notes regarding a solar electric system

My consideration of a solar photovoltaic (PV) system began with a lot of reading. I thought a summary of my gleanings might be of interest to other beginners.

But first, I must mention a most important resource - HAREI (**H**illsborough county **A**rea **R**enewable **E**nergy **I**nitiative), a volunteer group which provides information and mentoring for those interested in building, or having built, a solar PV energy system. HAREI has been involved in over 50 solar PV systems. Their website provides detailed advice on all phases of PV system design from conception, design, permitting through construction. They hold meetings (currently virtual) twice a month during which current projects are discussed and next steps planned, often including site visits. When it is time to install the panels they organize "solar raiser" events, most taking only one day, in which volunteers arrive with tools and expertise to help with the panel installation. An extraordinary resource! Dues are $40/year. <**HAREI.org**>

I am assuming here that a "net metering" system is being considered - one that simply feeds excess electricity back into the grid. These are the most simple and least expensive systems. Their one disadvantage is that during grid black-out they also shut down, leaving you in the dark.

Off-grid systems, or those intended to provide electricity during a grid black out, require expensive batteries and accessories which can easily double the cost. Such systems are not considered here.

Summary (very approximate, assuming you have a well oriented and unshaded sunny site):

how much to generate/year: about 1,500 kWh + 16% more than you use to zero out your electrical bill; include any planned additions, for example an EV car (~ 330 kWh/1,000 miles driven each year).

how big a solar array will you need: estimate 1 kW of solar panels per 1200 kWh of annual consumption

how big will such an array be: roughly 55 square feet per 1 kW of solar panels, or about 2.5 panels/kW

how critical is orientation: facing due South is best, but anything from SE to SW will get at least 90% as much, and even due East or West can capture 75% as much.

how critical is tilt: for a due South facing array, 40° tilt is best, but tilts between 20° to 60° still capture 95%, and even tilts of 10° or 70° capture 90% as much. Tilts of 30° or more help shed snow.

how important is shading: very important. If the array is not in directly sunlight it can't capture much energy. Furthermore, shading any part of a panel greatly decreases its output.

The Details:

A net metering system simply feeds its electricity into your house's electrical system. Think of it as being at any instant in one of these 3 conditions

1) at night: no solar, all your electricity is "bought" from the grid
2) during sunlight hours:
   2a) more solar than you are using: the excess is "sold" (exported) to grid
   2b) less solar than you are using: the deficit is "bought" (imported) from grid

Energy that you use locally while generating does not show up at all in the bill. For example if you are generating 2 kW while using 1 kW, it looks to the meter as if you are generating and selling 1 kW while not using any. Similarly, if you are generating 1 kW but using 2 kW, the meter only sees a 1 kW consumption.

At the end of each monthly billing cycle the amount of energy you've "sold" to the grid is subtracted from the amount you "bought" to yield a ***net*** kWh consumption. If the net is positive you are billed for that amount at 14.587 cents/kWh; if it is negative then you are credited 11.206 cents/kWh for the ***excess*** sold above the amount bought. In addition you are billed 1.78 cents/kWh for the total import. Any credits are applied against the next monthly bill. If credits remain at the end of the billing year you are sent a check.

Of course you pay more for the energy you buy from the grid than you are paid for the energy you sell back to the grid. According to Dan Weeks of ReVision Energy, in 2020 the split in NH was about $0.17/kWh to buy versus $0.11/kWh to sell.

Here is how Eversource charges are calculated, at present (8/2020), for Residential Rate R (in ¢/kWh)

Charge	¢/kWh bought ***Total***	¢/kWh bought ***Net***	¢/kWh sold ***above total bought***	
Energy	-	7.068	7.068	
Transmission	-	3.011	3.011	
Distribution	-	4.508	1.127	
Stranded Costs	0.982	-	-	
Network Benefits	0.743	-	-	
Consumption Tax	0.055	-	-	
Column Totals	**1.780**	**14.587**	**11.206**	¢/kWh

