers. I never tire of watching as these trackers keep our PVs facing the sun.

Facing the sun keeps us in tune with time. Adjusting the PV arrays is like getting in the winter's wood, or starting up the garden. All are in tune with the harmony of change…

Access

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