Solar PV and the meter box equation
Understanding your PV system better

There's more to what your home's energy meter is doing than meets the eye. Richard Keech takes an energy-accounting approach to understanding the energy measurements associated with domestic PV systems.

THE way solar electricity flows are accounted for in a typical domestic electricity meter is not always well understood. Central to this is a perspective on the energy flows encapsulated by a simple equation that I call the meter box equation. The meter box equation can help you answer questions such as, "how much money is my solar installation really saving me?"

This equation follows from the fundamental physical principle that energy is never created or destroyed—the first law of thermodynamics. Applied to electricity this is normally known as Kirchoff's current law but it's all much simpler than it sounds. In the case of generation from a grid-connected solar PV installation, this is about four different energy flows:

1. generated electricity, G, measured on your inverter
2. electricity imported, I, from the electricity grid, measured at your meter
3. electricity consumed by the household, C, which is not normally directly measured
4. electricity exported back to the grid, E, also measured at the meter.

Your electricity retailer simply sees all electricity flowing into your property as being consumed, but what goes on behind the meter can be a much more complex story. Electricity imported from the grid (I) is not necessarily the same as total electricity consumed by the household (C).

Meter basics

The old accumulation (spinning disc) meters have only one measurement element, in the same way that a car has one odometer. Imagine if driving backwards caused your odometer to wind back (it doesn't actually do this, as Ferris

↑ What's really happening here?

Bueller discovered the hard way in the movie). This is actually what happens, though, with the old spinning disc meters.

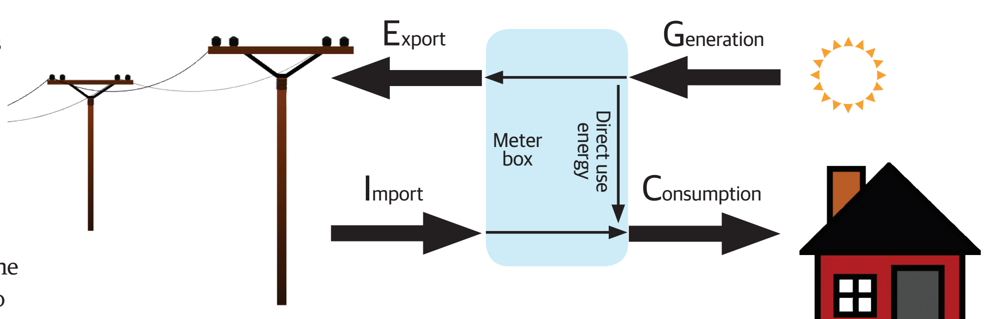
Modern digital meters can typically record electricity flow in two directions. These are generally called bi-directional or even 'smart' meters (with the 'smart' part generally referring to additional remote communications and control capability).

However, even though these meters can measure flows in both directions, they usually have just one measurement element. If the energy flows inwards, then one counter increments; if the energy flows the other way, then the other counter increments.

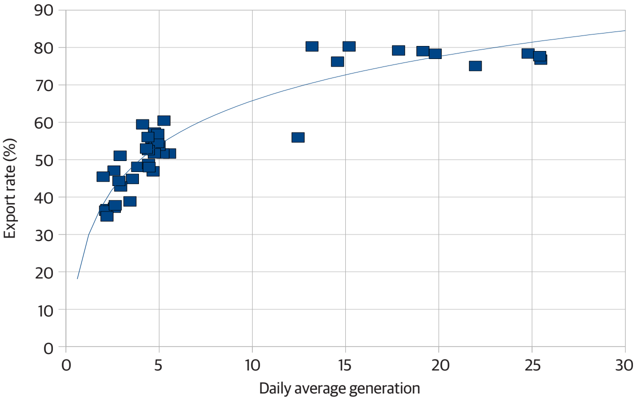
This is a bit like if our cars had a separate counter for the distance driven in reverse. You could imagine that forward distance is a bit like imported energy, and reverse distance is a bit like exported energy. Only one counter can be incrementing at any one time—just as a car can't be driving forward and backward simultaneously.

