PowerSpout
WATER GOES IN POWER COMES OUT

PLT Case Study 3 - High head installation

ecoinnovation

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CONTENTS

PLT in sound proof enclosure

1. Overview

1.1. Customer data

The Nelsons contacted EcoInnovation with the following site data:

- Head: 220 m
- Flow: 2 l/s
- Pipe length: 1800m

Ballpark calculations for the head and flow can be done as follows:

Annual energy **kWh per year = Head x flow x 37** = 16,280 kWh energy per annum
This compares well with Average Electricity Consumption for New Zealand homes, which is 7,700 kWh/y/house, a value that has remained constant for more than 30 years. (NZ govt. data http://www.mbie.govt.nz/)

Instant power output
The simple rule of thumb: "**Power = Head x flow x 5**" = 2.2kW
This power level 24 hours 365 days a year gives 19,272 kWh per year showing this rule is even more optimistic.

1.2. Advanced Calculator design process

If however we take the above data to the advanced calculator on the PowerSpout website we run into a problem. The 220m figure flips to 160 metres, and a message tells us:

> 130m (427ft) is the maximum operating head.
> Use a smaller penstock size to reduce the operating head. Smaller pipe is also cheaper.

Why 160 metres? This is the limit for plastic pipe that you will find for sale.

If we wanted to use all of the power from this site we'd need to put one turbine part-way up the slope and run a second turbine off the waste from the first. In this case we had ample power so this was not worth doing. Instead it was decided to vent the system at a "pressure break tank" 160 metres above the turbine site. Water is fed to this tank from the intake and flow is regulated to 2 litres/second.




Intake Pressure break tank 1850m of pipe laid with a pipe ripper in 1 day

The distance from the tank to the turbine is 1,450 m. Putting this pipe length into the Calculator gives a pipe internal size 59 mm. But bearing in mind the warning message we choose 50 mm. The warning disappears and we have 78% pipe efficiency for a net head of 125m at the turbine. 50 mm internal is a common pipe size that can be obtained easily. See Section 3 for full details of the pipe specifications.

We now have the output at the turbine defined as 1,332 W output. If sustained, this will yield 11,668 kWh per year before electrical losses in the system. See Section 2 for the final calculator result.