In other words, you pay:	to cover:
1.780¢ for ***all*** kWh bought:	Stranded Costs + Network Benefits + Consumption Tax
14.587¢ for ***net*** kWh (bought-sold):	Energy + Transmission + Distribution
and are credited:	
11.206¢ for ***excess*** kWh sold:	Energy + Transmission + (Distribution**/4**)

For example, if you bought 600 kWh and generated 400 kWh (leaving 0 excess to sell):

net kWh = 600-400 = 200 kWh net bought, so your bill would be
600 x 1.780 = ¢1068 = $10.68 **total** kWh charges
200 x 14.587 = ¢2917 = $29.17 **net** kWh bought

resulting in a bill of 10.68+29.17 = $39.85, or under 7¢/kWh used, assuming that all your energy usage was in the morning and evening while all of your energy generation was during the day, i.e., no overlap between your generation and your usage. Overlap would result in less bought kWh thus lower costs.

With a larger array, say you still consume 600 kWh but now are generating 800 kWh, so your net consumption is 0 and you have 200 kWh surplus to sell:

net kWh = 600-800 = 0 kWh net, and **-**200 kWh surplus, so your bill would be
600 x 1.780 = ¢1068 = $10.68 **total** kWh charges
0 x 14.587 = ¢0 = $ 0.00 **net** kWh bought
-200 x 11.206 = **-**¢2241 = **-**$22.41 **surplus** kWh sold

resulting in a ***credit*** of $11.73, almost enough to cover the $13.81 fixed monthly charge.

Of course the above figures are approximate. There will be times when you do consume energy at the same time you are generating it - that will result in less energy "bought" and "sold". In Winter, when the days are shorter, you will be generating less, resulting in more "bought" and less "sold".

The relevant documents are:
RSA 362-A:9 Net Energy Metering - the NH law establishing net metering
<http://www.gencourt.state.nh.us/rsa/html/XXXIV/362-A/362-A-9.htm>

PUC (Public Utility Commission) Rule 900 which implements RSA 362-A:9
<https://www.puc.nh.gov/Regulatory/Rules/PUC900.pdf, https://www.puc.nh.gov/Regulatory/rules.htm>

Eversource - information about net metering:
<https://www.eversource.com/content/nh/about/about-us/doing-business-with-us/builders-contractors/interconnections/new-hampshire-net-metering>

Eversource - two example bills:
<https://www.eversource.com/content/docs/default-source/nh---pdfs/purchase-greater-than-sales.pdf>
<https://www.eversource.com/content/docs/default-source/nh---pdfs/sales-greater-than-purchase.pdf>

First question: how much solar energy do you want to capture?

The usual goal is to generate at least the same amount in a year as you would use. Less will be generated during the Winter months, and more during Summer months, so you may be "buying" more in Winter and "selling" more in Summer. This means that you actually want to generate somewhat more annually than you use in order to cover the buy/sell difference along with the fixed monthly charge of $13.81.

The ***average*** residence in NH consumes around 600 kWh per month, amounting to about $100 worth of electricity, but this varies widely. For example we use about 40% of that amount while a house with electric heating or air conditioning would use a lot more.

To zero out your bill, including the $13.81 fixed fee, generate 1.16 x monthly usage + 123 kWh per month, or 1.16 x annual usage + 1500 kWh per year.

Assuming an average of 600 kWh/month = 7200 kWh/year, you would want to generate at 1.16 x 7200 + 1500 = 8,352 + 1,500 = 9,852 or about 10,000 kWh/year to zero out your bills..

Next question: how powerful a solar array would be needed?

The amount of energy captured depends on many things, including the time of year, local weather (overcast days generate much less than sunny ones), orientation of the solar array (best in Mason is facing due South and tilted 40° from horizontal), presence of any shadows, etc.

We have some very useful data from Mike McGuire whose 8 year old array in Mason has been generating an average of ***1,200 kWh/year per 1 kW of solar array***. His array is very well oriented - facing due South, tilted 30° and with a clear view of the sky.

Using Mike's data, to produce 10,000 kWh/year you would need

10,000 kWh/year / 1,200 kWh/year/1 kW = **8.3 kW** worth of solar array.

