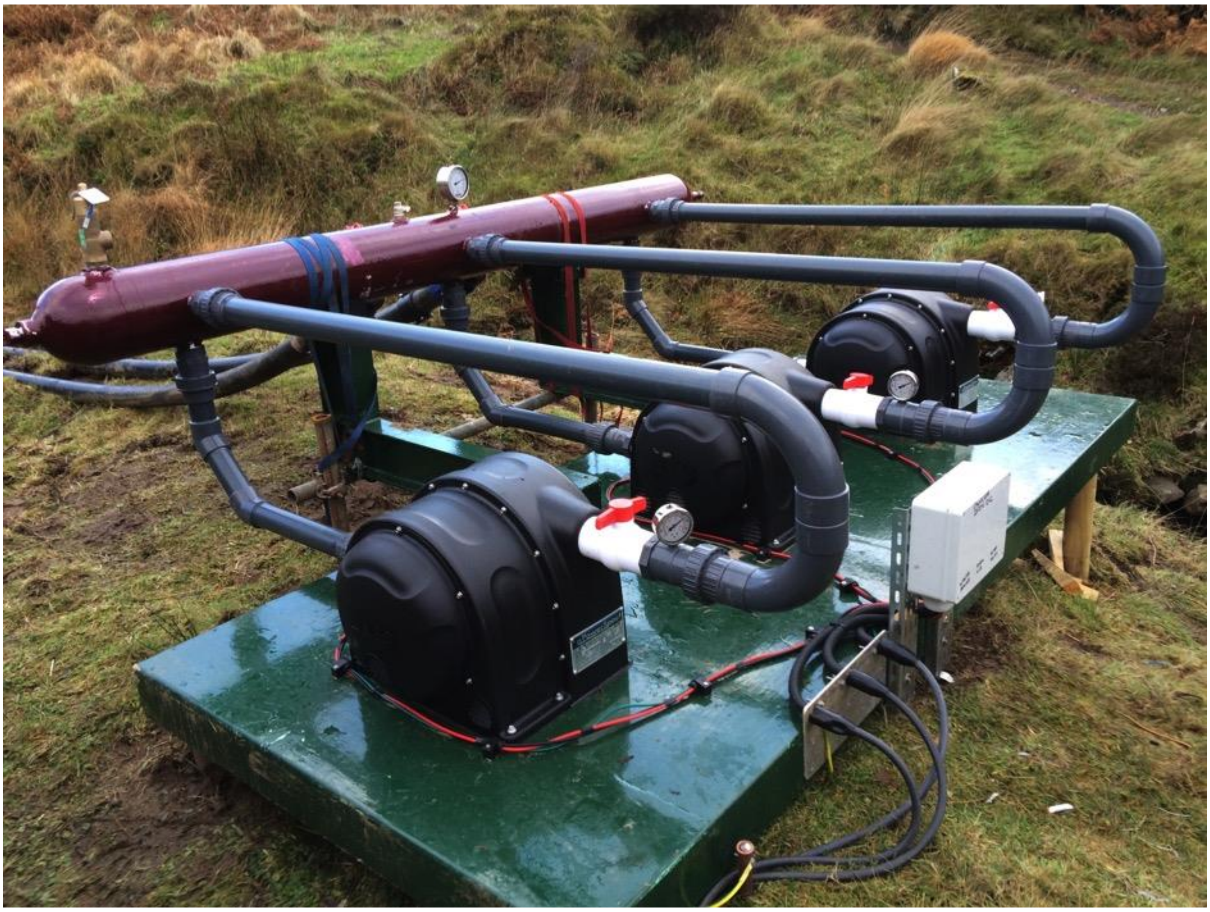
PLT Case Study 4 - Multiple PLT installation