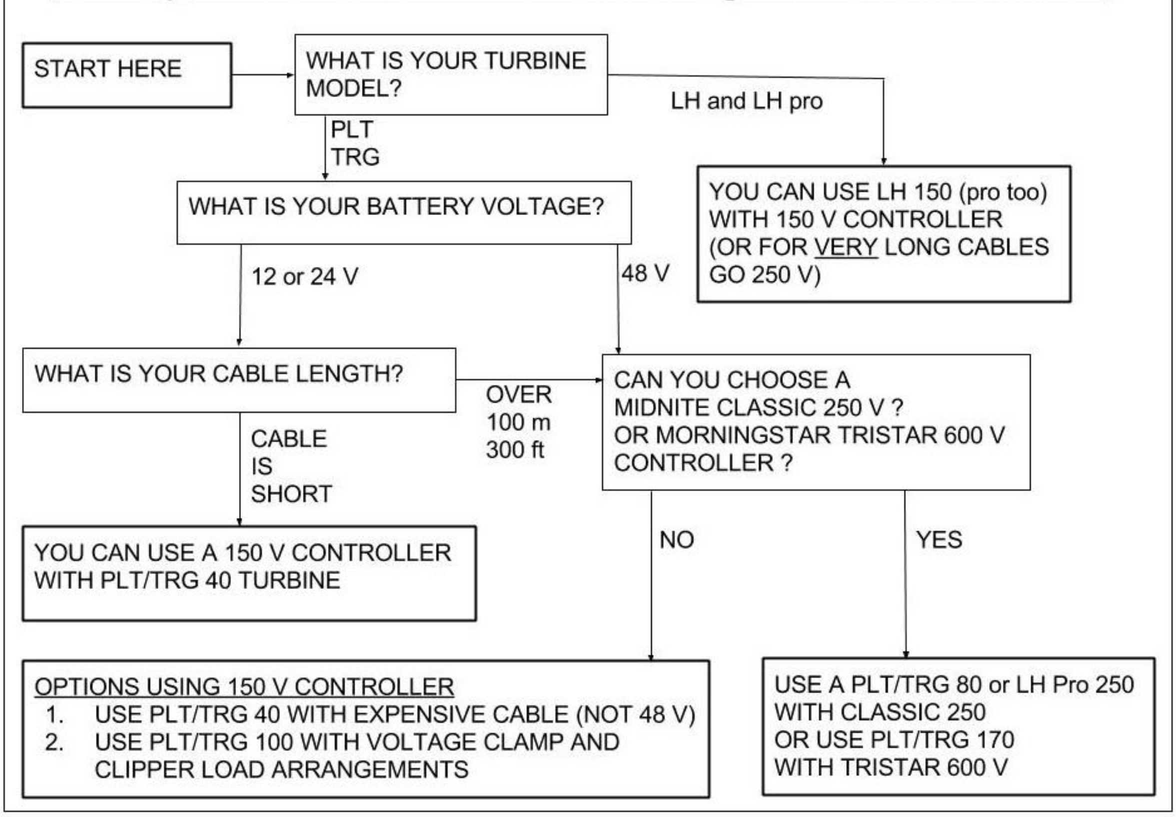
1.3. Electrical design

The system is off-grid and therefore we need to select a battery voltage. We would like to choose 48 V nominal battery because this is the most efficient option for wiring (being higher voltage than 12 or 24V) but we need to look first at our options for controllers.

PowerSpout strongly recommend the use of MPPT controllers on the off-grid turbines. Whilst it is possible to operate the turbine connected directly to the battery, there are several advantages to using an MPPT controller, the main one being its ability to maximise the power obtained from the turbine.

1.3.1. Choosing the MPPT controller

The turbine must be designed so it cannot damage the controller with excessive voltage. At this point in time it was not possible to obtain a controller with higher than 150 volt maximum rating. The PLT can produce up to 3 times higher voltage than it's rated output in runaway "open circuit" mode. To avoid the complexity of using a protective voltage clamp that would limit our system voltage we chose a PLT40 turbine that will never exceed 120 V. The PLT 40 cannot charge a 48 V battery. Accordingly we chose a 24 V battery system.



PowerSpout turbine and MPPT controller voltage selection decision chart

1.3.2. Cable sizing

We enter 40 volts in the Calculator box "design load voltage". Cable run from the turbine to the battery shed is 75 metres. So we find using the Calculator that $25mm^2$ copper cable works for us at 92% efficiency giving 1231 W output at the shed. A thicker cable would be more efficient, but the cost is not justified.

1.3.3. Equipment choice

The Outback 3kW inverter and Flexmax MPPT controller were supplied as a prewired panel complete with all the necessary circuit breakers and "Mate" control display. The 24V battery bank consists of 8 x Crown 6V 440 Ah batteries (for a total of 880 Amphours at 24 V).

This battery and hydro system can power a 3.0kW load for up to 1 hour, after which the load must fall to 1.3 kW or less. The inverter can deliver 5kW for brief periods to meet surges and in the worst case would shut down to protect itself rather than suffering any damage from overload. It is not difficult to learn to live within these power limits. Several high power appliances can be used together with care.


Inverter system


Battery enclosure


Power shed

1.3.4. Surplus power usage

On-demand power usage can never match the available power exactly, so there will be a surplus or a shortfall. A shortfall will result in unreliable operation and short battery life. It is very important to control energy usage so as to allow a small surplus, but this brings two less serious problems:

- Turbine runaway causing excessive bearing wear and noise
- Lost opportunity to use this energy for something and save burning fuel

If the MPPT controller sees the battery charging at its optimum rate, and there is power to spare, then it will simply not use that extra power and the turbine will become unloaded to a greater or lesser extent and start to overspeed. On some sites this will not be a worry but with this very high head we get the following message in the Calculator:

> No load speed is 4126rpm!!! Contact your supplier (and read the manual) on regulation methods that can be employed to prevent turbine runaway.

To keep the turbine on load at all times and to avoid missing out on energy that can be used, we installed a diversion load. The water heating load draws power from the battery via a Solid State Relay (SSR) controlled by an auxiliary output of the Outback controller. More details of the diversion load can be found in Section 6

It looks likely that the house will overheat in summer and be cold in winter, so we have suggested they fit a small 400W heat pump that can do 2kW of heating/cooling as a good solution for excess energy usage.

1.4. Turbine installation notes

Installation details (see also Calculator)		Performance data	
Pipe inside diameter:	50mm	Head	125m
Pipe length from break tank	1450m	Flow rate of water through turbine	2.0l/s
Jet size x 2	5.6mm	DC MPP Voltage at FM80:	45VDC
Static pressure on gauge:	160m	Voc at Inverter:	98VDC
Dynamic pressure on gauge:	125m	DC Watt out of turbine:	1375W
Turbine nominal voltage:	40 VDC	DC Watt on FM80 display:	1320W
Cable length:	75m	Turbine efficiency:	56%

The measured output exceeded the calculated output somewhat, as is frequently the case with the PowerSpout PLT turbine.

For PLT turbines the rule of thumb to be safe is that Voc is three times the nominal working voltage (MPPV), in this case 40 volts. Voc was in fact lower than the nominal 120 V (ELV and the safe level for Flexmax MPPT controller). This was partly due to the use of a "High Power PMA" (this means the turbine has a larger PMA fitted then is actually needed) and to the high air drag at this very high runaway rpm.

