Nepal Case Study - Part One

Installation and performance of the Pico Power Pack

by Nigel Smith and Ghanashyam Ranjitkar

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.

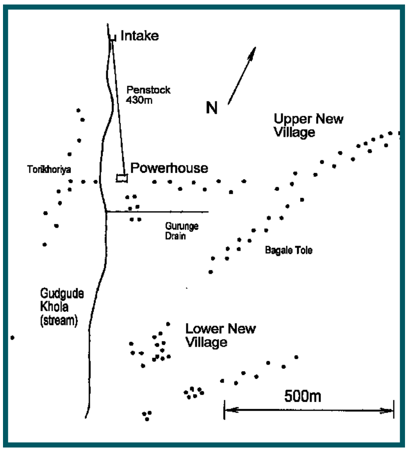
4 CFLs have often been found to be unreliable when used on micro hydro schemes. How much of this is due to quality of the CFL and how much is due to poor voltage regulation is unknown. Hence, the decision to avoid a CFL only system.

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

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:

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

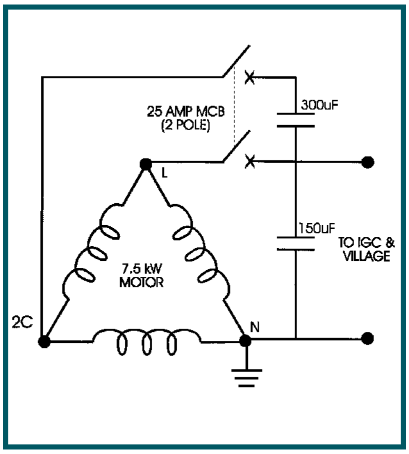
Clearly, from Table 3, the 2 pole motor was not an option as the maximum flow rate for the turbine is too small. A 6 pole motor could be used but the cost of both the turbine and generator are higher than for the 4 pole motor option. Hence the 4 pole option was selected.

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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Nepal Case Study - Part Two

Power distribution, safety and costs

by Nigel Smith and Ghanashyam Ranjitkar

Introduction

This article follows on from the 'Installation and performance of the Pico Power Pack', as described in Issue 6 of the newsletter. It describes the following:

- The design and installation of the electricity distribution system
- The selection and use of load limiters to ensure equal allocation of power between households and to prevent overloading of the generator
- Electrical safety
- Scheme cost

Distribution system

The cable types considered for the distribution system are shown in the table below. Aerial Bundle Conductor (ABC) would have been the preferred choice as it is a strong aluminium cable with a weatherproof insulation which makes it easy to install. However, it was discounted as it would have had to be specially imported for the scheme. Aluminium Conductor Steel Reinforced (ACSR) is the cable normally used for distribution in Nepal. It is strong and relatively cheap, but has a high installation cost because it requires insulators and longer poles, as the conductors must be spaced apart. Also it is not available in small sizes. Insulated stranded copper equipment wire is often used on pico hydro schemes in Nepal as it is easy to install, avoids the expense of insulators and allows cheaper poles to be used. However, it is more expensive than ACSR for an equivalent volt drop and the service life is unknown, as it is not designed for outdoor use on overhead lines.

The distribution system was designed for a maximum voltage drop of 12%, so that by setting the generator voltage at 6% above normal supply voltage the voltage throughout the system will be within +/- 6%. The distribution was optimised using the software described in Issue 5 of the newsletter. Three options were considered: ACSR conductor only, Insulated Copper conductor only, and a combination of ACSR and Insulated Copper. The results are shown below.

It was clear that the combination of ACSR and copper conductors was cheapest, the ACSR being used for the main current carrying section of the distribution and the copper for the rest. To be certain of long term reliability, the ACSR option would have been preferable. However, since the scheme was to be carefully monitored it was felt that this was a good opportunity to investigate the life expectancy of insulated copper conductors, given their financial advantage.

7/20 (7 strands of 20SWG) and 7/22 (7 strands of 22 SWG) copper cable were used as the large number of strands makes the cable more flexible and therefore less likely to break. The only reported breakages on other pico hydros have been with 3/20 cable (3 strands of 20 SWG) which has a smaller overall diameter and less flexibility. The distance between poles was decreased as the cable was tensioned less to avoid stretching of the conductors. The disadvantage of the increased number of poles was reduced as shorter and thinner poles were used because the cable was insulated. Darker colours of insulation were selected as these are considered to be degraded less by sunlight.

