# building a system

Up until now I have been discussing the various parts of the system and what they do, as well as giving lots of background. Now is the time to start putting things together and to elaborate on any components from the *system components* chapter (page 23) that have not previously been covered in detail.

Figs 52 and 53 show complete systems depending on whether you are using battery backup or a grid-connect system.

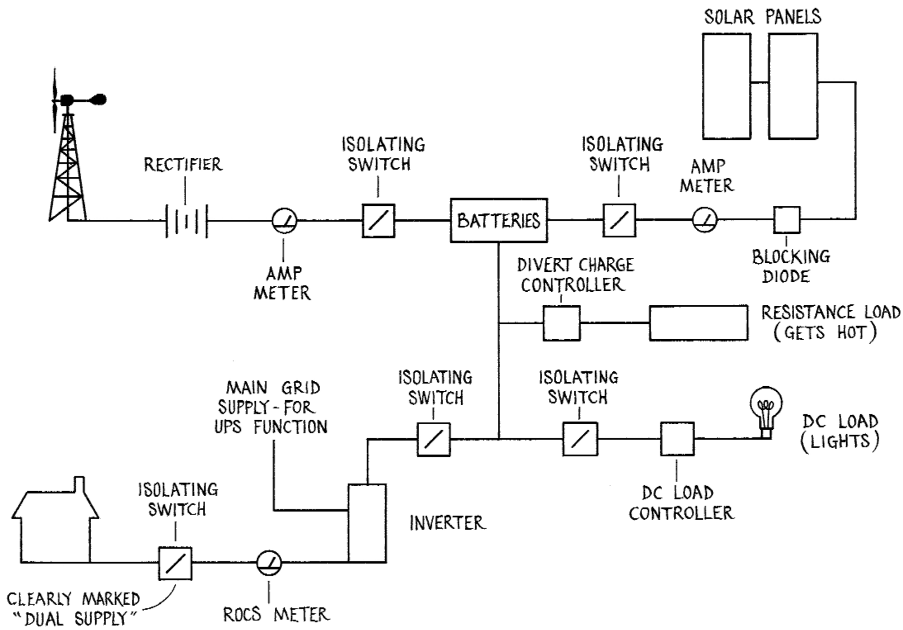


*fig 52: battery system wiring*

At various points in the book so far I have talked about system voltage without really going into any detail. Well, the choices for system voltage on a battery charging system are from 12 volts upwards. System voltage is the voltage that the turbine and solar panels are designed to work at, and so is also the battery's nominal voltage and determines the number of cells in the battery pack.

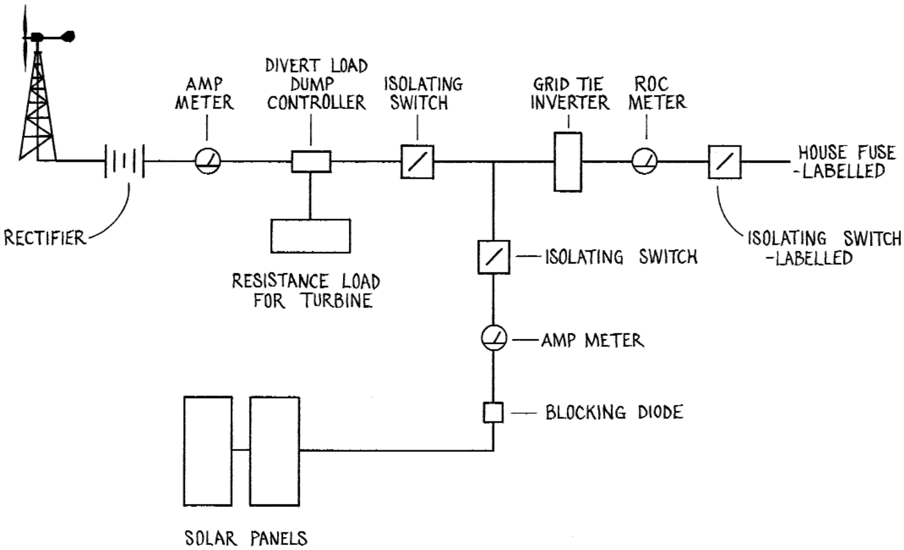


*fig 53: grid tie system wiring*

So let's have a look at the factors affecting your decision about which system voltage to go for. The most important factor is volt drop, as discussed in the *electricity* chapter (page 109) and, as explained there, the higher the system voltage the less volt drop there is. So, if either the turbine or the solar panels are a significant distance away from the battery bank then a low system voltage has a negative effect on system efficiency. Just to remind you: 1000 watts = 83 amps at 12 volts, 41 amps at 24 volts, and 21 amps at 48 volts. This is important because it's the current (amps) that is the cause of volt drop.

Points to consider when using a system voltage of 12 volts are:

- everything needs to be close together to reduce volt drop
- the inverter in a powerful system will be switching a lot of current, which puts it under strain and is a bad thing
- very large cables are required to reduce volt drop
- isolator switches and fuses need to be huge to deal with the current
- one extra 12 volt solar panel can be added at a time to increase output, which is relatively inexpensive.
- only 6 battery cells are needed to make up a battery pack to system voltage, but you will need more packs to supply large currents

Points to consider when using a system voltage of 24 volts are:

- there is less volt drop than with a system voltage of 12 volts due to there being less current for a given wattage so panels and turbine can be further away from batteries
- the inverter in this system will be switching less current than in a 12 volt system
- cables don't need to be quite so big as in a 12 volt system and the same applies to switches and fuses
- one extra 24 volt solar panel can be added at a time to increase output but they are more expensive than the 12 volt panels
- 12 cells are needed to make up a battery pack to system voltage

Points to consider when using a system voltage of 48 volts are:

- the solar panels and turbine can be further away from the battery bank than systems with a lower voltage
- the inverter in this system will be switching even less current than in either or the two systems with lower voltage
- cables don't need to be as big as in a 12 or 24 volt system and the same applies to switches and fuses
- it is possible to have some direct current (DC) lighting at a reasonable distance from the batteries without too much volt drop. DC lighting is a benefit because it works directly off the batteries and so is not dependent on the inverter. With the advent of modern low-energy light bulbs it is more efficient to use inverted alternating current (AC) power as opposed to DC power but in certain situations the DC power may be of benefit – for instance in the battery shed and for outside lights. So if your inverter goes pop then at least you have DC lights in important places, and you can fix it. In *Small Scale Wind Power* by Dermot McGuigan, which was written in 1978, he suggested that DC lighting was more efficient than AC lighting. This, of course, was true at the time but now with modern, reliable inverters and the low-energy light bulb, it is no longer the case. Using AC lighting systems also means that the power produced can go through the ROCs meter and increase your ROCs payment
- two extra 24 volt or four extra 12 volt solar panels need be added at a time to increase output
- 24 cells are needed to make up a battery pack to system voltage, but it will store a large amount of energy