Modern solar panels are rated at 350 to 400 watts per panel. Assuming 400 watt panels (0.4 kW), you would need 8.3 kW / 0.4 kW/panel = 21 panels, assuming perfect orientation, tilt and sky view.

The National Renewable Energy Lab (NREL) provides some wonderful programs that calculate the output power of an array based on its size, location, orientation and tilt, combined with the historical weather patterns in that area. Their ***PVWatts*** program is an on-line program while their ***SAM*** program is a downloaded program. SAM, in addition to PVWatts' capabilities, adds the effects shading and a full financial analysis.

NREL's PVWatts® Calculator
<https://pvwatts.nrel.gov/>

NREL's System Advisor Model (SAM) download site (Windows, Mac or Linux)
<https://sam.nrel.gov/>

How large would a 20 panel 8 kW array be?

The area of typical panels is 18 (for 60 cell panels) to 22 (for 72 cell panels) square feet. Assuming 72 cell panels, 20 panels would cover about 20 panels x 22 sq.ft./panel = 440 square feet (say 17 feet x 27 feet) Or, in more general terms, with modern panels **expect about 55 square feet of array per 1 kW rating.**

How important is having exactly the right tilt and orientation?

When using a ground-mounted array it is easy to set the tilt to the optimum value. However, roof-mounted arrays usually must match the roof's tilt. ***So, how important is having the exact optimum tilt?***

Similarly, your roof may not face due South (Azimuth=180°), so how important is having the optimum Azimuth? Since you may have some obstructions, such as trees or buildings, it may be better to face the array towards a less obstructed sky view - see "shading" below.

I used NREL's PVWatts to predict the output, in kWh per month, for a 1 kW array as a function of tilt and azimuth (Az 180 = South). I've bolded the peak values for each month; Δ% is the % relative to 40° tilt. Note that NREL's predicted kWh/year are around 12% higher than Mike's actual results.

1) DUE SOUTH (180) azimuth, **effect of tilt**, kWh/month for 1 kW array

Az	Tilt	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	kWh/y	Δ %
180	0	50	65	103	114	130	***131***	139	123	99	69	47	38	1,108	82.0
180	10	67	79	114	119	***133***	***131***	***141***	129	108	81	60	53	1,215	89.9
180	20	82	91	122	***123***	132	129	140	***131***	115	91	72	66	1,294	95.7
180	30	94	100	128	***123***	129	125	136	130	***119***	99	80	76	1,339	99.0
180	40	103	106	***130***	121	123	118	130	127	***119***	104	87	84	***1,352***	***100.0***
180	50	109	110	***130***	116	115	109	120	121	118	***106***	91	90	1,335	98.7
180	60	112	***111***	126	108	105	97	109	112	113	***106***	***93***	93	1,285	95.0
180	70	***113***	109	120	98	93	84	95	101	106	104	***93***	***94***	1,210	89.5
180	80	111	105	110	86	78	70	79	87	96	99	91	93	1,105	81.7
180	90	106	98	98	71	63	55	62	71	84	91	86	89	974	72.0

I've bolded the maximum values for each month and for the year. As can be seen, steeper tilt increases Winter production at the expense of Summer and vice-versa. In Mason a tilt of 40° (approximately our Latitude) maximizes annual production.

However, tilts ranging between 20° to 60° still capture 95%, and even tilts of 10° or 70° still capture 90% of the 40° optimum - ***so being able to match the perfect angle is not really a major issue***. Bear in mind that snow is also a consideration - in general slopes of 30° or steeper help shed the snow.

There might appear to be a seductively simple way to optimize month by month: hinge the bottom edge of the array so that its tilt can be adjusted each month. However, here is the data:

2) DUE SOUTH (180) azimuth, TILT ADJUSTED MONTHLY, kWh/month for 1 kW array

Az	Tilt	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	kWh/y
180	|	113	111	130	123	133	131	141	131	119	106	93	94	**1425**
	|>	70°	60°	50°	30°	10°	10°	10°	20°	40°	50°	70°	70°	<=adjusted tilt

Note that the gain is small, 1425 instead of 1352 - only about 5%. ***Much cheaper to add 1 more panel***.

What about the azimuth (orientation)?

