PICO HYDRO FOR VILLAGE POWER

A Practical Manual for Schemes up to 5 kW in Hilly Areas

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Disclaimer

The authors accept no responsibility for injury or death resulting from incorrect manufacturing, installation or operation of equipment described in this manual. All electrical and mechanical installation and repair work should always be supervised and checked by a qualified and experienced technician or engineer.

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CONTENTS

1 INTRODUCTION

What is Pico Hydro?

Pico hydro is hydro power with a maximum electrical output of five kilowatts. Hydro power systems of this size benefit in terms of cost and simplicity from different approaches in the design, planning and installation than those which are applied to larger hydro power. Recent innovations in pico hydro technology have made it an economic source of power even in some of the worlds poorest and most inaccessible places. It is also a versatile power source. AC electricity can be produced enabling standard electrical appliances to be used and the electricity can be distributed to a whole village. Common examples of devices which can be powered by pico hydro are light bulbs, radio's, televisions, refrigerators and food processors. Mechanical power can be utilised with some designs. This is useful for direct drive of machinery such as workshop tools, grain mills and other agro-processing equipment. This manual explains how to select and install pico hydro systems for hilly and mountainous locations.

The Market

On a global scale, a very substantial market exists in developing countries for pico hydro systems (up to 5 kW). There are several reasons for the existence of this market.

- Often, small communities are without electricity even in countries with extensive grid electrification. Despite the high demand for electrification, grid connection of small communities remains unattractive to utilities due to the relatively low power consumption.
- Only small water flows are required for pico hydro so there are numerous suitable sites. A small stream or spring often provides enough water.
- Pico hydro equipment is small and compact. The component parts can be easily transported into remote and inaccessible regions.
- Local manufacture is possible. The design principles and fabrication processes can be easily learned. This keeps some equipment costs in proportion with local wages.
- The number of houses connected to each scheme is small, typically under 100 households. It is therefore easier to raise the required capital and to manage maintenance and revenue collection.
- Carefully designed pico hydro schemes have a lower cost per kilowatt than solar or wind power. Diesel generator systems, although initially cheaper, have a higher cost per kilowatt over their lifetime because of the associated fuel costs.

Hindrances to Market Development

The principle reasons why the market for pico hydro remains untapped are that pico turbine-generator units are not available in many countries. Where they are available, few people know how to design and install complete schemes.

Aims

This manual aims to help overcome these problems by providing clear instructions for design and installation of schemes on a local level. Designs are recommended which emphasise simplicity, low maintenance and long life expectancy. The induction generator is one example of technology which is becoming increasingly incorporated into low cost / high reliability schemes of this size. It is especially suitable for direct-drive with small Pelton turbine runners which can rotate at the required speed. The operation of induction motors as generators is described and full instructions are given for the electrical connections.

The penstock pipe and distribution cable are often the most expensive components in pico hydro electrification projects. Cost saving approaches to the civil works and distribution systems play an important part in successful implementation and these are also described.

Scope

The focus of this manual is the implementation of hydro technology for the electrification of small villages in hilly or mountainous regions. This constrains the scope of the designs to turbine and generator units which are suitable for medium to higher head sites (more than 20m metres) and AC generation as low voltage DC systems cannot easily convey electricity over more than a few metres. Many aspects of the implementation methods described however, are common also to other designs including those suited to low head sites and to those which benefit individual consumers rather than small communities.

Complementary Publications

Complementary manuals have been written to help encourage more widespread adoption of pico-hydro technology. A manual for manufacturers, "The Pico Power Pack – Fabrication and Assembly Instructions" aims to stimulate local production of recommended designs and therefore help to reduce the problems of availability which exist in many countries.

The "Starting a Business Using Water Power" guide encourages applications for income generation and community benefit using pico hydro. In particular, proven examples of successful commercial applications are described. By encouraging local entrepreneurs to use pico hydro as the source of power for a business, the technology can be more readily financed even in areas where development loans or subsidies are not available to rural people.

Readership

Finally, this manual is aimed at everyone with an interest in pico hydro or rural electrification. It is particularly intended for those who are thinking about this technology for the first time. It seeks to inspire sufficient confidence to encourage local implementation by "first-time" hydro engineers. With this in mind, criticisms from readers would be welcomed to allow the guidelines and procedures to be refined and updated in the light of further experience.

Figure 1-1 Pico hydro resources are abundant – the flow in a spring is often sufficient to generate electricity. (Jarcot, Mustang, Nepal)

2 THE BASICS OF PICO HYDRO

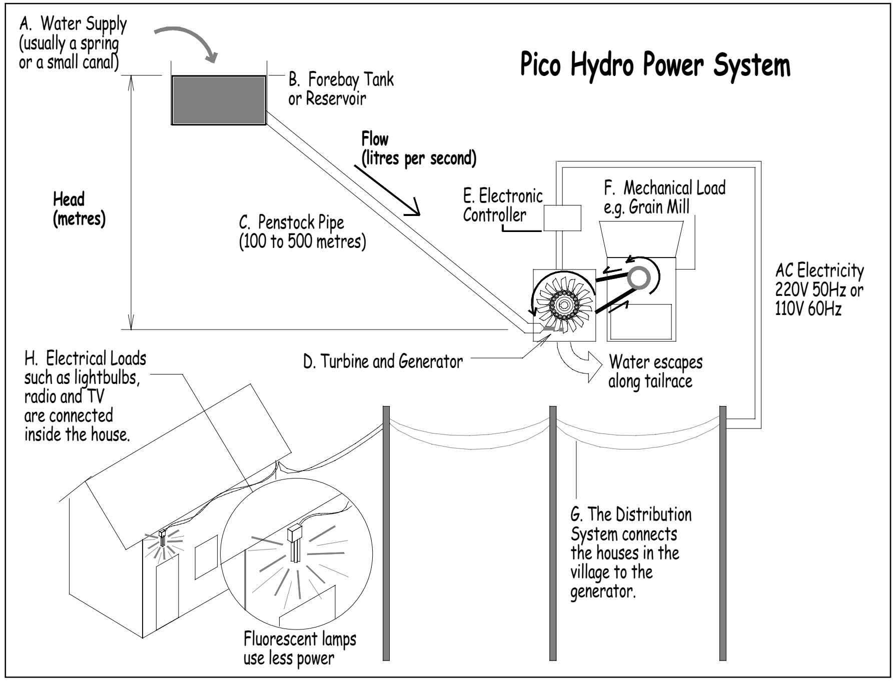


Figure 2-1 Components of a Pico Hydro System

A pico hydro system makes use of the power in falling water. Figure 2-1 shows the layout of a pico hydro system. Each of the components has been described in more detail below.

A The source of water is a stream or sometimes an irrigation canal. Small amounts of water can also be diverted from larger flows such as rivers. The most important considerations are that the source of water is reliable and not needed by someone else. Springs make excellent sources as they can often be depended on even in dry weather and are usually clean. This means that the intake is less likely to become silted up and require regular cleaning. For more information about the water source and intake, look at Section 10.1.

B The water is fed into a forebay tank. This is sometimes enlarged to form a small reservoir. A reservoir can be a useful energy store if the water available is insufficient in the dry season. For advice on design and construction of forebay tanks, read Section 10.2.

C The water flows from the forebay tank or reservoir down a long pipe called the penstock. At the end of the penstock it comes out of a nozzle as a high-pressure jet. See Section 11 for help with choosing the right penstock. The design of pico hydro system described in this manual is suitable for places where there are hills or mountains. In fact, a drop (or head) of at least 20 meters is recommended. A drop of 20 metres or more also means that the amount of water needed to produce enough power for the basic needs of a village is quite small.

D. The power in the jet, called hydraulic power or hydro power, is transmitted to a turbine runner which changes it into mechanical power. The turbine runner has blades or buckets which cause it to rotate when they are struck by water. The turbine is a general name that usually refers to the runner, the nozzle and the surrounding case. The runner typically spins 1500 times each minute. The turbine is attached to a generator. The purpose of the generator is to convert rotating power into electrical power. This is how the water flowing in a small stream can become electricity.

E. An electronic controller is connected to the generator. This matches the electrical power that is produced, to the electrical loads that are connected. This is necessary to stop the voltage from going up and down. Without a load controller, the voltage changes as lights and other devices are switched on and off.

POWER

Power is measured in **Watts (W)** or **kilowatts (kW).** There are 1000 W in 1 kW. Pico Hydro Power has a maximum electrical power output of 5 kW. It is important to say which type of power you are referring to when discussing a hydro power project as there are three types and they will all have a different value. The water power (or *hydraulic power*) will always be more than the mechanical and electrical power. This is because, as the power is converted from one form to another, some is lost at each stage as illustrated in Figure 2-2

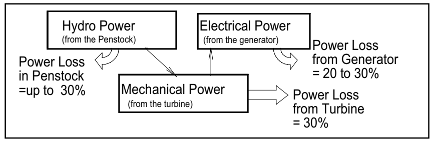


Figure 2-2 Some power is lost at each stage during the conversion from a water jet to electricity

The biggest loss usually occurs when the power in the jet of water is converted into rotating, mechanical power by hitting the turbine runner. On a well-designed and constructed scheme approximately one third (30%) of the power of the jet will be lost here. The losses can be much higher on poorer quality schemes. A further 20% to 30% will be lost in the generator when the mechanical power is converted to electricity. Some power is also lost in the penstock. Water in contact with the walls of the pipe is slowed down by friction. This power loss is expressed in metres of head loss. Its value is typically up to 20%-30% of the total head. Before the losses in the pipe are taken into account, the drop is referred to as the gross head and after losses have been subtracted it is called the net head.

EFFICIENCY

Efficiency is the word used to describe how well the power is converted from one form to another. A turbine that has an efficiency of 70% will convert 70% of the hydraulic power into mechanical power (30% being lost). The system efficiency is the combined efficiency of all the processes together. **The system efficiency for electricity generation using pico hydro is typically between 40% and 50%.**

i.e. as a rough estimate, if there is found to be 2.8 kW of hydraulic power in a small stream, the electricity which could reasonably be expected is:

2.8 x 45% = 2.8 x 0.45 = 1.26 kW

Example 1 Calculate the hydraulic power in a small stream

The **Hydraulic Power** in a stream can be calculated when the **Head** and the **Flow** have been measured. The formula to calculate Hydraulic Power is as follows:

Power = **Head** (metres) **x Flow** (litres/sec) **x9.81**

What is the Power in a stream if the head is 60 m and the flow is 10 l/s?

Power = 60 x 10 x 9.81
= **5886** watts (**W**) or **5.9** kilowatts (**kW**)

F. The Mechanical Load is a machine which is connected to the turbine shaft often using a pulley system so that power can be drawn from the turbine. The rotating force of the turbine runner can be used to directly turn equipment such as grain mills, or woodwork machinery. Although approximately 10% of the mechanical power is lost in the pulley system, this is still a very efficient way of using the power. More power is available because none is lost in the generator or in an electric motor. For advice on mechanical loads look at Section 13.4.

G. The <u>Distribution System</u> connects the electricity supply from the generator to the houses. This is often one of the most expensive parts of the system. Section 14 gives detailed information on how to design the distribution system and choose the correct size of cable.

H. The <u>Consumer Loads</u> are usually connected inside houses. Electrical load is a general name which refers to any device which uses the electricity generated. The type of electrical loads that are connected on a pico hydro scheme will partly depend on the amount of power that is generated. Fluorescent lights are preferred because they use much less power for an equivalent amount of light as filament light bulbs do. This means that more lights can be connected to the same generator. More information on choosing light bulbs and other electrical loads is given in Section 13.1.

Example 2 Calculate (i) the net head, (ii) the useful mechanical power and (iii) the electrical power which could be generated from the stream described in Example 1

Use the following assumptions: 25% of the head is lost as friction in the penstock, the turbine is 65% efficient and the generator is 80% efficient?

(i) Calculate the net head

If 25% of the head is lost as friction in the pipe the head loss is 0.25 x 60 = 15m. If 15m are lost then the useful head (or **net** head) is

= 60 - 15 = **45 m**

The net hydraulic power available at the turbine is now less than the hydraulic power using the total (gross) head:

Power = Net Head x Flow x 9.81
= 45 x 10 x 9.81
= **4414 W**

(ii) Calculate the mechanical power

If the turbine is 65% efficient the mechanical power produced will be:

Power (Mechanical)
=net hydraulic power x turbine efficiency
= 4414 x 0.65
= **2870 W**

(ii) Calculate the useful electrical power

If the generator is 80% efficient, then the electrical power available for lighting and other purposes is:

Power (Electrical)
=mechanical power xgenerator efficiency
= 2870 x 0.8
= **2295 W** or **2.3 kW**

3 IDENTIFYING YOUR FIRST SCHEME

If you are starting up in the pico hydro business or starting a programme of community pico hydros it is important to carefully select the first scheme as this will act as a focus for future interest. When identifying the site for your first scheme it is important to maximise the gain and minimise the pain! The following hints and tips will help.

3.1 General Location

1. **Accessible to you:**

Look for sites in districts that that you can get to easily so that your travel costs are minimised and you can visit easily if problems occur.

2. **Accessible to customers/funders:**

Select districts that are near to where many of your future customers are based and close to project funders to make it easy for the people that are key to your future business to visit you.

3.2 Specific Location

1. **No major technical challenges:**

Identify a site that is not too challenging technically, i.e. no complicated civil works required to transport water, ample flow, and a head that is well suited to available, well proven turbine technology.

2. **Close proximity to consumers:**

Short distribution lines keep costs low, are easier to construct and maintain.

3. **Small number of consumers:**

Select a site where the number of customers will be small, as the power capacity can then be small, reducing risk. Also the smaller the number of consumers the easier it is to organise and manage the project.

4. **Well organised and motivated community:**

It is very important that the recipients of the power are a harmonious community, with no major divisions, highly motivated towards having a pico hydro and prepared to contribute labour and money to the project. If there are skilled people within the community that can help with installation then this is a further benefit.

5. **Close to a road or other major route:**

By choosing a popular location it will be easy to encourage people to visit the project and to spread the news about your capabilities.

3.3 Achieving Maximum Publicity

- Invite an important local person to open the scheme and encourage the local press to come to the opening by producing a carefully written press release (it is worth spending a few dollars getting a marketing expert to help with this).
- Produce an eye-catching leaflet or flyer to give to people and to encourage them to use you to install a scheme for them.
- Put up some nice signs to direct people to the scheme.
- Encourage the owners of the scheme to start small enterprises using the pico hydro power. A highly illustrated, easy to read booklet on 'Water Power for a Village Business' is available from the same source as this manual.

4 PLANNING A PICO HYDRO SCHEME

This section gives an overview of what is required to implement a pico hydro project for village electrification. This allows the developer to fully understand what is involved beforehand. The order of the steps is important to ensure that the implementation is well organised.

STEP 1 COST AND AVAILABILITY

Establish the source of key components particularly the turbine-generator and controller Determine the range of head / flow / power outputs of available equipment. Obtain approximate cost of total scheme from turbine-generator supplier and / or other schemes. Otherwise assume a cost of $3,000/kW.

Visit other schemes and suppliers of turbines-generator equipment, pipe, and cable. These will be the most expensive components.

STEP 2 INITIAL OVERVIEW

Determine whether there is:
a) local desire for electricity or mechanical power, b) willingness to pay,
c) local ability to manage a scheme,
d) grid electricity available or planned

STEP 3 POWER ESTIMATE

Make a preliminary estimate of the heads and flows in the area to determine whether there is likely to be sufficient power for a pico hydro.

STEP 4 DEMAND SURVEY A

Estimate the number of houses within a radius of 1km from the water supply and, of those, which are willing to pay for an electricity supply.

1km radius is the distance over which the electricity can most easily and economically be transmitted. Make assumptions about the capital, maintenance and operating costs and use these to decide on a suitable tariff and connection cost (see Section 5.3)

STEP 5 DEMAND SURVEY B

Examine what existing activities that require expenditure on energy or which take large amounts of time to carry out would benefit from hydro power?

STEP 6 SIZING AND COSTING

Estimate the size of generator required to meet the energy demand. Estimate the cost based on information collected at STEP 1.

STEP 7 VIABILITY CHECK

Choose the most favourable size of scheme using the demand survey and power estimate. Then compare the likely annual income with the capital cost. A rough guide to financial viability is:

- if the annual income <10% of the capital cost then the scheme is not viable.
- if the income is 10-25% of the capital then the scheme could be possible .
- if the annual income is more than 25% of the capital cost then the scheme is viable.

STEP 8 HEAD & FLOW

Decide on a suitable combination or combinations of head and flow to produced required power from available turbine-generator. Assumptions about the system efficiency should also be made. If in doubt assume an overall efficiency (water power to electrical power) of 45%.

STEP 9 VILLAGE MEETING

Present the findings of the survey to the community at an open meeting to which local government staff and local development organisations should also be encouraged to attend.