In my opinion the optimum system voltage is 24 volts unless the system is spread out and it is a long way to the batteries. On our 48 volt system the panels are 60 metres away and the turbine on its 15 metre tower is 20 metres from the batteries. A 12 volt system is only suitable for low wattage systems and on vehicles, and even then it is surprising how quickly the batteries go flat. Voltages above 48 volts can present a real danger to life through electrical shock: imagine a potential of 1000 amps at 110volts. I had a 110 volt battery bank a few years ago when I was using an old Whirlwind 4 kilowatt wind turbine. The battery system worked very well with little volt drop but the battery always made me nervous and in the end I decided to treat it as if it was mains power. Before then I had worked on low-voltage systems while they were still live (I don't recommend this), but with 110 volts several inches of cable would just vaporise if I got anything slightly wrong. Apparently the small molten bits of copper are very bad for the eyes (blacksmiths of old often went blind in at least one eye from molten spatter). The thing I did do to make things a bit safer was to organise the positive and the negative ends of the battery so far away from each other that they could not be touched at the same time. I think that was a wise move and as a result I am still here and writing this.

A 24 volt system seems to be the best, as long as the cable lengths are not too great, due to the number of units that are required, so when you want to increase solar output you only need to buy two 12 volt panels or one 24 volt panel at a time, which is less expensive. The number of batteries required to start with is less than for a 48 volt system but, of course, more 24 volt packs are required to store the same power as one 48 volt pack. It effectively means that you can build and upgrade a system with a smaller number of units at any one time and spread the financial burden.

## battery bank

Having decided what system voltage would suit you best, the next thing is to fit out or build a decent battery shed. This must be dry and well insulated, but have some ventilation to prevent the build up of explosive gases. The floor should be good, acid-resistant, and have a damp-proof membrane as discussed in the installing batteries section of the *batteries* chapter (page 79). The batteries should be fitted on a frame off the concrete floor and at a height where it is easy to check the electrolyte levels.