DOUNE HYDRO



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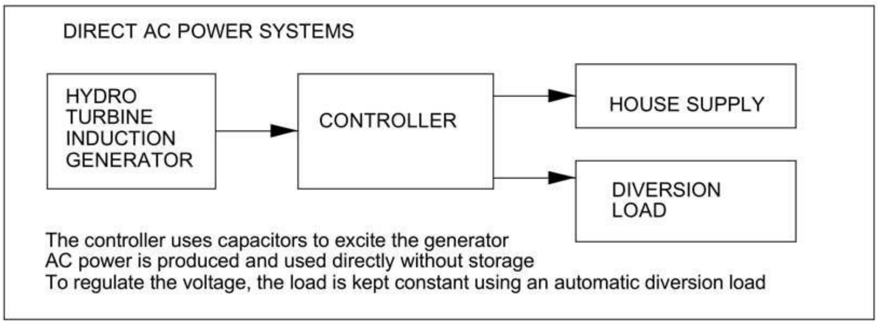
CONTENTS

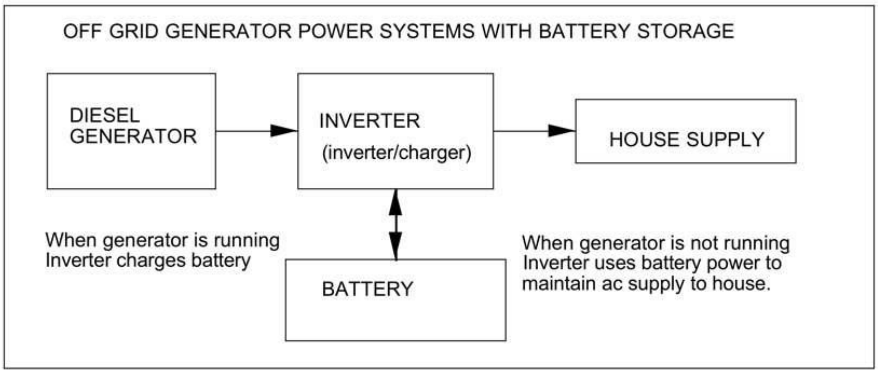
1. Background

There are numerous small, off grid properties in this part of Scotland, accessible only by sea. The cost of bringing in diesel for generator power is large in both time and outlay. By the time it is in the tank and ready to be burned by a generator, the value of diesel fuel must be between 2 and 3 times the actual cost of purchase. This combined with the naturally steep ground and heavy rainfall makes small scale hydro a very appealing supplement or alternative to diesel power.

Several households have installed micro hydro systems in this area over the years, using capacitor excited induction motors (driven by pelton or turgo runners) to generate AC power directly (without batteries). Their control circuitry has often been destroyed by lightning.

The hydro site at Doune does not have as much head as other sites in the area, so it was always going to offer a relatively low output, which would be a problem for running large AC loads directly. The simplicity of the Powerspout concept was very appealing. It can interface with the existing batteries and inverter (already used to provide 24 hour power from off-grid diesel generators) to meet peak loads. This makes it not only cheaper than direct AC but also more versatile.





There are 4 dwelling houses in this hamlet and a larger restaurant, holiday accommodation and a big workshop. The residents have always shied away from hydropower partly due to a lack of technical knowhow and partly due to the high peak loading of various parts of the set up. They were always looking for a centralised generating system, and due to the high peak loading, they assumed that there was just not sufficient water available to satisfy the needs.

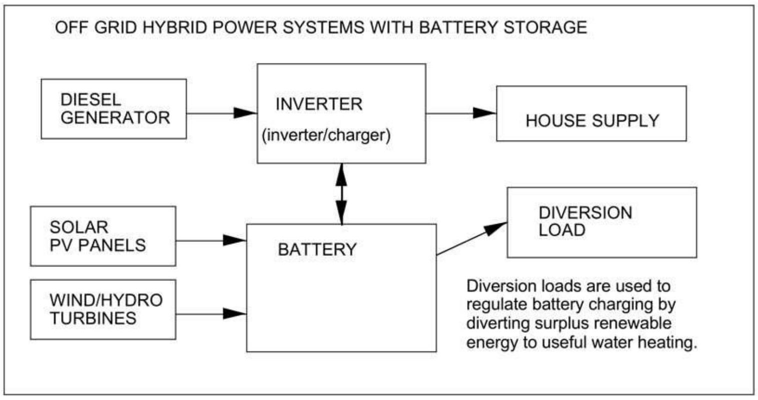
One or two kilowatts of hydro power would never meet the peak loads on this site but when you look at the average power, as reflected in the kWh of energy consumed per year, the hydro power potential of the site can make a huge contribution to this. Each house has an inverter that can supply 3kW of continuous power whilst battery charge permits, and 5kW peak outputs.