To answer this question I again used PVWatts, this time with a fixed 40° tilt but varying orientations from East (Az=90) through South to West (Az=270) in 15° steps. Δ% column is % of the best (S) orientations:

3) FIXED 40° TILT, effect OF AZIMUTH

Az	Tilt	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	kWh/y	Δ%	
90	40	52	65	99	108	117	118	129	117	93	66	47	40	1,051	77.7	East
105	40	64	76	109	114	120	120	131	122	101	75	57	51	1,140	84.3	
120	40	75	86	117	118	123	***121***	133	125	108	84	66	61	1,217	90.0	
135	40	86	94	123	121	124	***121***	***134***	127	113	92	74	70	1,279	94.6	SE
150	40	95	101	128	***122***	***124***	120	133	***128***	117	98	81	77	1,324	97.9	
165	40	101	105	***130***	***122***	***124***	119	131	***128***	***119***	102	86	83	1,350	99.9	
180	40	***103***	***106***	***130***	121	123	118	130	127	***119***	***104***	***87***	***84***	***1,352***	***100.0***	South
195	40	100	104	128	119	123	118	128	126	118	102	85	83	1,334	98.7	
210	40	94	98	123	117	123	119	128	124	115	98	80	77	1,296	95.9	
225	40	85	91	117	113	123	119	127	122	110	92	73	69	1,241	91.8	SW
240	40	74	82	109	109	122	119	125	119	104	85	64	60	1,172	86.7	
255	40	63	72	101	104	119	118	122	114	97	76	55	50	1,091	80.7	
270	40	51	61	91	98	116	116	119	109	90	66	45	40	1,002	74.1	West

As can be seen, orientations as much as 45° to either side of due South produce at least 90% energy compared to the optimum due South orientation. ***Strict adherence to the optimum is not a big issue***.

Next I looked to see if other tilts might be better when the orientation is far away from due South. In these tables the Δ% column is % energy compared to best tilt in that orientation.

4) SOUTHEAST azimuth (135) effect of tilt

Az	Tilt	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	kWh/y	Δ%
135	10	62	76	112	119	***132***	***131***	***141***	128	106	77	57	49	1,190	93.0
135	20	73	84	118	***122***	131	129	***141***	***130***	111	84	64	58	1,245	97.3
135	30	81	90	122	***122***	128	126	138	129	***113***	89	70	65	1,273	99.5
135	40	86	94	***123***	121	124	121	134	127	***113***	***92***	74	70	***1,279***	***100.0***
135	50	***89***	***95***	122	117	117	114	127	123	111	***92***	***76***	***73***	1,256	98.2

5) SOUTHWEST azimuth (225) effect of tilt

Az	Tilt	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	kWh/y	Δ%
225	10	62	75	110	***117***	***132***	***131***	***139***	126	105	78	56	49	1,180	94.8
225	20	72	82	114	***117***	131	129	137	***127***	109	85	64	58	1,225	98.4
225	30	80	88	***117***	116	128	125	133	125	***111***	89	69	64	***1,245***	***100.0***
225	40	85	91	***117***	113	123	119	127	122	110	92	73	69	1,241	99.7
225	50	***88***	***92***	114	109	116	112	119	117	108	***93***	***75***	***72***	1,215	97.6

In the case of arrays oriented as much as 45° off of due South - SE or SW - the 40° tilt remains close to optimal. In other words, using a 40° tilt from SE through South to SW is perfectly OK.

Note, however, that the array's best output in these configurations averages only 1262 kWh/year, about 7% less than a South facing array.

Beyond 45° the situation changes somewhat. As shown below, for a due East or West facing array, a 5% to 10% improvement can be achieved by using a horizontal, or near horizontal, array.