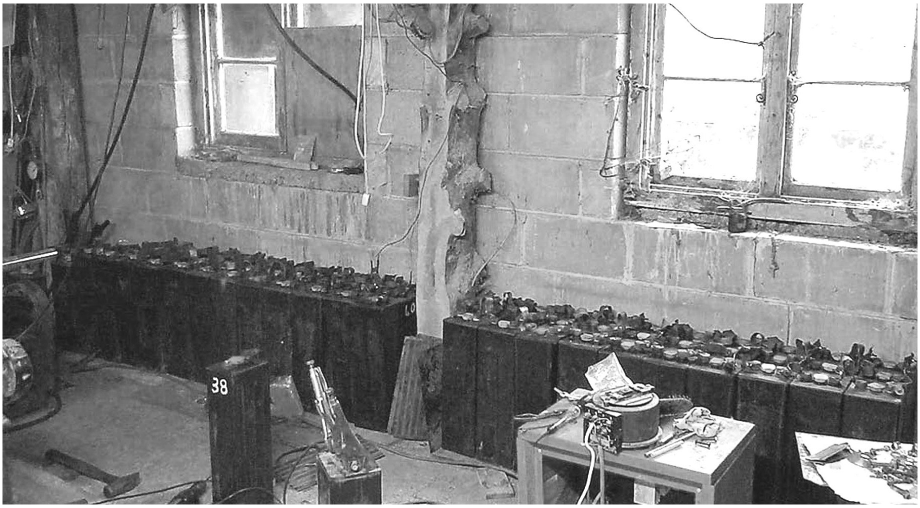


*fig 54: 110v battery bank*

*fig 55: battery bank*

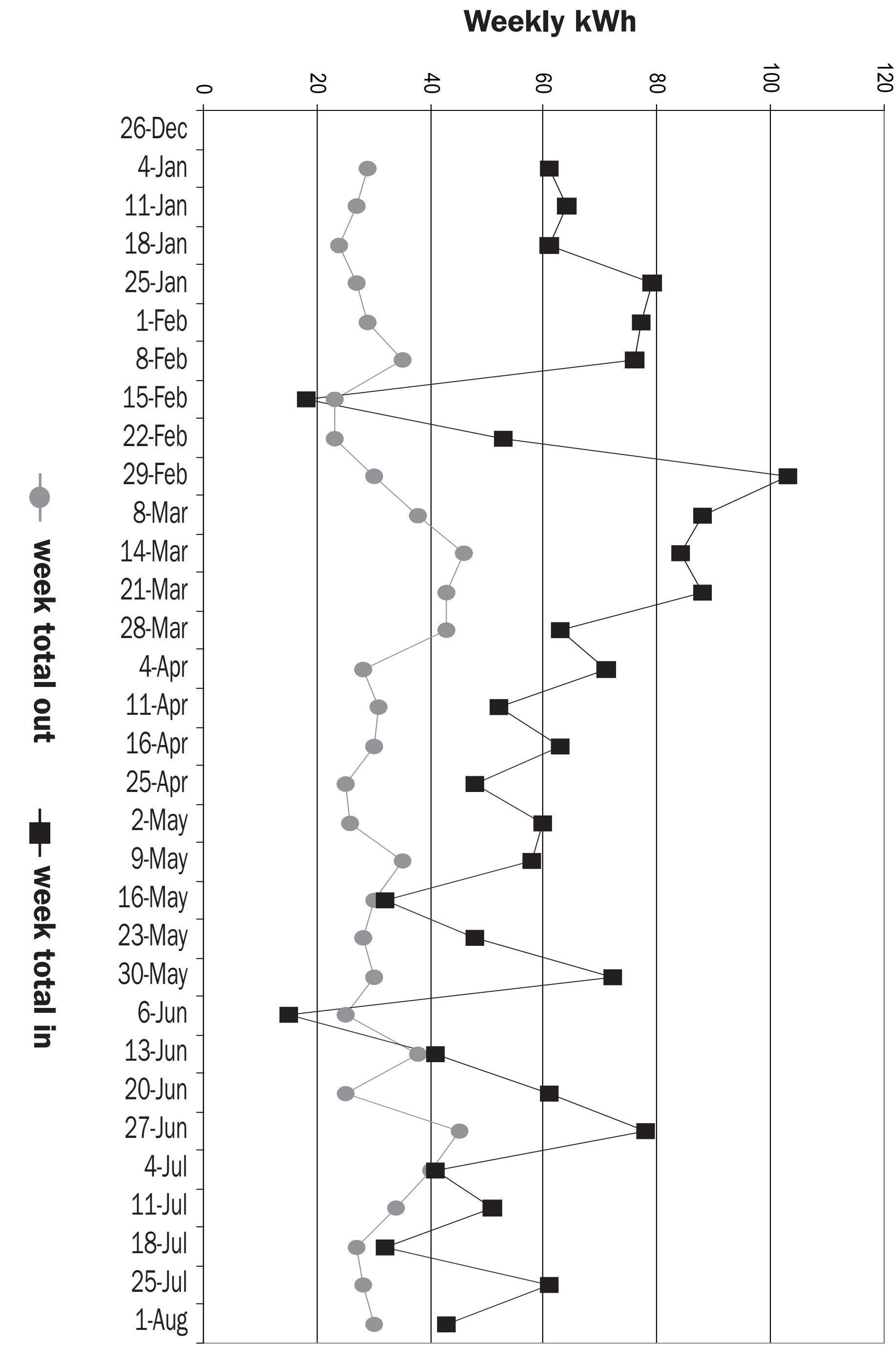


*fig 56: generation and consumption by week*

## battery size

This is quite a thorny problem due to the cost of batteries. There is a fine balancing act needed between the installed capacity of the wind and solar generators, the amount of electricity you use, local weather patterns and whether you have both wind and solar or just one type of generation. If you look at the graphs in the *research* chapter (page 151) then you will see that solar generation is lower in winter and wind generation is lower in summer, which brings you back to your site and its benefits or limitations. The graphs are for my site and so I have included a weekly generation and consumption graph here (fig 56) that may help. It describes our use of electricity, which will vary from other households and I suppose should be defined.

We have mains electricity on site and big loads are on the mains for convenience and to prevent overload of the inverter and discharging the batteries completely. These big loads are:

- electric shower (This is not a good use of energy and is a residual fitting waiting for inspiration to change the system)
- water-heating immersion heater as an emergency back-up. Mains electricity for heating purposes is the most $CO_2$-polluting of all heating methods due to the huge losses in the system and the conversion efficiencies. You are better off burning something to create heat, rather than burning something to produce steam, to produce electricity, to transport miles, only to convert back to heat through resistance.
- washing machine
- big power tools and woodworking machinery
- welding and steel fabrication machinery. Not everybody uses these last two of course.

It may sound as if we don't actually run very much off the home-generation system but we use between 25 and 40 kilowatt hours per week. The graph (fig 56) shows total input and output of the system.

Cooking is by wood and LPG gas and no microwave cookers or coffee makers and the like are used.

It also helps with the battery cost if you use second-hand fork lift batteries, but this means you have to put quite a lot of effort in to maintaining them and to be willing to scrap the occasional cell if it consistently misbehaves. This is covered in the *batteries* chapter (page 79).

So, on average my household uses about 30 kilowatt hours a week from the wind and solar systems, which needs constantly replacing at any time of the year and, if you look at fig 56, you will see that the whole system charges at an average of about 50 kilowatt hours a week.

If you take into account that the charge/discharge cycle can be about 80 per cent efficient this means that there is only 40 kilowatt hours available each week to break even. That margin can be lost easily when you get a few days of overcast and still weather. What I am trying to say is don't push things and consume to the limit of your system; and do try to reduce your overall consumption.

So, let's say that we use 30 kilowatt hours a week and that we need a margin to allow for poor charging weather, so we will increase that to 40 kilowatt hours to make this allowance.

So, 40 kilowatt hours at 48 volts equals 833 amp hours

Let's just do the maths as practice:

1000 (watts in a kilowatt) ÷ 48 (voltage of batteries)
= 20.8 (amp hours per kilowatt hour)

20.8 x 40 (required kilowatt hours per week)
= 833 amp hours

Take also into account that you should not discharge your batteries below 50 per cent of the amp hour capacity, which then means that the capacity of the battery bank should be 833 x 2 = 1666 amp hours.

Well my battery bank is made up of three packs, which are:

- 1 with a capacity of 400 amp hours
- 1 with a capacity of 550 amp hours
- 1 with a capacity of 600 amp hours

Which gives a total capacity of 1550, which is near enough, and I'm sure that 1400 amp hours would work equally well, but the calculation above is handy to give you a good rule of thumb to see whether what you are planning is in the right region, or off on some entirely different planet.

It does not, however, take into account any ongoing charging, and it would be rare to receive no power in a week from a combined wind and solar generating system. If it were just solar I could foresee weeks where generation would be minimal, especially in winter. Looking at figs 57 and 58 we can see that there was a drop down to 15 kilowatt hours in combined output in February which, if taken as a worst-case scenario, could mean you could reduce the size of the battery bank but that wouldn't allow for a week where you get nothing. So it's up to you to decide how much you want to spend on batteries in the first instance.

So if you take 15 kilowatt hours from the original 40 kilowatt hours that gives 25 kilowatt hours net.

This would then equate to 520 amp hours x 2 = 1040 amp hours

So from this we could say that our bank is ample.

I think this is the right place to revisit the issue of battery banks that are either too large or too small. An elderly chap I know has a 2.5 kilowatt Proven wind turbine on an unsuitable site with a 250 amp hours battery bank. The system inverter has a UPS (uninterruptible power supply) function and, because the battery bank is too small for his electrical consumption, the inverter switches over to mains power most of the time due to a low volts signal from the flat battery.

This is caused by several things, and the situation is useful to highlight these issues, but we must remember that in this case the turbine is not producing anything like rated output and so maybe the battery size is accidentally the right size for the low system generation.