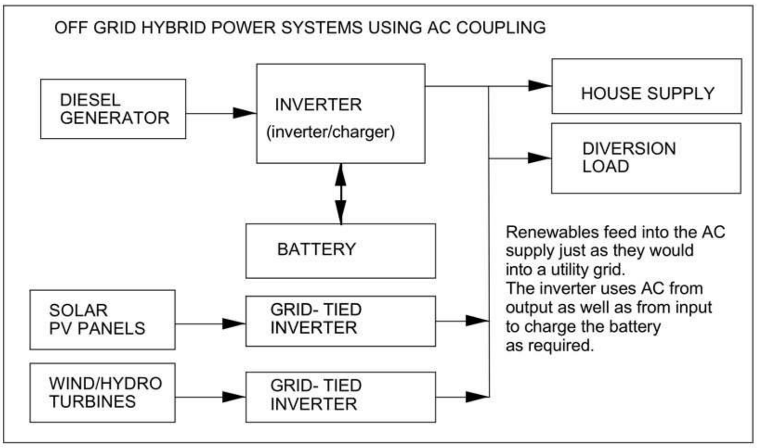
The success of the pilot scheme that Jamie put in 2 years earlier prompted the rest of the community to opt for a micro-hydro site to be developed, and a system to be installed to provide electricity to each of the dwelling houses over the wetter winter months. The larger commercial buildings will always need diesel power, but they are mostly shut down over the winter, so this new hydro system could still bring in significant diesel savings by cutting down on winter generator hours. They decided to see how pilot scheme actually ran before developing the other site as this involved re-locating the water supply for the entire village.

2. Pilot Scheme

As a demonstration project, Jamie opted for a Powerspout Turgo machine. His own site has a head of 24m and operates at 8-10 litres/sec. The turbine is "AC coupled" (see diagram below) to the existing system in his house via an Enasolar grid-tie inverter and Victron Quattro battery inverter.

The system was already a "hybrid" one, with both solar PV and wind turbine input. He opted for AC coupling partly out of interest, and partly because he wanted to increase the potential peak AC power output to the house. Sustained loads above the Victron inverter's rated output would previously trigger a generator start.





The Pilot project went, mostly, very well. The penstock is all 90mm MDPE pipe which, in this area, can be obtained second hand from fish farms. Various lengths of this were towed in by sea and pulled up the hill from the beach by the trusty quad bike.

The dam was constructed out of oak from the boatyard and before long the machine was running merrily.

2.1. Teething troubles

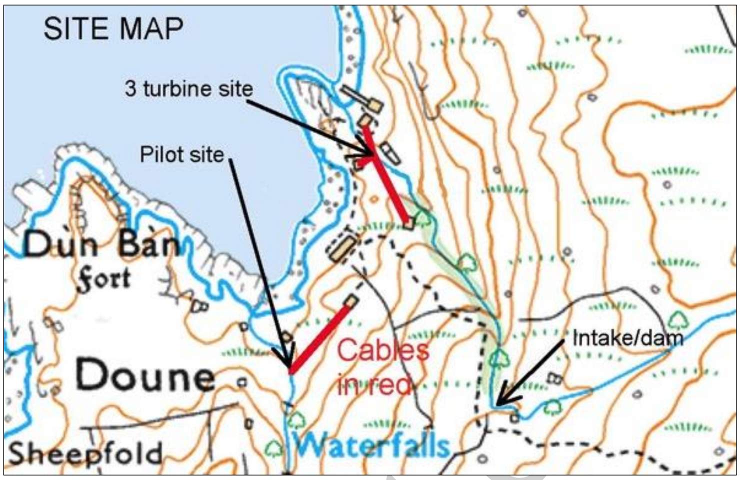
The electronic side of things caused a bit more of a headache. The grid-tied inverter chosen was an ABB Aurora, and Jamie had major issues getting it to run in a stable fashion. Being a wind turbine inverter, it controls the turbine voltage following a power curve (or "table") that is input by the installer, rather than automatically finding the "Maximum Power Point" (MPP) as solar inverters do.