1.4.1. Noise abatement

Turbine noise is very much a function of the head, and so this one is noisy and this was anticipated and mitigated by the construction of a special enclosure made from double skin panels with insulation between layers. This was very effective, as the measurements show.


Build phase


Double skinned noise insulated enclosure


Install team


Finished job in a sound proof enclosure


52 db @ 2m

Noise level was measured at 2 m from turbine	Without enclosure	With enclosure
Noise level for normal operation	80 dB	52 dB
Noise level with turbine runaway (no load)	90 dB	60 dB
Background noise level	35 dB	

Local electrical inspector checking out the system, there are no inspection requirements below 120V DC (in NZ/AUS) but he was onsite to inspect the homes new 230VAC connection. Make an effort with local electricians and inspectors to engage them, most will never have seen a job like this before and they will find it very interesting. Any genuine system issue/concern is best handled in a friendly manner on site rather than with formal letters. Make an effort to be friendly, you are in their patch.

1.4.2. Working at high pressure

The high operating head brought some other difficulties to the installation. All of the joiners on the lower DN16 pipe sections needed extra tightening to prevent leakage. Fortunately the pipe section had not been backfilled prior to pressure testing.

The ball valve was not strong enough (130m rated not 160m rated), and its handle flew off while closing. This was repaired on site. These conditions can result in some dramatic failures with high velocity debris, and it is important to take care. Valves have to be closed slowly whilst watching the pressure gauge. After all, you are stopping a mass of almost 3 tons of water moving at walking speed. If the static pressure is already as much as the pipe and fittings are designed for, then any extra will be risky. It's a good idea to take several seconds to fully close the valve. Above 130m static pressure brass gate valves should really be fitted.

1.4.3. Airlock

It's not unusual to encounter some teething troubles with the penstock, especially a long one that is not always steeply graded. In this case there was an airlock in the section just below the "pressure break tank" that prevented the pipe beyond from filling properly.

High spots in the pipe run can often be eliminated by carefully grading the route and checking the slope frequently, but in some cases they are inevitable, and then it's vital to be aware of where they are. In this case the problem was solved by the simple trick of drilling a small hole at the highest point so that the trapped air could escape. The hole can be sealed with a stainless steel screw. Or it may be helpful to fit a vertical vent branch pipe that rises above intake level. But take care because sometimes a vent near the intake will actually start to suck air in once the full flow is established. Vent the air out with the turbine valve closed. If water stops emerging when the turbine valve is open (and system running) then you are allowing air to be drawn in and such an issue will have to be addressed.

2. PowerSpout Advanced Calculator Results

Please find the requested results from the PowerSpout Advanced Calculator:
Your Reference is: **PS4708-B38F99D8**
Your Job Reference is: **Jude Nelson - as built - 100-2S-7P-S fitted with HP type 2 rotor**
Click here to view them in the calculator.

Preferences
These are the preferences you indicated and any applicable safety notes.
Units: Metric
Type: PLT

Hydro
These are the notes and results from the hydro calculations.
No load speed is 4126rpm!!! Contact your supplier (and read the manual) on regulation methods that can be employed to prevent turbine runaway.

Units: Metric
Flow: 2.0 lps
Used Flow: 2.0 lps
Pipe Head: 160.0 m
Pipe Length: 1450 m
Pipe Efficiency: 90 %
Pipe Diameter: 50 mm (This value was locked and may not have been the diameter recommended by the calculator)
Number of Powerspouts: 1
Nozzles: 2
JetDiameter: 5.6 mm
ActualPipeEfficiency: 78 %
Speed: 1856 rpm
Output: 1332 W
Total Output: 1332 W

Electrical
These are the notes and results from the electrical calculations.

OuputVoltage: 48 V
CableEfficiency: 95 %
CableLength: 75 m
LoadVoltage: 45 V
ActualLoadVoltage: 45 V
CableMaterial: Copper
CableSize: 25.0 mm^2 (This value was locked and may not have been the size recommended by the calculator)
CableAWG: 3 AWG
CableCurrent: 27.8 A
ActualCableEfficiency: 94 %
ActualTotalOutput: 1250 W
Thank you for using the PowerSpout Advanced Calculator.