The issues as I see it are:

- the site is wrong for wind
- solar generation would be better in this situation
- he has not matched consumption to generation

If the site is good for wind then it should be good for solar generation, but if other constraints make wind power a problem then you will be left with the solar option. In this case there is no reason to be fundamentalist about it, just fit as many panels as you can afford and then treat the National Grid as a back-up. It is better to do that than nothing at all. You can always add more panels in the future, but if generation is limited then consumption should be limited as well. This could mean just running the lighting circuit and maybe the fridge to see how you get on.

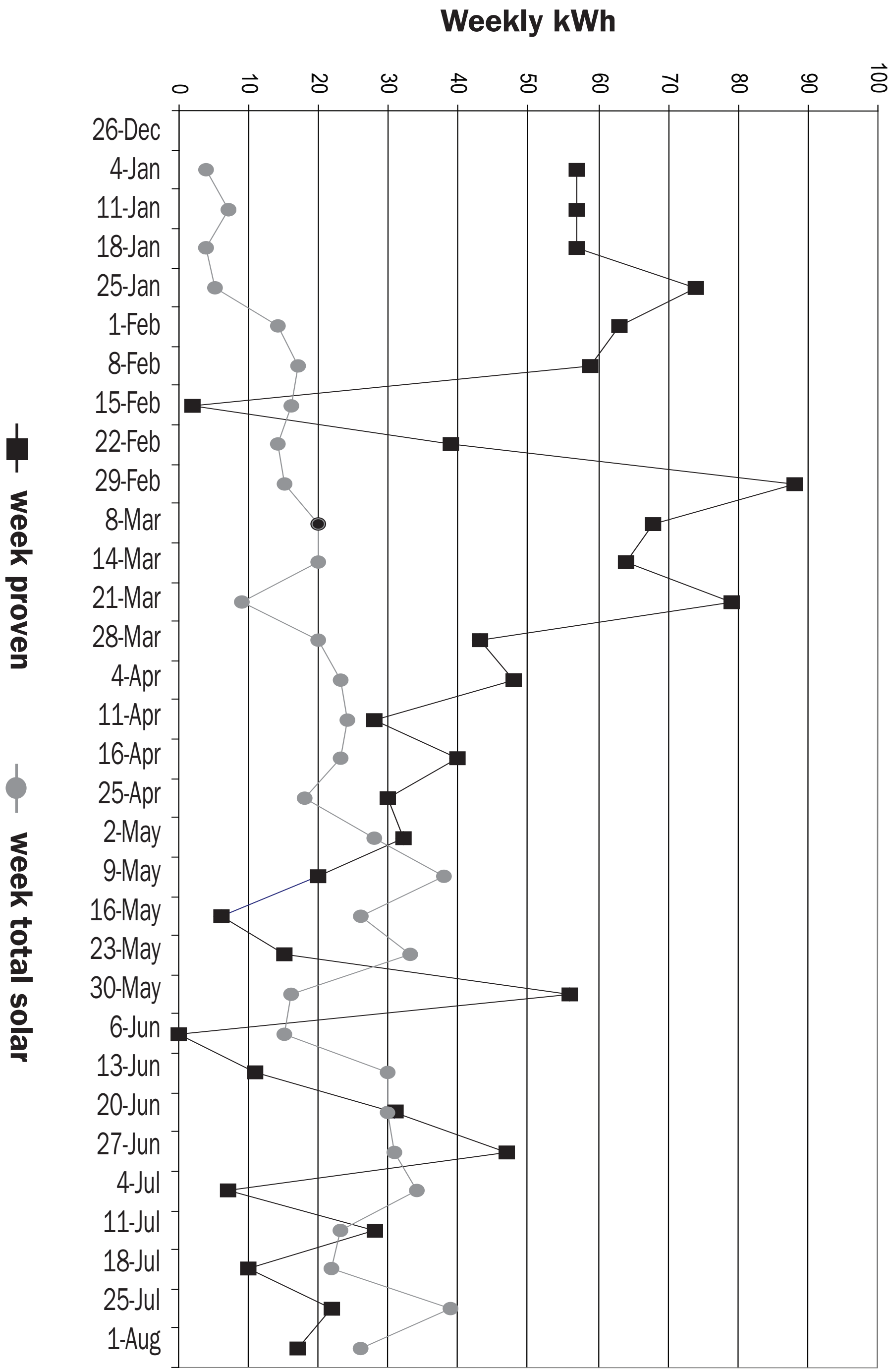


*fig 57: contribution made by wind and solar*

The most important factor is to keep the batteries well charged and this may mean that you occasionally waste power through a charge controller. The system has to be reliable which means the batteries should be in good condition and well charged: as we know the best way of destroying batteries is to consistently undercharge or leave them in a low state of charge. I keep banging on about battery condition, but I have seen several systems where system failure was down to an inability to comprehend the value of good battery maintenance. Just as an added point, solar panels are passive and only provide power during the day, which is obvious, but wind generation carries on through the night which is a benefit as far as output is concerned, but can be a hindrance for close neighbours.

## solar panel wiring

The simplest way of wiring a solar panel or array is to connect it straight across the battery bank, positive to positive and negative to negative. There are, however, a few things that are needed to make things reliable.

### blocking diode

A blocking diode is required to prevent any chance of power passing backwards through the solar panel from the battery at night. This is unlikely on a low voltage system because the panels behave to some extent like a diode. Just to remind you, a diode is an electric one-way valve which, as it says, only allows electricity to flow one way. Fit a blocking diode, which is a standard power diode, in series with the positive cable to the batteries. Diodes need to be mounted on a bit of aluminium sheet to dissipate the heat created when current is passing through them to the batteries.

### amp meter (ammeter)

An amp meter is also required to show whether the system is working and the level of charge. The amp meter is wired in series into the positive cable either before or after the blocking diode, it doesn't matter which. I like to use large old meters that give a Victorian mad-scientist feel to things, but I suppose they're more difficult to find these days. It does show that you can have fun when fitting these systems.

This will provide a basic solar charging system, but to make sure the batteries are not overcharged you can fit a charge controller.