Present all information as estimates. Overestimate the costs and underestimate the power available. Suggest options for ownership (individual, group, community) and explain the responsibilities and funding possibilities. Only proceed to the detailed survey when there is local agreement on ownership and funding. Consider requirement for payment for survey.

STEP 10 DETAILED SURVEY

Conduct a detailed site survey.

Is the available net head sufficient to meet requirements? Will the penstock be excessively long? Can it be shortened by the use of a channel? Can the flow be relied on throughout the whole year or is storage required? Use local knowledge. If in doubt, wait until the end of the dry season and check flows.

STEP 11 FINALISE POWER OUTPUT

Modify the original estimate of generator size based on accurate assessment of site hydraulic potential (available power in the stream).

It may seem tempting to implement a larger scheme than has initially been planned if the site characteristics allow. There are a number of reasons why it is preferable to keep the size of the scheme small, even if the site has potential for a larger turbine/ generator combination:

- Small schemes cost less and easier to implement
- If mistakes are made with the installation of a small scheme, then they are cheaper to correct
- Maintenance and repair costs will be lower

STEP 12 SCALE MAP

Draw a scale map of the site

STEP 13 SCHEME LAYOUT

Sketch scheme layout, using the site plan map as the basis. Write on lengths of penstock, any canals and each different section of the distribution system if one is required. Draw to scale.

STEP 14 REVISE LAYOUT

Look for alternative layouts that could allow the length of the penstock or the distribution system to be reduced so that costs can be cut. This may involve repositioning the powerhouse or the use of canals.

STEP 15 DETAILED COSTING

Make a realistic cost assessment of the major scheme components and obtain written quotations.

Scheme components: penstock, turbine and generator unit, distribution system, civil works and additional items. Add at least 5% for contingencies (unforeseen additional costs) Constantly be on the look-out for cheaper suppliers but do not cut corners which will reduce the quality of the scheme. Negotiate discounts based on the quantity of materials which will be required.

STEP 16 FINANCIAL VIABILITY

Use cost assessment to check if the scheme is still financially viable. Compare forecast income from electricity tariff with loan repayment costs.

If not, look where the major costs are occurring and see if they can be reduced. Seek cheaper estimates for cable, water pipe. Consider a different size of scheme or connecting more consumers and use energy efficient lamps so revenue/repayment levels are increased.

STEP 17 CONSUMER CONTRACTS

Agree consumer contracts for electricity supply which include the amount of monthly tariff and the number of light-packages provided in each house.

STEP 18 ORGANISE FINANCE

Arrange finance based on supply contracts.

STEP 19 ORDER MATERIALS

Order materials and equipment and deliver to site

STEP 20 INSTALLATION

Install scheme

STEP 21 OPERATOR TRAINING

Train local operator in operation and maintenance and safety of the system and the owners in management of the scheme.

Management training should cover collection of repayment or tariff and repayment of credit. Also the operation of a maintenance fund to ensure that scheme continues to operate.

STEP 22 CONSUMER TRAINING

Provide information and training to consumers about safety and usage of electricity.

STEP 23 COMMISSION SCHEME

5 OWNERSHIP AND VIABILITY

5.1 Ownership Options

There are two main ownership options for pico hydro schemes:
Community Ownership- consumers of the power pay for the scheme and any net income goes back to the community
Entrepreneur Ownership- one or more entrepreneurs pay for the scheme and receive the profit from sales of power.

Other models such as Government Ownership are less common for pico hydro schemes. The requirements for viability vary depending on the ownership model. In the case of Community Ownership, viability is assessed in terms of whether the quality of life improvements and financial savings over other energy sources are greater than the cost of the scheme. In the case of Entrepreneur Ownership, viability is measured mainly by the return on investment for the entrepreneur. Each ownership model has advantages and disadvantages.

	Pro's and Con's
C.O.	Usually the benefits are more evenly distributed with a higher proportion of households receiving a connection.
E. O.	Profit motive usually ensures that maintenance and repair is given more attention, income-generating end-uses for the power are a priority, management by an individual rather than a committee is more straight-forward. However, poorest community members may be excluded because of higher tariff's.

Table 5-1 Comparison of Community Ownership (C.O.) with Entrepreneur Ownership (E.O.) of pico hydro schemes.

A demand survey and financial viability calculations are very important to establish whether or not a pico hydro scheme is viable and to determine the most appropriate scheme size.

5.2 Cost Breakdown

Scheme costs can be divided into capital costs and running costs:
Capital Costs – The capital cost is the total cost of purchasing and installing all of the scheme components. The capital cost is raised through a combination of one or more of the following: private funds, bank loans, government subsidy and charitable donations. If no other data is available, $3000/kW can be used as a conservative figure for the total capital cost of a pico hydro scheme, excluding house wiring, building work and distribution poles.

Running Costs - In order to collect the tariff and repay the loans it is essential that the scheme remains operational once installed. The running costs are those costs associated with the operation and maintenance. The wages of the scheme operator vary from country to country although US$ 30 to US$ 50 per month is typical, as the job is normally considered to be part-time and this salary can be supplemented with other income. The salary will also depend on the number of individual consumers as a distribution system for a scheme with many houses connected will require more maintenance than one with fewer houses. On very small schemes, the operator may have a free lamp instead of receiving wages.

Maintenance costs arise because of the need to repair or replace damaged and worn components in order to keep the scheme operating reliably. These can be assumed to be a fixed proportion of the total capital cost (e.g. 4-6% per year). The exact figure depends upon equipment and installation quality and attention given to maintenance. If in doubt, assume 6%.

5.3 Tariff Setting

The tariff is the amount that consumers are charged for their electricity service. For pico hydro schemes the tariff is usually a fixed amount which is charged each month. This is made possible by the use of load limiters instead of electricity meters as these prevent the consumer from drawing more current than they have subscribed to, as explained in Section 15.3. How the tariff level is set depends on the type of scheme ownership and how the scheme is financed. Provision must be made to increase the tariff to compensate for price increases (inflation). Linking the rise in tariff to other price rises, such as national electricity tariffs, may make this process easier. The use of 'light packages' enables the consumer to see a directly link between the level of service which they receive for the tariff which is paid.

Light Packages

A light package is an electricity supply that is sufficient for one lamp and possibly a radio. The advantage of this system is that the cost of the service can be easily compared to the benefit obtained. If tube lighting is used, a single light package may typically provide 15W. Load limiters are fitted which limit the power supplied to that required for the number of light packages chosen. The consumer pays a fixed monthly fee per light package.

Community-owned scheme with no bank loan

In this case the consumers pay a one-off fee which pays for the capital cost of the scheme and a small monthly tariff which covers operation and maintenance.

The costs to the consumers can be estimated as follows:

1. The connection cost per light package is calculated using data from other pico hydro schemes or by assuming $3000/kW excluding house wiring. For example, if the scheme cost is $3000/kW and each light package is 15W then the capital cost of one light package will be $45. This must be paid up-front to allow the scheme components to be purchased. House wiring must also be paid for.
2. Estimate the maintenance costs of the scheme. This will be $0.23 per package per month if the maintenance fund is 6% of the capital cost ($3000/kW) as recommended above.
3. Estimate the monthly cost of operator wages and divide by the approximate total number of light packages to find the operation cost per light package. For example if approximately 100 light packages are expected to be subscribed to and the wages will be $30 per month, the operator cost per package will be 30/100 = $0.3
4. Add the operator costs to the maintenance cost to obtain the running cost per light package which will be payable by the consumers each month.

Community scheme with no capital available

Often rural households lack sufficient disposable funds to pay for pico hydro and under these circumstances a loan, usually from a bank, should be considered. A realistic payback period for the loan should be determined. This is usually between 3 and 15 years. Having determined a suitable payback period, banks and other credit sources should be approached to establish the repayments required per $1000 borrowed and the terms of the loan especially regarding collateral.

Having found the best credit deal, the steps to determine the tariff in this case are as follows:

1. Determine the capital cost per light package as before. (e.g. $45)
2. Calculate the monthly loan repayments for each $1000 borrowed and from this work out the repayment for $1. (e.g. if $30 per month for $1000 borrowed then 30/1000= $0.03 per $1 borrowed.)
3. Calculate the monthly repayment per light package by multiplying the capital cost per light package by the monthly repayment for $1. (e.g. 0.03x45 = $1.35 per light per month).
4. Add maintenance costs, calculated as before and an allowance for the operator wages to obtain the total monthly tariff per light package.

Entrepreneur-owned scheme

The entrepreneur needs to determine the return on investment that they require for a pico hydro scheme to be sufficiently profitable and a worthwhile investment. For example, this may be 10% above the cost of a bank loan. This can be used to calculate the monthly cost per light package in a similar way to that described above. The survey will then determine whether there are sufficient households willing to purchase the light packages at this rate.

5.4 Consumer Agreement

Before the demand survey is conducted the terms of the consumer agreement should be clearly established. This will help to clarify exactly what benefit the consumers will receive and at what cost and level of labour contribution. Key points to explain are as follows:

- What a light package is and the implications of a limited electricity supply (e.g. what appliances can and cannot be connected if a socket for an electric plug is provided)
- The costs per light package (Connection charge, cost of house wiring, monthly tariff) and how the monthly tariff will change with time.
- If the electricity will be provided between particular times of the day (e.g. 4pm to 11pm) then this should be stated.
- During the dry season the times may vary due to reduced availability of water.
- The labour contribution required to construct the powerhouse, penstock, intake and distribution poles.

EXPLAIN THE ADVANTAGES and DISADVANTAGES

When finding out who is interested in receiving an electricity connection, it is important to explain the advantages. The main advantages of electricity for most people in rural communities are:

- improved lighting for cooking and study
- better air quality because no kerosene lamps
- less money spent on batteries or kerosene
- less risk of fire

The ability to demonstrate electric tube light in local houses is very advantageous. One method of doing this is by using a pre-charged "emergency light" (see Section 13.1)

A disadvantage of the pico hydro scheme for lighting and other small loads is that the consumers must make a commitment to pay the tariff every month. This differs from other energy types such as kerosene and small batteries which are bought whenever funds are available.

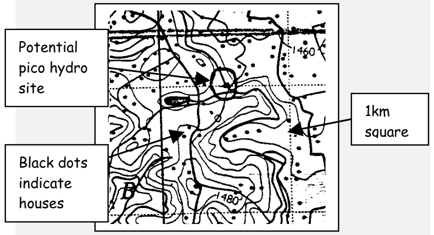
5.5 Demand Survey

The demand survey is a very important step for most schemes. It enables the developer to find out how many light packages are required at the tariff and connection fee which have been calculated and hence the correct size of scheme to be installed. The following questions will need to be answered in order to proceed with the scheme design:

1. How many houses are there within a 1km radius of the source of water / proposed generator site?
2. Within this area, how many people are prepared to pay for electricity and how much?
3. What activities currently occurring would benefit from pico hydro power?

How many houses are there?

The number of houses within a 1km radius will probably be known by local people and can be checked by walking around the area. 1km is usually the economical distance over which electricity from a pico hydro unit can be transmitted. For some countries recent Ordnance Survey maps are available. Map scales of 1:50,000 may have individual houses marked. If a map can be expanded on a photocopier, this makes it easier to identify features in a particular area and to mark on additional houses that are not shown. A map of a rural community living near to a small hydro resource in Kenya is shown below.



It is sometimes possible to supply power to houses that are further away by using a transformer although this adds cost and complexity. Battery charging for people more than 1 km from the generator is an additional possibility (see Section 13.1). The best place for the generator is usually as near to the centre of the village as possible. The position of the generator also depends on the water source. For more advice on selecting the best site and the scheme layout, read Section 6.

How many people will pay for electricity?

1. Conduct a survey of households within a 1km radius of the best generator location. Obtain name, address and the number of light packages that would be purchased using the tariff level and one-off fee / house wiring cost which have been calculated. This can be done through community meetings or visiting the houses individually. The consumers must make a firm commitment to the supply agreement and sign for the number of packages which they will subscribe to.

2. Use the results of the survey to decide on the power required to supply the total number of light packages and size the scheme.

What other activities could benefit?

Other activities, normally done by hand or using diesel engines can use pico hydro-power instead. Planning uses for the hydro system during the day, when energy is not needed for lights, is called increasing the load factor. Improving the amount of time that the hydro system is 'busy' can help to lower the cost per light package. However, the extra income should only be included in the calculations if these businesses will be established from the beginning of the project. Popular uses for pico hydro-power in addition to lighting include:

- agro-processing including threshing and milling
- battery charging
- ice-making and refrigeration
- power for tools in a workshop.

Use Section 13 to find out how other activities could be powered by pico hydro. The complimentary publication **"Starting a Business Using Water Power"** gives more income-generating ideas.

Example of Viability Calculations:

At a village in Ethiopia, Africa, there is interest in developing power from an irrigation canal. There is up to 4.5 kW electrical power available all year round at this site. The community leaders want to know how much it will cost to install the scheme and connect to 60 houses.

There are two possibilities:

1. **the community funds all the costs themselves**
2. **the community borrow the capital costs from a bank and just fund the house-wiring themselves**

Calculate a tariff for a 15W light package for each financing option and decide which is the most viable.

1. No bank loan

Assuming the capital cost of the installed system is $3000/kW, the capital cost per 15W light package is 15/1000 x 3000 = $45.

The costs for the house wiring of a light package of this size have been investigated in Addis Ababa. Component details and costs for the house wiring and load limiter are as follows:

Item	**Specification**	Cost $
Bulb + holder	9W CFL	8.22
Switch	In line	0.60
Socket	Wall Mounted	0.72
Cable	0.75mm² x 5m	0.60
Fuse + Holder	3A / 220V	0.60
Load limiter	PTC Thermistor	0.97
Switch	220V Isolation	0.97
Plastic Box	75 x 50 x 25mm	1.20
Seal for box	Printed Label	0.12
	Total	**$14.00**

The annual maintenance costs will be calculated as 6% of the capital costs. Per Light package this is
45 x 0.06 /12 = $0.23 per month.

The operator is expected to be paid $30 per month. It is expected that each of the 60 houses will take an average of two light packages each. That gives an operator cost per light package of 30/120 = $0.25

So for this option the consumer will need to pay the following per light package:

One-off fee	$45.00
House wiring	$14.00
Monthly maintenance	$0.23
Monthly operator cost	$0.25

For example, a consumer subscribing to 2 packages would have to pay 2x[$45 + $14] = $118 initially and a monthly tariff of approximately 2x[$0.23 + $0.25] = $0.96.

2. Scheme financed through bank credit.

The interest rates at local banks have been investigated. One bank is prepared to lend the capital required at an annual interest rate of 25%. This is the best deal. They require the land registration papers of community members as collateral.

The annual repayments (R) for each $1000 borrowed can be calculated using the following formula:

$$R = L \times \frac{i(1+i)^n}{(1+i)^n - 1}$$

L = loan amount (e.g. $1000)
i = interest rate (e.g. 25%)
n = number of years of repayment

The repayments have been calculated for loans taken over 5, 10 and 15 years.
For 5 years the annual repayment is :

$$R = 1000 \times \frac{0.25(1+0.25)^5}{(1+0.25)^5 - 1} = \$372$$

Over 5 years this is a total repayment of $1860

Similarly,
for a 10 year term
the annual repayments are $280
(total repayment = $2,800)

for a 15 year term
the annual repayments are $259
(total repayment = $3,887)

Based on the annual repayments it is now possible to calculate the monthly tariff per light package:

The capital cost for one light package is $45 and the house wiring cost is $14. Assuming that bank credit is used to pay for 100% of the scheme costs including house wiring (but excluding poles and building works) then the monthly tariff is calculated as follows:

For a five year loan repayment
Monthly repayment costs per $1000 borrowed
= 372 / 12 = $31

Per light package +house wiring this is a monthly repayment of $59 x 31/1000 = $1.83

Similar repayments can be calculated for repayment terms of 10 years and 15 years

Summary of tariff costs for one lamp package:

Loan repayment period	5 years	10 years	15 years
Repayments for scheme and house wiring	$1.83	$1.38	$1.27
Maintenance (6%)	$0.23	$0.23	$0.23
Operator cost	$0.25	$0.25	$0.25
Total monthly tariff	**$2.31**	**$1.86**	**$1.75**

Comments

Operator and maintenance costs are calculated as before. The interested is assumed to be calculated annually and unchanging for different repayment periods. In reality the interest rates are usually lower for longer repayment periods and for larger sums.

6 SCHEME LAYOUTS

6.1 What factors decide the layout?

Since decisions regarding the scheme layout will affect the power output, reliability, cost and convenience of the service, it is worth considering several options to make sure that the best layout is chosen.

The factors requiring consideration when selecting the best layout are as follows:

- **Location of the houses in relation to the water**
  If the houses are a long way from the turbine, the scheme is likely to be expensive. Reduce this cost by careful planning.

- **Power requirement**
  The power generated depends on how much water is taken (flow rate) and the number of metres which it falls (head). These are both affected by the layout.