3. Site survey and penstock details

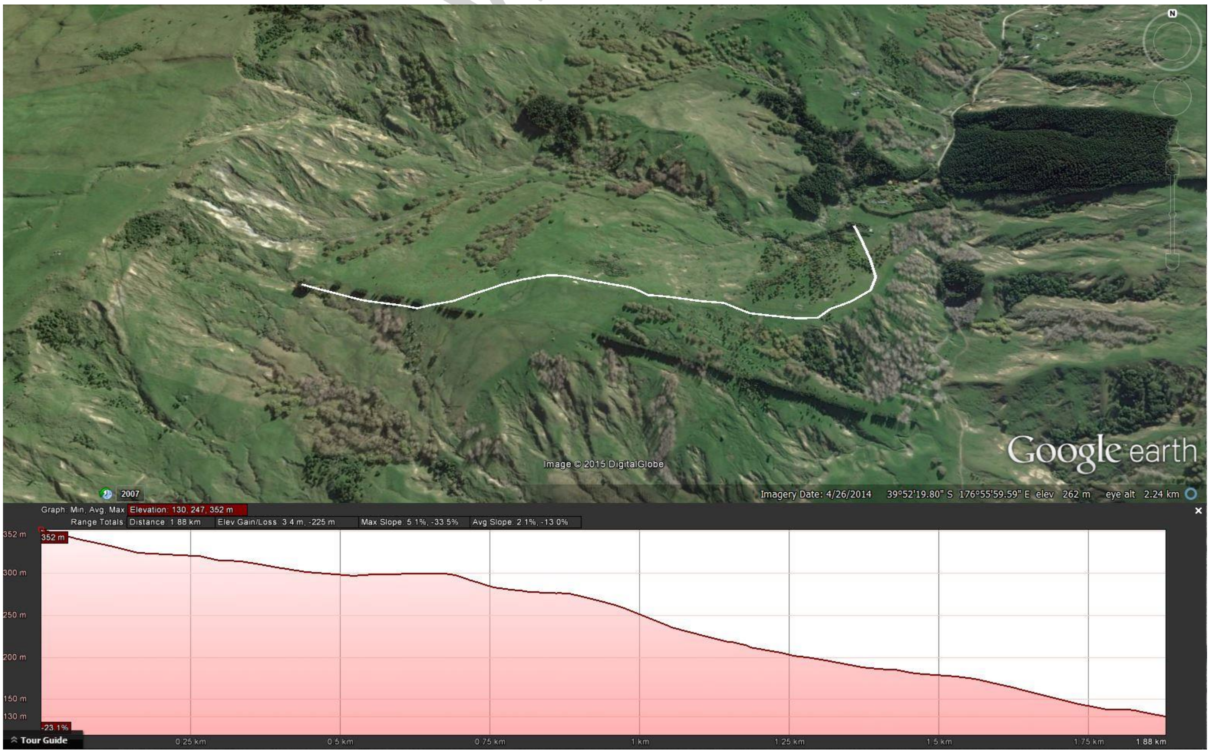
3.1. Data from several site surveys

3.1.1. Nike watch data

Note GPS signal was lost for the straight section on the plot below.
Elevation estimate 207m

3.1.2. Google Earth desktop study

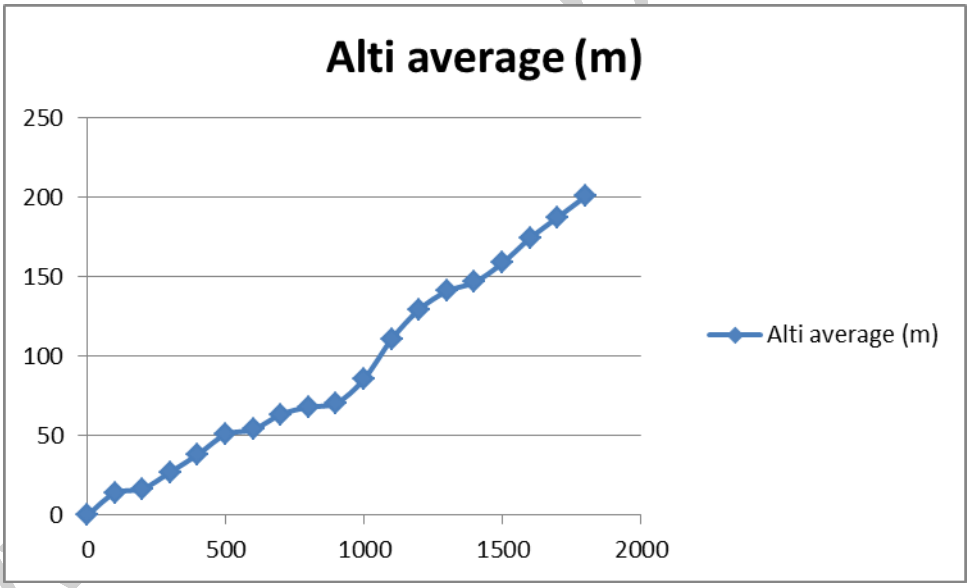
This one predicts 223m fall and 1800m of pipe to centre of lower pond
This looks consistent with Nike watch GPS data



3.1.3. Data collected from 2 hand held altimeters

Pipe length m	Vertical fall of pipe line		
	Alti 1 (m)	Alti2 (m)	Alti average (m)
0	0	0	0
100	12	16	14
200	15	18	17
300	24	30	27
400	37	40	38
500	49	53	51
600	52	56	54
700	61	66	63
800	67	69	68
900	70	71	71
1000	85	86	86
1100	110	112	111
1200	128	131	130
1300	45	141	93
1400	146	147	147
1500	158	159	159
1600	174	175	174
1700	189	186	187
1800	201	200	201