There were 2 problems with this. The first was if you had a dry spell and needed to shut down a jet or two (reducing both the flow and the power output), you then needed to upload a fresh power curve from the computer to the inverter. Not impossible, but a bit of a “faff”. The second was that the ABB inverter was really sensitive to the ID signals broadcast by the micro inverters in the PV panels (which are also AC coupled). The ABB would reject the turbine input, and reboot every time the sun came out. Also a bit of a faff turning off the PV panels every time you wanted to put the hydro on.

"Powerspout and the UK dealer, Hugh, were absolutely fantastic during this period of head scratching," Jamie writes. "Nothing was too much trouble and the support was really first class. I wish the same could be said for the micro inverter manufacturer. Having sold me the micro inverters, quite happily I was then informed in no uncertain terms that they are not warranted for stand-alone systems, end of story." Jamie finally changed the ABB inverter to an Enasolar one and the problem was solved. The micro inverters do not disturb the Enasolar, and it automatically tracks the MPP in solar mode so you can change the number of jets running according to the weather and the inverter harvests what is available automatically. The machine has run with out trouble ever since.

3. The second, larger hydro system

The success of this pilot system, along with the fantastic support that went with it, then persuaded the rest of the community to go for hydro as well. The other site has a more stable flow and has more than twice the head, so was always an obvious choice. It did mean relocating the water supply for the entire village but, once the benefits were to be seen, this was achieved with little effort.



More 90mm pipe was found and threaded up the gorge, between the trees. Taking advantage of a brief dry spell in November they installed another wooden dam with some debris screens from yet another fish farm.

Measuring the head was very difficult in the planning stage due to the terrain and the many trees in the way of the laser level. The initial estimate of 45m was proved to be a bit conservative when the pipes were flooded and the pressure was 5.4bar (55 metres of head). All good for the final output.

Providing power from a single supply to 3 different dwelling houses with different loads and lifestyles was always going to be a bit tricky so they opted for 3 individual turbines, each with its own DC charge controller; one for each property.

These turbines were mounted on a single plywood board with wooden framing underneath.

The 2 x 90mm water pipes were put into a large manifold made out of an old high-pressure air cylinder. All the various apertures were welded in place and the whole thing was mounted on the same plywood board. A pressure relief valve was added in case somebody closed a valve abruptly and caused a burst.

The pipework to the individual turbines was completed in 63mm PVC pipe, with unions at each end of each supply to facilitate removal and maintenance.

The turbines and valves needed to be accessible on dry land so they could be easily turned on and off. The tailrace was constructed using GRP coated plywood and was screwed to the underside of the mounting board so the water exhaust was ducted away and could not undermine the mounting of the turbines.

"Installing a hydro system in West Scotland in the middle of winter was possibly a little foolhardy in retrospect. We were lucky to have a brief dry spell in early November and managed to get the dam in place and all the concreting done then. After that it has rained heavily and non-stop. We opted for a prefabricated system built inside our workshop facilities and then put in place in its entirety, purely because of the weather. The system was broken down to be as light as possible on the day of installation and yet again we must have forgotten to read the sign that says "*do not use this machine as a crane*" on the trusty mini-digger! The turbines and tailrace went in without a hitch and it just remained to hook it all up".

The MDPE pipe was second hand and after a quite spectacular blow out in a worn patch it was finally water-tight.

"A quick VOC test proved that the unloaded voltage was below the 250V that the Midnite Classic charge controllers could handle so it was all systems go. Steel Wire Armoured cable was then laid out to each property. A bit of wiring for the charge controllers and load diversion was carried out by each property owner then came the configuring of the charge controllers.

"This was surprisingly straightforward once we had got used to the language in the manual. I have never seen words like “twiddle”, “dither” or “whizzbang” used before in a technical manual but it proves that the guys at Midnite have got a sense of humour. Hugh’s explanation of the process was invaluable. There is a lot of info in the manual and not all of it relevant to this particular application. The Powerspout guide to the Midnite Classic turns what is a potentially confusing explanation into a relatively straightforward procedure".