Spark gap type lightning arrestors were specified for the distribution, for installation at the powerhouse and close to the main clusters of houses.

Load limiters

Many micro and pico hydro systems suffer from severe overloading because the load connected by the consumers exceeds the output of the generator. Fitting electricity meters in each consumer's house is not the answer as meters do not limit the amount of power that the consumer can draw. The best option is to use current limiting devices, often known as load limiters.

Load limiters limit the amount of current that the consumer can draw. If they draw a current higher than the rating of the load limiter it automatically disconnects the

Cable Type	Availability	Service Life	Cable cost*	Installation cost
ABC	None in Nepal	High	Medium	Low
ACSR	Good except small sizes	High	Low	High
Insulated Copper	Good	Unknown	High	Low

*For same V/km

Cable comparison

Option	Length of ACSR	Length of Copper	Total Price
ACSR only	4,100m	-	$1,924
Copper only	-	4,100m	$2,261
Mixed conductors	650m	3,450m	$1,595

Comparison of distribution options

Transporting a distribution pole

supply. Some load limiters have to be manually reset and others automatically reset, as shown in the table. The consumer pays a fixed monthly fee according to the rating of his load limiter, irrespective of the kilo-watt hour consumption.

By selecting the current ratings of the load limiters so that even with all households drawing maximum current the generator is not overloaded, the supply voltage will not fall and consumers' appliances will work reliably and with good efficiency.

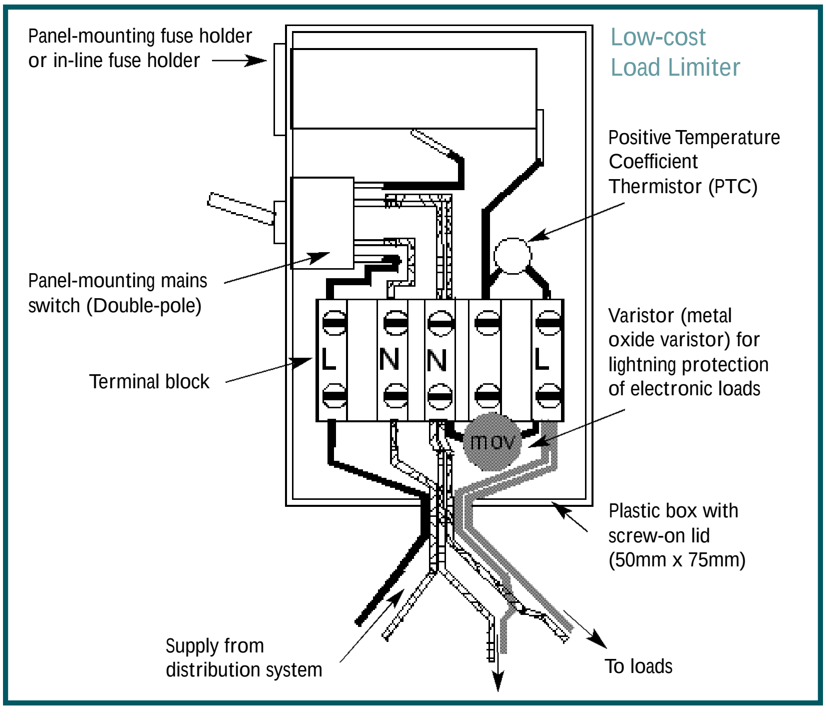
	Thermal Miniature Circuit Breaker	Magnetic Miniature Circuit Breaker	Thermistor (PTC)	Electronic Circuit Breaker
Reset mechanism	Manual	Manual	Auto	Auto
Accuracy	Poor	Medium	Very Poor	Medium-Good
Short-circuit proof	Type dependant	Type dependant	No	Type dependant
Min. Current (A)	0.5 Amps	0.5 Amps	0.01 Amps	0.1 Amps
Max. Current (A)	>50 Amps	>50 Amps	0.7 Amps	5 Amps
Availability	Good for > 6 Amps	Limited	Limited	Limited
Price	Low-Medium	Medium	Low	Medium-High

Comparison of Load Limiter Options

The scheme was designed with a worst case power output from the generator of 4 kW. Using the worst case voltage drop on the distribution of 12% the minimum total power available to the consumers was 3.5 kW. It was agreed with the community that this would be divided equally between the 88 households to be connected and hence a load limiter was required for each house with a 40W limit.