6) DUE EAST azimuth (90), effect of tilt

Az	Tilt	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	kWh/y	Δ%
90	0	50	65	103	114	***130***	***131***	139	123	***99***	***69***	47	38	1,108	99.5
90	10	51	***66***	***104***	***115***	***130***	130	***140***	***124***	***99***	***69***	47	39	***1,114***	***100.0***
90	20	51	***66***	103	114	127	128	138	123	98	68	***48***	***40***	1,104	99.1
90	30	***52***	***66***	102	111	123	123	134	120	96	67	***48***	***40***	1,082	97.1
90	40	***52***	65	99	108	117	118	129	117	93	66	47	***40***	1,051	94.3

7) DUE WEST azimuth (270) effect of tilt

Az	Tilt	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	kWh/y	Δ%
270	0	50	***65***	***103***	***114***	***130***	***131***	***139***	***123***	***99***	***69***	***47***	38	***1,108***	***100.0***
270	10	50	***65***	101	111	129	130	137	122	98	***69***	***47***	38	1,097	99.0
270	20	***51***	64	98	108	126	127	132	118	96	69	46	39	1,074	96.9
270	30	***51***	63	95	103	122	122	126	114	93	68	46	***40***	1,043	94.1
270	40	***51***	61	91	98	116	116	119	109	90	66	45	***40***	1,002	90.4

Thus arrays facing farther away than 45° from South require more careful analysis - PVWatts should be used to analyze these configurations.

Also note that the array's best output in these due East or due West configurations averages 1111 kWh, about 18% less than a South facing array. Also bear in mind that arrays tilted 30° or more will generally self clear snow, but flatter arrays will need hand clearing after every snow storm.

So, while East or West facing arrays are possible and can capture a significant amount of energy, generally it is best to stick closer to South facing.

Tracking array options

There are "1D" and "2D" tracking array designs. The "1D" versions track the Sun's East to West path during the day by pivoting the array around the tilt axis. The "2D" versions track the Sun by pivoting the array around 2 axies so that the array is always at right angles to the Sun. These can increase energy collection over a 40° tilt South facing fixed array by 22% for "1D" and 35% for "2D".

However, your 8 kW array's 440 square foot area is both a large heavy object and a very large sail. Tracking mounts have to be very rugged to withstand wind and snow loads, and are extremely expensive. In practice such an array would be broken down into several smaller arrays, greatly increasing complexity. ***It is always more cost effective to simply add 22% or 35% more panels to a fixed array***.

Roof versus ground mounting

Roof mounted arrays are the most common and the least expensive because the existing roof provides support for the panel mounting rails. Their disadvantage is that your roof may not provide optimum orientation and tilt. Roof mounting does add complexity and expense if you later need to replace the roofing as you will have to first remove the array. It is recommended that new roofing be installed before the array unless the existing roofing is fairly new and has a long life expectancy. Old houses built before building codes may need to be inspected to ensure the roof is capable of handling the added load (though not huge, under 3 Lbs / square foot). An advantage is that the array is mounted high up and may have a more open view of the sky.

Ground mounted arrays cost more because you have to build a support structure to which the panel mounting rails attach. The support structure must handle large loads - in Winter at 70 Lbs/sq.ft snow loads your 440 sq.ft. 40° tilt array must support 24,000 Lbs, or 12 tons, and the wind loads on that large sail will also be large. On the other hand, ground mounting gives total control of orientation, tilt and location.

Shading

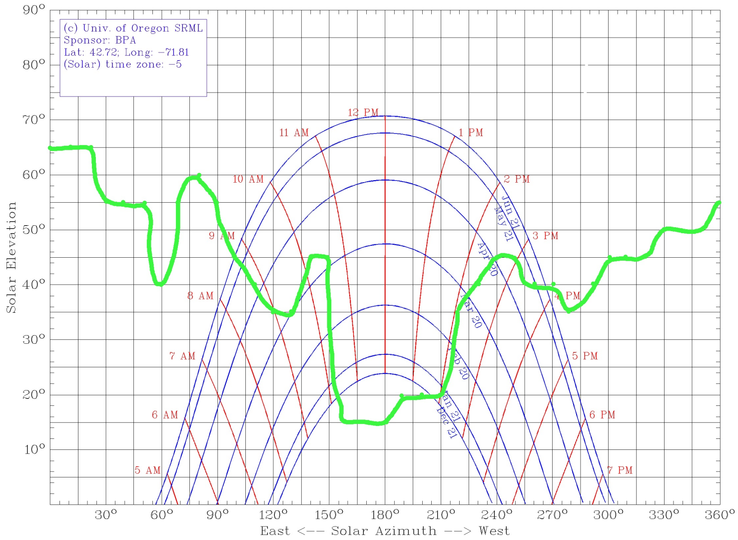
Shading refers to anything that casts a shadow on the array, thus reducing its output.