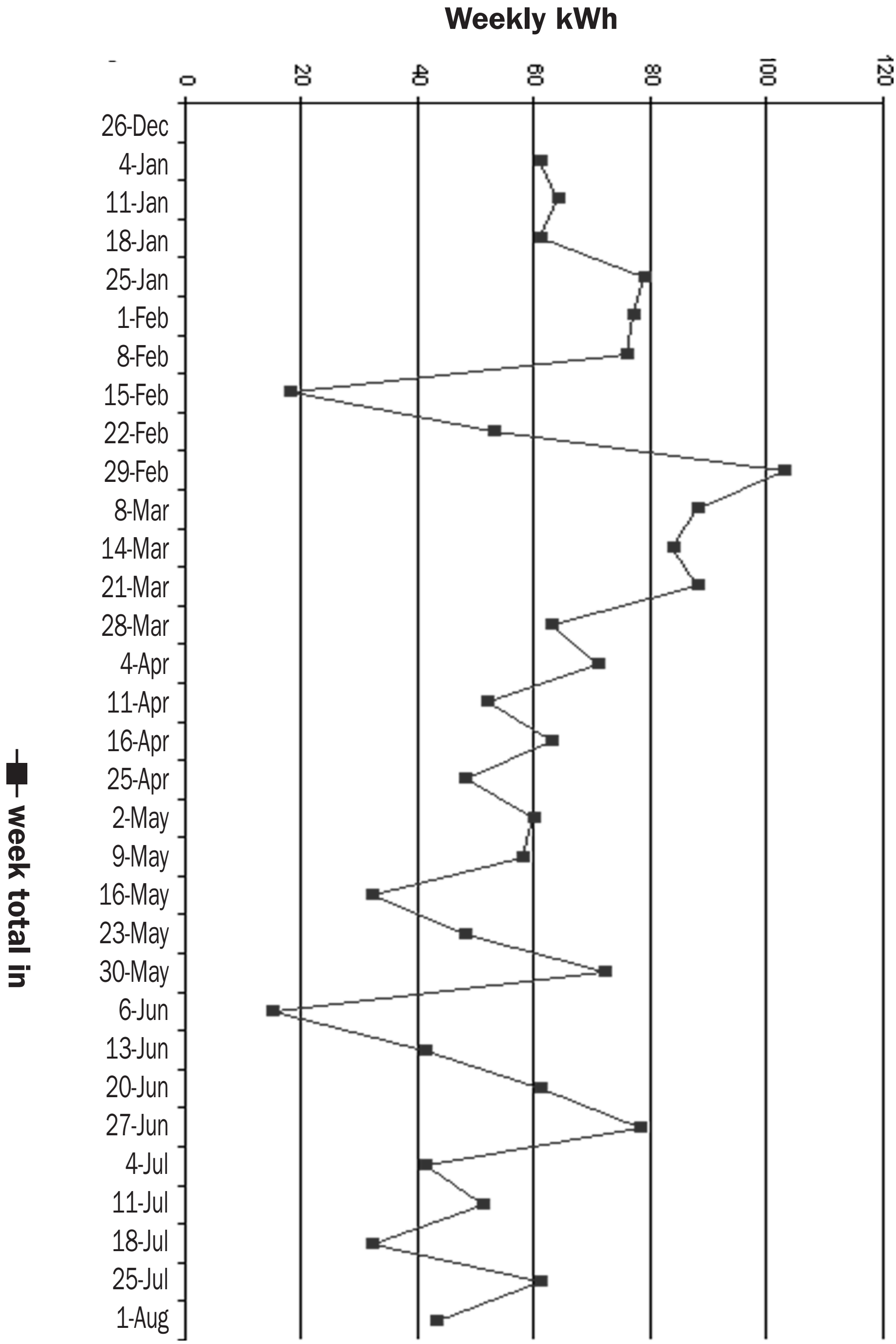


*fig 58: total wind and solar generation*

*fig 59: blocking diode on anodised aluminium sheet*

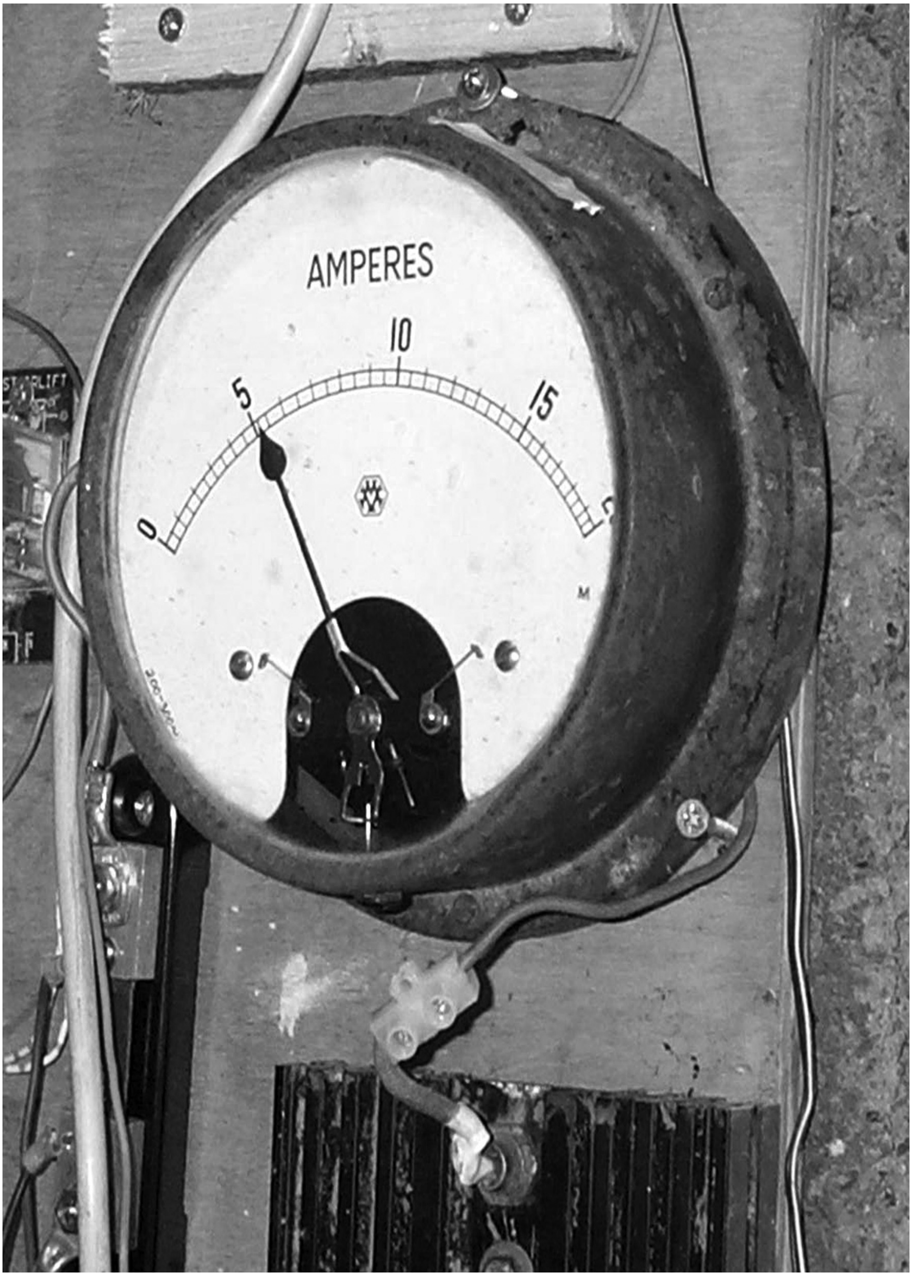


*fig 60: amp meter*

## charge controller

Charge controllers are particularly required when the battery pack is on the small side and overcharging could lead to battery problems. A charge controller for solar generation can be as simple as a manually operated switch that disconnects the solar panels from the battery bank. Solar panels suffer no damage when disconnected from the battery load, which is not the case for wind turbines.

Most people prefer to fit an automatic system that is controlled by battery voltage and fig 45 in the *batteries* chapter (page 79) shows the relationship between specific gravity and cell voltage. The charge controller comes into operation before the battery pack voltage enters the steep voltage rise that shows the cells are fully charged. This prevents too much of the water in the electrolyte being broken down into its constituent gases, and so reduces not only overcharging, but the need to constantly top up the batteries with distilled water, which is an additional cost. It is important for the cells to gas to keep the plates clean and so on good charge controllers there is an equalising function which allows the cell voltage to rise above normal controller voltage as required.

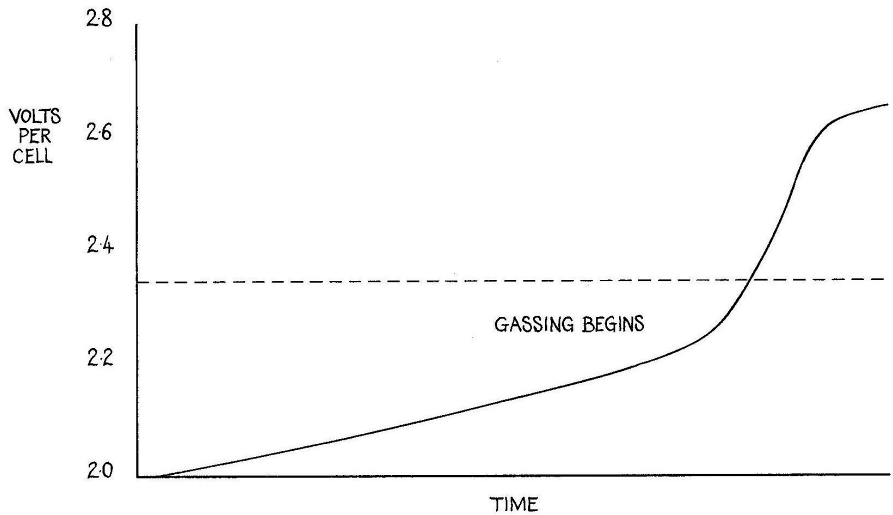


*fig 61: cell voltage rise and gassing point*