- **Water rights**
  Checking water rights and negotiating water usage with everyone affected is an important part of the planning process. Questions such as the following should be asked:
  Whose land will be used for the scheme?
  Who else uses the water and for what purpose?
  Clear agreements should be reached before any installation work begins. This will avoid disputes that could affect the operation of the scheme after commissioning.

- ***Cost and availability of different components***
  The layout affects the cost and the power output. The major challenge of the layout designer, is to keep the penstock and the distribution system as short as possible. Both the cost and power losses increase as they get longer. Remote areas will have more limited access for transportation of building materials. This may affect the design of civil works such as intakes, canals and reservoirs.

- **Water supply and irrigation projects**
  In some cases it is possible to combine a pico hydro scheme with other local initiatives such as the development of domestic water supply or new irrigation systems. This may affect decisions regarding the layout.

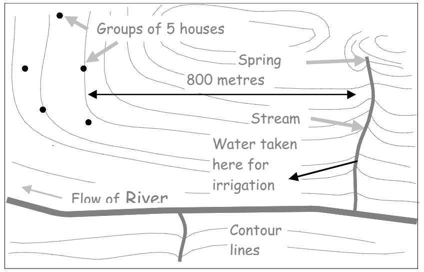
The task facing the layout designer usually involves several compromises. The most obvious layout for a particular site may not be the best and other options should be considered.

The length of the penstock pipe and the length of the distribution cable, in particular, must be carefully judged. It will be helpful, when considering different layouts, if the local cost for different sizes and types of plastic pipe and cables are available. This will allow rough estimates to be made for quick comparison.

Detailed designs are not required at this stage, but it will be helpful if the designer has read and understood Sections 10, 11 and 14 before making final layout decisions.

6.2 Examples of Scheme Layout

Figure 6-1 A map of the site is essential when planning the layout. On this map, points of the same height have been joined with contour lines.



Four different scheme layouts are considered in the following example of a typical hillside electrification project.

At this site, there is sufficient water in the stream all year round to supply approximately 100W of electricity to each of 25 houses. However, there is a considerable distance between the water source and the nearest houses in the village (approximately 800m) and during the dry season, some water is taken from lower down the stream and used to irrigate farm land. A map of the site has been drawn and is shown in Figure 6-1
Contour lines have been added which join together places of the same height. There is 10m difference in height between each of the contour lines increasing away from the river which flows through a valley.
Note: In figures, each dot represents 5 houses.
As the stream is some distance from the village there are a number of possible layouts to consider. The main points of each layout have been summarised to allow a quick comparison to be made.

6.3 Layout 1: Long Penstock, Short Cable

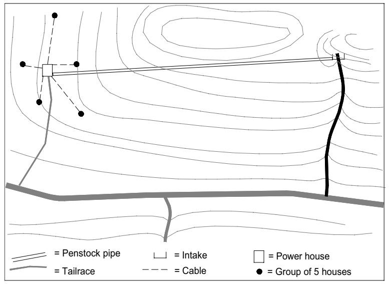


Figure 6-2 Layout 1 has a short distribution system saving on cable cost. However, a longer penstock will be more expensive.

In Layout 1, a long penstock brings water to a convenient powerhouse in the village keeping the distribution system short. The civil works are kept to a minimum, because the intake is also the forebay tank.

- Water in the tailrace is not returned to the original stream and therefore irrigation is affected. Water rights will be an important issue with every layout except with Layout 2.
- Much of the head will be lost unless a penstock of large diameter is used.
- The cost of this pipe is likely to be the most significant scheme cost with this layout. See Section 11 for advice on choosing a penstock.

6.4 Layout 2: Short Penstock, Long Cable

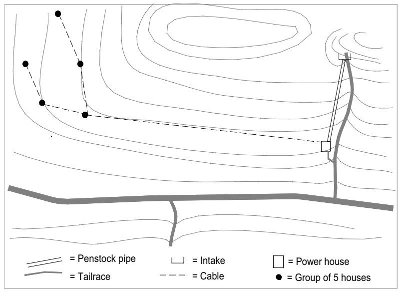


Figure 6-3 Layout 2 Short penstock and long distribution system. Water rights are not affected.

In this design, the cost and the head losses will both be reduced because the penstock is shorter. The water in the tailrace rejoins the original stream so irrigation is not disrupted

- Distribution cable will be expensive and needs careful selection to minimise the cost and avoid a large volt drop.
- The powerhouse is a long way from the village which may be very inconvenient.

For advice on designing and costing the distribution system, consult Section 14.

6.5 Layout 3: Using a Canal

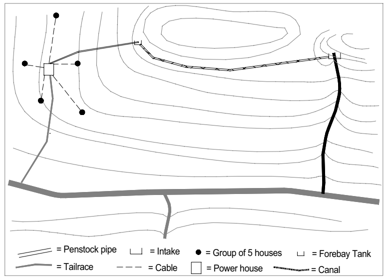


Figure 6-4 Layout 3 Use of a canal replaces the need for a long distribution system or penstock.

In this layout, the water is brought nearer to the village using a canal. A lot of manual work is required to dig a long canal like this but the penstock and distribution cables can both be short and will therefore cost less.

- An earth lined canal will require regular maintenance
- A concrete lined canal will be more reliable but expensive particularly at remote sites
- Canals should be avoided in areas which have landslides

Section 10.2 gives information about designing a small canal.

6.6 Layout 4: Low Pressure Pipe and Storage

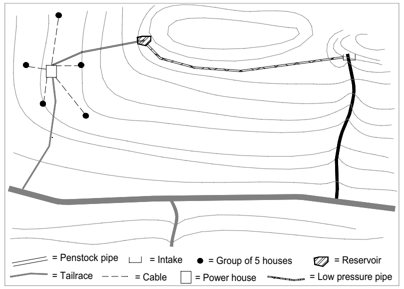


Figure 6-5 Layout 4. A modified version of the last layout The canal is replaced with a low-pressure pipe. The forebay has been enlarged to add a means of energy storage.

Layout 4 is almost the same as 3 but the canal is replaced by a piece of low-pressure pipe and the forebay is enlarged to form a small reservoir. A suitable low-pressure pipe is often sold as drainage pipe. This type of pipe is considerably cheaper per meter than penstock pipe.

- Maintenance is reduced as there is no canal
- A pipe is easier to install than a canal.
- More building materials, labour and maintenance are required for the reservoir and extra pipe must be purchased.
- A reservoir allows easier management of water resources during the dry season and smaller pipe to be used to bring the water from the stream.

Section 10.3 explains how to design a small reservoir.

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7 SITE SURVEYING

7.1 Power from a stream

The amount of power that can be provided by a stream depends on two things. These are called the *head* and the *flow.*

1) The *head,* measured in metres (m), is the vertical drop from the top of the penstock to the bottom. The greater this drop, the greater the power and the higher the speed of the turbine. It is important not to confuse this height with the penstock (or stream) length.

2) The *flow,* measured in litres per second (l/s), is the amount of water which flows past you in one second when you stand by the stream.

Hydro-Power is calculated by multiplying the *head* and *flow* by the force of gravity. The unit of power is the Watt (W). 1000 Watts = 1 kilowatt (kW). Since the force of gravity is fairly constant ($9.81 m/s^2$), the formula for Hydro Power can be written as follows:

Hydro Power (W) =head (m) x flow (l/s) x 9.81

Example Calculate the power in a stream

The maximum head of a stream on a farm in Western Nepal is 70 meters. The flow that has been measured is 5 litres per second. What hydro power is available in this stream?

Answer: Power = head x flow x gravity
= 70 x 5 x 9.81
= 3433 W or **3.4 kW**

It is important that the head is carefully measured. In some places the flow is clearly more than is needed. If this is true then accurate flow measurements are not required. If there is doubt about any of the calculations then the measurements should be repeated. It is better to underestimate the head and flow rather than to overestimate them.

7.2 Obtaining the Necessary Equipment.

A variety of equipment to help determine the head and flow is discussed in this section. Some methods require practice in order to be used accurately. Methods have also been included which involve no specialist equipment or training enabling anyone to be able to estimate the power.

For head measurement, the water-filled tube method is the lowest cost though time consuming. Use of digital altimeters and Abney Levels has also been described. Where available, these methods can provide a relatively quick and accurate alternative if used correctly. Digital altimeters are becoming more widespread and lower in cost though a quality one cost about $200.

The flow measurement techniques described are the bucket method and the float method. The float method is much less accurate but very easy to perform. Use of the digital conductivity meter in what is called the 'salt gulp' technique of flow measurement has also been included. At many sites this method is much more practical and accurate than the others. Like the digital altimeter, conductivity meters are gradually becoming more widely available and have a similar cost.

7.3 Measuring the Head

The techniques, summarised in Table 7-1, differ in terms of cost, complexity, and accuracy. Generally, the lower the head, the more critical the accuracy of the measurement.

The head should be measured at the most likely place for the penstock. This means that the site layout will have been studied and possible places for the power house and forebay tank will be under consideration. Don't forget, keep the penstock as short as possible to obtain the required head. The head required for a pico hydro project like the ones described in this manual (medium to high head) will need be at least 20 metres and ideally 50 metres or more.

	Method	Cost	Accuracy	Time	Difficulty	Equipment Required	No. of People
1	**Water-filled plastic tube**	Low ($20)	Accurate with practice	Takes time (3-6hrs)	Easy to learn	Plastic tube, tape measure, wooden pegs, notebook and pencil	2 or more
2	**Altimeter**	Medium / High. ($200 each) Borrow or hire if possible	+/-1m to +/-5m depending on model (greater accuracy is possible using 2 altimeters)	quickest method (less than 1hr)	No skill required	Digital altimeter, wooden pegs, notebook and pencil	1 (though better with 2)
3	**Abney Level**	Quite low. Borrow or hire if possible	Accurate with practice	Quite slow (up to 2hrs depending on experience)	Practice required	Abney Level, long tape measure, two sticks (1.5m), pegs, notebook and pencil	2

Table 7-1 A comparison of methods to measure Head in metres

Water-filled Tube

This is the cheapest method of head measurement to learn. No specialist equipment is required. A piece of clear, plastic tube, about 20 metres long with a diameter of 10 or 12 mm, is the main piece of apparatus.

Fill the tube with water so that when the two ends are held together, the water level is about 30cm from the top. The water inside the tube will always find the same level on either side. A plastic funnel will help to pour in the water. Bubbles in the tube should be avoided as they can cause inaccurate readings. They should be removed where possible by allowing them to rise out of the tube (very small bubbles don't matter).
At least two people are required for this method but more can help with taking measurements and recording the results.

Procedure
Step 1: One person holds each end of the tube and does not allow the water to spill out. Begin by matching the water level in the tube to the expected water level of the forebay tank which should be marked by a stick. Your assistant should remain still, holding their end of the tube at this point. Meanwhile, move downhill carefully holding your thumb over the end of the tube as you go so that the water doesn't spill out. Once your eye level is approximately the same as the expected water level in the forebay, raise the tube to head height and take your thumb off the end.. Adjust your position as necessary so that the water level in the tube matches exactly your eye level and the expected level in the forebay. Record that one reading has been taken and stand still.

Step 2: The assistant now moves downhill past your position keeping the water in the tube by holding a thumb over the end. As they walk further down, lower your end of the tube until the water in your end is at the level of the soles of your shoes. The assistant stops walking downhill when the water reaches eye level. Record that a second reading has been taken

Step 3: The process is repeated until one side of the tube is held in the expected location of the turbine. The number of reading taken are then totalled up. This is multiplied by the average height (to eye level) in metres of the two people who took the measurements. to give the total head. The procedure should be repeated two or three times until you are sure that the head measurement is accurate. Good marking at the forebay site and the powerhouse position enable the same section of hillside to be measured again. If the head is more than required then an intermediate position, can be found. The distance between the two marker points should be measured to decide the length of penstock required.

A variation of this method is to seal one end of the tube with a pressure gauge. The pressure at each measuring point is recorded and the sum of the total pressures can be used to calculate the overall head. The pressure gauge must be calibrated before use so that the readings are trustworthy. A tall building an long tape measure can be used for calibration.

Digital Altimeters

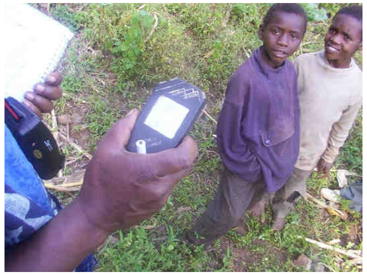


Figure 7-1 Head measurement using a digital altimeter in Kenya

Digital altimeters are the most convenient way to measure the head at a site. Height is calculated using changes in air pressure. All that the user has to do is to record one reading at the proposed forebay location and one at the site of the turbine in order to determine the head. The second reading should be taken as quickly as possible to prevent atmospheric changes in pressure (changing weather) from affecting the readings.

The best way to remove weather effects is by using two identical altimeters and to take measurements at the same time. One altimeter remains in the same position, either at the top or the bottom of the slope to check the effects of changing weather. The other is used to calculate head. Meanwhile any changes in head caused by atmospheric conditions are noted and then adjustments can be made to the final figure. It is easy to repeat the test several times in order to check the head. If the altimeters can be zeroed, zero both at the same time. Agree the time required for the person who carries the second altimeter to move to their new position. Using watches take the new readings on both altimeters at the same time. The two readings can be subtracted to give the head. An accuracy of at least +/- 5m is expected with digital altimeters although +/- 1m should be possible with some.

The Abney Level.

The Abney Level (or Clinometer) is a hand held sighting meter. It requires skill to use but once mastered can measure heads with an accuracy of +/- 5%.

With this method, the angle of the slope is measured. The linear distance is also measured and using simple trigonometry, the height difference between two points is calculated. When these are added together the total head is obtained.

Procedure for head measurement using an Abney level
Step 1: Two posts are needed which are 1.5 to 1.6 metres in length or the distance from ground to eye level, (they must be the same but their exact length is not important). The first is held at the proposed location of the turbine and the second about 30m towards the intake. A clear line of site is necessary so this may affect the route taken. A brightly coloured ribbon or similar object is useful to identify the top of the sighting post
Step 2: The distance between the top of the two posts is measured and recorded (distance d). Some Abney levels have a built-in range finder and this can be used instead of a tape measure.
Step 2: The angle between the tops of the two siting posts is carefully measured using the level and recorded. Both posts should be held straight with the level resting on top of one.
Step 3: The process is repeated up the hill until the proposed intake level is reached.
Step 4: The heights between each pair of points are calculated using the sine rule and added together to give the total head.

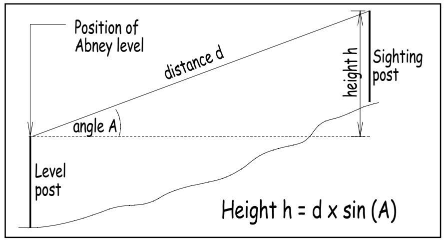


Figure 7-2 Calculation of the height between two points using an Abney Level

	Method	Cost	Accuracy	Difficulty	Time	Equipment required	Number of people
1	**Bucket Method (only suitable for flows less than about 10 l/s)**	Negligible	Reasonable / poor depending on method / experience	Not difficult	10 minutes + time to block stream if required	Bucket and stopwatch	2
2	**Float Method**	Negligible	Poor although reasonable accuracy in smooth parallel-sided channels	Not Difficult	30 minutes	A float (piece of wood), tape measure, stopwatch	2
3	**Salt Gulp Analysis**	High ($200). Borrow / hire a meter	Medium to high accuracy with practice (±5%)	Requires care to perform	1 hour	Conductivity metre, Salt weighed into bags, bucket, calculator	1 or more

Table 7-3 Suitable methods of measuring small flows (<50l/s)

Figure 7-3 Head measurement using an Abney Level in Nepal

Station No.	Distance D	Angle A	D x sin(A)
1	31.5 m	14°30'	7.89 m
2	29.0 m	7°15'	3.66 m
11	23.1 m	10°20'	4.14 m
		Total head	57 metres

Table 7-2 Using an Abney level, the distances and angles are recorded at several points between the turbine and intake position so that the total head can be calculated as shown above.

7.4 Measuring the Flow

The accuracy to which the flow needs to be measured depends on the site. A demand survey and estimates of the head help to determine the required flow. In many cases, the flow available will be more than is needed for the scheme, since the flows for pico hydro are small. The most critical time of year is towards the end of the dry season when rain has not fallen for some time. This is the best time to measure the flow. Local people will be able to say if the water level in the stream is typical for that time of year and help the surveyor estimate the flow throughout the year. Three methods of flow measurement are explained which are particularly suitable for the measurement of small flows (less than 50 litres per second) The methods are summarised in Table 7-3.

The Bucket Method

A simple method of finding small flows (up to about 10 l/s) is to use a bucket and a watch. In fact any large, waterproof, container is suitable, providing that you can first find its volume in litres. A 15litre bucket is suitable for the smallest flows (3 litres per second or less) and larger ones for bigger flows.

STEP 1: Find the volume of the bucket (if unmarked).

