Solar energy systems—solar panel and inverter power ratings

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ABSTRACT

In a typical solar energy generating installation for a residence with modest electrical energy usage, the photovoltaic panel array might be "rated" at a total output of 6.4 kW, while the inverter, which takes the DC power generated by the panel array and converts it into AC to feed the house load and/or feed back into the power grid, might be rated at a maximum output of only 5.0 kW. This at first seems inconsistent. This article discusses that and related issues.

1 THE PV PANEL

What is often spoken of as a *solar panel* is also properly described as a *photovoltaic* (PV) *panel* (the term reminds us that it converts light energy into electrical energy), and that term is widely used in the industry. Here I will usually say *PV panel* for consistency (sometimes just "panel").

2 QUANTITIES AND UNITS

2.1 Solar flux density

Solar flux is the "stuff" of sunlight, not as it affects what is seen by the eye (as we deal with in the field of *photometry*) but rather in terms of power or energy (regardless of wavelength).

At some point where sunlight arrives, its "power potency" is described by the metric *[solar] flux density*. This is the amount of power per unit area that crosses a plane perpendicular to the line of travel of the solar rays at that point. The SI unit of solar flux density is the *watt per square meter* (W/m^2).

At the top of the earth's atmosphere, the solar flux density is approximately 1.36 kW/m^2. The exact value varies slightly over the year due to a small variation of the distance to the sun as a consequence of the eccentricity of the Earth's orbit.

At the Earth's surface, the flux density is less, in part due to scattering by the Earth's atmosphere, and beyond that, at any instant, due to any obscuration of the sky by clouds.

But typically, on a clear day, the solar flux density at the Earth's surface is very near 1.00 kW/m^2 (almost regardless of latitude).

In fact, a flux density if 1.00 kW/m^2 (1000 W/m^2) is often used as a *reference flux densit*y at the surface of the Earth.

2.2 Solar irradiance

The "power potency" (my term) of the solar radiation on a surface (one not necessarily perpendicular to the direction of arrival of the sun's rays) is given by the metric *solar irradiance*, usually just called the *irradiance* when the context is understood. It is also denominated in the unit *watt per square meter* (W/m^2).

The *irradiance* on a surface ay any instant is the incident *flux density* times the cosine of the angle between the *normal to the surface* (the line perpendicular to the surface) and the direction of arrival of the sun's rays.

We can see that in the best situation (when the surface is in fact perpendicular to the direction of arrival of the sun's rays), the *irradiance* will be the same as the *flux density* at the surface.

Accordingly, an *irradiance* of 1.00 kW/m^2 is often used as the *reference irradiance* at which the fundamental performance parameters of a PV panel are often measured or described.

3 POWER RATINGS

3.1 The photovoltaic (PV) panels

PV panels are often "rated" by their possible DC output power when illuminated by the *reference irradiance* (1.00 kW/m^2).[1] That would be essentially the average power over the daylight hours that the panel could deliver if it were continuously "aimed" directly at the sun (rarely done in actual practice) and when there is zero obscuration by clouds.

A typical residential solar electrical energy system will have a number of PV panels. We typically think of the "panel power rating" of the system as the sum of the ratings of all the panels.

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[1] "Possible" refers to the fact that, at a given irradiance on a certain panel, it will only deliver that amount of power if its load arranges for the current drawn to be the "optimal" ("maximum power") current for that situation (which modern inverters do, by themselves or via the intervention of a separate "power optimizer" circuit.

3.2 The inverter

The inverter of a solar generating system takes the DC power generated by the PV panel array and converts it to AC power. The inverter typically can do this with an efficiency of over 99% (when it is operating near its capacity rating).

The typical inverter has a fairly “hard” limit as to the amount of output power it can generate. Accordingly, the inverter will typically not draw more power from the solar array than that output limit (assuming the inverter efficiency is close to 100%, as is true of many modern inverters).

4 THE OVERALL SCENARIO

4.1 Energy flow

The power delivered by the inverter is then used to supply the power needs of the house or, if more power is generated than is presently being consumed in the house, the excess power is fed back into the power grid.

Commonly, the watthour meter used by the power utility to determine how much power has been consumed during a billing period (so that it can be billed for), when a solar energy system is in place, will be bidirectional and symmetrical, meaning that the advance of its indication between readings will reflect the net flow of energy from the utility during the period.

We can consider this “advance” to be positive if the net flow is from the utility to the house, and negative if the net flow is to the utility from the house.

4.2 Reckoning and billing

There are many arrangements between the solar system operator (typically the homeowner) and the electric power utility company as to how this scenario is dealt with from a “billing” standpoint.

One arrangement (which may be very advantageous to the homeowner) can be described as “true net metering”.

With such a plan, if, during any billing period, the amount of energy created by the solar energy system is less than that consumed by the household, the remainder has been drawn from the power utility (it is today popular to describe this as “from the power grid”). The utility meter reading difference will be positive.