The minimum load limiter current rating was calculated for the 230 volt supply as 175mA. This cannot be achieved with miniature circuit breakers as load limiters as these are not available for current ratings below 500mA. A locally manufactured electronic circuit breaker was available for this current rating; however, the price was quite high at US$15 each. The alternative was a positive temperature coefficient thermistor, which for this current rating costs just US$1 and, as the devices are small, they are cheap to import.

A major disadvantage of the PTC is its poor accuracy due to its poor tolerance and the fact that the tripping current varies significantly with ambient temperature. To reduce this problem a make of PTC with good temperature stability and reasonable tolerance was selected. The tolerance stated by the manufacturer was 170mA to 255mA at 25°C. This was improved upon by purchasing twice the quantity of PTCs required and, by testing, selecting only those with a trip threshold between 190mA and 210mA. The minimum value was selected as 190mA rather than 175mA to take into account the reduction in tripping current at maximum summer temperatures in Kushadevi. In the winter the tripping current will be higher and could result in a small overloading of the generator. The generator has sufficient capacity to allow for this, though there would be a small drop in voltage. The saving in cost was considered to be worth this small disadvantage. A small number of houses were fitted with electronic circuit breakers for comparison purposes. Both of these types of load limiter automatically reset after tripping due to an overcurrent, provided that all the load is switch out.


Low-cost Load Limiter

The diagram shows the connection arrangement. A one amp fast fuse is fitted in series with the thermistor to protect it in the event of a short-circuit. The diagram also shows a varistor which is fitted to protect electrical appliances from the effect of voltage surges due to lightning storms. The decision to fit varistors was taken after a number of lamps were damaged due to lightning (see next issue for details). A seal was used to deter the consumers from bypassing the thermistors.

Electrical Safety

A Residual Current Device (RCD), sometimes known as an Earth Leakage Circuit Breaker (ELCB), was fitted directly after the generator for electrical safety. The neutral was earthed at the generator using a thick copper plate (0.6 x 0.6 metres) buried to a depth of 2 metres. This RCD has a trip sensitivity of 30mA and helps to provide protection against dangerous electric shock. If a person comes into contact with a live wire and is making reasonable contact with the ground the RCD senses that some current is returning to the generator via the earth rather than the neutral conductor and trips, preventing a potentially lethal shock. The RCD is not effective in all situations and therefore shock avoidance through good wiring standards is essential. People can still receive lethal shocks if they are well insulated from the earth and touch both live and neutral conductors.

Fixing the cable

Ideally each house or group of houses should be fitted with an RCD so that a fault only isolates a few consumers rather than the complete supply. However, RCDs are expensive and therefore just a single unit was fitted. The inconvenience of having just a single RCD will be assessed during the monitoring phase.

The scheme installer provided on the job training in house wiring to one of the operators and checked that this was carried out to a high standard. Some households used electricians from the nearest town instead, as the villagers were very keen to have their house wired.

Scheme Cost

The cost per kilowatt output of the generator was US$2,300, which is very similar to other pico hydro schemes in Nepal. There were a number of factors that pushed up the cost: the penstock and distribution lengths were very long due to the site conditions. The price for the Pico Power Pack was high as the manufacturer had to charge more to cover the cost of learning a new design. IGCs, load limiters and compact fluorescent lamps (CFLs) are not always fitted on pico hydro schemes. These factors were offset by the high efficiency of the turbine-generator unit, which helped to hold down the cost per kilowatt.

In many ways the most important cost comparison is the cost per household. At Kushadevi it is currently US$134 per household and this will fall further to US$104 if all 88 households are eventually connected. This should be compared with US$204 per household for a typical pico hydro in Nepal(1). Furthermore, the quantity of light per household at Kushadevi is generally higher than at existing schemes, in spite of the reduced power per household, as the load limiters prevent the voltage from falling too low and the CFLs are much more efficient than ordinary lamps.