"All 3 turbines are now putting out more power than the calculator predicted. The generator is happily silent and all that remains is to say a big “Thank You” and crack open that bottle of whisky!"

PowerSpout PLT turbines often produce a little more than the Advanced Calculator predictions.
(The TRG and LH predictions tend to be more accurate, and so it is important to take account of all of the possible losses when predicting the output of these other turbines.)

4. Intake and penstock details

4.1. The dam

The intake is a dam, which impounds a body of water. At full flow (8 litres/second) the 3 turbines need nearly 30 cubic metres of water per hour, so this dam will not provide meaningful storage, but it is an effective way to capture the flow and slow it down so that debris has a chance to either float over the top or sink to the bottom. Dam height 1.5m, width at water level 3.4m, length of contained water 6.5m, so storage is about 10 cubic metres.

Some consideration must be given to the needs of flora and fauna in the stretch of water between dam and turbines. A small leak would not be a bad thing to sustain some flow when the dam is not overflowing. But overflow will be the norm, as the operators will wish to keep the pipe full by adjusting the number of jets in use so the demand is always less than the available water supply.

4.2. The filter

The filter screens are based around two 110mm PVC waste pipes with 50mm vertical slots cut in the sides, and the screens around them are 150mm pipe with mesh set in them. The screens can also be removed from water level and cleaned easily. There is a general upwelling of current around the screens and most rubbish seems to be flowing over the top of the dam. Wash-over screens are generally more effective at self-cleaning, but they would not be compatible with using the small storage capacity of the dam.

4.3. The vents

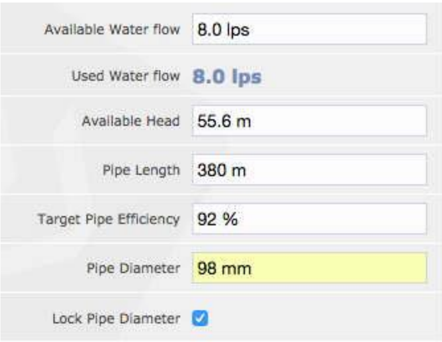
Below the dam are two full flow ball valves. If these valves were closed then the pipe would develop a vacuum along most of its length, so there are vertical vent pipes below the valves that stand above the water level in the dam. If the valves are closed then the pipes will drain.

If the filters were to block completely without these vents then the mesh would be sucked into the pipe.

When stopping the flow for maintenance or repair it is preferable to close the valves at the bottom of the penstock, so that it remains full. Refilling the pipes and purging the air can take some time.

4.4. The pipes

The penstock consists of 380 metres of twin 90 mm OD MDPE pipes surplus from fish farm feeding equipment. Using the advanced calculator with two pipes in the penstock is a bit of a challenge. Normally we would use a single, large pipe. In some cases smaller pipes are cost effective and simpler to install. In this case they were available secondhand with a large saving in cost.



To work with the calculator it is necessary to find the equivalent size single pipe. This is easy to do by entering half the flow at first (4 l/s), and setting the pipe size to 77 mm (the internal diameter of these 90 mm MDPE pipes). Observe that the actual efficiency becomes 92%. Now set the flow to 8 l/s and set efficiency to 92%. The calculator gives a pipe size 98 mm internal. Finally lock the pipe to this size and you can go ahead with studying the various options for flow and power output.

4.5. Choosing jet sizes

The calculator states the correct jet sizes for three turbines of equal power output on the site. Life is never simple though and in reality some houses need more power than others. The target was to get 600 W each from two of the turbines but to run the third at 800 W or more. The HP option was chosen for the latter turbine so that it's output would not be restricted.

To choose the correct jet size you can restrict the flow to 2.4 l/s in the calculator. The only snag is that the pipe efficiency rises with only one turbine in operation whereas in reality all three will want to work together. So when looking for the correct jet size we needed to set the pipe efficiency to 92% and allow the calculator to imagine a smaller pipe diameter so as to maintain the correct net head of pressure, and come up with the desired jet.

