PowerSpout

WATER GOES IN POWER COMES OUT

Case Study 5 - Grid tied PLT installation

ecoInnovation

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Ernst Steiner with his turbine.

1. Introduction

1.1. Customer data

Andreas Steiner contacted Ecoinnovation from Switzerland with the following site data:
Head: 70 m
Flow: 2.5 l/s
Pipe length: 210m

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

Annual energy **kWh per year = Head x flow x 37** = 6,475 kWh energy per annum
This compares well with Average Electricity Consumption for Swiss homes, which is 5,000 kWh/y/house. But this assumes constant flow.

Instant power output
The simple rule of thumb: "**Power = Head x flow x 5**" = 875 W
This power level 24 hours 365 days a year gives 7,665 kWh per year, showing this rule is even more optimistic.

1.2. PowerSpout Advanced Calculator

The PowerSpout website calculator gives the following result with 52mm (internal) diameter pipe:

Units: Metric
Flow: 2.5 lps
Used Flow: 2.5 lps
Pipe Head: 70.0 m
Pipe Length: 215 m
Pipe Efficiency: 90 %
Pipe Diameter: 52 mm (This value was locked and may not have been the diameter recommended by the calculator)
Number of Powerspouts: 1
Nozzles: 2
JetDiameter: 7.4 mm
ActualPipeEfficiency: 90 %
Speed: 1320 rpm
Output: 810 W
TotalOutput: 810 W

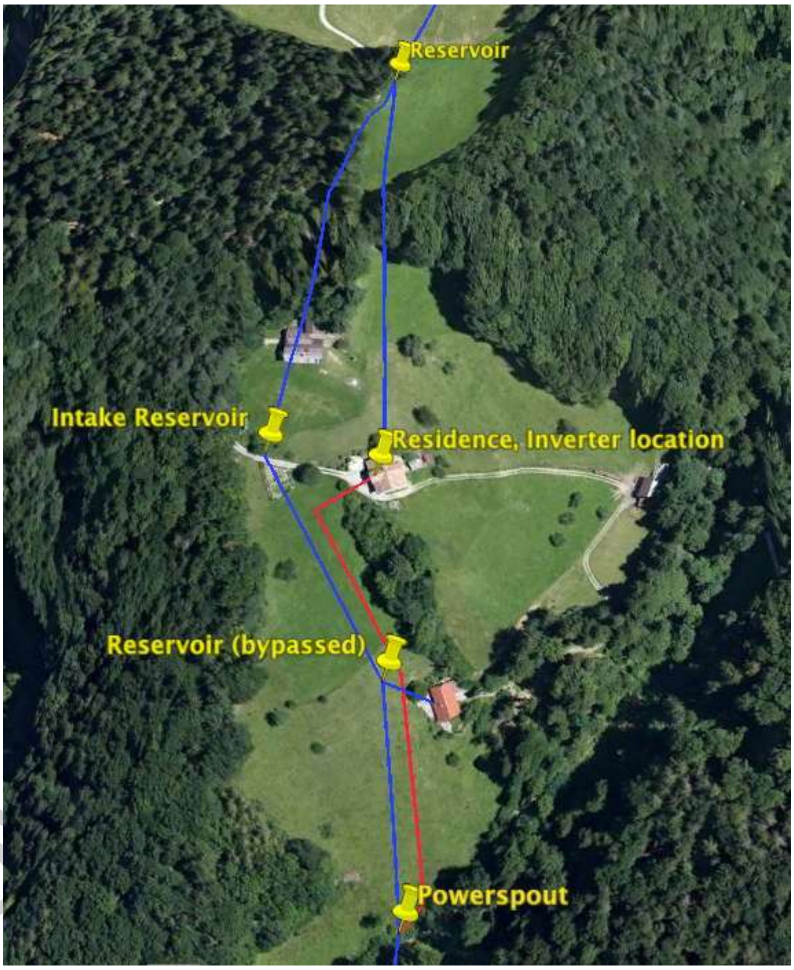
2. Site survey and penstock details

2.1. Existing water system

Andreas writes:
"Growing up in the foothills of the Alps, hydropower has always caught my interest. Many large and medium size power plants are in operation producing over 50% of the Swiss power production.

