Nepal Case Study - Part One

Installation and performance of the Pico Power Pack

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Introduction

This article describes the process from site selection to installation and commissioning of a pico hydro scheme at Kushadevi, a small community close to Kathmandu. The pico hydro scheme is a demonstration project for the Pico Power Pack (PPP), the design and manufacture of which were described in issue 5 of the Pico Hydro newsletter.

Potential and demand

An initial estimate of the hydro resource was made in order to determine whether there was sufficient potential. This was done so as to avoid raising the expectations of the community unnecessarily. The site was visited at the end of the dry season enabling the minimum flow to be estimated. This was found to be approximately 10 l/s. The available head was in excess of 100 metres, and therefore ideal for a Pelton turbine. Assuming an overall efficiency of 50%, there was sufficient year round potential to generate in excess of 5 kW.

There are 88 households within approximately 1 kilometre of the likely location of the power house. The principal demand was for lighting and radios. There was also interest in having a grain mill as this would process maize much more rapidly than the traditional water mills, and would be more accessible for most households.

On many micro hydro schemes in Nepal, approximately 100W per household is allocated, allowing use of two or three light-bulbs. However, energy efficient lighting, such as Compact Fluorescent Lamps (CFLs), can be used to provide a similar level of lighting with just 24W per household.

The table below compares different lighting options for connecting 90 households. A figure of $2,000 per kilowatt is used for the scheme cost, excluding lamps and other end-uses, and 10% distribution loss is assumed. Even using high quality CFLs, at $10 each, there is a major financial saving on a lighting only scheme from using energy efficient lighting.

While the cheapest lighting option is the 24W system, the decision was made to go for a third option, of 40W using a 15W CFL and a 25W bulb. There were four reasons for this:

1 A 4kW scheme can drive a more powerful grinder than a 2.4kW scheme and would therefore enable more grain to be processed and at a faster rate.

2 A number of households wanted to be able to use small Black and White TVs which require 40W.

3 The 40W option provides 67% more power for only 35% more cost and could later be used to supply three of four CFLs rather than the two in the 24W option, thereby improving the benefits to the households.

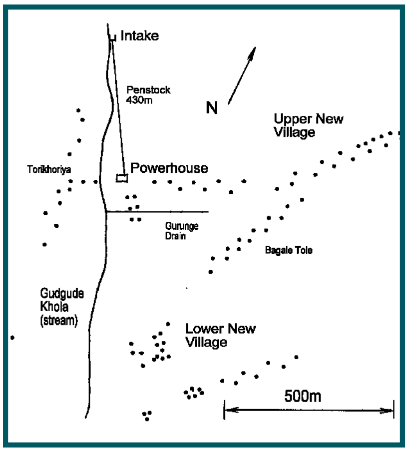
Power per house	Lighting supplied	Scheme capacity	Scheme cost	Total Lamp cost	Total cost
100 Watts	60W + 40W bulb	10kW	$20,000	$90	$20,090
24 Watts	15W + 9W CFL	2.4kW	$4,800	$1,800	$6,600
40 Watts	15W CFL + 25W bulb	4.0kW	$8,000	$900	$8,900

Table 1: Options for connecting 90 households

4 CFLs have often been found to be unreliable when used on micro hydro schemes. How much of this is due to quality of the CFL and how much is due to poor voltage regulation is unknown. Hence, the decision to avoid a CFL only system.

European types of CFL are found to be very reliable but expensive ($10), whilst Chinese makes are often unreliable but cost as little as $1. A compromise was made by selecting 'export quality' Chinese CFLs, costing $5.

A decision was taken to design with a 10% safety margin, i.e. 4.4kW rather than 4kW, to allow for any errors in the head measurement or lower than expected efficiencies.



Village Plan

Survey

Having established that a 4.4kW scheme design was required, a detailed site survey was carried out. The flow was measured at the end of what happened to be a particularly long dry season. The bucket method and salt-dilution method were used and the flow was found to be 9 l/s. Since this was a worst case flow, that should only occur in exceptional years, it was decided that a design flow of up to 13.5 l/s could be used, provided that a smaller turbine nozzle suitable for 9 l/s was supplied that could be fitted at very dry times.