Take a smaller container with a known volume. A one litre water bottle is a good example. Fill the bucket with water using the smaller container and count how many litres you have added. Mark the level in the bucket clearly when the maximum number of complete litres has been added.

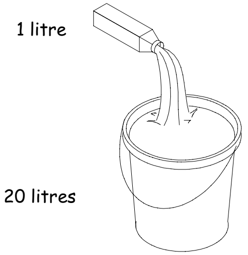


Figure 7-4 Use a small container of known volume to find the volume of a larger one.

STEP 2: Find a place to measure the flow.

This can be difficult. You need to find a method of directing the water in the stream into the bucket. It is important that as little as possible escapes. If some does escape, estimate a percentage and add on to the measured flow.

STEP 3: Take the measurements.

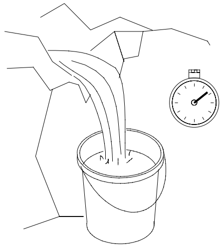
Using a stopwatch or ordinary watch with a second hand, record how long the bucket takes to fill to the marked level. Repeat this at least 3 times and average the results. If you find that the bucket fills in less than 5 seconds, your results will not be very accurate. For more accuracy it is better to use the largest container which you can find or try another method of measuring the flow.

STEP 4: Work out the flow in litres per second.

If the bucket holds 15 litres and takes 8 seconds to fill then the flow is 15/8 l/s or 1.87 litres per second

Suggestions of methods to divert water into the flow measuring container

1. Natural Waterfall



2. Build a weir from available materials and use a wooden channel, a corrugated sheet or a piece of stem from a banana plant to channel the water

3. Build a simple weir and use a piece of pipe

The Float Method.

It works well in canals or channels. It can also be used in rivers and streams although with less accuracy Two pieces of information are needed to calculate the flow by this method. The first is the **cross-sectional area** of the water flowing in the stream or channel. The second is the **speed** that the water is flowing. This is measured using a float and timing its travel between two points a known distance apart.

Procedure

STEP 1: Find the cross-sectional area (CSA).

The difficulty of measuring the cross-sectional area depends on the type of flow under consideration. Estimating the CSA in a smooth-sided channel is much easier than in a shallow, rocky stream.

To estimate the area at a particular point, measure the width and then take depth measurements at regular intervals across the flow. Plot the depth measurements on squared paper as shown in Figure 7-5. Join them up with straight lines to the width that is marked along one axis to create an enclosed area. The area can be estimated by counting the number of squares that are enclosed. Multiply the number of squares by the area which one square represents in m^2. Repeat these measurements in the middle and at the other end of the length over which the float is being timed (approximately 10 metres). Three values of the CSA will allow an average to be calculated.

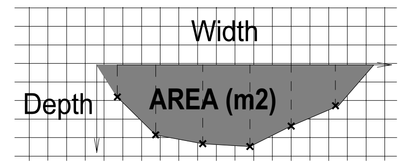


Figure 7-5 Squared paper can be used to help estimate the cross-sectional area

STEP 2: Measure the speed of the flow (surface velocity).

A length (L) of 10 metres between the marking points should be sufficient. Begin to time the float when it passes the first marker and stop as soon as it passes the second. Repeat at least three times for consistent results. For the test, choose the straightest section of stream with the most even cross-sectional area.

STEP 3: Calculate the flow in litres per second

The flow is the product of the average stream area and the average velocity (or average speed) of the flow: Since the water moves more quickly on the surface than in other parts of the stream, an additional factor must be introduced which takes this difference into account. The difference between the surface velocity and the average stream velocity depends on the type of stream. Guideline "velocity correction factors" are given below. The table also gives an indication of the accuracy that can be expected.

Type of stream	**Velocity correction factor**	**Accuracy**
A rectangular channel with smooth sides and bed	0.85	Good
A deep, slow moving stream	0.75	Reasonable
A small stream with a smooth bed	0.65	Poor
A quick, turbulent stream	0.45	Very poor
A very shallow, rocky stream	0.25	Very poor

The equation to calculate the flow is:

$$Q = A_{ave} \times V_{surface} \times \text{Correction Factor}$$

where

Q= Flow rate (m^3/s)

A_{ave}= Average cross-sectional area (m^2)

$V_{surface}$= Surface velocity (m/s)

Divide the answer by 1000 for a flow rate in litres per second. Clearly, the accuracy of the float method is limited because of the requirement for correction factors and the difficulty of measuring the cross-sectional area of many streams.

Example Calculate the Flow using the Float Method

What is the flow in a small channel where the following information has been obtained?

1) The water in the channel is 25 cm deep, the sides of the channel are approximately square and the width is 40 cm. The side are quite smooth

2) When a stick was floated down a 20m section of the channel it took a) 36 b) 40 and c) 44 seconds

Answer:

(i) Cross sectional area of the water in the channel

= 0.25 x 0.4

= **0.1 m^2**

(ii) Average time taken

= (36+40+44)/3

= **40 seconds**

Average surface velocity

= 20metres/40seconds

= **0.5 m/s**

(iii) Correction Factor for a smooth channel

= 0.85

(iv) **Flow = Area x velocity x correction factor**

= 0.1 x 0.5 x 0.85

= **0.0425 m^3/s**

The flow in litres per second

= 0.0425 x 1000

= **42.5 litres per second**.

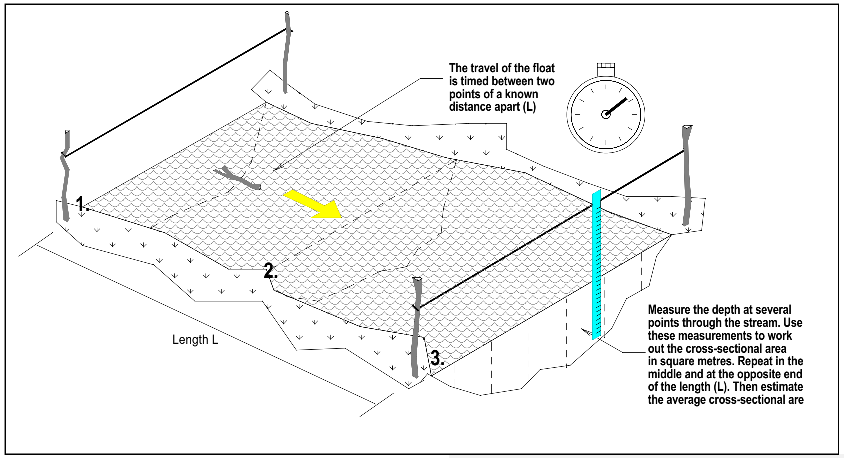


Figure 7-6 The float method of flow measurement

The Salt Gulp Method

This method requires more complicated calculations than the others but is easier to carry out. With some practice however, it can be the most convenient, rapid and accurate method of measuring flow in a stream.

A portable digital conductivity meter and some means of accurately weighing salt are required. Digital conductivity meters are becoming more widespread and it is hoped that they will eventually be available in all areas where pico hydro development is taking place. Access to a computer is useful. A spreadsheet allows the results to be rapidly converted into a flow rate. Otherwise a calculator and graph paper are required to calculate the results.

Figure 7-7 Portable conductivity meter and carefully weighed bags of salt

This method is accurate to within 5% if performed carefully. It relies on the fact that the conductivity of water in a stream will rise when salt is added. The flow rate is determined by measuring the speed and concentration of a cloud of salty water as it passes downstream.

Procedure:

STEP 1: Add the salt solution to the stream

A known mass of salt is mixed with some water in a bucket until fully dissolved. The amount of water in the bucket doesn't matter but once the salt has been added then the water must not be spilt. Record the mass of salt added, to the nearest gram. All the salt water solution is then tipped into the stream. The mass of salt used depends on the size of the flow. As a rough estimate, use approximately 25g of salt for every 5 litres per second of flow (the flow will have to be guessed on the first occasion).

STEP 2: Record the conductivity change downstream. The conductivity meter probe is placed in a swiftly moving area of flow, 25 to 30 metres downstream of where the salt solution is added. The normal conductivity level of the water is recorded. This is called background conductivity. As soon as the conductivity readings begin to climb, record them every 5 seconds. This will usually happen 2 or 3 minutes after the salt water has been tipped in upstream. If, within 15 minutes, the conductivity has not reached at least twice the background level, then the procedure must be repeated with a greater quantity of salt. Readings continue to be recorded every five seconds until the conductivity has returned to its background level. This will normally be after a further 10 to 15 minutes. If possible select a scale on the meter that is just sufficient for the maximum conductivity to be read. This may mean loss of the first set of results.

The meter readings are typically given in micro Siemens (μS) which are units of conductivity (ohms^{-1} x 10^{-6}).

STEP 4:Plot a graph of changing salt concentration against time

These readings should be plotted on squared paper as a graph of conductivity against time. The shape of the graph allows the results to be evaluated. A smooth curve with a peak value at least twice the level of the background conductivity, indicates that the procedure has been successful. If the curve is badly skewed or the readings are uneven then the procedure will need to be repeated.

STEP 5: Calculate the area under the curve

The area under the curve must be established in order to calculate the flow rate. This is done either by counting the squares underneath the curve or by summing the results using a spreadsheet. If you count the squares then the axis scale must be taken into account.

STEP 6: Calculate the flow rate

The equation for calculating the flow rate is as follows:

$$Q = \frac{M \times k^{-1}}{A}$$

where:
Q = flow rate (l/s)
M = mass of salt (mg)
k^{-1}= conversion factor (ohm^{-1}/mg l^{-1})
A= area under curve (s x 10^{-6} x ohm^{-1})

The conductivity is converted into salt concentration by multiplying by a conversion factor that takes water temperature into account. The conversion factor, k^{-1} has units ohm^{-1}/mg l^{-1} and assuming a water temperature of 22°C, the value of k^{-1}= 2.04.

Note: The mass of salt must be converted to milligrams (grams x 10^3) before being used in the equation.

Salt Gulp Flow Measurement		
Location:	Thulo Phako, Basantapur, Eastern Nepal	
Date:	20th May 1998	
Time:	7.30 am	
Water Temperature:	22	°C
Net Head:	50	metres
Mass of salt used :	25000	milligrames
Background Conductivity	29.2	microSiemens
Time period between results	5	Seconds
Conversion Factor k	2.04	ohm-1/mg l-1
Flow Rate = mass of salt in mg x factor k / area under curve		
Area under curve = Total of condutivity change x time period		
Area under curve =	10698	
Flow Rate =	4.77	litres per second
Power Available = Flow Rate x Head x Gravity		
Power Available =	2338	watts

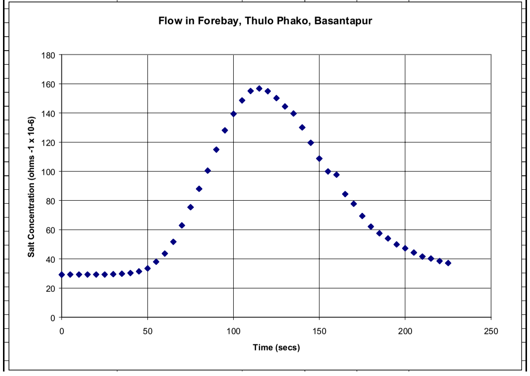


Figure 7-8 Results from the 'salt gulp' method of flow measurement can be analysed quickly using a spreadsheet.

Time	Conductivity	Conductivity	Time	Conductivity	Conductivity
	Reading	Increase		Reading	Change
(seconds)	Ohm^{-1} x 10^{-6}	Ohm^{-1} x 10^{-6}	(seconds)	Ohm^{-1} x 10^{-6}	Ohm^{-1} x 10^{-6}
0	29.2	0	230	36.2	7
5	29.3	0.1	235	35.1	5.9
10	29.3	0.1	240	34.3	5.1
15	29.3	0.1	245	33.8	4.6
20	29.3	0.1	250	33.3	4.1
25	29.3	0.1	255	32.9	3.7
30	29.5	0.3	260	32.5	3.3
35	29.8	0.6	265	32.3	3.1
40	30.3	1.1	270	31.8	2.6
45	31.5	2.3	275	31.6	2.4
50	33.5	4.3	280	31.4	2.2
55	38	8.8	285	31.3	2.1
60	43.7	14.5	290	31.2	2
65	51.7	22.5	295	31.1	1.9
70	62.9	33.7	300	31	1.8
75	75.4	46.2	305	31	1.8
80	88	58.8	310	29.9	0.7
85	100.5	71.3	315	29.9	0.7
90	114.9	85.7	320	29.8	0.6
95	128.1	98.9	325	29.8	0.6
100	139.4	110.2	330	29.8	0.6
105	148.6	119.4	335	29.7	0.5
110	155.1	125.9	340	29.7	0.5
115	156.8	127.6	345	29.7	0.5
120	154.9	125.7	350	29.6	0.4
125	150.2	121	355	29.6	0.4
130	144.4	115.2	360	29.6	0.4
135	139.6	110.4	365	29.6	0.4
140	130.1	100.9	370	29.5	0.3
145	119.6	90.4	375	29.5	0.3
150	108.8	79.6	380	29.5	0.3
155	100	70.8	385	29.4	0.2
160	97.7	68.5	390	29.4	0.2
165	84.4	55.2	395	29.4	0.2
170	77.8	48.6	400	29.4	0.2
175	69.4	40.2	405	29.4	0.2
180	62.1	32.9	410	29.3	0.1
185	57.5	28.3	415	29.3	0.1
190	54	24.8	420	29.3	0.1
195	49.9	20.7	425	29.3	0.1
200	47.3	18.1	430	29.3	0.1
205	44.3	15.1	435	29.3	0.1
210	41.6	12.4	440	29.3	0.1
215	40.2	11	445	29.3	0.1
220	38.5	9.3		**Total**	**2140**
225	37.1	7.9			

8 PICO HYDRO DESIGNS

8.1 The 'Pico Power Pack'

The 'Pico Power Pack' is a new design of pico hydro-power system. It is low cost, reliable and suitable for electrification of remote villages. For information on how to manufacture this design, a complimentary publication entitled "The Pico Power Pack - Design and Manufacture" has been prepared.

8.2 Inspiration for the 'Pico Power Pack'

The Peltric Set: Different pico hydro systems have been developed in several countries to help solve the growing demand for rural electrification of remote communities. The Peltric Set and FDTA pico hydros in particular provided the inspiration behind the development of the 'Pico Power Pack.' The 'Peltric Set' was developed at Kathmandu Metal Industry in Nepal and is shown in Figure 8-1. A vertically mounted induction generator is directly coupled to a Pelton turbine. The turbine casing also forms the base for the generator which makes the design simple and economical with material. AC electricity is generated which means that the power can be distributed economically over hundreds of metres. There are approximately 500 units of this type electrifying villages in Nepal at the present time.

Figure 8-1 The 'Peltric Set' has provided many rural villages with an economical electricity supply in Nepal

Low Cost DC System: A different system has been designed at FDTA (Fundacion Desarollo de Technologias Appropriadas) in Colombia, South America. The turbine runner is also a small Pelton wheel but a 12V DC car or truck alternator is used as a generator. The turbine is coupled to the alternator using a pulley belt and mounted on a simple steel-angle frame that is easy to manufacture. An installation of this design in shown in Figure 8-2. Since the turbine shaft is horizontal, it is also possible to run other machines with hydro-power in addition to the generator. This design has been used to provide the energy source for a mechanical refrigerator, for example. No extra control system is required other than the voltage regulator which is already included with the alternator. Since DC (direct current) is generated, no frequency regulation is required but the electricity must be used close to or at the powerhouse.

Figure 8-2 A Colombian manufacturer (right) installs a DC pico hydro system.

The pico power pack combines the low-cost steel-angle base and horizontal shaft of the Colombian alternator unit with the simple design of a Pelton turbine directly driving an induction motor used with the Peltric Set. The three designs are compared in Table 8-1.

Figure 8-3 Installed Pico Power Pack

Type of Pico Hydro System	Type of electricity Produced	Amount of power generated	Number of houses which can be electrified	Possibility for using mechanical power	Easy access to nozzle and turbine	Cost
Peltric Set	AC	500-5000W	1 to 300	No	No	Low Cost
Colombian Alternator System	DC	50 - 500 W	1 or 2	Yes	Yes	Very Low Cost
Pico Power Pack	AC	500-5000W	1 to 300	Yes	Yes	Low Cost

Table 8-1 This table compares three designs of pico hydro system

The 'Pico Power Pack' components are shown in Figure 8-4. The generator is mounted horizontally on a steel angle base frame. Since AC (Alternating Current) is generated, the system is suitable for electrifying houses that are up to one kilometre away from the powerhouse, like with the 'Peltric Set'. The removable case makes it easy to inspect the turbine and the nozzle and to clean them when necessary.

The generator shaft is extended at the opposite end from where the turbine is attached. This allows a pulley to be fitted. Small machines such as mills, grinding wheels or saws can be driven with a pulley. In this way, the hydro-power can be used for a wider range of productive purposes. The extra money made through running a small business using pico hydro-power, makes it easier to repay the cost of the scheme.