"Our drinking water system was initially built over 100 years ago supplying many houses downhill from the well. It is a well functioning system with reservoirs almost every 100m/330' of pipe. Due to the high lime content of the water, the old clay tubes built up limestone and were gradually replaced with 52mm/2" PVC pipes. The pipe runs from the top to the bottom of our steep property and I always dreamt of harnessing that energy to produce electricity.

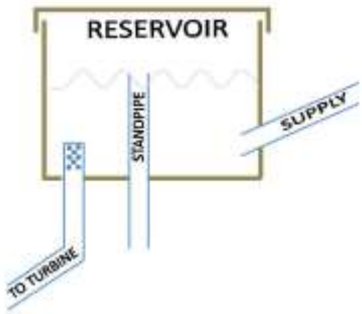
"The section of the pipe on our property that we planned to use had a reservoir along its way, which we bypassed to increase the pressure. The total measured pipe length came out to 210 meters with a head of 70 meters and a measured flow of 2.5 liters per second.



The photos below show the reservoir.

2.2. Intake

The turbine does not exactly use the full flow that is available, so it was necessary to install an overflow pipe alongside the penstock. This leads from a standpipe within the reservoir and discharges into the reservoir below the turbine.



2.3. Turbine installation

A new concrete well shaft was built, which stores water and ensures supply to the subsidizing users. The turbine itself is mounted on a timber board on top of the well shaft. As you can see in the pictures, the turbine can be shut off with one valve, and the bypass can be opened to keep the water flowing to the reservoir below. The two unions at the jets can be removed to allow for turbine maintenance. The pipes are wrapped with insulating tape to prevent condensation.

After running for 9 months, the turbine wheel and housing show some signs of limestone deposits. It may have to be cleaned at some point.

3. Electrical system

3.1. Inverter

Andreas writes:
"When I started gathering information about micro hydro. I quickly learned that most of the hydro turbines produce AC, which is rectified to DC. The DC current is then connected to an inverter, which feeds constant AC voltage to the grid. We used an Enasolar inverter (shown on the right).

"In the event of a blackout, the grid tie inverter is designed to shut down to prevent the energy it transfers from harming any line workers who are sent to fix the power grid. Without a battery backup, it is impossible to use the electricity from our own turbine to power our home in case of a power outage.

"Most micro hydro installations use an over voltage protection system to prevent the turbine from overspeed and the inverter from overvoltage in case of a power outage. We decided to purchase a Powerspout PLT pelton turbine because in case of turbine runaway (no load) the voltage will not exceed the Enasolar inverter's maximum input Voltage. This means the electrical side is extremely simple: Turbine – Breaker – Inverter – Grid!

3.2. Cable sizing

"Since the turbine was installed at the lowest elevation of our property, we had a contractor to install 225 meters of $4mm^2$ wire to the inverter in our home. The main power supply to our home runs very close by the turbine shed and we were able to tap into the existing casing and run the wire to the house. We installed a 10amp DC circuit breaker in the turbine shed and a waterproof connector. The inverter is installed in the basement of the house and feeds into the electricity meter."

(The calculator shows 94% efficiency for this size cable. A thicker cable would be slightly more efficient, but the cost is not justified.)

"After checking all the wiring for shorts and unwanted ground connections, we opened the water valve and measured runaway voltage (Voc) at the turbine, which was 500VDC (inverter can handle max 600VDC). We were then ready for the first test run connected to the grid. After opening the valve, the turbine spooled up and within a few seconds the inverter connects to the grid and finds the most efficient rpm. The power company inspector simulated a power off situation and the inverter immediately disconnects the power to the grid and the turbine rpm increases, and after turning the power on the inverter connects again."

4. Noise Abatement Enclosure






5. Turbine operation notes

5.1. Pressure measurements

The pressure gauge is mounted on the pipe manifold that feeds the turbine jets. When the valve is closed there is no pressure. In order to measure the static head it the jets were replaced with blanks that blocked the flow and then the valve was opened.

Static pressure was 116 PSI or 800mB. This corresponds to nearly 82 metres of head which was unexpectedly higher than the original estimate of 70m, measured using an iphone. Google earth was more accurate than the iphone in this case.