Tensioning the cable

Part Three

The lessons learnt from the implementation process and first year of operation of the scheme will be described in the next issue of the newsletter. These include mobilisation issues in communities with political and ethnic divisions, installation quality considerations and lightning protection. ✸

Expenditure Heading	Cost (Rs)	Cost (US$)
Civil works (inc penstock)	271,500	4,052
Pico Power Pack	147,000	2,194
Controller (IGC)	44,000	657
Distribution*	132,800	1,982
Load limiters	30,000	448
Lamps (CFL)	28,800	430
TOTAL	654,100	9,763

* Note that this price is slightly different from the design cost due to small price variations and the inclusion of labour costs

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(1) Socio-economic Assessment of Pico Hydro Scheme at Kushadevi carried out by Subarna Kapali

NEPAL CASE STUDY – Part 3

Lessons from project implementation and 20 months of operation

By Bhola Shrestha and Nigel Smith

INTRODUCTION

This article is the third and final part of the case study on the pico hydro scheme at Kushadevi in Nepal. It follows on from the previous articles 'Installation and performance of the Pico Power Pack' and 'Power distribution, safety and costs', which were published in issues 6 and 7 of the pico hydro newsletter. It covers the lessons learnt from the implementation process and first 20 months of operation, and conclusions regarding the long-term sustainability of the project.

COMMUNITY MOBILISATION

The implementation of the demonstration project was managed by the Intermediate Technology Development Group (ITDG), through their Kathmandu office. To facilitate community mobilisation they involved the Participatory District Development Programme (PDDP) and Rural Energy Development Programme (REDP) of UNDP, as they have offices in this district and are active in the local area. The Village Development Committee Chairman and District Development Committee Chairman also played important roles in the social mobilisation process.

The village consists of all the houses in Ward number 6, scattered over a large area. Using a limit of 1km for the maximum economic distribution length, it was possible to supply electricity to 88 of the 108 households in Ward 6. All households in Ward 6 are represented in four savings and credit groups set up by PDDP. And the PDDP community mobiliser invited all members of these four groups to attend a meeting to form the Users' Committee (UC) for the pico hydro. Each group were asked to nominate three or four members of the UC, and these members then agreed on a chairperson and manager.

There are ethnic and political divisions in Ward 6. The ethnic distribution is Brahmin 62%, Tamang 35% and Chhetri 3%. Tamangs inhabited the area originally with land gradually being sold off to the Brahmins and Chettries over the course of time. The Tamangs mostly live at the outskirts of the village and farm more marginal land, and some are resentful regarding the land that they have lost. Most of the Tamangs and a few of the Brahmins are followers of the Congress Party and the rest of the ward follow the Communist Party. The political and ethnic differences have resulted in significant divisions.

The Brahmin and Chhetri households showed more enthusiasm for the scheme than the Tamangs, who were under-represented at the community meetings. The mobilisers helped to ensure that one Tamang and three women were elected to the thirteen person committee and it was agreed that the 88 households closest to the generator would all have the opportunity to be connected to the electricity supply.

Only 68 households have received connections. Most of the Tamangs and the Brahmin followers of the Congress Party are not connected. The main reasons for this are:

- Some Tamang households are too poor to afford electricity, even with the subsidy offered.
- Many Tamang households do not have legal land papers, as they do not officially own their land. These are required as collateral for the government loan and the cash alternative offered by the UC was not easily affordable.

- The scheme was implemented just before parliamentary elections and the Congress Party candidate tried to win votes by telling the villagers that he would supply them with electricity from the grid. He even brought distribution poles to the edge of the Ward to convince them that this would be done.[1]

Lessons learnt

1. *In divided communities the community mobilisers should ensure that all factions are fairly represented on the electricity committee and that the terms for obtaining an electricity connection are reasonable.*
2. *Where more than one organisation is involved in community mobilisation, careful co-ordination is required and one person should preferably oversee the process.*
3. *The use of land papers as collateral for loans discriminates against poor and landless households and must be avoided. The turbine-generator equipment purchased would be a better choice.*
4. *A lower cost connection option for a 20W rather than 40W supply should have been offered to make electricity more affordable for the poorest households.*
5. *Clear grid extension plans and timetables must be agreed by the appropriate government departments and made available. These will enable off-grid schemes to be installed in places where there are no short-medium term prospects of a grid supply whilst avoiding interference due to local politicians' electioneering.*

COMMUNITY CONTRIBUTION

The community contributed labour to build the turbine-generator house and for the erection of the distribution system. In addition they contributed 21% of the cost of the scheme by means of a loan provided by the Agricultural Development Bank. This financial contribution (US$30 per household) is less than that for most pico hydro schemes in Nepal, as Nottingham Trent University (NTU) paid for the turbine-generator and controller and half the cost of the distribution cable. This payment was in addition to the subsidy from the Agricultural Development Bank, and was made in view of the demonstration nature of the scheme, particularly the turbine-generator.