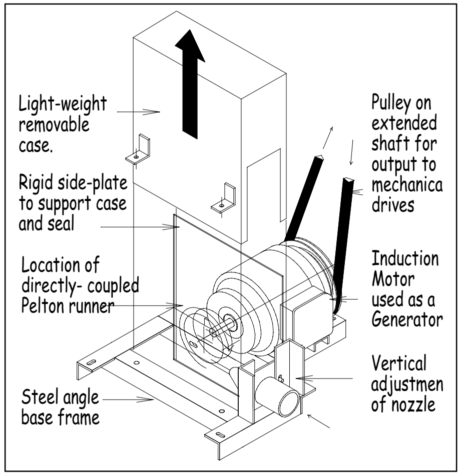


Figure 8-4 The Pico Power Pack generates AC electricity and allows mechanical equipment to be driven.

Table 8-2 Suitability of different turbine designs for pico hydro

Turbine Name	Head Range	Cost for 5kW	Maintenance	Damage by Silt
Pelton	Medium and high	Low	Simple and robust so low maintenance	Little effect from silt
Cross Flow (Michel-Banki)	Medium and low	Low / Medium	More turbine maintenance required than Pelton	Little effect from silt
Turgo	Medium and high	Medium - more complex than pelton	Low maintenance	Little effect from silt
Propeller	Low	Low / Medium	More maintenance required than Pelton	More problems with silt over time
Pump-as-Turbine	Medium and low	Low	More maintenance required than Pelton	More problems with silt over time
Francis	Medium	High - uneconomic at 5 kW	More complicated to maintain	Not for use with heavily silt-laden water

8.3 The Turbine

This is the part of the system which harnesses the hydro power and turns it into mechanical (rotating) power. Several different designs of turbine have been developed. Some of their characteristics are compared in Table 8-2. The type of turbine that is used in the Pico Power Pack is the Pelton wheel.

The Pelton Turbine

The Pelton turbine runner is used for many small-scale hydro power systems if the head is more than 20 metres. It is relatively low cost to manufacture but tough enough to last a long time. The case and nozzle are also simple to build and even a very small Pelton turbine can work very efficiently converting most of the hydraulic power into mechanical power to turn the generator.

Figure 8-5 Locally Manufactured Pelton p.c.d.180 mm (Sri Lanka)

How It works

A Pelton turbine has one or more nozzles that direct pressurised jets of water onto specially shaped buckets that are fixed to a wheel. The buckets absorb the force of the water jet and push the wheel round at high speed, often at 1500 revolutions per minute. The bucket shape is designed to divide the jet into two halves and then to deflect the water away smoothly to stop it interfering with the jet or with the other buckets. A cut-away section allows the next bucket to move further round into position while the first is still in contact with the jet.

The correct size of Pelton Turbine Runner

The size of a Pelton wheel or 'runner' is measured using the 'pitch circle diameter' (p.c.d.). This is twice the distance from the centre of the jet to the centre of the runner.

The size of the turbine runner for a pico hydro system is usually no more than 200mm p.c.d.. This distance is used because this is the place where the jet strikes the buckets and determines how fast the runner rotates.

The smaller the runner becomes the faster it will rotate. This means that direct coupling to the shaft of the generator is possible. This reduces the cost of the parts and makes the system simple to install as pulleys and belts are not required.

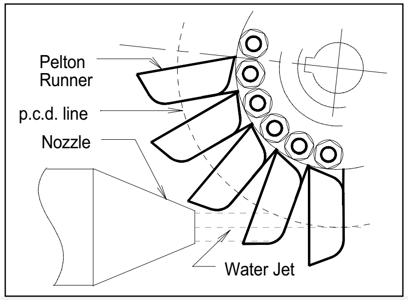


Figure 8-6 The Nozzle directs the water jet on to the p.c.d. line of the turbine runner

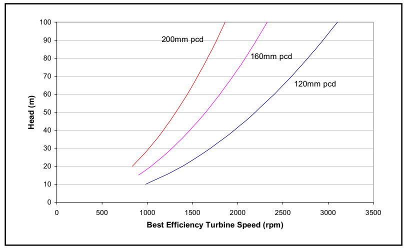


Figure 8-7 Graph showing the operating range of three Pelton runner diameters

9 GENERATING ELECTRICITY

9.1 Safety Warning

Electricity can be extremely dangerous. If a person comes into contact with a live wire or faulty equipment with a voltage higher than 50V, it is possible for them to receive a fatal electric shock. The electricity generating system described here is designed to operate at mains voltage (120V or 220V AC depending on the national standards). Anyone carrying out electrical installation work at these voltages must be supervised by a qualified and experienced electrician. In addition the following safety instructions must be strictly followed:

- Before attempting any installation or maintenance, ensure that the generator is not turning and that the flow control valve on the penstock is firmly closed. Hang a label on the valve to warn others if maintenance is done outside the powerhouse (e.g. "Maintenance in progress – do not operate!").
- Earth all metal cased equipment with a suitable earth connection (see 9.3)
- Never touch any electrical equipment with wet hands.
- Install all equipment according to manufacturer's instructions.
- Do not adjust or attempt to repair equipment unless trained to do so.
- Notices that warn of the danger of high voltages should be clearly positioned on the door of the powerhouse, on the case of the controller and on the front of each load limiter.

9.2 Electrical Standards

National electrical standards should be followed. In some countries, special standards for micro hydro and/or isolated village electrification have been agreed. These standards should be followed even if they disagree with the recommendations given here. Please read the disclaimer at the front of this manual.

9.3 Earth-fault protection

An earth fault occurs, for example, if a live wire becomes loose inside a device and touches its metal case. An **RCD** (Residual Current Device) will disconnect the supply if a fault like this causes a large enough current to flow to the ground (i.e. if the case is earthed or someone touches the case and makes a path to earth). It can also disconnect the supply if someone accidentally touches a live wire causing current to be conducted through them to the ground. This reduces the risk of fatal electric shocks though these can still occur if someone touches both line and neutral and is insulated from the earth. The RCD required is one with a residual tripping current of 30mA. It should be connected directly to the generator as shown in Figure 9-7.

Figure 9-1 3-phase RCD

In addition to an RCD, **earth electrodes** are required to allow the RCD to function. These are metal conductors that are in close contact with the soil and provide a low resistance path for the current to the ground. Connection to an earth electrode is required near the generator. Earth electrodes are also required if any of the electrical loads have metal cases (electric cookers, for example). The resistance of the earth should not be greater than 1kΩ if an RCD with a 30mA tripping current is used. Measurement should be carried out with an earth tester. The manufacturer's instructions should be carefully followed to ensure accurate results. Earth testers are expensive (typically $600 to $1000). Consider hiring or borrowing unless you do a large number of schemes.

Three methods of installing an earth electrode are described:

Method 1 The easiest electrode to install is usually a 1 metre copper-coated steel rod that is driven into the ground near to the powerhouse. The electrode is connected to the neutral terminal at the generator using a low-resistance heavy-gauge copper cable (e.g. SWG 10mm²) and a brass, connecting nut that slides over the rod and allows the cable to be clamped in place. Two shorter rods can be used and connected together if it is not possible to drive the rod 1 metre into the ground. They should be spaced at least two metres apart and connected with the same earth cable.

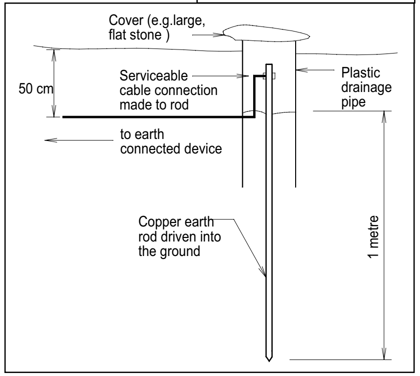


Figure 9-2 A 1m copper-coated steel rod can provide a suitable earth electrode.

Method 2 A second method is to use a loose coil made of about 10 metres of SWG 10 bare copper wire. This should be spread out and buried in a hole about one metre deep. If the soil is damp where the powerhouse is constructed, then the coil of wire can be buried underneath the foundations. Do not bury under the foundations if the soil type is very dry as the resistance is unlikely to be low enough.

Method 3 A third method is to use a copper plate measuring at least 500mm x 500mm. This should be buried in a hole at least one metre deep in an area which remains moist.

Figure 9-3 Installation of a copper-plate earth electrode, Multiple earth cables have been soldered in place to reduce the resistance and increase the reliability.(Nepal)

9.4 Generator Options

Figure 9-4 3-Phase Induction Motor (7.5 kW) with double-ended shaft, used as a generator. (Nepal)

Induction generators and synchronous generators produce AC power. Alternating current (AC) and direct current (DC) are explained in the Appendix. The main advantage of AC is that the power can be transmitted over quite long distances. This makes AC suitable for village electrification projects because the electrical loads (such as light bulbs) are usually quite spread out and often a long way from the generator.

Induction generators are good for providing electricity in remote areas because they are robust and very reliable. However, they are not the only generators that are used for hydro power projects. Different generators have been compared in Table 9-1. Situations where it may be more practical to consider other generators in addition to the induction generator include the following:

1. Very low cost power systems for battery charging or lighting only in a single dwelling next to the powerhouse. Consider a DC generator.
2. Schemes required to power motor loads greater than 15% of the generator rating are best supplied by synchronous generators. For more information about motor starting using induction generators, read Section 13.

9.5 Using 3-Phase Induction Motors as Single-Phase Generators.

Purpose built induction generators are expensive but three-phase induction motors can be used as generators when run in reverse. These are mass-produced and so are quite cheap and easily available.

For most small electrification projects, a single-phase supply is required. It is quite easy to produce a single-phase supply from a three-phase motor. This is done by connecting unequal amounts of excitation capacitance across the winding of the machine as shown in Figure 9-6. This is called C-2C because across the second generator phase, twice the amount of capacitance is connected. On the third phase no capacitors are connected.

It is important that capacitors of the correct type are chosen and properly connected otherwise the generator could fail to operate or overheat. The manufacturer who supplies the turbine and generator should also supply capacitors of the correct size. If the individual components are bought separately, then follow the advice given in Section 9.8.

Figure 9-5 Power Capacitors suitable for connection to induction generators

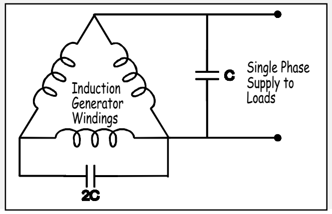
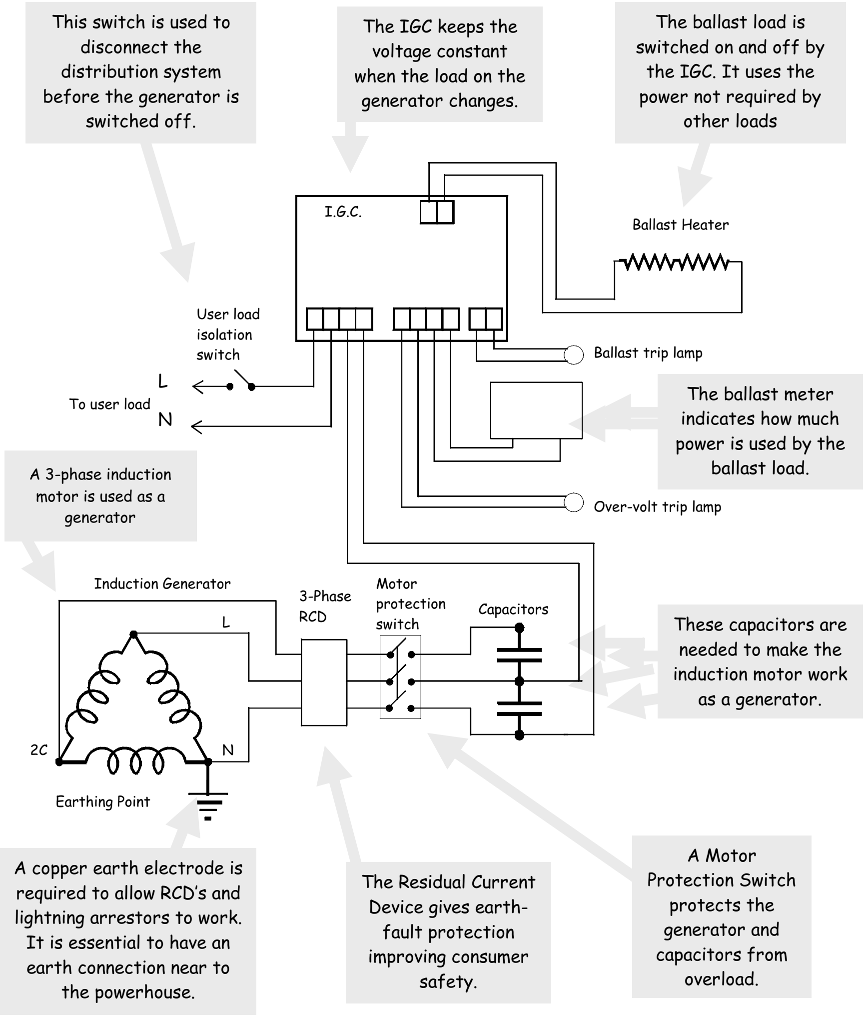


Figure 9-6 Single-phase supply from 3-phase motor

Type of Generator	Source	Typical Cost for 3kW Machine	Speed (rpm) Options	Disadvantages	Advantages
Induction	Standard industrial motor used as a generator	Low: $200 - $250	1000, 1500, 3000	Needs correctly sized capacitors connected to operate as a generator. Poor motor starting ability	Widely available, slow speed ranges, robust simple construction. Can withstand overspeed. Cheaper than synchronous generators
Synchronous - Brushed	Commonly used with petrol or diesel engines.	Low – medium: $300 - $500	3000, sometimes 1500	Brushes and slip rings wear out and require replacement. Must be strengthened for over-speeding	Higher efficiency than induction at part-load and better motor starting capability
Synchronous - Brushless	Occasionally used with diesel engines	High: $600 - $1000	1500, 3000	Not widely available. Repairs are often complex / expensive. Must be strengthened for over-speed	As synchronous-brushed but with better reliability
DC	Car or truck alternator	Not Applicable Max. output ≈ 500W	Car > 2000, truck > 1200	Not suitable for village electrification. Restricted range of appliances. Brushes and slip rings wear out	Very low cost, no controller required.

Table 9-1 Comparison of Generators suitable for use with Pico Hydro Turbines



This switch is used to disconnect the distribution system before the generator is switched off.

The IGC keeps the voltage constant when the load on the generator changes.

The ballast load is switched on and off by the IGC. It uses the power not required by other loads

The ballast meter indicates how much power is used by the ballast load.

A 3-phase induction motor is used as a generator

These capacitors are needed to make the induction motor work as a generator.

A copper earth electrode is required to allow RCD's and lightning arrestors to work. It is essential to have an earth connection near to the powerhouse.

The Residual Current Device gives earth-fault protection improving consumer safety.

A Motor Protection Switch protects the generator and capacitors from overload.

Figure 9-7 Connection of generator and controller

9.6 Electronic Load Control

If the voltage and frequency are not kept at the right level then the user loads connected to the generator can be damaged.

	Too High	Too Low
Voltage	Motors, televisions and radios can be damaged. the lifetime of lightbulbs and heaters becomes shorter.	Most appliances have reduced performance or fail to operate
Frequency	Will not usually cause problems with most consumer loads. Except speed dependant motor loads.	Can cause internal circuits to overheat and fail in radios, TV's and motors.

Table 9-2 Effect of voltage and frequency variation on loads

The speed of the turbine changes when the load connected to the generator changes. For example, if more lights are switched on then the speed of the turbine will decrease. Since this change of speed affects the voltage and frequency, the load on the generator must be kept constant or the flow of water through the nozzle must be adjusted. The most reliable method of controlling the load and keeping the voltage and frequency constant is by using an electronic load controller.

The speed of an induction generator can be kept near constant by using an IGC (Induction Generator Controller). This device sends any unused power to a ballast (or dump load) so that the total load on the generator remains constant. For example, if the generator produces 1000 Watts and the total load connected by the consumers is only 600W then the IGC will control the switching on and off of the ballast so that the remaining 400W is also dissipated. If the consumer load changes at any time, the IGC will automatically adjust the power diverted to the ballast so that the voltage and frequency are kept constant.

The IGC cannot, however, prevent the generator from becoming overloaded. For example, if the generator is producing 1000W but more than 1000W of load is connected then the voltage will fall and the IGC is unable to prevent this. To avoid overloading, the use of load limiters is strongly recommended. This is explained in more detail in Section 15.3.

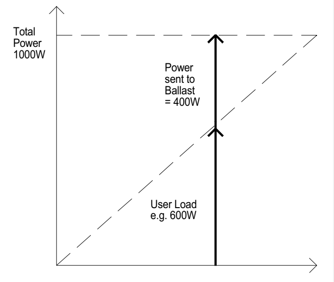


Figure 9-8 Division of power between user load and ballast

The Ballast

The ballast is an essential part of the electronic control system. Great care must be taken with the choice and connection of the ballast. The most common source of problems with induction generator controllers is with the ballast.