This point is even more important with sealed or, worse still, gel batteries where damage from overcharging can occur rapidly. Some charge controllers contain a blocking diode or some form of panel-disconnect system, but I have included it separately in the diagram. The arrangement of amp meter, diode and charge controller does not have to be in any specific order, but it is useful to know that diodes have their own resistance and there is a volt drop across them of about 0.6 of a volt, which is why I have shown the diode before the charge controller.

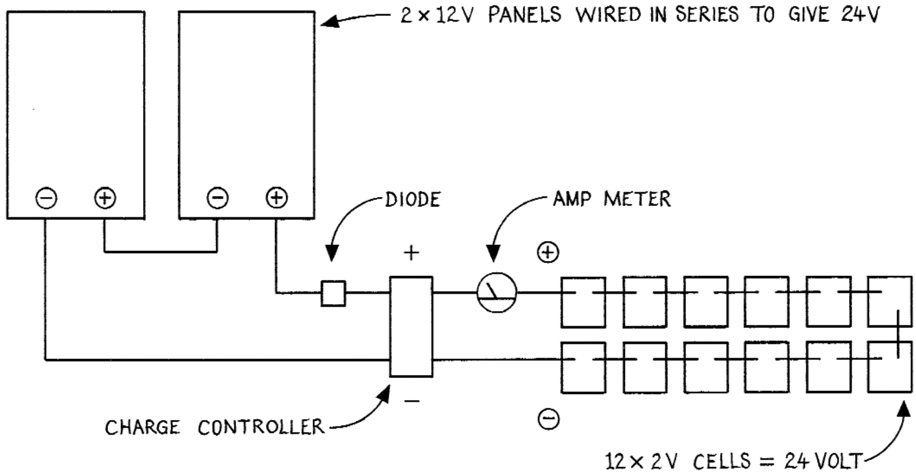


*fig 62: solar wiring*

## wind turbine

So, you have your turbine fitted to the tower but before you get carried away by 'fireitupitis' it needs to be wired up to the battery bank. If the unit is quite old then it may produce direct current, in which case it can be wired straight to the battery bank with a blocking diode and no charge controller. Charge controllers are totally different for turbines than for solar panels, and we have mentioned before the reasons why it is not a good idea to disconnect the turbine from its battery load, but to remind you – if a turbine is not connected to anything that creates an electrical load, then the rotational speed of the blades will increase dramatically to the point of destruction. This is the case unless the blades are fitted with a self-furling mechanism, see *wind turbines* chapter, (page 35).

Most modern turbines, however, produce three-phase alternating current in which case a three-phase rectifier is required. These have six diodes instead of the four shown in the *system components* chapter, fig 50 (page 120), and because they contain diodes a blocking diode is not needed. The three wires that come down the tower from the turbine are connected to the three input connections on the rectifier and the positive and negative outputs are connected to the respective battery terminals. There is an amp meter fitted in series in the positive battery cable.