A plan of the village was drawn, showing all the houses and the stream, in order to help determine the best location for the powerhouse. The highest position for the intake was found to be an accessible point just below where a number of small water sources combined. Since the stream flowed through a steep sided valley there were only a few accessible places where a powerhouse could be located above the flood level of the stream. One location had the advantage of being very well positioned for electricity distribution (see plan) and provided a gross head of 80 metres with respect to the highest position for the intake, as measured using an Abney level. The next suitable site was much further down stream and would have resulted in a considerably more expensive penstock and a longer and more costly distribution system.

Assuming a turbine efficiency, η_t, of 65% and a generator efficiency, η_g of 75%, the minimum net head, H_{net}, to generate a power, P, of 4,400W with a flow, Q, of 13.5 l/s can be determined from the following formula:

$$H_{net} = \frac{P}{\eta_g \times \eta_t \times Q \times g} = \frac{4{,}400}{0.75 \times 0.65 \times 13.5 \times 9.8} = \underline{\underline{68m}}$$

Hence, the maximum head loss is 12 metres in 80 metres, which is 15%. This is quite a realistic value and therefore indicates that the choice of intake and power house is acceptable to produce between 4 and 4.4 kW.

Intake/Forebay

The intake and forebay were combined in this project, as the soil and topography made the construction of a long canal unrealistic, especially as there was no surplus flow to allow for seepage losses.

The intake is located at the side of the stream, along the line of water flow, and the water is directed along a short channel 0.4m wide and 3m long into a 1m square forebay with 1.3m depth. The intake is a concrete and stones structure, and has a trash rack installed to prevent floating debris entering the forebay. An overflow is built into the side of the forebay so that surplus water returns to the stream without undermining the structure and a flushing pipe is installed in the bottom so that silt can be easily removed. The inlet to the penstock is placed 0.5m from the base of the forebay and has a filter fitted to prevent large objects from entering.


Intake/Forebay under construction

Section Length (m)	Pressure rating (kgf/cm^2)	Outside Diameter (mm)	Inside Diameter (mm)	Price ($/m)	Head loss (m)
130	2.5	140	132	3.78	0.99
100	4	125	113	4.55	1.62
100	6	125	107	6.54	2.11
100	10	125	94	9.86	4.01

Table 2: Head loss per pipe section

Penstock

Since a canal was not a viable option, a long penstock was required. High Density PolyEthylene (HDPE) pipe was chosen as the penstock material as it is cheaper than PVC pipe in Nepal, is flexible, smooth walled, strong and does not degrade in sunlight. The total length required was estimated to be 400m, though at installation it was found that an additional 30m was required. The pipes were buried in a shallow trench to keep them in place and to protect them.

The 72 lengths of 6m pipe were joined using a hot plate to fuse the ends together. This is a skilled and time-consuming task and is a disadvantage of using HDPE. The installation and fusing process was supervised by the turbine manufacturer and took about two weeks.

In order to calculate the head loss in the pipe due to friction, it was necessary to select a suitable value for pipe roughness. A value of 0.03mm is quoted in reference books for smooth walled plastic pipe. However, this does not allow for the bead of material which forms at each joint due to the fusion process. For this reason a value of 0.06mm was used. A spreadsheet was used (see optimisation article) in order to calculate the head loss for different pipe options. In order to reduce costs, the pressure rating of pipe was varied along the length, as shown in the table, so that the higher pressure ratings were only used when required, as these are more expensive.

The total head loss was 8.73m and hence less than the maximum allowable loss of 12m. The option of using the next smallest pipe size for the final hundred metre length was considered, as this is the most costly section. However, this would have increased the total head loss to over 12m and was therefore not implemented.


Fusion joining of pipe

Powerhouse

The Powerhouse was constructed using locally available mud, stone and wood. The stone and mud was used to make the walls which were approximately 0.5 metres thick and the wood was used for the door and two windows and to support the roof. The roof was made from corrugated galvanised iron sheet, pitched at approximately 30 degrees to ensure that water does not collect on it. The internal dimensions were 4.8 x 2.7 metres to provide sufficient room for milling as well as for the turbine, generator and control equipment.