Air heaters
Convection heaters are the best type of ballast to use for pico hydro schemes. They are usually reliable and have the longest life. They are sold as electrical room-heaters. Designs that can be mounted on the wall are the safest type. A low-cost 'DIY' design of ballast using cooking rings is shown in Figure 9-9. This will work as a radiant heater when wall mounted on a suitable frame. The cable insulation and frame must be able to withstand very high temperatures. Radiant heaters generally have a shorter life than convection heaters because they operate at a higher temperature.

Water heaters are often used as ballast loads although experience has shown that these often cause problems on small schemes and therefore they are not recommended. Cheap water-heating elements and steel ballast tanks often corrode rapidly. The temperature requires monitoring and cold water must be introduced to the tank before the water boils. Automatic flow control systems can be designed to achieve this but they are complicated and are not cost-effective for pico hydro.

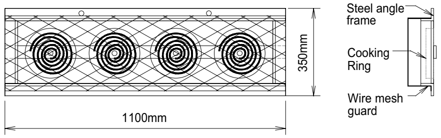


Figure 9-9 Low cost ballast using electric cooking rings

Low Cost Ballast Design

A ballast of this design should be mounted on the wall. The cables must be protected using a heat-resistant sheath and connections made to the heating elements from below.

Calculating the power dissipated
Cooking rings are available with a range of power ratings and are cheap and robust. By connecting two rings in series the voltage is halved and the lifetime is considerably extended. Since the voltage is halved with series connection, the current is also halved and so the power dissipation is therefore quartered. For example, a ballast to dissipate 3.0kW would require 8 rings rated for 1.5kW. That is four pairs of series connected rings across the controller or two of the units shown in Figure 9-9.

$V/2 \times I/2 = P/4 = 375W$ dissipated per ring if series connected in pairs. 8 x 375W = 3.0kW.

The connection of the cooking rings for this example is shown in the circuit diagram below.

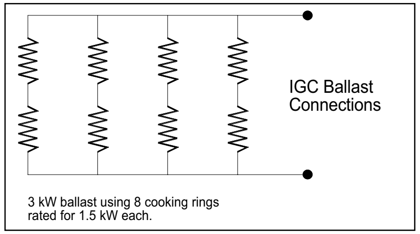


Figure 9-10 Electrical connection of cooking ring ballast (4 pairs of series connected rings)

Protection features of the IGC

Over-voltage trip If the voltage rises too high, then the supply will automatically be disconnected to protect the consumer loads. The over-voltage trip lamp(s) will light to indicate this condition.

Ballast trip: The ballast is automatically disconnected if the ballast is too large or if the ballast connections are shorted out. The ballast trip lamp(s) will light.

Lightning protection: Many IGC designs contain a varistor that minimises the risk of damage to the controller due to indirect lightning strikes.

Meters

The IGC will function without meters fitted. However, these enable the user to maximise their use of the power available and are helpful for identifying the cause of electrical problems.

Ballast meter: This meter indicates the percentage of power being dissipated in the ballast load. It is the most useful meter because it indicates how much spare capacity there is and how close the generator is to being overloaded (when the controller is functioning normally but the meter reads zero).

Voltmeter: This is useful for setting the operating voltage on the controller and for observing the voltage if the generator becomes overloaded. It should be rated for 300V AC and connected to the supply output terminals so that it is protected by the over-voltage trip.

9.7 Alternatives to load control

It is tempting to operate the generator with no load controller present. Two options are available.

Fixing the Load

One method of controlling the voltage and frequency is to have a load connected that exactly matches the output of the generator. However a fixed load is difficult to achieve if more than one consumer is connected and appliances, such as refrigerators, that continually switch on and off cannot be used. It is not recommended

Manual Control of the Turbine Speed

Manual control requires the presence of an operator to correct the flow of water to the turbine and control its speed whenever the load is changing. This method is not recommended for achieving good voltage and frequency regulation and is costly in the long term due to operator wages.

9.8 Selection and Sizing of Generator, Capacitors, Cable and Protection Equipment

Figure 9-7 shows how the generator, capacitors controller and ballast are connected. The are a number of considerations when specifying a motor to use as a generator.

a) Voltage range: The voltage rating of the three-phase induction motor to be used as a single-phase generator must be carefully selected. If the rating is too high, the generator will be unstable. If the rating is too low it will not be possible to achieve the required generator voltage without overheating the windings.

	Motor Rating (kW)		
Type of motor	0.55 - 1.1	1.5 - 3.0	4.0 - 7.5
2 pole	V_{GEN}+6%	V_{GEN}+3%	V_{GEN}
4 pole	V_{GEN}+9%	V_{GEN}+6%	V_{GEN}+3%
6 pole	V_{GEN}+12%	V_{GEN}+9%	V_{GEN}+6%

Table 9-3 Recommended motor voltage.

Note that the operating voltage of the generator (V_{GEN}) is usually set slightly higher than the national single-phase voltage to allow for the voltage drop on the distribution system. Table 9-3 shows the recommended motor voltage, in relation to the generator voltage, for different motor sizes and speeds. This will give stable operation and a near optimum efficiency. The reason why smaller and slower speed generators require higher motor voltage ratings is to compensate for their lower power factors. **The acceptable limits for the voltage rating are +/-6% of the recommended voltage.**

Example: If a 4-pole 3kW motor is to be used to generate 245 Volts, using Table 9-3, the recommended motor voltage is 245V +6%, i.e. 260 Volts. The acceptable limits of motor voltage are 245V (recommended value -6%) and 275V (recommended value +6%).

The effect of increasing the voltage of the motor can be achieved by increasing the frequency by the same percentage. Varying the frequency has drawbacks as shown in Table 9-2. However, small increases of up to about 6% are acceptable. For example, if 230 Volts is a standard voltage available for the 3kW motor described above, this can be used at 6% increased frequency in order to generate at 245 Volts.

The terminal box of many induction motors allows connection in a star or delta pattern giving the possibility of two voltage ranges. The voltage range for star and delta is given on the nameplate. Either of the following is suitable for a 220V scheme:

Either 380-415V star / 220-240V delta
Or 220-240V star / 127-139V delta

Note: Motors of 3kW and above are often wound for 660–720V star/ 380–415V delta. These are not suitable as 220–240V generators. Most manufacturers will supply motors wound to the voltage you require, with a longer delivery time.

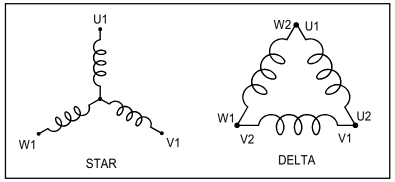


Figure 9-11 The two voltage ranges are possible with many induction motors by connecting the windings in 'Star' or 'Delta'

b) Frequency: The frequency rating should be the same as that required by the loads (i.e. 50Hz or 60Hz). For a direct drive system, the generator speed must be matched to the turbine speed. Note that the generator speed is always about 10% higher than the motor speed. Shaft speeds for common sizes of induction generator are given in the table below. Select a machine with the correct number of poles.

No. of poles	50 Hz	60Hz
2	3.120 rpm	3,750 rpm
4	1,560 rpm	1,875 rpm
6	1,040 rpm	1,250 rpm

Table 9-4 Examples of induction generator shaft speeds

c) IP Number: Select a motor which is IP 55. The IP number is a measure of how easily liquid or dust (e.g. flour) can enter the machine. IP 55 models are resistant to either and therefore suitable for hydropower applications.

d) Insulation Class: Always select the highest available winding insulation class. The two most common types are B and F. Class F has a longer life than Class B. For the same operating temperature, Class F insulation will last four times as long as Class B.

d) Power Rating: Estimate the maximum electrical power output, P_{max}, by calculating the hydraulic power and assuming an overall efficiency of 50% (unless actual efficiencies are available). Use P_{max} and the generator voltage (V_{GEN}) to work out the operating current.

$$I_{op} = 1.1 \times \frac{P_{\max}}{V_{GEN}}$$

where I_{op} = maximum operating current
V_{GEN} = generator voltage

The (rated) line current of the motor, I_{line}, must be greater than or equal to the operating current:

$$\mathbf{I_{line} \geq I_{op}}$$

Example: A 2-pole generator is to be used on a pico hydro with a maximum electrical power output of 1,500 Watts. The national voltage is 220 Volts and the generating voltage 220V + 6%, i.e. 233V, calculate I_{op}:

I_{op} = 1.1 x 1500/233 = 7.1 Amps.

A 2.2kW 2-pole motor is available which, when delta connected, has a voltage rating of 240Volts (the recommended voltage as given in Table 9-3), and a line current of 7.6 Amps. This motor is ideal for use at this site.

Over-current protection

The generator windings and cables must be protected from excessive currents. These can cause them to overheat and fail. High currents also damage the capacitors.

Figure 9-12 Motor Protection Switch

For maximum protection a motor protection switch should be used as the tripping current can be adjusted to the precise current rating of the generator. Typical current ranges for motor protection switches are 2-4A, 4-6A, 6-10A, 10-16A, 16-20A, 20-24A. For the 2.2kW motor in the example, a 6-10A motor protection switch would be ideal. The alternative to the motor protection switch is the Miniature Circuit Breaker (MCB). However, these have the disadvantage of being only available with fixed current ratings and so cannot be set to the line current of the motor.

Figure 9-13 Miniature Circuit Breaker

Current rating of the cable

The cable current rating should be at least 40% greater than the maximum current rating of the Motor Protection Switch or MCB. Conduit should be used for the powerhouse wiring. The current ratings given, apply to single-core, PVC insulated cables which conform to BS 6004, BS 6231 and BS6346.

CSA of copper cable (mm^2)	Current capacity (Amps)
1.0 mm^2	13.5A
1.5 mm^2	17.5A
2.5 mm^2	24A
4.0 mm^2	32A
6.0 mm^2	41A
10.0 mm^2	57A

Table 9-5 Current carrying capacity of single-core electric cables enclosed in conduit

Selection of Capacitors

The excitation capacitors (C-2C) required to enable a 3-phase induction motor to work as a single-phase generator will determine the frequency of the electricity produced. The capacitance required to generate at a particular frequency varies between one motor and another and depends on whether the motor voltage rating is higher or lower than the recommended value in Table 9-3. The basic rule for calculating the required capacitance C is as follows:

$$C(\mu F) = k \times \frac{I_{line}}{V_{GEN} \times 2\pi f}$$

where:
π = 3.1416
f = frequency of the generator (Hz)
k depends on the voltage rating of the motor which is used. As described earlier, the acceptable limits for the motor voltage rating are +/-6% of the recommended value (given in Table 9-3). The multiplying factor, k, can be found from Table 9-6:

Recommended voltage is used (as in Table 9-3)	k = 0.35
Recommended voltage +6% is used	k = 0.3
Recommended voltage -6% is used	k = 0.45

Table 9-6 Values of multiplying factor, k.

The value of C, as calculated above, should be rounded up to the nearest 5µF and the 2C (2 x the calculated value, C) rounded down to the nearest 5µF. It will probably be necessary to adjust these values further in order to obtain the exact frequency required. The total capacitance C and 2C should be made up of a number of individual capacitors. This will allow some adjustment of the C-2C to be made during installation. The voltage rating of the capacitor should be comfortably greater than the maximum generator voltage, e.g. capacitors should be rated for 380V AC if generating at around 220V. They should preferably have a screw fitting underneath to allow them to be securely mounted (see Figure 9-5). The 'motor-run' type of capacitors should be used as these are rated for continuous use. 'Motor-start' capacitors are only designed for intermittent use and are therefore not suitable. For information about connection of the capacitors, see Section 9.9.

Selection of the IGC

The power rating for the controller must be equal to or greater than the maximum electrical power output of the generator, P_{max}. A good quality IGC from a reputable manufacturer must be used as it cannot be repaired by the operator.

Additional electrical protection

1. A **lightning arrestor** should be fitted close to the powerhouse. This will protect the generating equipment from high voltages caused by nearby lightning strikes and act in addition to the varistor that protects the IGC (see Section 16).

2. The cables in the powerhouse must be protected from mechanical damage by using **cable conduit**. The conduit must be fixed to the generator connection box and to the controller/ capacitor casing with threaded fittings. This provides an additional layer of insulation, prevents the cables from being pulled accidentally out of their connection boxes and provides a watertight connection.

3. An **isolation switch** is needed to disconnect the distribution system as the generator must be started and stopped without user load connected. Also it may be necessary to disconnect the user loads when driving mechanical loads. A mains switch or an MCB can be used as an isolation switch.

9.9 Installation and Connection

In addition to Figure 9-7 the following guidelines should be used when installing and connecting the generator and additional electrical equipment.

Connecting the generator

As described under "Generator Selection" in Section 9.8, an induction motor with either of the following connection possibilities is suitable for a 220V scheme:

a) 380-415V star / 220-240V delta
b) 220-240V star / 127-139V delta

Using motor a), the metal links should be arranged in the terminal box to give the delta connection. Using motor b), the links are arranged to give the star connection. This is illustrated in Figure 9-14. The three cables to the RCD are tightened under the terminal washers at the generator.

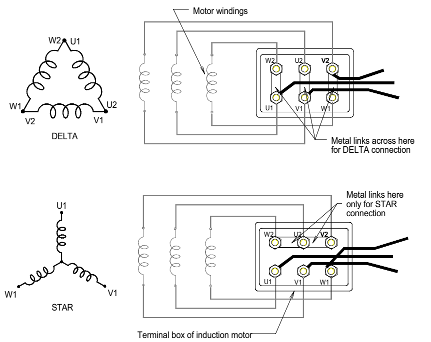


Figure 9-14: Make sure the metal links are arranged correctly in the terminal box to give STAR or DELTA connection with the correct voltage range.

Connect the earth electrode to any of the three terminals if the delta connection is used. For a star connected motor, use any of the three separate terminals but not the star point attached to the metal links. The earthed terminal becomes the neutral (N) and the remaining two terminals are labelled live (L) and 2C. It does not matter which way round L and 2C are as this will be determined when the generator is commissioned.

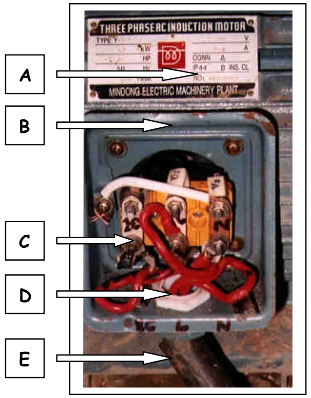


Figure 9-15 Connections inside generator terminal box. Several problems have been identified and solutions given in the Table 9-7

	Problem	Solution
A	IP 44 only	Use IP 55 which have better protection against liquid and dust
B	No seal on connection box	
C	Loose connections causing over-heating	Tighten connections every 6 months and use 'shake-proof' washers at terminals
D	Lack of colour coding	Cables of different colours should be used to avoid wiring errors.
E	Pipe used as conduit	Use cable conduit and conduit connectors to terminal box. (see photo)

Table 9-7 Problems with generator connections

Installation of the RCD

This should be mounted on the wall between the generator and controller. Ideally it should be enclosed in a purpose built housing with a transparent front allowing the operator to see when a trip occurs.

Connecting Capacitors

Connect the 3-phase RCD (2C, L, N) and motor protection switch as shown in Figure 9-7. The capacitor connections will depend on the number of capacitors that are used. For example, a particular generator requires C=52μF, 2C=104μF. The capacitors available are 5μF, 15μF and 30μF. Rounding C up to 55μF and 2C down to 100μF allows these to be used and connected as shown in Figure 9-16. The 100kΩ / 2Watt resistors are used to discharge the capacitors if the protection switch or RCD trip, preventing shock.

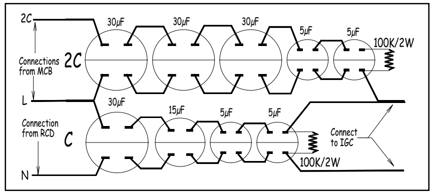


Figure 9-16 Suitable connection of capacitors if C= 52μF

Connecting several capacitors of different sizes together, to make up the total values of C and 2C, enables small adjustments to be made and allows the frequency to be corrected when the generator is commissioned. Removing small amounts of capacitance increases the frequency. If the C capacitance is reduced by a certain value then 2C should be reduced by approximately twice that value.

Most large capacitors have two connections on each side and cables may either be soldered in place or attached using suitable connectors that are usually clamped onto the end of the wires with the aid of crimping pliers. Connectors and the appropriate tool should be used if they are available as soldering is impractical in isolated locations and prevents on site adjustment. Damaged capacitors are also difficult to replace if the connections are soldered. When crimping, ensure that the connections are very tight, both between the wire and crimp and crimp and capacitor terminal.

Installing the IGC.