That amount of energy is then charged for under the applicable rate schedule (often the same one as if no solar system were in play).

However, if during the billing period the amount of energy created by the solar energy system is greater than that consumed by the household, the excess is fed back into the grid. The utility meter reading difference will be negative.

That amount of energy will be “escrowed” for the user (on a energy in kWh, not dollar, basis). Then during any future period where the energy consumption is “positive”, the energy delivered is first considered to come from the user’s “escrow account” (so long as there is enough in there), and no charge is made for that amount of energy.

Any energy beyond that is charged for under the regular rate schedule.

Note that in many areas the serving electrical power utility may not offer exactly that arrangement (a matter that is beyond the scope pf this article).

5 AN EXAMPLE SYSTEM

5.1 Power ratings

A solar energy generating system for a small residence might have an array of PV panels with an rated output rating (at an irradiance of 1.00 kW/m^2) of 7.0 kW, feeding an inverter rated at 5.0 kW. Why this seeming inconsistency?

5.2 One key to the mystery

One key is that of course this panel array rated at 7.0 kW would only deliver that when the irradiance on it was 1.00 kW/m^2. But perhaps the latitude of the site and the aiming of the panels was such that, at the location, the irradiance would never be that much; even at the peak hour (usually, *solar noon*) on a cloudless day in the best month, the peak power that this array could generate was only 6.25 kW. This is still more than the inverter could (or would try to) handle.

And in any case, the irradiance at other times of the day would by definition be less than at that peak time (a matter that will be given great attention in the next section).

5.3 The other key to the mystery

5.3.1 *Introduction*

The other key to the mystery comes from the variation in the potential power output of a solar array with a fixed orientation over the day.

For this section, we will assume that the solar irradiance on our panel array is, at its daily peak (on a cloudless day) 1.00 kW/m^2.

5.3.2 *Power and energy*

In these graphs, the horizontal axis is time of day (spanning only the "daylight" hours). The vertical axis is instantaneous *power*. Shaded areas under the various curves represent the total amount of *energy* developed during the day.

We assume that the solar irradiance on the panel array is, at its peak on this day, 1.00 kW/m^2.

5.3.3 *Example system A*

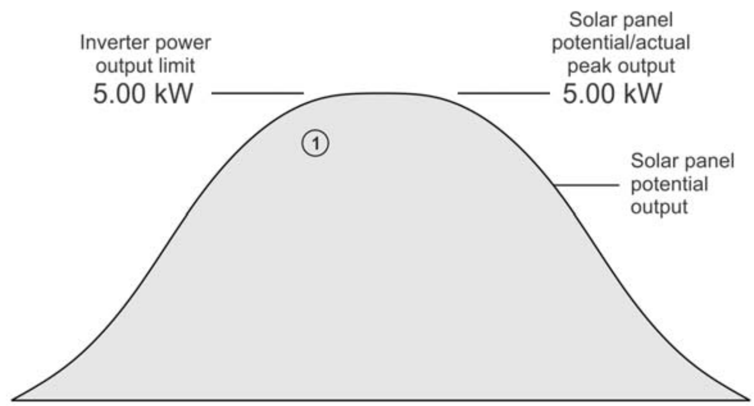

Figure 1.

In the hypothetical system (A) to which the above curve relates, the rated output of the solar array (at 1.00 kW/m^2) is 5.00 kW, [2] and the rated capacity of the inverter is also 5.00 kW.

The curve shows, for any particular time of a certain day, the output power the solar panel array could provide, **assuming that the inverter is prepared to take it.**[3] The maximum potential output of the panel array on this day (at solar noon, when the irradiance is 1.00 kW/m^2) is 5.00 Kw, and is loess at other times.

The inverter has a power output limit of 5.00 kW. Thus, at any time of a day such as this, this inverter has the capacity to take all the DC power the panel array could deliver and turn it into AC power. We will assume that the inverter does this with 100% efficiency, and modern inverters are close to that.

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[2] This could, for example, be an array with an overall effective area of 24 m^2 and a photovoltaic conversion efficiency of 20.8%: the output power is 20.8% of the toal incident solar power.

[3] Note that in a real case, the curve of potential power output of an array solar panels is not usually exactly the shape of the curve of solar irradiance. That is because potential output is nearly linear with irradiance, but not exactly.

Thus the shaded area under the curve is the amount of energy that, for all practical purposes, would be delivered by the inverter for that day. That amount is labeled "1" for future reference.

5.3.4 *Example system B*

Suppose instead we had a larger array [4] (with of course a greater cost), which could actually deliver 6.25 kW at the peak on this day (where the peak irradiance is 1.00 kW/m^2). But we still have our 5.0 kW inverter.

Now the day's action might look as like this.