Plot of above data



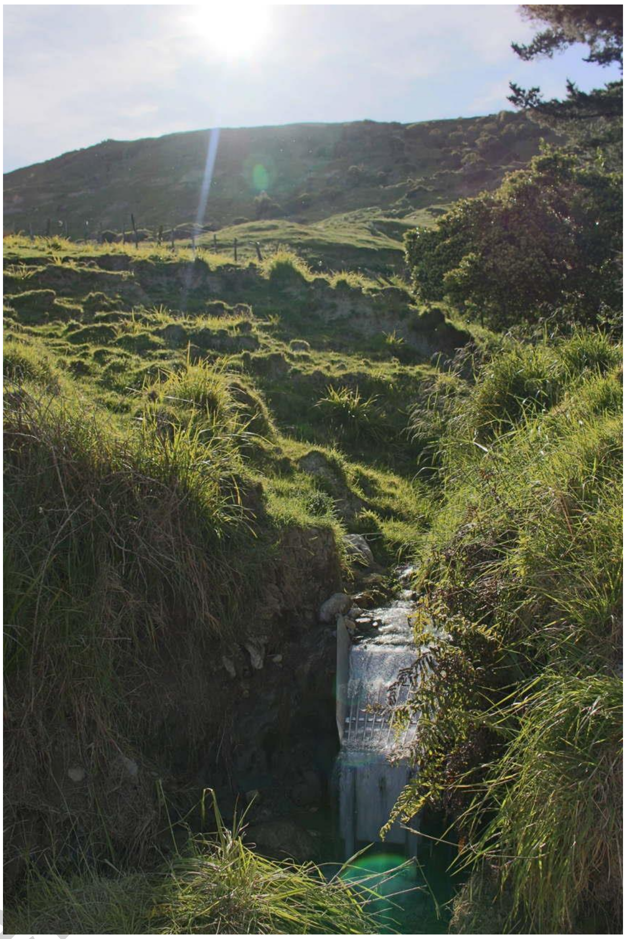
The total of 201m of fall in 1800m of pipe compares very well with the data below

3.1.4. Site data: (collected by Guy Nelson)

- Head = 209m
- Pipe distance = 1820m
- Flow rate at intake 5l/s

3.2. Intake

The intake is made from stainless steel in the form of a tank into which the water falls through a sloping screen.



In this case the screen is much too coarse. The customer will need to fit a finer mesh on top of the sloping bars.

3.3. Pressure break tank

This tank is situated at 160 m elevation above the turbine, and water is admitted at a controlled rate using a valve so as to meet the full flow requirement.

3.4. Pipe options

Rural Direct advised the following:

- PN16 100m = $729   160m rated
- PN12 100m = $613   120m rated
- PN9 100m = $409   100m rated

Enduroflex 2 is a lower cost 50mm ID pipe rated for 70m, as per table below.
Normal low cost 50mm ID LDPE is rated for 35-50m

Pressure Rating Comparisons at 20°C

Nominal Diameter (mm)	Enduroflex2 m/head	Enduroflex2 PSI	LDPE m/head	LDPE PSI
15	100	145	90	128
20	90	128	80	116
25	80	116	65	92
32	80	116	50	70
40	70	100	45	64
50	70	100	35	50

Schedule of pipe requirements for the penstock (including the feeder for the tank):

Pipe Length (m)	Pipe fall (m)	Pipe selection	Pipe Pressure (m)	Pipe cost (approx)
0	0		0	
100	14	100m of 35m rated LDPE (50mmID)	14	350
200	17	100m of 35m rated LDPE (50mmID)	17	350
300	27	100m of 35m rated LDPE (50mmID)	27	350
400	38	100m of 35m rated LDPE, presssure break tank	38	350
500	51	100m of 35m rated LDPE (50mmID)	13	350
600	54	100m of 35m rated LDPE (50mmID)	16	350
700	63	100m of 35m rated LDPE (50mmID)	25	350
800	68	100m of 35m rated LDPE (50mmID)	30	350
900	71	100m of 35m rated LDPE (50mmID)	33	350
1000	86	100m of Enduroflex2 or PN9 pipe (70m rated - 50mm ID)	48	409
1100	111	100m of Enduroflex2 or PN9 (pipe (70m rated - 50mm ID)	73	409
1200	130	100m of PN9 63mm OD pipe	92	409
1300	141	100m of PN12 63mm OD pipe	103	613
1400	147	100m of PN12 63mm OD pipe	109	613
1500	159	100m of PN12 63mm OD pipe	121	613
1600	174	100m of PN16 63mm OD pipe	136	729
1700	187	100m of PN16 63mm OD pipe	149	729
1800	201	100m of PN16 63mm OD pipe	163	729
				8403

The following joiners were also needed:

- 8 x 50mm ID joiner
- 3 x 50mm ID tanks connectors (2 for tank 1 for intake)
- 1 x 50mm ID to 63mm OD joiner
- 6 x 63mm OD joiners

Rather than run an overflow pipe from the tank back to the river which would require another 200-300m of pipe, it was decided to simply restrict the flow into the tank using a valve.