The IGC is normally housed in a metal case that is mounted on the powerhouse wall. The case should preferably have a hinged door and be large enough to comfortably accommodate the capacitors in addition to the IGC circuit board.

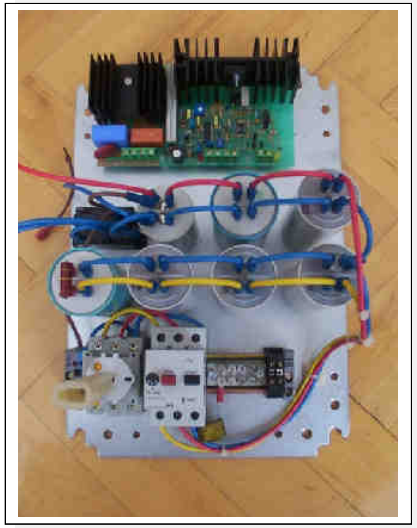


Figure 9-17 Correctly installed IGC and Capacitors

The trip lamps on the IGC may be mounted are usually mounted the circuit board and in the door of the metal case.

Follow these instructions for IGC installation:

- IGC must be installed vertically, in a well-ventilated and dry location.
- Connect according to labelling of terminals and label all connecting wires.
- The case must have ventilation holes that allow a flow of cool air to pass over the finned heat sinks of the IGC. The air vents should be above and below the IGC, covered with wire mesh and a solid protective cover raised above the surface that prevents entry of dripping water (as shown in Figure 9-18).
- Check that no cables are touching the heat sinks as the insulation could be damaged when the controller is operating.
- If housed in a metal case, then the case must be earthed.
- The ballast heater must not be installed underneath the IGC but above or at the side.

The case must be locked, with a 'high voltage' warning label on the door. A second label should state that the box must not be opened unless the IGC has been isolated from the Generator

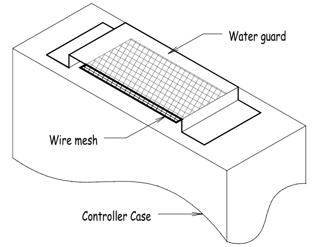


Figure 9-18 Suitable design of air vent for controller and capacitor casing. A vent should also be provided at the bottom of the case to allow air-flow over the components

10 FLOW MANAGEMENT

10.1 The Intake

The intake of pico hydro schemes can be a simple and inexpensive arrangement. Non-permanent solutions are favoured over elaborate weirs due to their lower cost and greater flexibility. The effect of floods must always be considered when designing the intake.

Pipe intake – for ample flows

Boulders used to divert part of a river flow into a simple canal or submerged length of pipe as shown in Figure 10-1 are often sufficient. With such simple and inexpensive solutions, storm damage can be repaired with local materials. Though careful construction is required to prevent frequent repair being necessary. The pipe must sometimes be quite long to ensure that the entrance is higher up than the exit to the canal. Flexible pipe is easier to use than rigid pipe and it should be anchored in the flow with large stones. The entrance should be raised slightly off the bed of the river or stream. This will prevent silt or debris from blocking the entrance.

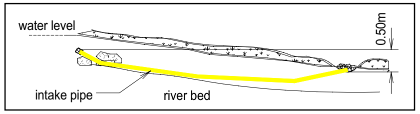


Figure 10-1 The simplest intake design is a pipe anchored in the flow

Weir intake – for low flow sites

A small weir can be constructed out of concrete to ensure that all the available water is diverted during the dry season. This may be a practical solution at some sites. The flexible pipe, which removes the water, is set into the weir. The foundations and the sides of the weir should be joined to solid rock to prevent water from leaking round and eventually undermining the structure.

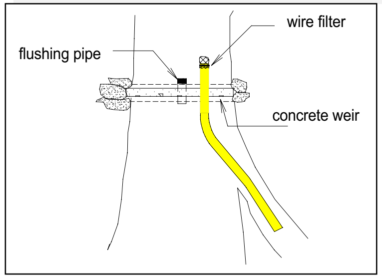


Figure 10-2 An intake using a small concrete weir is useful if the flow is very low during the dry season

Construction of Small Concrete Weirs

The proportions for small concrete or masonry weirs should follow approximately those given in Figure 10-3. Often large stones cemented together can be used for the construction of the weir. The strength of the structure is significantly improved by using a gabion. This is a wire cage that holds the structure together. It is particularly useful where strong flows are expected. The wire mesh is usually made from 2 or 3mm diameter wire with a mesh size of 50mm to 100mm.

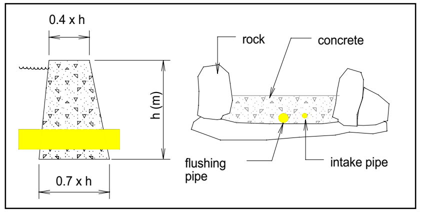


Figure 10-3 The construction of a weir should follow the above proportions.

Figure 10-4 A concrete weir can be used to form a small reservoir (Nepal).

Filters

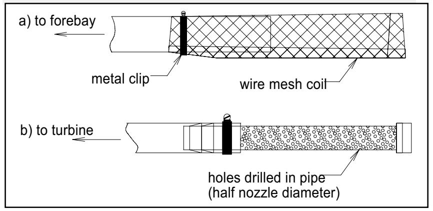


Figure 10-5 Filter designs for a) intake and b) penstock

Filters are required to prevent pipes that are used for pico hydro installations from becoming blocked with materials such as silt, wood and leaves. There are two situations where a filter is required:

1. the intake pipe leading to a canal, forebay or reservoir as illustrated above.
2. the entrance to the penstock pipe (see Section 11).

For the first case, the size of the holes in the filter is not important. The only thing to consider is how to prevent the pipe from becoming blocked. One method of building a suitable filter is to use a tube of wire mesh. The tube can be fixed to the pipe with a metal clamp such as a jubilee clip.

In the second situation, when the filter is positioned at the entrance to the penstock, it is important that the holes in the filter are smaller than the nozzle at the other end. Actually, they should be about half the diameter of the nozzle to be sure that any particles that enter the pipe can not cause a blockage at the other end. (If the nozzle becomes blocked then there is a danger that the penstock will burst due to the sudden pressure.) A filter with small holes can be made out of a piece of plastic or metal pipe that is capped at one end. Lots of holes are made using a correctly sized drill. It is important that the total area of the number of holes drilled is more than the area of the pipe to make sure that enough water can be drawn in. The filter is threaded or clamped over the pipe to ensure a tight seal.

10.2 Canals

Figure 10-6 Canal installed in a difficult location supplying a small hydro scheme for local electrification (Peru)

A canal can be a low cost method of conveying water from a source some distance to a more favourable intake position. For some sites, this can really improve the economic viability by reducing the length of penstock and cable required. At other sites a canal is an expensive addition and can often require regular maintenance due to leaks, soil erosion and landslides.

Using a canal and deciding on the route it should take, are decisions that must be considered carefully. The following factors are important:

- Local experience and history with building and managing similar water systems such as irrigation canals.
- The availability of cheap / free labour to dig and maintain the canal
- Soil type, lining requirements and cost of transporting materials such as cement.
- The cost of other options such as a longer penstock / longer distribution cable compared to the cost of a canal. The use of low-pressure pipe to convey water to the intake may also be a lower cost alternative.
- Could a new canal serve a dual purpose, irrigating land during the dry season in addition to supplying the turbine?
- Are there any existing (or abandoned) irrigation canals that could be directly used or improved or extended if necessary?

If the canal is lined with concrete or stones and cement, then its strength and reliability will be improved. However, such a lining will increase the cost considerably. In many remote areas this will not be practical because of the difficulty of transporting building materials. Lining a canal also increases its efficiency. Water can travel at higher speed without causing the sides to erode so for a particular volume flow rate, the dimensions can be reduced (see Table 10-1).

Canal design

The flow of water in a canal depends on:

- The speed or velocity of the water
- The cross-sectional area of water

The equation for flow rate is

$$Q = vA$$

where:
Q = flow rate (m^3/s)
(multiply by 1000 for flow in litres per second)
v = velocity (m/s)
A = Cross-sectional area of water (m^2)

1. The **velocity** of water flowing in a canal (v) depends on the slope of the canal and the 'roughness' of the material which has been used to line it.

There is an **upper limit** to the velocity for different building materials. Above this value the sides can quickly become eroded.

Canal material	**Max. velocity to avoid erosion in shallow canals**
Sandy soil	0.4 m/s
Clay soil	0.6 m/s
Concrete / masonry	1.5 m/s

Table 10-1 Velocity limits for shallow canals (<0.3m deep)

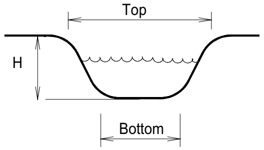
From Table 10-1 it is apparent that for earth lined canals, the maximum velocity of the water is much less than for those with a durable lining. If the water contains silt then there is also a **lower limit** to the velocity of 0.3 m/s. This is to prevent the silt being deposited and blocking the canal. If the water is clear then the lower limit is not important. A low velocity means that the drop required over the length of the canal is small. For this reason, the canal dimensions given in Table 10-2 have been calculated using a design velocity of 0.3 m/s. This allows the head loss in the canal to be reduced and maximises the head available for the penstock.

In the following examples of canal dimensions a roughness of 0.07 has been assumed. This is suitable for a shallow canal with some vegetation. The roots of vegetation growing along the canal cause some friction but they are useful because they support the sides.

2. Design of canal cross-sectional area (A)

Naturally, the canal cross-sectional area must be bigger than the cross-sectional area of water needed to give the flow required. The extra height (called the freeboard allowance) is usually about 30%. This reduces the risk of the canal walls being damaged by overfilling.

The sides of an **earth canal** should slope outwards. This reduces the risk of the walls collapsing due to the erosion caused by the flow of water. It is possible to construct a canal with vertical walls if it is strengthened by lining the sides with stones and cement or with concrete. In this case the top and bottom dimensions are the same. However, masonry and concrete linings are expensive and are rarely cost-effective for pico hydro schemes.



In order to simplify the process of canal design, suitable dimensions for the cross sectional area are given for different flow rates in the following table. The head loss is the drop for 100m of canal. If the required length of canal is 200m then multiply the head loss by 2 and build with this drop over its length.

	Canal lining and minimum dimensions		
10 l/s	Sandy soil	Clay soil	Concrete/ masonry
Height H	13 cm	15 cm	15 cm
Top Width	59 cm	44 cm	29 cm
Bottom Width	6 cm	13 cm	29 cm
Head Loss (100m length)	1.6 m	1.3 m	1.4 m
20 l/s			
Height H	19 cm	22 cm	21 cm
Top	84 cm	62 cm	42 cm
Bottom	9 cm	18 cm	42 cm
Head Loss (100m length)	1.0 m	0.8 m	0.9 m
30 l/s			
Height H	23 cm	27 cm	25 cm
Top	103 cm	75 cm	51 cm
Bottom	11cm	22 cm	51 cm
Head Loss (100m length)	0.8 m	0.6 m	0.7m

Table 10-2 Suitable minimum canal dimensions for different flow rates and lining materials

Seepage

Earth lined canals loose a significant proportion of the water due to seepage. In sandy soil areas expect at least 5% to be lost through seepage per 100m (e.g. 0.5 l/s for a flow rate of 10 l/s)

Providing additional water is available, it is worth sizing the canal for a larger flow rate than that required by the turbine. Assume that an additional 10%-20% will be required. This will allow for some loss through small leaks as well as seepage. Sometimes water in the canal will also be used for a number of purposes such as irrigation or domestic supply. The requirements should be taken into consideration at the design stage.

Canal Construction.

The route taken by the canal must be carefully selected. If possible the following areas should be avoided:

- Excessively porous ground
- Rocky areas which prevent excavation
- Steep and unstable sections

Sealing the canal with clay or concrete in porous areas may be an option but large rocky outcrops should be avoided. Steep sections and storm gullies are also difficult but in many rural areas, ingenious solutions have been found. Canals have, been successfully constructed in some very difficult locations (see Figure 10-6 and Figure 10-9). These require careful planning, local motivation and persistence but not necessarily great expense.

Figure 10-7 A length of pipe can be used to bridge a difficult gulley with a small canal. The pipe is secured with rocks on either side.

When crossing a storm gulley, for example, it is particularly important to allow adequate drainage for rainwater that could otherwise destroy the sides of an earth canal. Short lengths of pipe (Figure 10-7) or small wooden aqueducts (Figure 10-8) can sometimes be used to bridge difficult sections of the route.

Figure 10-8 A wooden aqueduct can be used to transport water in the canal across uneven ground

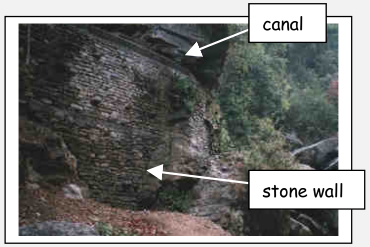


Figure 10-9 and Figure 10-10 show a raised canal that runs on a narrow ledge underneath a vertical rock face. The canal has a masonry lining and is supported by a high stone wall underneath.

Low Pressure Pipe

An alternative method to convey water to the intake is to use low-pressure, plastic pipe. This is available in some countries as drainage pipe. Low-pressure pipe is cheaper than penstock pipe because the walls are thinner. It will often be a cheaper alternative than a concrete lined canal.

Figure 10-11 Land drainage pipe

Some consideration needs to be given to the best diameter and the slope of the pipe since this will affect the flow rate and head loss. See Section 11.

10.3 Forebay Tanks

Figure 10-12 A small forebay is suitable where flow is sufficient throughout the year

The forebay tank provides a sufficient depth of water to ensure that the top of the penstock is always covered. In some cases the penstock is extended to the intake and then no forebay is required. A forebay is required where a canal is used or if water from more than one source is collected.

The design of the forebay may vary depending on factors such as:

- accessibility of location
- availability of building materials
- type of ground and soil
- cost of labour and local skills

However, it is highly recommended that all designs include an overflow facility and some means of draining to allow the tank to be cleaned.

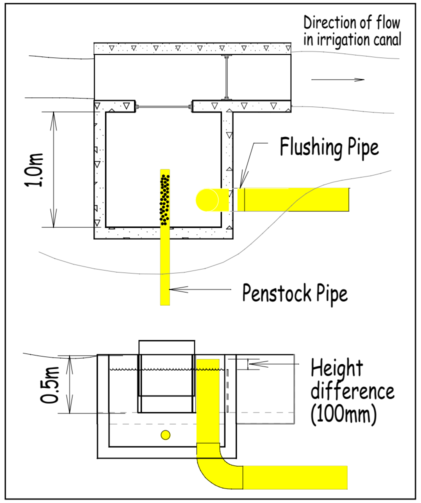


Figure 10-13 Suggested design of forebay tank fed from an irrigation canal.

Depth of Water

The depth of water in the forebay tank should be sufficient to cover the penstock by 4 times its diameter. The penstock should also be approximately one diameter clear of the bottom.

Example

What depth should the overflow in the forebay be set at if the penstock is 75mm in diameter?

Answer

Depth above penstock = 4x75 = 300mm
Depth below penstock = 75mm
Penstock diameter = 75mm
Therefore approximate depth of overflow
= 300+75+75 = **450mm**

Silt

Since the water in the forebay tank is slow moving, silt falls to the bottom where it forms a thick layer of mud. This can block the penstock if it is allowed to become too deep. Larger hydro schemes often have desilting basins to remove the silt. This is rarely necessary for pico hydro providing that a sluice gate or a flushing pipe is included (see Figure 10-13). This makes the job of cleaning out the silt much easier.

Overflow

If the forebay becomes full, the water must escape without causing damage. The overflow can be a notch or channel cut into the lowest wall of the forebay (see Figure 10-15). An alternative method is to use a pipe that combines the overflow and the flushing facility. This is illustrated in Figure 10-13. The vertical pipe can be removed from the elbow to flush out the tank. This example shows a forebay that is fed by an irrigation canal although the water could equally well be provided by a low-pressure pipe. The flow can be diverted into the forebay when required. Otherwise the water always continues to flow down the canal.

Whichever method is used, the overflowing water should be directed away from the forebay, preferably into another stream or a ditch.

Forebay Construction

Providing that labour is available a small forebay, using stones and clay as a seal, is not expensive to construct. The intake to the penstock is easier to secure if stones are used in the construction of the walls. If the forebay frequently overflows then the clay will be quickly eroded and will require regular repair.

Cement and stones or concrete are used to construct forebays with a longer life and greater erosion resistance. A suitable method for cementing stones or bricks to line a forebay, canal or reservoir is shown in Figure 10-14

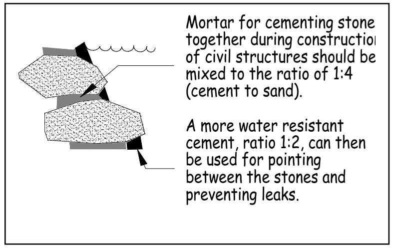


Figure 10-14 Masonry techniques for pico hydro civil structures

Figure 10-15 Construction of stone forebay (Kushadevi, Nepal)

Figure 10-16 The flow of water into the forebay is controlled by a sluice gate. An overflow is cut into the wall on the downhill side so that excess water is returned to the stream without undermining the masonry. A flushing pipe, sealed with a wooden bung has been incorporated at the lowest part of the tank.