Turbine and generator

The induction motor is driven at approximately 5% above its synchronous speed in order to function as a generator. The speeds required to generate 50 Hz from 2 pole, 4 pole and 6 pole induction machines are shown in Table 3. Since the generator shaft is directly coupled to the Pelton turbine the pitch circle diameter (D_{runner}) of the Pelton runner can be calculated using the formula:

$$D_{runner} = \frac{38 \times \sqrt{H_{net}}}{rpm} = \frac{38 \times \sqrt{71.3}}{rpm}$$

For the available turbines, the maximum jet size was 11% of D_{runner}. Hence it was possible to calculate the maximum flow rate, Q_{max}, in litres per second for a single jet using the formula:

$$Q_{max} = 1000 \times \frac{(0.11 \times D_{runner})^2 \times \pi}{4} \times \sqrt{2 \times g \times H_{net}}$$

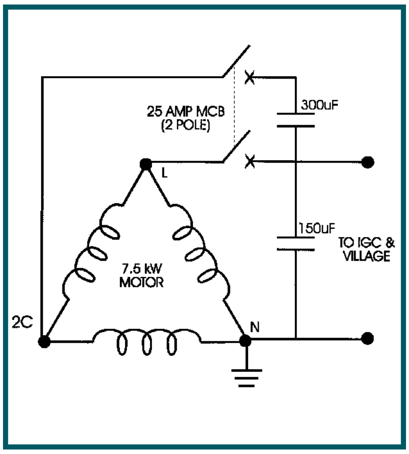
Clearly, from Table 3, the 2 pole motor was not an option as the maximum flow rate for the turbine is too small. A 6 pole motor could be used but the cost of both the turbine and generator are higher than for the 4 pole motor option. Hence the 4 pole option was selected.

The choices of motor capacity were 5.5 kW or 7.5 kW. A derating of 20% must be applied, as motors run hotter when used as generators. While the 5.5 kW motor would have been just sufficient for the design power, there was a possibility that the design power could be exceeded slightly and therefore the 7.5 kW motor was chosen.

Attachment of turbine to generator shaft

Both motors were only available wound for 380 Volts per phase. To achieve 220 Volt operation the motor was opened up and the nominal voltage halved by reconnecting series sets of coils in parallel. All competent motor repairers know how to carry out this task. The motor can then be used at 220 Volts rather than 190 Volts though at the expense of some extra saturation/loss of efficiency. The C-2C capacitor connection was used to excite the generator for single phase operation. The value of C was determined by using the approximation of 20 uF/kW, with a view to on-site adjustment at commissioning if necessary.

A 25 Amp double-pole MCB was installed as shown below, in order to protect the capacitors, generator and wiring from overheating under fault conditions.



Wiring diagram

With a 21 mm nozzle fitted to the turbine, the flow rate was approximately 12.5 l/s and the power output of the generator was 4.25 kW at a Voltage of 230 Volts and a frequency of 52.5 Hertz. At 13.5 l/s the power output will be approximately 4.6 kW, indicating that the gross head or efficiencies were slightly under-estimated. No on-site adjustment of capacitance was necessary as the frequency was acceptable.

Controller

A locally manufactured 5 kW Induction Generator Controller (IGC) was used to directly regulate the voltage of the generator and to indirectly control the frequency and shaft speed. Two Pico IGC boards were used in parallel as each board only has a capacity of 3 kW. One board was connected with a 3 kW ballast consisting of three air heaters, and a further two air heaters were connected to the second board.

Number of Poles	Shaft speed (rpm)	D_{runner} (m)	Max flow rate (l/s)
2	3150	0.10	3.6
4	1575	0.20	14.2
6	1050	0.30	32.0

Table 3: Generator and turbine runner options

Mill

The mill consists of a 12” grinder coupled to the PPP by two B class V-belts and can process 150 kg of grain per hour. The pulley size on the PPP is 3” and on the grinder 12”, to give an operating speed of the grinder of just under 400 rpm. The base of the mill was initially concreted to the floor of the power house, which was a mistake as the belt tension could not be adjusted. Slide rails are to be installed to allow the belt to be tightened correctly.

The generator and controller will operate during milling and control the speed of the mill. This enables milling to be continued into the evenings as lighting will be available in the powerhouse.

With the mill operating at maximum load the power output of the generator was 1.4 kW, indicating that approximately 3 kW of power was being taken by the mill.

Installation of Mill

Acknowledgement

The authors wish to express their thanks to Shyam Raj Pradham and the staff of Nepal Yantra Shala Energy for their assistance with the installation and advice on local manufacture of the PPP.

Part Two

The next issue of Pico Hydro newsletter will describe the design of the distribution system along with the load limiters, tariff system and scheme costs.

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Authors contact details, see last issue.

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