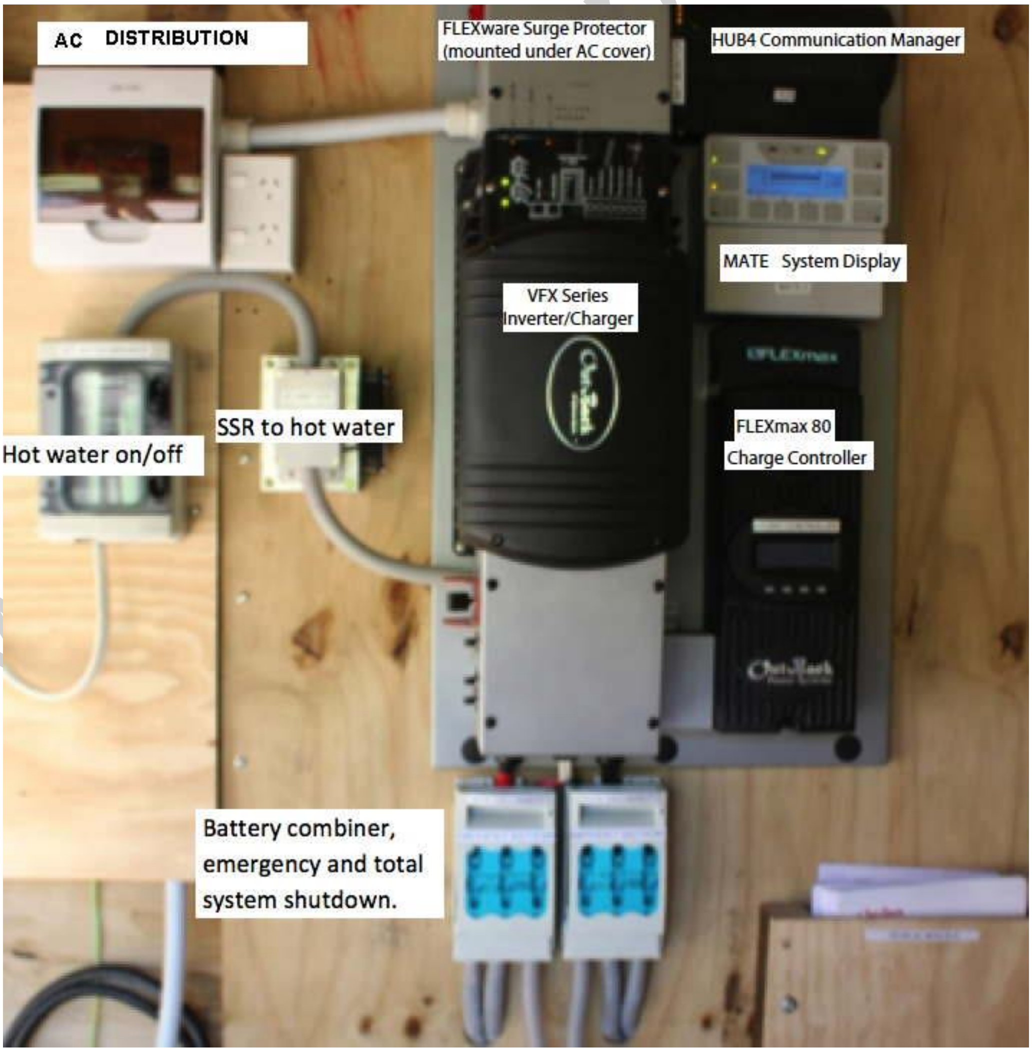
4. Electrical system

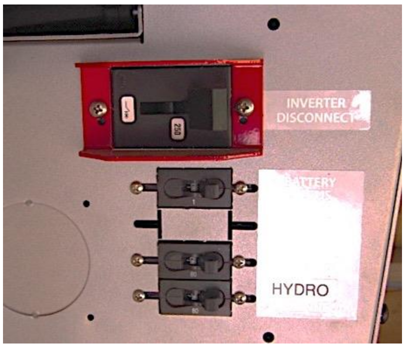
4.1. The Shed

All of the electrical gear is housed in a purpose built shed (previous life a chicken house), 75m from the turbine and 25 m from the house. In the photo the walls are not finished so you can see the layout clearly. Batteries need to be close to the inverter, but not directly below a vented inverter as the fumes can rise and corrode the circuit boards.