Operating pressure with both jets open ("net head") was 98PSI (70m). The drop in pressure is due to "head loss" in the penstock. The calculator predicted that this penstock would be 90% efficient, but for some reason the net head is only 70m. (70/82 = 85%) Possibly this was due to buildup of lime scale in the penstock. Partly it was due to the rather large jet sizes.

But in any case the net head was higher than the original assumption (90% of 70m would have been 63m).

5.2. Open Circuit Voltage "Voc"

Before connecting the inverter it is important to measure the open circuit voltage and verify that it is not high enough to threaten damage or interfere with the proper operation of the inverter. The limit for this inverter is 600V whereas the **Voc measured was 480V**.

It is very important to check the Voc and also very important to **take care** when doing so. These are extremely dangerous voltages!

5.3. Jet sizes and power outputs

The flow through the turbine is controlled by the number and size of jets installed. The jets supplied with the turbine were 7.7mm in diameter and produced substantially more power than had been predicted by the calculator. The PLT calculator is very conservative, so it is normal to see some bonus extra power, and this was boosted further by the unexpectedly high head and the rather large jet diameters.

Unfortunately the flow in the water system was not always enough to sustain this power level and so the Steiner family had to experiment with a variety of jet sizes. Here are some data from their turbine:

Date	Jet no. and internal diam.	Max power Voltage DC	Inverter input kW	Inverter output kW
June 2015	2 x 7.7mm	228 V	1.16 kW	1.06 kW
Later 2015	1 x 6mm	120 V	0.3 kW	0.22 kW
March 2016	2 x 7.4mm	177 V	0.91 kW	0.85 kW
April 2016	2 x 7mm	170 V	0.88 kW	0.82 kW

5.4. DC voltages

The DC voltages are slightly anomalous. Voltage is related to turbine speed and power. Higher speed will result in higher DC voltage. Higher power will however depress the voltage somewhat. The job of the inverter is to find the best operating voltage (using **maximum power point tracking**) and thus maximise the output power. By adjusting the voltage, the inverter actually controls the RPM speed of the turbine runner.

Optimum turbine RPM depends on the square root of the net head of pressure. This PLT turbine was tested in the factory to give 810W at 200V at 1320 rpm (Stator 100-14S-1P-S) based on the original data in the calculator. Given that the head is a little higher and the power also a little higher we could expect the optimum voltage to remain somewhere close to 200V. In the table above the voltages are mostly around 200V but it is surprising to see higher voltages at higher power and lower voltages at lower power.

Provided that the penstock is kept full (water supply is adequate and overflowing) then we would expect higher flow and higher power to mean lower net head and more droop in voltage too. So we would expect to see lower optimum operating voltage. Whereas at low power the losses in pressure and voltage are less and we might expect to see best results with a higher operating voltage. The data above shows the opposite trend. This may be due to air entering the penstock at times of low flow.

5.5. Energy production

The bottom line for any electricity generator is how much electrical energy it can produce and the inverter tells us the reality in the screen shot on the right. 6800 hours is over 9 months of turbine operation with variable flows and different choices of jet size.

Average power = 3624 / 6800 = 0.533kW or 533W of power. This is less than the 810W we might have hoped for but the lesson is that site data often turns out to be different from what we assume. Head was higher, but flow was lower at times. In the end the turbine produced roughly the same as a typical Swiss home would use in that period. This usage might represent $1,000 (US dollars) per year, whereas the cost of the equipment was only about $3,000. And you cannot put a price on the satisfaction of producing your own power from natural energy.

5.6. Future enhancements

With variable flow it is important to be able to control the size and number of jets easily and quickly so as to be able to respond to changes with the minimum of effort. If the inverter shows power dropping below the normal then it is time to close down a jet or use smaller sizes. If the weather is wet then it's worth opening up and generating more power. This turbine could benefit from having valves installed on the jets themselves so that they can be controlled individually. For example one 6mm jet and one 9mm jet would allow for three different flow rates and power outputs: 250W, 600W and 900W roughly.

Andreas also dreams of extending the penstock higher up the hill and using more head....