NTU also offered a 50% subsidy on end-use equipment and the committee chose to use this for a grinding mill and an energy efficient light-bulb in each house.

Lessons learnt

1. *The labour contribution was important for establishing a sense of ownership. This was underpinned by the cash contribution, which was suitably reduced in view of the demonstration nature of the project.*
2. *The part-subsidy for end-use equipment was effective and encouraged the community to consider energy utilisation from the outset.*

ELECTRICITY PRODUCTION

The generator ran without problem from December 1999 to June 2000. The voltage regulation was very good as the load limiters prevented overloading. During the monsoon a lightning strike damaged the main power transistor of the Induction Generator Controller (IGC) and all the Compact

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[1] There is still no grid supply to Ward 6.

Fluorescent Lamps (CFLs) switched on at the time were also damaged. The IGC circuit board was taken to Kathmandu where the power transistor was replaced. However, during more lightning the controller was damaged again. Lightning arrestors had been supplied but not fitted, and it was found that these were designed for three-phase (400V) rather than single-phase (230V).

The plant was operated without the controller, by connecting extra loads to the generator to prevent the voltage rising too high when the user load was removed. After approximately 6 weeks the connector block on the generator burnt-out. Corrosion on the terminals had been noticed for some time, due to the damp environment and poor quality material, and this was probably made worse by overloading. The plant was closed down for 4 weeks whilst the generator was repaired.

In May 2001, new IGC circuit boards were fitted, which incorporated extra transient voltage protection, and lightning arrestors for single-phase lines were installed. The system has been functioning for 5 months now without problem, even through the monsoon.

At one time the Residual Current Device (RCD) was found to trip repeatedly and as a result the operator bypassed it, even though this made the system less safe, as he was unable to locate the fault. Careful inspection of the distribution line enabled the fault to be found, which was due to corn stalks growing so high that they touched the aluminium conductors. Connectors were installed in branches of the distribution line to enable isolation of groups of consumers, so as to ease identification of earth faults or short-circuits. Varistors have been installed in the load limiters (as shown in Part 2 of the case study) to provide extra lightning protection to sensitve loads, such as CFLs with electronic ballasts.

Minor leakages have occurred from the turbine casing, though the situation has been improved by using better gaskets (sections of old bicycle inner tube have proven very effective). One penstock joint has come away twice, though it has been rejoined by the villagers, one of whom is trained as a plumber.

The wooden poles are showing no signs of deterioration, despite being untreated wood from local trees. The UC are quite capable of replacing poles when necessary, as they erected the distribution. The use of PVC insulated cable in the distribution has been found to be acceptable. The only problem has been one instance of a short circuit due to peeling off of the insulation due to excessive tightening on the pole.

The Pelton turbine runner has proven to be very durable and the electrical power output in October 2001 was 4.25 kW, which agreed with the original measurement at the time of commissioning. A new turbine runner (on the left of the photograph) was manufactured by the original manufacturer in Kathmandu (Nepal Yantra Shala Energy), using an improved design from NTU, and this gave an electrical power output of 4.59kW, an increase in efficiency of 8%. The old runner (on the right of the photograph) will be used as a spare.

Lessons learnt

1. *Don't underestimate lightning and ensure that all reasonable steps are taken to protect the generator, controller and consumer loads.*
2. *Purchase a good quality induction motor as generator that is IP55 rated so that the terminal box can be fully sealed against moisture.*
3. *When using an Residual Current Device (RCD) to protect all consumers, ensure that switches or connectors are installed so that groups of consumers can be isolated to facilitate fault-finding.*

GRAIN MILLING

The grinder was belt-driven from the extended shaft of the induction generator and worked well at commissioning. The generator and IGC control the speed of the milling, as the controller will dissipate more power in the ballast when the mill is lightly loaded. However, two weeks after commissioning the grinder broke down because the operator reduced the gap between the two stones too much, damaging the stones and the shaft.