This is a big issue because even a small shadow on a PV panel can drastically reduce the output of that entire panel. Each panel contains either 60 or 72 small cells, each contributing 0.6 volts, connected in series to produce 36 or 43 volt output - if any cell is shaded the current from the other cells won't be allowed through.

In PV systems in which each panel has its own inverter or optimizer, a small shade only affects the shaded panels.

In PV systems in which several panels are connected in "strings" which connect to a central inverter, shade on any panel affects the entire string of panels. Low voltage (150V) central inverters may connect panels in strings of 3 while high voltage (600v) may connect a dozen panels in each string.

Shadows from poles, vent pipes, chimneys or branches can shade a panel - something to consider when designing the array and its location on a roof, or deciding where to place a ground mounted array. Another consideration with ground mounts is to ensure that the panels' lower edges will remain above any growing shrubbery or flowers, and above any snow mound that results when the snow slides off the array...



If maximum energy is to be collected, the whole array needs be able "see" the Sun during most of the daytime . Of course, the Sun's position in the sky varies during the day and seasons.

There is a very useful sun charting program at: <http://solardat.uoregon.edu/SunChartProgram.html>

You enter the location Latitude and Longitude, or just the ZIP code, and it creates a downloadable PDF chart like the one shown to the right.

The blue lines show the path of the Sun at various seasons while the red lines correspond to hours on either side of solar noon. The horizontal axis is Azimuth with

South (Az=180) at the center. The vertical axis is elevation angle. Green is my site horizon.

While standing at the location of the array, one draws the observed elevation in degrees of obstacles (trees, buildings, etc.) on the chart to create an observed horizon at that site. You can then see how many hours of sunlight will fall on the array during each season; from that you can guesstimate actual energy generation.

First you need to establish true South, which is about 14° to the East (clockwise) from South as indicated by a compass. Set a stake at the array position and a second stake to the true South to establish a reference sight line.

From that sight line you can use a horizontal protractor to estimate azimuth angles to obstructions. A vertical protractor with plumb bob or level can be used to estimate the elevation angles of obstacles.

Or borrow a transit...

There are also smartphone apps which can provide similar information using photographs, but I hav no experience with these - see the HAREI website.

However, the best way is to use NREL's SAM program which accepts a chart of obstacle azimuth/elevation pairs and will take those into consideration in calculating production. I mapped out my site from SE (Az 90) to SW (Az 270) and entered the results into a plain text file using this format:

```
 0,   90,  100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200, 210, 220, 230, 240, 250, 260, 270
 5,   100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100
 10,  100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100
 15,  100, 100, 100, 100, 100, 100, 100, 0,   0,   0,   100, 100, 100, 100, 100, 100, 100, 100, 100
 20,  100, 100, 100, 100, 100, 100, 100, 0,   0,   0,   0,   0,   0,   100, 100, 100, 100, 100, 100
 25,  100, 100, 100, 100, 100, 100, 100, 0,   0,   0,   0,   0,   0,   100, 100, 100, 100, 100, 100
 30,  100, 100, 100, 100, 100, 100, 100, 0,   0,   0,   0,   0,   0,   100, 100, 100, 100, 100, 100
 35,  100, 100, 100, 0,   0,   100, 100, 0,   0,   0,   0,   0,   0,   0,   100, 100, 100, 100, 0
 40,  100, 100, 0,   0,   0,   100, 100, 0,   0,   0,   0,   0,   0,   0,   100, 100, 0,   0,   0
 45,  100, 0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0
 50,  100, 0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0
 55,  0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0
 60,  0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0
 65,  0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0
```

A comma is used to separate values (standard ".CSV" Comma Separated Values format)

The first row starts with 0 followed by the azimuth values, in this case from 90 to 270 by steps of 10. Actually my file covered from 0 to 350 (a bit OCD on my part), but in the above I pared it down to fit.