4.2. Prewired Outback power Systems board

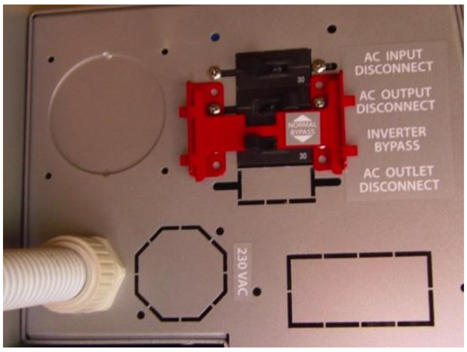
The heart of the electrical system is a pre-wired "FP1" board from Outback Power Systems containing the inverter, hydro turbine controller and system display.





Left hand sides of breaker boxes.
Lower, DC box shown left.
Upper AC box shown right.

All DC & AC breakers should be as shown for normal operation



4.3. Batteries -

Vented battery enclosure – keep locked

Keep your battery:

- Locked – children must be kept out
- Clean
- Free of rats and mice
- Topped up with battery grade water as required
- External air vents clean
- Safety equipment readily on hand

Battery type: Wet cell lead acid

- Battery make: Crown CR430
- Amp hour capacity/battery: 430 (at the 20hr rate)
- Mass 55kg each battery
- Number of batteries per bank: 4
- Number of parallel banks: 2
- Short circuit current will exceed 1000 amps

The battery is kept in a well ventilated box within the shed.

It is important to check the batteries at regular intervals and top them up with deionised water. If they dry out they will be damaged, and may even explode.

4.4. Wiring HRC fuse-holders

3-pole HRC fuse holders were used on both positive and negative battery wires leading to the equipment panel. Two of the poles are used for the two battery strings (each combined at the top with a busbar).

The third fuse pole is used for the incoming hydro turbine wiring. Pulling out the fuse holders will result in an emergency shutdown of the system that disconnects all power sources
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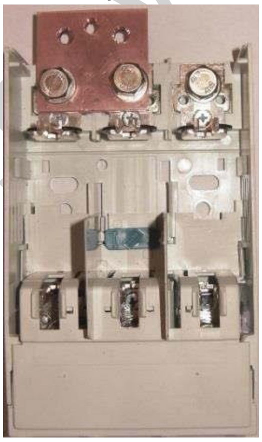
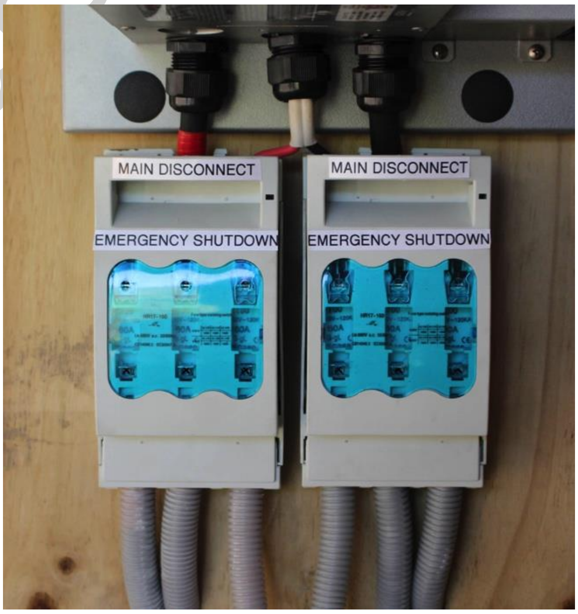




5. Diversion load

5.1. Auxiliary relay control

The diversion load is turned on automatically by the hydro turbine controller using its AUX relay, programmed in "Diversion solid state mode" as described in the document “PS MPPT Outback FM guide” in the INDEX. This is done with pulse width modulation (PWM), so it ramps the power up smoothly.

Without a diversion load the controller has nowhere to put excess power after the battery has been charged, which means that the turbine has no choice but to over-speed. This Aux relay mode will divert power to the heater when the rising battery voltage is getting close to the chosen charging set-point (-1.0V and 0.2V hysteresis) so as to prevent the turbine from over-speeding.

The load is chosen to be slightly less than the turbine power so that even when it is operating the turbine can eventually bring the battery up to its setpoint.

At float set-point of 27V, only 730W (out of 1300W generated) goes to element, so FM80 does unload the turbine a little.

Once the home gets connected and we get some base load then there will be less likelihood of it getting unloaded.

The actual switching of the load is done by a Solid state relay (SSR) provided by EcoInnovation.

The water tank was not available at the time of installation, so a temporary air heater was used. This will work to prevent overspeed, but the water heater will make much better use of the excess energy.

The air heater is simply a wire wound resistor in the battery shed. This will make a slight buzzing noise in operation.

5.2. Water tank over-heating

One issue that needs to be addressed with fitting a diversion load water heater is the question of what happens when the water is hot enough. It is important to keep on diverting power. If there is a solar controller with an Aux output then it would be possible to fit a "backup" diversion to an air heater using that output.