The UC did not take any initiatives to repair the grinder until May 2001, even though the cost involved was small. One reason for this was that the more influential UC members do not use the grinder as it is far from their homes. Major beneficiaries of the grinder are the Tamangs of Ward 6, who benefit in this way even if they do not have any electricity.

The mill operated about 3-4 hours a day from May to July 2001. The mill had ceased to operate during August-October 2001, as there was hardly anything to grind during this time. The mill is now in good condition, and the operators are familiar with using and maintaining it. From November onwards, when the processing requirement begins, the mill should be in operation 3-4 hours per day. The mill largely processes maize for animal feed (60% of all grain processed) and for the staple porridge meal called Dhindo. Generally, people prefer the taste of flour from traditional ghattas in the neighbouring areas.

Lessons learnt

1. *Extending the shaft of the generator to enable a mechanical end-use to be driven works well and enables the same unit to be used for both electricity generation and motive power.*
2. *Operator training is important. In this case the operator was trained when the pico hydro was installed but clearly this was insufficient. A longer period of training by an experienced water-powered grain mill operator would have been better and could have avoided the breakdown that occurred.*

MANAGEMENT

The role of the UC chairman is to provide leadership to the committee and the role of the manager is to maintain the record of the minutes of the meetings and the book keeping. The chairman and the manager are also the signatory of the bank account of the UC. The Users Committee meets once every month and the decisions are recorded in the minute book. The term of the UC is generally one year. However, the community has asked the present committee to continue for a second year, indicating their satisfaction with their performance.

The committee employs two operators, who have been trained to carry out basic maintenance and fault-finding as well as operating the equipment. The operators are the only people who are paid for their services.

The management of the plant and tariff collection are generally running smoothly. The UC members collect monthly fees in their areas and pass these to the manager who is responsible for book keeping. Households who fail to pay the tariff, even for a month, are normally cut off until payment is made. However, the committee has been largely successful in avoiding such situations. A fine of US$7.50 or withdrawal of supply is carried out if consumers bypass the load limiter. This has been a successful deterrent. Unfortunately there has been some abuse of privilege, with the chairman and one of the operators bypassing their load limiter, which sets a bad example.

The operator interviewed felt that the management is not responsive to the technical problems in the powerhouse. The need for preventive maintenance is not heeded and only when there is a major problem does the committee take notice. As a result, the operators find themselves under pressure to keep the plant running, even when there are serious problems that need attention.

Lessons learnt

1. *The use of load limiters, and penalties for bypassing them, have been largely successful in preventing consumers from drawing more power than they are allowed.*
2. *Paying operators helps to ensure that maintenance and repair is given attention. However, they are limited in what they can do by the committee. A system where the operators are contracted to maintain the plant as well as operate it, and are given the necessary funds to do so, would give clear responsibility for maintenance to one or two people and enable them to carry it out.*

FINANCIAL VIABILITY

At present all 68 households subscribe to a 40W connection at a tariff of $0.75 per month, resulting in a total monthly income from the sale of electricity of US$51. However, this corresponds to a total load of just 2.7kW. The UC are offering the households that have not been connected the opportunity to subscribe to a connection and have also purchased higher current PTCs to allow consumers to upgrade to 60W or 80W, with the tariff increased in proportion to the additional power rating. It is expected that in this way the full 4.6kW capacity of the plant will be utilised and the monthly income will increase to US$85.5 per month.

The annual expenses are as follows:

2 Operators' salary = US$ 270
Repair & maintenance = US$ 150 (estimate)
Office expenses = US$ 30 (estimate)
Total US$ 450

The net income with sales of 2.7kW is US$ 612 – US$450 = US$162.

The net income with sales of 4.6kW is US$1,026 – US$450 = US$576.

The loan to be repaid is $2,044 (with an interest rate of 16%), which cannot be repaid with the present income. However, when the full capacity of the plant is used the loan can be repaid within approximately 4 years.

The mill can be used, if required, to produce a substantial additional income. However, at present it is being used more as a community service. Payments are in the form of a small percentage of the grain milled, and have an approximate value of $15 per month. The community are also interested in establishing a small sawmill to be run from the generator, which would also act as a source of income.

Overall the financial viability of the scheme is good, and once the loan is paid off there will be a significant surplus for the dedicated repair and maintenance fund that the committee has proposed to establish.