4.6. Performance details

In the event the outputs were higher than expected. This is a common experience with the PowerSpout PLT turbine. See next page for the calculator results for each house.

House number	Jet size (x2) @ 5Bar/51m	Predicted flow	Watts at house	Cable length (6 sqmm copper)	Predicted output	Output exceeds by
1	7.6 mm	2.4 l/s	625 W	110 m	574 W	8.9%
2 (HP unit)	8.8 mm	4.2 l/s	880 W	80 m	772 W	14%
3	7.6 mm	2.4 l/s	688 W	40 m	598 W	15%
TOTAL		8.0 l/s	2193 W		1944 W	12.8%

Jamie put pressure gauges at the jets themselves so as to check for manifold losses but there were none. Pressure at each jet was 5.0 Bar, same as at the steel vessel.

ADVANCED CALCULATOR ONLINE

	HOUSE 1	HOUSE 2	HOUSE 3
Available Water flow	2.4 lps	3.2 lps	2.4 lps
Used Water flow	2.4 lps	3.2 lps	2.4 lps
Available Head	55.6 m	55.6 m	55.6 m
Pipe Length	380 m	380 m	380 m
Target Pipe Efficiency	92 %	92 %	92 %
Pipe Diameter	62 mm	69 mm	62 mm
Lock Pipe Diameter	☐	☐	☐
Number of PowerSpouts	1	1	1
Lock PowerSpouts	☐	☐	☐
1 or 2 Jets Per PLT	2	2	2
Jet diameter	7.6 mm	8.8 mm	7.6 mm
Actual Pipe Efficiency	92 %	92 %	92 %
Rotor Speed	1183 rpm	1183 rpm	1183 rpm
Output per PowerSpout	618 W	835 W	618 W
Total PowerSpout output	618 W	835 W	618 W
PowerSpout Output Voltage	75 V	77 V	67 V
Target Cable Efficiency	95 %	95 %	95 %
Length of Cable	110 m	90 m	40 m
Design Load Voltage	70 V	71 V	65 V
Actual Load Voltage	70 V	71 V	65 V
Cable Material	Copper	Copper	Copper
Cable cross section	6.0 mm^2	6.0 mm^2	6.0 mm^2
Lock Cable Size	☑	☑	☑
Next size up cable	9 AWG	9 AWG	9 AWG
Cable Current	8.2 A	10.9 A	9.2 A
Actual Cable Efficiency	93 %	92 %	97 %
Power at Your Shed	574 W	772 W	598 W

4.7. Flow management

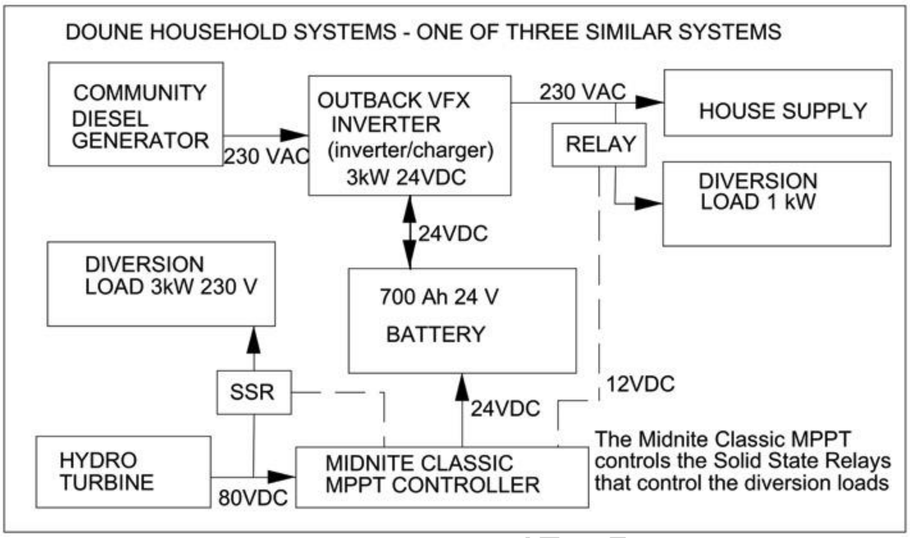
The plan for flow management is to close a jet or jets when the dam ceases to overflow. Assuming that the flow declines gently, the shortfall will be small in relation to the total flow so that the dam will take several hours to actually empty. Jamie can see his dam (pilot scheme) from his home but the larger scheme has a less visible dam. A method of monitoring is yet to be devised.