## wind turbine charge controller

The charge controllers for turbines reduce battery volts by putting an electrical load across the battery, which is effectively the same as loading the turbine. This can either be a resistance load built into the controller, or a separate load switched on remotely. They are called divert controllers because they divert the power elsewhere. These loads are just electrical resistance heaters (like electric fires, storage heaters or immersion heaters) and provide somewhere for electricity to go, which then means that the turbine has to work to produce the electricity and so reduces the speed of the blades. See fig 52 (page 127).

You could get the controller to power the coil of a relay, the contacts of which then switch inverter power. In this way electrically-heated oil-filled radiators and the like could be used and so the heat is not wasted.

If you have a combined wind and solar generating system then it is possible to just have a divert controller because they work by sensing the battery bank volts. Good controllers have a delay built into them so that when the power-divert mechanism is switched on and the load pulls the volts down they don't immediately switch off. The delay means that either the volts have to drop below a preset dropout voltage or the load stays on for a preset time. As you can imagine with a wind turbine when the batteries are fully charged then the voltage rises with each strong gust of wind, and you don't want the controller to be switching on and off all the time.

## inverter

In the *electricity* chapter, (page 109) we covered sine-wave alternating current electricity. This is the natural wave form produced from a generator where magnets move past coils of wire – i.e all generators. All mainstream electrical equipment is designed to run best on this type of alternating current.

Inverters change the direct current from the batteries into alternating current, but some do it better than others. Some produce what is called ‘square-wave’, or ‘modified square-wave’ electricity, which just isn’t as good and some things will not run on it. A square wave is exactly what its name suggests: instead of the gentle curves of the sine wave (fig 47, page 117) the voltage changes instantly from negative to positive giving a form that looks like the castellation found on medieval battlements. So don’t get a cheap inverter and make sure that it produces pure sine wave.

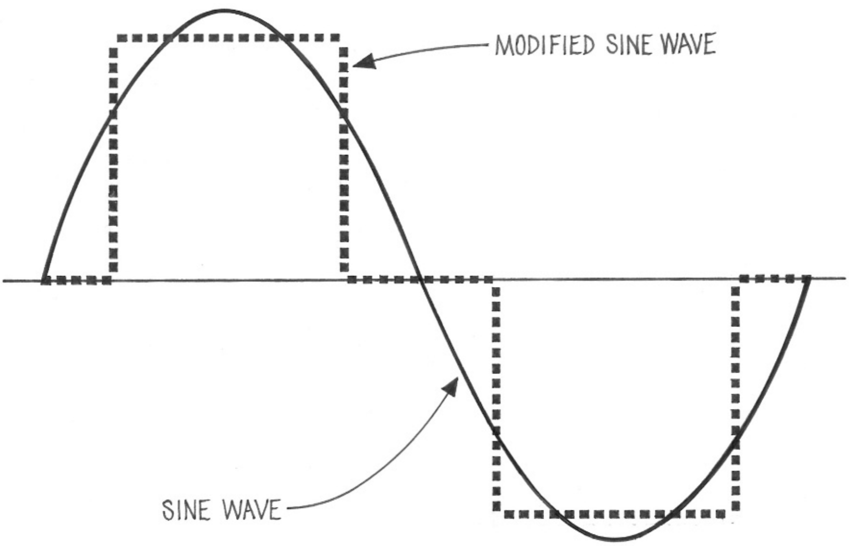


*fig 63: modified sine wave shape*

The next thing you need to know about inverters is that they are made for a specific battery voltage, which means that, having determined your battery voltage, you are then stuck with it as far as inverters and wind turbines are concerned. What I am trying to say is, having decided on a particular system voltage it is then expensive to change because you have to buy new, compatible units.

There are two types of inverter, a standard inverter and a ups. A standard inverter is wired to the battery bank through a disconnect switch and fuse, and produces alternating current. This is the type of system you would fit for an off-grid situation where mains power is too far away, too expensive to connect, or you believe that grid power is not a long-term solution. However, with any off-grid situation you still need a back-up battery charger for low energy times of the year.

Back-up systems are commonly in the form of a diesel generator and so you are still reliant, to some extent, on oil-based technology. The reliance on the back-up system can be reduced by fitting a big charging system containing both wind and solar generating elements.

A UPS inverter does the same as the standard unit, but also acts as an uninterruptible power supply. I've mentioned these before, and they work by automatically switching to the mains power whenever there is a lack of power or an overload. On my Dutch Victron unit there are lots of parameters that can be set within the software to make the inverter change under various situations. For example, you can set the wattage level at which the unit changes over to the mains, and you can set the time when the inverter switches back to battery power after the overload has stopped. It means that everybody in the household does not need to be an electrician, and you will not get phone calls whenever you are out that someone has done something silly and the power has gone off. There is also a low volts setting that is adjustable so that you don't run the batteries anywhere near flat; mine is set at 47 volts on a 48 volt system.

The wiring for a UPS inverter of this size is quite simple. The direct current side is taken straight from the batteries through a disconnect switch and fuse. Big, second-hand, three-phase industrial switches and fuse boxes are ideal for this sort of stuff, and can be found in scrap yards from time to time. When wiring up the battery side make sure, and then double check, that the direct current polarity is correct, or else the inverter will go bang. This means positive (+) to positive, and negative (-) to negative, so colour code all the wires to prevent very expensive mistakes. The mains electricity input to the inverter is simply through a standard 13 amp mains plug and socket.

The output from either type of inverter can then go to your dedicated load circuits. Basically what I did was go to my mains consumer unit (fuse box) and disconnect various circuits and wire them into another consumer unit that was then wired directly to the inverter. The only way mains power can get to these circuits is through the inverter on UPS function. Wiring the inverter load this way means that any large loads, for example welding equipment, woodworking machinery, electric showers, can be left wired to the mains power consumer unit.

For off-grid situations large loads are run directly off generators and it is useful to have the battery charger permanently wired in so that when the generator is running the batteries are automatically being charged. When mounting or fixing your inverter it needs to be close to the batteries to keep the cable runs as short as possible. However inverters should *not* be mounted above or next to batteries because of the acid fumes that are given off by the batteries during periods of high charge. These can be drawn into the inverter by the cooling fans and have a cumulative corrosive effect.

## home wiring

This could be a thorny problem, but it depends on your attitude. There are certain people who would like everyone to be entirely helpless, so that they can charge a fortune for all the things that you cannot, or are not allowed to do. With home wiring your insurance company would not be too impressed if it had not been checked by a registered electrician. But (and this is the size of butt that you see buying six double cheeseburgers) trying to get a registered electrician to check your work and understand a wind and solar generating system can be difficult.