COST-BENEFIT CONSIDERATIONS FOR THE CONSUMERS

With the use of electric light, kerosene has been replaced completely. At the present tariff the saving in kerosene for wick lamps is slightly more than the payment for electricity, and the electric light is much brighter. The pre-electrification expenditures on batteries for torches and radios, which were $0.40 and $0.80 per month per household on average, have also been substantially reduced due to availability of electricity. The use of torches is particularly reduced where households have purchased portable rechargeable lights.

People are happy that they no longer have to risk eye and respiratory problems from the black smoke that kerosene lamps produce. Children find reading at night with bright light much more comfortable. Women and men are able to work longer hours if they wish and daily chores are found to be easier in brighter light. There are more than a dozen black and white TVs in the village now, compared to just one before the project, which are enjoyed for entertainment during the evening. The mill is seen as a valuable facility by most households, as it will save time and the effort of carrying grain large distances. So far no negative impact of electricity has been reported.

SUSTAINABILITY

The long term sustainability will depend on three main factors:

- Reliability
- Financial performance
- Management

The additional lightning protection fitted is beneficial for the reliability of the scheme and the fact that there was no damage during the last monsoon is encouraging. In addition, the operators have developed a greater understanding of the system and skills to deal with minor faults and maintenance. The financial performance is set to improve as a result of selling more power and, once the loan is paid off, substantial amounts can be saved for major repairs. The necessary skills for all types of repair are available in Kathmandu, provided the funds are available to pay for them.

The UC have retained the confidence of the community in their ability to manage the plant. A few months ago seven members of the UC went on a study tour to a micro hydro site in another district to learn how other plants were managed. The cost of transport was shared by the UC and PDDP. This indicates that the UC is interested in improving it management and use of the pico hydro.

The mill is working again and there are plans to invest in a sawmill. In addition, Kathmandu University are planning to conduct a survey downstream of the present powerhouse and the community is enthusiastic about being able to use this study for the possible addition of new plant. These facts indicate confidence in the present system and an interest in developing the local hydro power for the future, and are encouraging signs for long term stability.

Occasional visits by PDDP or a similar organisation would help to ensure long-term sustainability, through checks particularly on financial management and load management. This would enable early identification of problems before they become serious. A local support centre could fulfil this role for this project and the many other micro and pico hydro scheme in the vicinity.

ACKNOWLEDGEMENTS

The authors are grateful to Daya Sagar Shrestha of PDDP, Bhim Neupane - Chairperson of Kushadevi VDC, and Mahendra Neupane of REDP for facilitating community mobilisation. Thanks are also due to Thakur Humagain - UC Chairperson and Pos Prasad, operator for their help, particularly during the field visits.

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The Pico Power Pack: a new design for pico hydro

by Phil Maher & Nigel Smith

A new type of pico hydro unit is soon to be tested in the village of Kushadevi, Nepal. The unit is called the Pico Power Pack (PPP) and as well as producing mains AC power it has a free shaft that can be coupled to mechanical loads. If successful, it will improve the financial viability of pico hydro projects by enabling greater use to be made of the power produced. A grinding mill is planned in Kushadevi, which will operate during the day-time. Electricity will also be produced, primarily for lighting, although it is hoped that home-industries will develop.

The heart of the new design is a Pelton runner directly coupled to an induction generator, an arrangement that has proven to be very successful in the form of the Peltric Set pioneered by Akkal Man Nakarmi (see newsletters 1 and 3). This is a simple, robust and low-cost turbine-generator arrangement. The Pelton runner and induction motor are sized according to the site characteristics and standard sizes can be used over a range of head and flow conditions. Capacitors are connected to the induction generator to provide the necessary excitation currents for AC generation and an electronic load controller is used to regulate the voltage and frequency of the electrical supply produced. Excess power is diverted to a suitably sized heater load.

Unlike the Peltric Set, the generator for the Pico Power Pack is positioned horizontally. One advantage with this arrangement is that the turbine and nozzle can be easily accessed for inspection and maintenance. The lightweight turbine case can be removed by unscrewing it from the side-plate, leaving the other components in place. The side-plate is fixed rigidly to the steel-angle base frame and also to the face of the generator. The seal between the turbine and the generator is achieved by means of a short length of plastic pipe fixed to the side plate and adjusted to give a very small clearance between it and the runner.