Given a long enough communication cable, it would be possible to operate motorised valves driven by a float switch at the dam, as discussed in the document PS TRG automatic valves.

The only way to perfect the system is to gain operating experience over a period of a couple of years and to tinker with the controls along the way. This community is very lucky to have Jamie in their midst to help them to perfect it and minimise their generator needs.

5. Electrical system details

Each house has a pre-existing Outback inverter and 24V traction battery that supply 24-hour power when the generator is not running.



The PowerSpout turbine for each house generates nominal 80VDC for maximum power (MPPV). Actually this turned out to be 70 V in most cases.

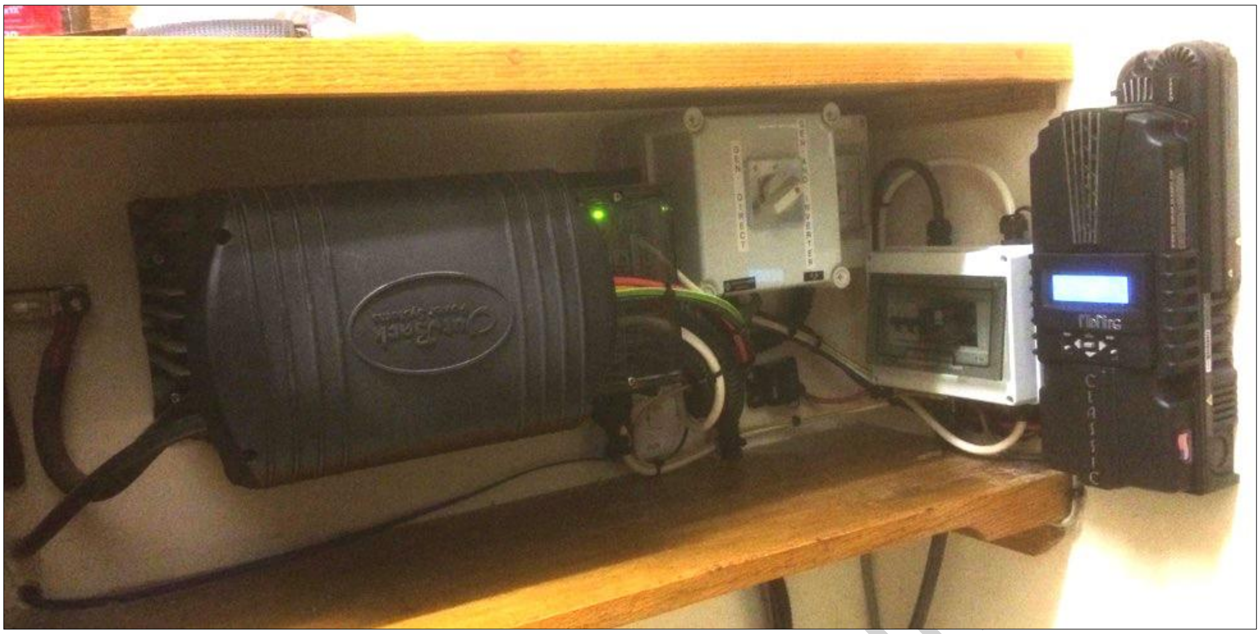
The Midnite Classic controller finds the MPPV and converts down to 24 VDC nominal output to charge the battery whenever water is available.

The battery is located in a box against the wall of a house. It would take up a lot of space inside, and the fumes would be unwelcome and possibly dangerous. Provided there are no serious frosts this is the best arrangement. The cables between battery and inverter need to be short and heavy. You can see them penetrate the wall on the left. The white bottles contain de-ionised water for topping up the battery levels at frequent intervals.

Here are the settings chosen by the owners of the individual systems. These may continue to be tweaked over time to produce the best results.