If you are considering installing grid-tie inverters and the mains electricity side of a battery inverter system then, unless you are confident and experienced, find a friendly electrician. The electrician's qualifications should be to BS 7671 edition 17 (as I write), and only covers the mains supply side as direct current and low voltage is outside the scope of this qualification. To work with this aspect of home generation the electrician should also be part of the Microgeneration Certificate Scheme, see *resources* (page 177) and any available grant funding will only be payable if the contractor is part of this scheme.

## ROC meters

Detailed information about ROCs and ROC meters can be found in the *system components* chapter (page 23). They are wired on the output side of the inverter somewhere between the inverter and the consumer unit (fuse box).

At the time of writing a chap has just been to see me asking about wind turbines and inverters. He has 12 x 200 watt solar panels on his house situated in a built-up area, fig 28 page 72. Having been informed about ROCs he tried to register with his electricity supplier as a home generator of electricity – to no avail. Initially they tried to deny the existence of

ROCs and then promised to phone back (they never do, do they?). The upshot of his investigations was that the only supplier he could find which was actively engaging with ROCs was Good Energy; which is also our supplier.

Basically what we can glean from this is that the big energy companies are more interested in profit than environmental considerations, and that they would rather pay fines for non-compliance than to take carbon issues seriously. You do what you think is right, but your buying power is your only leverage with this issue. This information is correct at the point of writing but, because environmental problems are becoming increasingly evident and home-generation of energy will increase, I suspect other supply companies will begin to work with the ROC system. The main thing is to do some homework before you sign up with a supplier. The good thing is that it is no problem to change supplier unless you are locked into a contract, so research that aspect carefully.

I obtained our meters from Universal Meters, see *resources* page 177, and the advice given was clear and helpful. It seems that the older-type wheel meters are more accurate at lower wattages than the modern, electronic versions. A refurbished and recalibrated second-hand unit cost almost nothing and it was on the doorstep the next day.

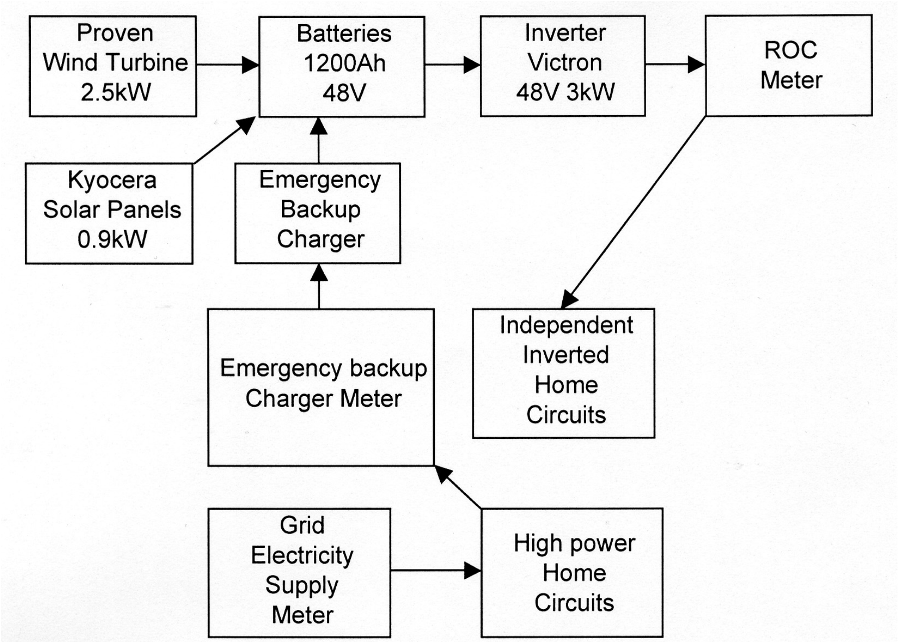


*fig 64: ROC meter system – Rose Cottage schematic diagram*

My registration with the Home Generation Team of Good Energy was quite straightforward and, although it took a bit of time, was no real hassle. There were several easy-to-fill-out forms and a schematic diagram to produce. I did this on the computer just using boxes for the various units and arrows to show connections, see fig 64. You will notice I have shown a mains power input and another meter showing any mains power used.

## bonding

This is effectively creating an earth to the system. In mains electricity systems the negative cable is attached to earth at various points in the distribution system. This means that if the positive should accidentally make contact with an earthed equipment case it will create a dead short and blow the fuse. This system does, however, mean that you only have to touch the live (positive) and stand on the earth to get a shock.

According to Rex Ewing in his book *Power with Nature*, see *resources* (page 177) the negative alternating current power from the inverter should also be connected to earth and the negative of the battery bank. This is effectively creating an earth similar to that of a mains power supply, but it does mean that the batteries need to be physically well insulated from the earth or else corrosion of the positive terminals and connections will occur.

## cables and fuses

Cables for the direct current side of your system need to be big enough to carry the large currents required when dealing with low voltages. Cables in the ground should, ideally, be armoured or in conduits and, wherever they are buried, I always put bright plastic or bits of old guttering over then so they can be readily identified when digging. Fuses and isolators are needed on the direct-current side, and standard consumer unit fuses or trip switches on the inverted, alternating current side. Any damage to cables that are in contact with the ground will create a point of discharge if you have an earthed system and power will be lost. This discharge will also create corrosion, allowing the cable to rot, and produce an unreliable system.

## getting your system working

The first thing is to avoid 'fireitupitis', so make sure everything is right before commissioning each part of the system. Then you need to monitor it to see if you get what you expect from it. I am still going through this process with my 2.5 kilowatt Proven wind turbine after two years of use.

I was recently called out to a small off-grid, home-built installation, and was disappointed to find that no amp meters had been fitted. As a result the owners had no idea what the system was producing or what they were using, beyond knowing that they regularly had flat batteries. This is why I have spent so much time in this book going on interminably about meters, volts, amps, watts, cables, ROC meters and the like. With any battery system you need to balance production with consumption. If you look at fig 56 (page 132) you will see that production is more than consumption, and this is how it should be so that the batteries are nearly always charged in readiness for those few consecutive days of with no power generation. If you have a grid-tied system this balancing does not really apply because you are just adding home-produced power to the electrical system already existing for your property, and so reducing mains power consumption.