The following rows begin with the elevation, followed by either 100 if obstructed, or 0 if not, for each azimuth. As you can see, my horizon is around 15° due South, but rises up as high as 45° to the East and West - a far from ideal view of the sky.

In SAM's System Design page I click on Edit Shading Losses and then use Import to read in that file. Then when I click on Simulate it calculates production given the shading I've described. In my case it indicated a 25% loss in production compared to a fully unshaded array.

DC versus AC coupling

The solar panels produce DC electricity, typically between 35 to 45 volts DC at around 10 Amps. This DC current has to be converted to 240 V AC in order to be connected to the grid. The conversion is done using an "inverter". There are two basic ways to connect the panels to the inverter(s):

1) "Central inverter" the panels' DC outputs are combined together to connect to a single inverter.

Central inverters generally fall into 2 classes: low voltage (up to 150 V DC) and high voltage (up to 600 V DC). Panels are connected into series "strings" - commonly either 3 panel strings (3 x 40 = 120 V) or 12 panel strings (12 X 40 = 480 V), and the strings are then connected in parallel to the inverter.

For example, a 24 panel array could be organized as 8 strings of 3 panels each for a low voltage inverter, or 2 strings of 12 panels each for a high voltage inverter. Assuming 10 Amps per panel, the combined inverter input would be 80 Amps at 120 VDC into the low voltage inverter or 20 Amps at 480 VDC into the high voltage inverter.

2) "Microinverters" use a separate inverter on each panel, the 240 V AC outputs of the microinverters are combined together in parallel.

Although the central inverter approach would seem more efficient, there are complexities.

Central inverters connect some number of panels in series - which means that any shaded panel in a string reduces the output of the entire string. In a high voltage inverter system with 12 panels in a string, shading (or otherwise degraded performance) of a single panel compromises the output of all 12.

One solution is to use "***optimizers***" - small DC to DC circuits which mount on each panel to help compensate for low output panels - but of course these add to the cost.

Using shorter strings with a low voltage inverter reduces the problem, but at the cost of having to carry higher currents (80 Amps instead of 20) which require heavier and more expensive wires.

Another issue is that the connection from panels to the inverter is carrying DC currents. When switching or interrupting (e.g., with a fuse or breaker) an AC current, the voltage goes through zero 120 times per second which helps interrupt any arcing. Switching DC currents is much harder because the constant voltage can maintain an arc for much longer. For this reason, DC is considered more dangerous and the electrical codes require that DC wires be enclosed in steel conduit. This requirement was a "show stopper" for me because I would have needed to jackhammer a 150' long trench 18" deep through a lot of bedrock to connect my ground-mount array to the inverter in the house. This would not have been such an issue for a roof-mounted array.

In comparison, the output from microinverters is plain old 240 VAC house wiring, nothing special, so I could run an over-head cable to the house.

Another advantage of the microinverters is that any shading only affects the output of the shaded panels, not that of a whole string. "Optimizers" in a DC coupled system also can reduce shading issues but, even though less expensive than microinverters, their cost adds significantly to the system cost, and they still have the drawbacks of DC wiring.

Microinverters seem to be the simplest choice for ground mounted arrays. A DC coupled central inverter may be more cost effective with roof mounted panels where the wire run between panels and inverter is shorter.

While later addition of a battery system can be done with either AC or DC coupling, it is more efficient in a DC coupled system which avoids the double conversion of an AC coupled system (DC from panels to AC, then AC back to DC for battery charging). Also, a battery system is going to need a central inverter anyway to generate AC from the battery, so a DC coupled central inverter approach is simpler if you plan on adding batteries.

Don't forget planned additions, e.g., an EV @ ~330 kWh/1,000 miles/year = ~ 8 panels/12,000 miles/year!

I claim no special experience or expertise - the above are no more than my amateur thoughts as I worked through the solar possibilities for my particular site and needs. **In other words, do your own research and reading!** I would appreciate feedback as you discover the inevitable errors and ommissions.

I hope the above helps more than it confuses.

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