Another advantage of the horizontally driven shaft is that it is more suitable for driving mechanical loads. The drive shaft for the loads can be obtained by extending the shaft of the induction machine at the fan end. This avoids the need for additional bearings and bearing housings. Motors with extended shafts at either end are available from manufacturers, or as is the case for the demonstration project in Nepal, the shaft of a standard motor can be extended in a workshop. It is necessary to check that the fan-end bearing is the same as the other bearing. If not, it should be upgraded to cope with the mechanical loads by fitting a heavy duty ball bearing or a roller bearing.

The electronic load controller works well with mechanical loads. When the mechanical load is absorbing all the power from the turbine, the generator shaft speed is too slow to excite the generator. When the mechanical load is reduced the turbine speeds up causing the generator to excite and the controller to divert excess power to the heater load. Hence the generating system acts as an electrical brake and prevents excessive overspeeding. This is particularly beneficial with loads such as mills and saws, where the power requirement varies with throughput,

Scheme Data

Location: Kushadevi, Kabhrepalanchok,Nepal

Number of households: 108

Gross head: 80 metres

Flow: 9 litres per second

Penstock: 400m HDPE (140/125mm diameter)

Turbine: Single jet Pelton 200mm pcd

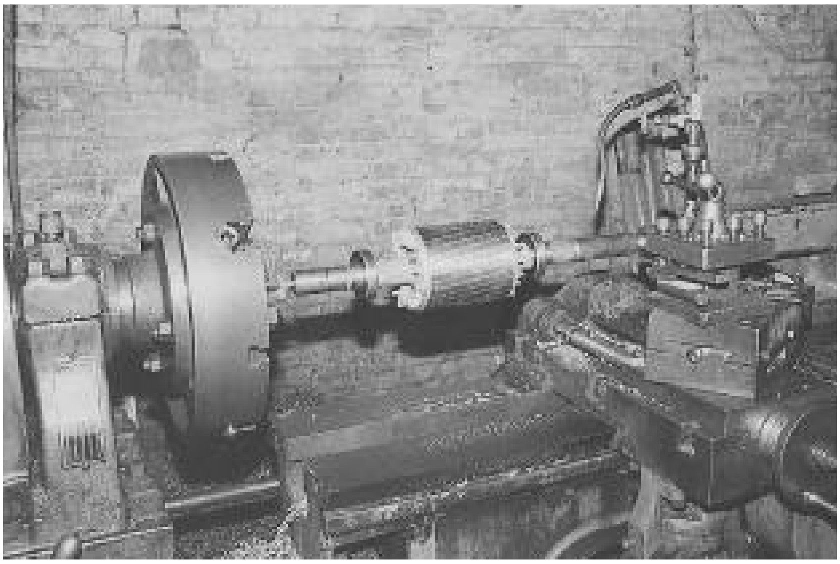
Generator : 7.5 kW 4 pole induction motor as generator

Design Power: 4kW

Induction generator with shaft extension and fitted with Pelton runner

The turbine buckets are polished with a drill attachment after casting, prior to assembly of the runner

Cutting the sheet steel for the casing with a guillotine



An extension has been welded to the motor shaft and is then turned on a lathe

because it improves their performance and operating life.

The new design shares the benefits of existing pico hydro designs. Being relatively light-weight, it is easily transported to remote areas, particularly when disassembled. The unit lends itself well to fabrication in a basic workshop and all the component materials have been chosen because of their good availability.

The flow required is typically 3 to 15 litres per second, often only a fraction of the amount of water flowing in an irrigation canal or a mountain stream. The head range is 25m to 100m. One disadvantage of a horizontal drive arrangement is that it is not so easy to produce and install multi-jet machines. With this in mind, research at Nottingham Trent University is in progress to develop Pelton runners, with acceptable efficiencies, which can accept a larger diameter jet (up to 20% of the turbine pitch circle diameter), so that a single jet machine can be produced which delivers the same flow as a multi-jet machine.

The first Pico Power Pack was built at The Nottingham Trent University with the help of German exchange student, Lutz Homeier. The design was tested and improved and has been manufactured for the demonstration site by Nepal Yantra Shala in Kathmandu with funding from the UK Department for International Development. Intermediate Technology (ITDG) in Nepal are managing the design, installation and monitoring of the demonstration scheme.

A report on the installation and performance of the PPP will be included in the next newsletter and a manufacturing guide produced to enable the design to be built in other countries.

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