Battery charge settings

PARAMETER	**HOUSE 1**	**HOUSE 2**	**HOUSE 3**
Battery size	700AH	700AH	700AH
Absorption	28.8V	29.0V	28.8V
Float	27.2V	27.2V	27.2V
Equalise	31.4V	31.4V	31.4V
Equalise	Manual	Manual	Auto
Rebulk	26.0V	26.0V	26.0V
Twiddle Dither	Min 60V Depth 1%	Min 45V Depth 3%	Min 60V Depth 2%
AUX1	Waste not High	Waste not High	Waste not High
	V high -0.2	V high -0.2	V high -0.1
	V low -1.5	V low -1.0	V low -0.6
	Delay 10s, Hold 180s	Delay10s, Hold 90s	Delay 10s, Hold 120s
AUX2	PV on High	PV on High	PV on High
	85V, Width1.0V	100V, Width 1.0V	85V, Width 1.0V



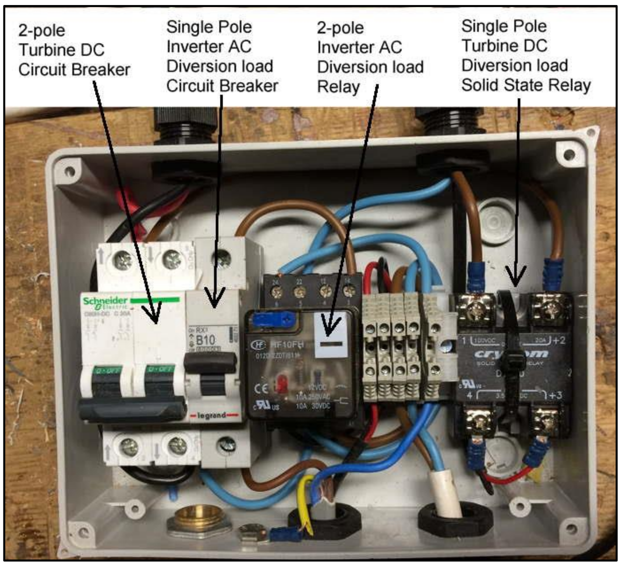
The Outback VFX 3kW inverter and Midnite Classic 250 V charge controller are on the inside of the wall. Again, the battery cables (and fuse) are visible on the left of the photo.

The inverter can be programmed for battery charge settings that apply when the diesel generator runs by an Outback display panel ("Mate") that is common to all three houses. It can be unplugged when not in use.

The Midnite Classic charge controller (on the right hand side above with "art-deco" styling) has a built-in display for configuring its various settings for battery charging and diversion load control. You can also do this with a laptop via Ethernet, and there is a lower cost "Lite" version of the classic without a display for those who do not need it. Full details of how to program and wire the Classic with a PowerSpout are set out in the document **PS MPPT Midnite Classic Guide**

A rotary changeover switch can be used to run the house directly from the generator supply in the event of an inverter failure.

5.1. Energy usage



The communal generator is a 15 kW single phase Perkins set which uses approximately 5000 litres of diesel fuel per year to supply households and commercial needs.

At a rate of 3 kWh per litre this would equate to roughly 15,000 kWh per year of electricity usage. The hydro scheme may be able to provide this much energy or more, given sufficient rain. (2 kW of power 24 hours and 365 days would make 17,500 kWh.) But the generator will still be needed to meet high peak loads, and to charge the batteries in dry periods.

5.2. Diversion loads

In reality much of the energy will be generated when it is not needed and the battery will be full. The Midnite Classic controller uses it's "Waste not" mode to operate a heater at these times so that the excess can be put to good use. If the generator is running or the battery is transitioning from bulk to float charge then it will not need any input from the hydro. At these times the Classic will use its "PV V on high" mode to connect a heater directly to the turbine and prevent it over-speeding and wearing itself out noisily. A 3kW, 230V heater controlled by a solid state relay (SSR) actually draws about 600 watts at 100 volts and keeps the turbine loaded safely.

Given that the voltage can actually surge above 100 V under these conditions it is wise to use a SSR with a 200 V rating or higher.