Some sites operate with a low pressure, 180 litre, open vented hot water cylinder than can cope with boiling water from time to time. Or sometimes a pump is used to remove surplus hot water into a heating system, such as a heated towel rail in your bathroom.

Alternatively, there are several possible strategies to use thermostats to divert the diversion to another heater. See the document “PS MPPT Diversion Loads Guide” in the INDEX file.

This picture shows 48V water heater with both element cores used. This 24V system only needs 1 element to be used

Always fit a metal cover over DC water elements, as the fire risk is higher for DC than for AC water elements. Make sure the warning “Turn off before draining tank” is in the correct place.

Check the terminals each year to ensure there is no visible heat damage and the terminals are tight (3 Nm).

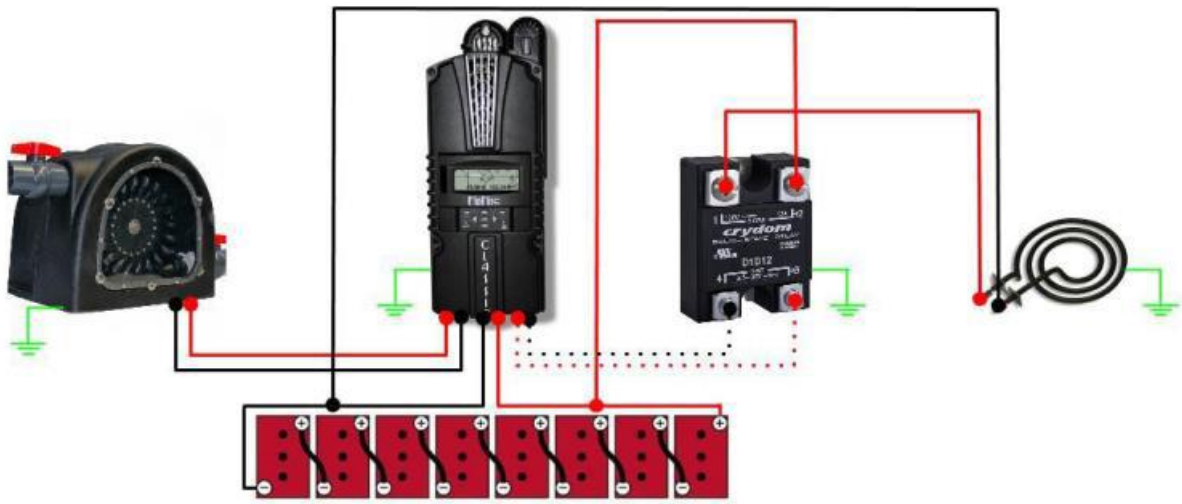
No hot water may mean:

- Not sufficient surplus power to heat it
- Failed element or terminal (your element has a spare coil)
- Failed SSR or breaker has been turned off

Boiling water means:

- Use more hot water
- Failed SSR (on)

(Turn off element breaker until issue can be fixed or reduce your hydro generation by fitting a smaller jet)



6. Economics

6.1. System costs

Turbine and related equipment:

• 1 x PLT40 turbine (3 year warranty)	2200
• 1 x PVC 2 jet manifold and mac union and 63mm pipe joiner	500
• 1 x 63 amp 2-pole 120V DC breaker in w/p housing	100
• 75m of copper 2-core 25 mm^2 cable	1500
• 3 x Auto grease cans, 1/year for bearings	400

Battery bank (1 year warranty – life typically 7-10 years)

• 8 Crown 6V440 batteries (24 Vdc storage system)	4600
• 24 x hydro caps for above batteries	240
• Battery links and heavy DC cables	250
• Stainless steel battery fixings	100
• Battery freight from Auckland to site	250
• Safety gear and signs as in picture	250
• Main DC fuse as per picture x 2	200
• Top up water	20
• Materials for battery enclosure and vents	500

Inverter system (warranty 5 years)

3kW Outback Power FP1 pre-wired system and hydro controller	8600

Diversion of surplus power to hot water tank

Special 24 Vdc 780W water element		250
SSR diversion relay		200
40 amp fuse for above and housing		100
Wire for up to 0.78kW at 25m to tank 10mm^2 2-core	(250)	
In fact we used the 25mm^2, as there was 25m left on the 100m roll		500

Labour cost

• Travel time both ways for 3 person:	1500
• Car, trailer use and petrol	750
• 3 men on site for 3-4 days to install	5000

Total cost
Total cost for our component of the job is $28260 + gst.

6.2. Savings

• Pipe, joiners break tank	$12,000
• Pipe laying and machine hire	$ 3,000
• Balance of system installed	$30,000
• Total	$45,000 NZ = 30,000US

This displaced a quoted grid connection cost of $200,000 ($131,000US) and will save about $3200NZ ($2,100US) per year in power bills, which will pay for system depreciation and maintenance. Hence the system has saved the client about $155,000 NZ ($101,000US).