Typically known as import/export or net metering, when solar generation is in place these meters record the resultant electricity import or export after household consumption is taken into account.

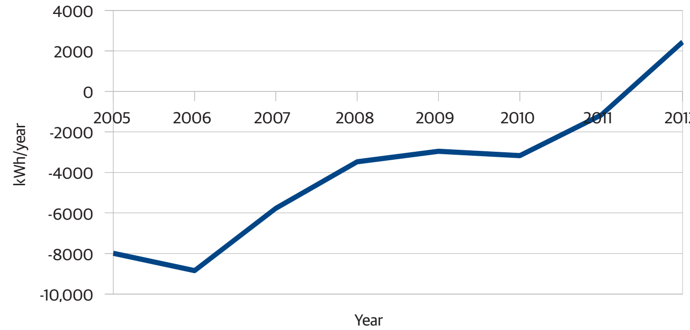
As an example, if you consume one unit of electricity in your house at the same time as your PV generates one unit of electricity, then your meter will measure zero change



↑ Figure 1. Energy flows through the meter box.



↑ Figure 2. Generation versus export rate. Note the increase in PV capacity from 1.3kW to 5.0kW in 2011 led to higher generation and a higher export rate.



↑ Figure 3. Richard's household energy balance. He should be achieving an energy surplus in 2012.

with regard to both imported and exported energy from the grid. If you consume two units of electricity in the house and are still only generating one from your solar system, then you will import (and purchase) an additional one unit from the grid—which will be recorded by your meter.

I've seen misunderstandings arise from not appreciating this meter box arrangement; for example, the person who says, "my meter is showing lower generation than my inverter, so my inverter must be lying". This person perhaps fails to see how solar generation and export to the grid are not the same thing.

Some meters have two measurement elements, and measure the full amount of solar generation as well as the import energy—this is known as 'gross' metering. Gross metering is not, however, typically in place in most states in Australia.

Calculating consumption

In its most simple form, the meter box equation is:

$$I + G = E + C$$

This expresses how electricity into the meter box equals electricity out. A typical PV installation will allow you to directly measure I, G and E in kWh using the meter and inverter.

The first useful implication of this formula is that it gives us a way to calculate C, the energy used by the household:

$$C = I + G - E$$

In the pre-PV household, one could simply assume that C = I since G and E are zero.

The term G - E corresponds to that part of the solar energy which is consumed directly in the household at the time it's generated. Let's call it the direct-use energy as in Figure 1. The equation tells us that this is the same as C - I, i.e. G - E = C - I.

Export rate

A concept often cited with respect to PV installations is the export rate, which is the proportion of generated electricity that is exported, i.e.

$$\text{Export rate} = E/G$$

The larger the PV installation for a given dwelling, the higher the export rate. This can be seen in Figure 2 reflecting an increase in my system's PV capacity from 1.3kW to 5.0kW in 2011.

Another useful way of looking at the same relationship is as:

$$E - I = G - C$$

This represents the energy balance over the period in which the measurement is taken. For example, if we have E and I measurements for both start and end of year, then $(E_{end} - E_{start}) - (I_{end} - I_{start})$ expresses whether the premises is a net importer or exporter of electrical energy for that year—or, to use economist speak, whether we're in surplus or deficit. In my own case, my quest to achieve energy surplus is shown in Figure 3, showing a projected surplus for 2012.

Calculating benefits

We can build on this to calculate economic benefit by including tariffs. Let's call the tariffs (in \$/kWh) T_{peak} and T_{export}. Your electricity account will include a credit for E x T_{export}.

But a full reckoning of the benefit of solar includes an allowance for the avoided import, i.e. the cost of the energy you would be paying for if you didn't have the solar. Just looking at peak tariffs, this benefit is (G - E) x T_{peak}.

So the overall saving, S, from having the PV installation becomes:

$$S = E \times T_{export} + (G - E) \times T_{peak}$$

This notation becomes a useful way of visualising and summarising the performance of an installation. Figure 4 shows my own system for January 2012.

The meter box equation, and different variants, are useful in better understanding the energy that a PV system produces. ✸

Figure 4. Solar summary for January 2012 (figures in kWh per day).