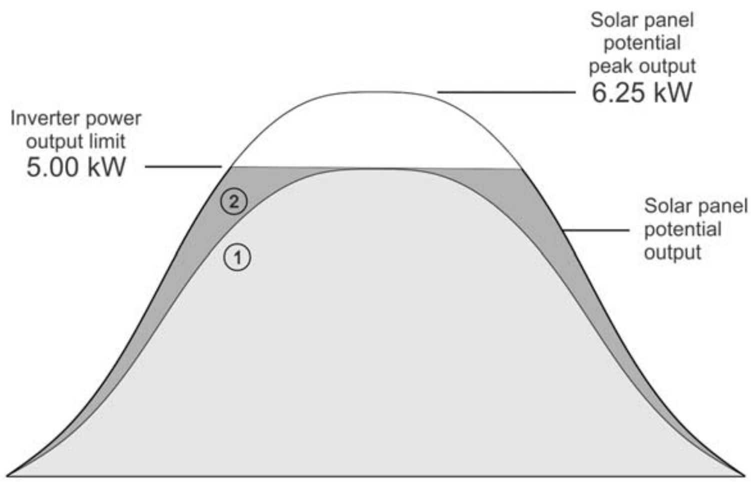

Figure 2.

The top curve shows the amount of power the panel array could deliver at that time of day **if the inverter could handle that amount of power.** During the central part of the day, the panels could generate more power than the 5.00 kW limit of the inverter, but this inverter will only "take" from the array as much DC power as it can convert to AC (5.00 kW), so the system only generates 5.00 kW of AC during that period. Never can the system deliver more than 5.00 kW, even if at certain times the array **could** supply a greater power.

But during the morning and afternoon hours we get energy (in the shaded area marked "2") we did not get with system A. The total energy delivered is now the sum of that represented by areas "1" and "2".

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[4] Perhaps 30 m^2 worth of the same kind of panel used in System A.

5.3.5 *Example system C*

Of course, having gotten the "larger" panel array, we could have chosen to also get a higher-capacity inverter, say one rated at 6.50 kW.

Now the same day's action would be like this.

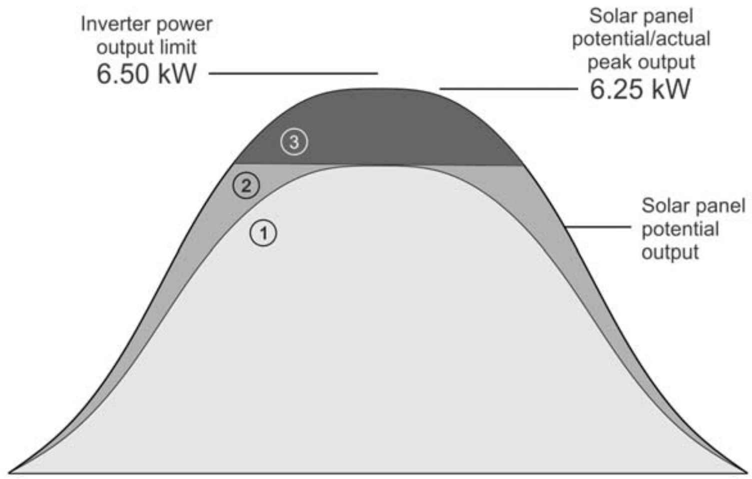

Figure 3. Example C

Now, at the highest output time of day, the full potential output of the panel array (6.25 kW) can be harvested and processed by this inverter. Now our overall energy yield is the entire area under the potential output curve (the sum of areas "1", "2", and "3"). It is greater than the energy yield for the system A by both the amounts shown as "2" and "3.

But of course this is just an "overall larger" system than what I called configuration A, and would be more costly than configuration B, because of both the greater cost of the solar panel array and the greater cost of the higher-capacity inverter.

6 ANOTHER CONSIDERATION

A consideration that may be important in deciding how to "play" this situation is that, with some power utilities, the advantageous arrangement with the homeowner mentioned in Section 4.2 (the "true net metering" arrangement) is offered but only if the system maximum AC output power (usually considered to be the nameplate rating of the inverter) not greater than a certain amount (perhaps 10 kW).

Thus, equipment cost aside, it might be advantageous to use an inverter of not greater than that critical capacity even with a PV panel array with a somewhat greater maximum output.

7 OVERALL

Of course, choosing the PV panel array rated power, and the power capacity of the inverter, is part of a complex reckoning that generally seeks, for the lowest total equipment cost, to generate, from the solar system, over the year, essentially the amount of energy expected to be consumed by the house over that year,

If the system consistently generated any more, the result would just be an ever-increasing “credit balance” in the “energy escrow account” with the electric utility company, which the homeowner could perhaps never monetize, at least on an advantageous basis.[5]

And of course in some cases the power utility’s “billing plans” (as discussed in section 6) may have an impact on the process.

Often the conclusion would be to use a system much like that seen in Example B.

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[5] The power utility typically sells energy at “retail price” but buys it back at “wholesale price”.