10.4 Reservoirs

Figure 10-17 A small reservoir provides low-cost energy storage which can be useful during the dry season. (Sankhuwa Sava, Eastern Nepal)

The forebay can be enlarged to form a small reservoir if the flow during the dry season is insufficient to operate the turbine continuously.

For example, water is stored up during the day and night when the turbine is not in constant use and then released to provide power for evening lighting.

Water storage can add a useful degree of flexibility and security to the scheme if either of the following are true:

1) The water will be collected from more than one source, some of which is likely to be intermittent.

2) The water is or will soon be used for other purposes apart from hydro-power, such as irrigation.

The storage requirements are easily calculated if the flow required by the turbine and the lowest expected flow into the reservoir are known. The manufacturer should provide information about the flow requirements of the turbine. The reservoir should be sized according to the minimum expected flow. This must be measured during the driest part of the year using one of the techniques described in Section 0. Alternatively it must be estimated by relying on local knowledge.

Example Storage Capacity of a Reservoir

A 1.5kW turbine and generator have been selected for the site in Western Nepal described in the example on page 7-1. The head has been measured at the site and found to be 70 meters after friction losses in the penstock have been taken into account.

In order to generate this power with this head the turbine manufacturer recommends a flow of 5 litres per second. Measurements of the flow in the nearest stream to the village have been taken during the driest part of the year, after several weeks of no rain and found to be only 2 litres per second. This is also the lowest flow that has been observed in the stream according to local knowledge (thought to be reliable as far back as 10 years). During the rest of the year, however, a flow exceeding 5 l/s is available. Storage will be required for the dry periods to enable the scheme to supply electricity to the village for 5 hours of lighting in the evenings and for two hours of mechanical power to drive a saw in the workshop during the mornings.

How big does the reservoir need to be?
Flow in during driest period = 2 l/s
Flow into penstock = 5 l/s
Maximum period of operation = 5 hrs
Shortfall in supply during this period
= 5 - 2 = 3 litres per second

The reservoir must have enough capacity to supply an extra 3 litres per second during the period of operation.
Volume of water required as storage:

5hrs = 5 x 60 x 60
= 18000 seconds
Volume = 18000 s x 3 litres per second
= 54000 litres or = 54 m^3
(1 cubic metre = 1000 litres)

What dimensions should the reservoir be in order to store 54 m^3?

The reservoir will be allowed to fill up overnight so that the saw can be driven in the morning.

The ground is rocky at the proposed site of the reservoir and it is unfeasible to dig a reservoir that is more than 1.5 m deep.
Suitable dimensions would therefore be 1.5 metres depth x 6 meters width x 6 metres length.
1.5 x 6 x 6 = 54 m^3

An alternative solution for this village is to supply the reservoir with water from a spring that is some distance away. They can transport approximately 1 litre per second though a narrow but inexpensive pipe from the second source during the driest period. What is the new storage capacity required?

[Answer = 36 m^3 so suitable dimensions would be 1.5m x 6m x 4m]

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11 THE PENSTOCK

11.1 How the penstock works

The penstock is simply a long pipe that fills with water. The weight of the water in the pipe provides the required pressure at the nozzle to drive the turbine. This pipe may run directly from the water source to the turbine or from the end of a canal that brings the water closer, saving on the cost of a longer pipe. A filter is connected at the intake end. At the turbine, there is a valve used for turning the water flow on and off. After the valve is the nozzle which concentrates the water into a high-pressure jet.

11.2 Penstock Selection

The penstock is often the most expensive component of a pico hydro scheme. It is therefore important that the pipe used is carefully chosen.
There are three things to consider when buying pipe for the penstock:

- **the material**
- **the internal diameter** - depends on the length and flow rate.
- **the pressure rating** - depends on the net head.

The Pressure Rating

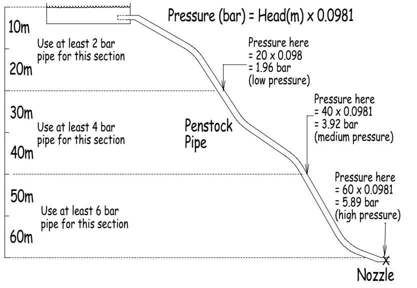

Figure 11-1 Penstock pressure rating

The penstock is designed to convey water under pressure in a safe and efficient manner to the turbine. The higher the pressure, the thicker the pipe walls must be and the more expensive it becomes. The pressure of the water in the penstock depends on the head. If pipe with a pressure rating which is too low is used, then there is risk of a burst. If the pressure rating is too high then money has been wasted. The ideal penstock will be low pressure at the intake and thicker at the nozzle where the pressure is greatest.

Selecting the correct pressure rating

The pressure at any point in the pipe can be easily calculated if the head at that point is known. Refer to Figure 11-1 in order to understand how the pressure in the pipe changes with the head.
Plastic pipe has a built in safety factor of between 1.5 and 2.5 to allow for pressure surges. This means that the pipe can be used up to the manufacturers pressure rating (providing that the joins between the lengths have been correctly made and the pipe is firmly anchored or buried). The flow control valve must be turned slowly on and off to minimise sudden pressure surges. If these guidelines are followed and the pipe is used up to the manufacturers pressure rating then costs will be kept to a minimum without a safety compromise.

The importance of pipe diameter

The diameter is important because it affects the power available to the turbine. The larger the diameter, the more power there will be. Although the pipe may appear smooth, it has some surface roughness that slows down the water. This slowing down is called ‘frictional loss’. The frictional loss is expressed in metres of head loss and is greater when the speed of the water is greater. The water speed and therefore the frictional loss increase if either the turbine nozzle is made larger or the penstock diameter is made smaller. Frictional loss also increases in proportion with the penstock length. If a pipe of larger diameter is used then the frictional loss is less but the price increases significantly. Typically, if the diameter of a pipe is doubled, then the price is increased four times. The frictional loss however is about 30 times less!

Selecting the Optimum diameter

First, find out the flow rate required for the turbine. This information should be provided by the manufacturer. If not, use the method based on the nozzle diameter which is described in the complimentary manual for manufacturers of the Pico Power Pack. Also needed, is the total length of pipe required (the distance taken by the pipe from the forebay to the turbine) and the total head available.

Look at Table 11-1. First find the flow rate nearest to the one required in the left-hand column. The recommended compromise between friction loss and cost of pipe is 15%-20% frictional loss. All the head losses given are for 100 metres of pipe. These figures must be multiplied by [required pipe length / 100] in order to give an estimate of frictional loss at the site. This loss should normally be no more than 25% of the total head. If the head loss is 20%, then the net head will be 80% of the gross (total) head:

NET head (available to turbine)
= GROSS head (total head)
– head loss due to friction

Sometimes a head loss different to 20% should be chosen. For example, if the gross head available at the site is scarcely enough to run the turbine, then a penstock only resulting in a 10% frictional loss could be considered. Alternatively, if the distance between the site for the powerhouse and the forebay tank is long and head is more than necessary, a loss of 30% could be tolerated if it meant a significant saving in cost with sufficient power still being provided.

Example :Selecting penstock diameter

a) Which is the diameter of penstock that will give a head loss of around 20% and be the most cost effective. The following information is known:
The turbine selected requires a flow rate of 6 litres per second
The gross head is 70 meters
The penstock will be 300 meters in length

Answer:

Head loss is required which will be approximately 20% of 70.
70 x 0.20 = 14 metres
The values in the table are for pipes of 100m in length. We require 300 meters therefore the values in the table must be multiplied by
300/100 = 3
Looking along the column for a flow of 6 l/s and calculating the head loss:
300 m of 50mm pipe = 3 x 17.07 = 51.21 metres
300 me of 63mm pipe = 3 x 5.48 = 16.44 metres
300 m of 75 mm pipe = 3 x 2.36 = 7.08 metres

Clearly the best choice is 63mm (2.5") pipe which gives a head loss near to 14 metres

b) If HDPE pipe of only 100mm and 50mm diameter were available, what would be the most cost-effective combination?
Answer:
80 metres of 50mm pipe (for high pressure section)
= 0.8 x 17.07 = 13.6 metres
220metres of 100mm pipe (for low pressure section)
= 2.2 x 0.58 = 1.28 metres
Total head loss = 13.6 +1.28
= 14.9 metres

Penstock Materials

For pico hydro schemes, the penstock pipe is usually made from plastic. HDPE (High Density Polyethylene) is used in many countries. It is particularly suitable because it is both flexible and weather resistant. This type of pipe is usually coloured black. Internal diameters up to 75mm (3") are flexible enough to be coiled up which makes transportation easier. Common internal diameters (or 'nominal bore') used for pico-hydro are 50mm, 63mm, 75mm, 90mm, 100mm and 110mm.

Alternative materials are PVC (Polyvinyl-chloride) and steel. PVC is widely available for use as domestic waste pipe. However, PVC pipe and fittings for domestic use are rated for low pressures only and therefore not suitable for penstocks. Low-pressure PVC pipe is suitable for use in the forebay (flushing pipe and overflow). Steel is commonly used for larger hydro when the flow and pressure in the pipe are higher. The three materials have been compared in Table 11-2.

11.3 Connecting the Nozzle

Figure 11-2 Reducer, gate valve and nozzle

A gate valve is recommended to turn on and off the water supply to the turbine. These are widely available and because they take more time to close, they reduce the likelihood of large 'surge pressures' from developing in the penstock that can cause it to burst. This can occur with "butterfly" or "globe" valves that allow the flow to be reduced more rapidly. Grease should regularly be applied to the threaded stem of the valve to prevent corrosion and eventual seizing. The turbine nozzle should be threaded on the outside to allow the valve to be screwed into place. The manufacturer should supply a compatible valve with the turbine. PTFE tape or paste is very useful to help lubricate and waterproof threaded connections and should be applied if available. Similarly on the penstock side, a suitable threaded connector is required. This may be provided on a reducer as illustrated in Figure 11-2 which can then be attached to a larger penstock diameter using a flange coupling (see Figure 11-10).

Table 11-1 Head Loss per 100m length for different diameters of plastic pipe at different rates of flow

Flow (l/s)	**Internal Pipe Diameter (Nominal Bore)**				
	50mm (2")	**63mm (2.5")**	**75mm (3")**	**88mm (3.5")**	**100mm (4")**
2.0	2.28m	0.75m	0.33m	0.15m	0.08m
4.0	8.03m	2.62m	1.13m	0.52m	0.28m
6.0	17.07m	5.48m	2.36m	1.09m	0.58m
8.0	29.09m	9.31m	3.97m	1.83m	0.98m
10.0	44.19m	14.05m	5.98m	2.73m	1.48m
12.0	61.9m	19.69m	8.38m	3.82m	2.05m

Penstock Material	**Transport to site**	**Installation**	**Joining sections**	**Lifetime**	**Roughness**
HDPE	Dia. 75mm or less can be coiled	Easy because flexible	Requires skill to fusion weld	Very weather resistant and tough	Low so not much head loss.
PVC	6m lengths only	More difficult because quite rigid	Easy with pipe connectors and PVC cement but high cost	Degrades in sunlight unless painted	Low so not much head loss
Steel	Difficult in remote areas because of weight	Rigid and heavy therefore difficult	Welding or bolting flanged sections together. Not cost-effective for pico hydro	Corrodes gradually and requires maintenance	Medium for new pipe becoming worse with corrosion

Table 11-2 Comparison of penstock materials

11.4 Penstock Installation

STEP 1 LAYING OUT

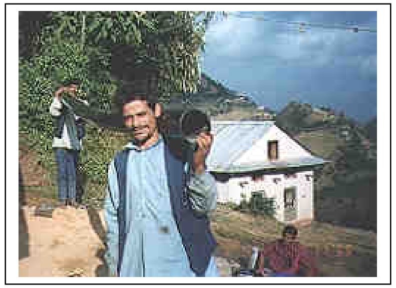

Figure 11-3 Delivering pipe sections to the site.

Check that the pipe that has been delivered is the correct type and length. The route for the penstock from the intake to the generator should have been marked out and vegetation cleared where necessary. Lay out the pipe sections along the proposed route, making an initial check that the quantity ordered is sufficient

STEP 2 PREPARING THE ROUTE

Figure 11-4 The penstock can be laid in a trench and then buried when the installation is complete to secure it

The pipe can be laid on the surface of the ground providing that obstructions such as rock and branches have been cleared. Care should be taken to prevent mud, stones and debris from entering the pipe sections. The penstock should follow a downhill course where ever possible and must at no point be higher than the penstock entrance in the forebay. In some situations it will be necessary to lay the pipe in a trench to maintain the correct gradient. In other areas the pipe will require supporting above ground level. How this is achieved will depend on the size of pipe and the height above ground. This is when the advantages of HDPE pipe become apparent. Its flexibility means that it is considerably easier to install than either PVC or steel.

Figure 11-5 Pipe sections that span gaps must be supported at the correct height.

Pipe above 75mm in diameter requires more support than smaller sizes. Initially, sticks can be used to help bridge difficult areas.

Figure 11-6 The supports must be suitably reinforced before filling the pipe.

Before the pipe is filled with water, more secure foundations, using stones and mud for example, must be constructed.

STEP 3 JOINING THE PIPE

HDPE pipe sections can be joined at the site using hot fusion. The tools required are a steel plate with diameter slightly larger than the pipe being joined and a jig to support the two sections.

Figure 11-7 The metal plate is heated in a small fire

First the plate is heated over the embers of a small fire

Figure 11-8 Both sides of the pipe are held against the hot plate.

The two ends of pipe are inserted into either side of the jig with the heated plate in between. The plastic is allowed to soften evenly at the end of both sections by holding the lengths firmly in place.

Figure 11-9 The plate is removed and the two sections are brought together forming a neat bead around the pipe.

When a bead has formed all the way around on both pipe sections, the plate is removed and the two lengths are forced together. An even weld 'bead' around the whole circumference indicates a successful join. The pipe must not be moved until the joint is completely cool. Teflon is a heat proof, non-stick material which is available in fabric form. A Teflon bag can be used to cover the hot plate and prevent the plastic pipe from sticking during the initial softening. The plate should be at 220°C for softening HDPE. Heat temperature indicating crayon ('Thermochoc' in Nepal) are available which change colour when the correct temperature has been reached. A small amount is applied to the plate during heating. The correct plate temperature is often learned by experience however, as the crayons are not always readily available.

STEP 4 CONNECTING TO THE TURBINE NOZZLE

Figure 11-10 Penstock connection using flanges

The connection between the penstock and the turbine is important because it is here that the water is at its highest pressure. Sometimes the penstock is connected directly to the gate valve that controls the flow. A reducer is usually required as the penstock diameter is generally larger than the valve. A suitable method of connecting a plastic penstock to a steel reducer is illustrated in Figure 11-10. An HDPE pipe flange fitted with a steel ring has been fused to the end of the penstock. This can then be securely bolted to the reducer after inserting a gasket.

An 'Excel' software program has been developed to help design the penstock and calculate the head loss in different pipe sections. For a copy of the program, please contact the editorial address.

12 The POWERHOUSE

12.1 Construction

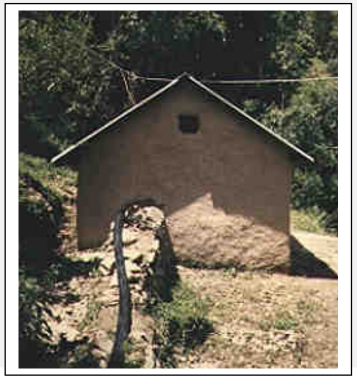

Figure 12-1 Typical stone powerhouse in Nepal

A good design of powerhouse will protect the turbine, generator and other equipment over its lifetime, which should be a minimum of 15 years. The construction of the powerhouse will vary depending on local availability of materials, local preferences and the local climate. However, cutting costs by building an insubstantial powerhouse is false economy. Constant maintenance and repair work will be required otherwise the life of the generating equipment will be considerably reduced. Equally, an over-built powerhouse will be more expensive than necessary. The following guidelines will help to construct a building that will be a suitable compromise between cost and quality for most locations.

Foundations:

- A foundation trench should be dug down to solid rock or otherwise to a depth of one metre below each wall. It should be twice as wide as the intended wall. Any soft areas at the bottom of the trench should be dug out and filled with stone or concrete. The trenches should be levelled as far as possible in a similar way. Soil dug out of the trench should not be used for this purpose.
- A footing is then required on which the walls will stand. This should be twice the width of the walls and stepped up at the top as shown in Figure 12-2. Suitable materials for the footing are concrete, brick and stone depending on what material is used for the walls.

Floor:

- Raised above ground level to prevent flooding during heavy rainfall.
- Lined with concrete to ensure secure foundations for the turbine and generating equipment.
- Sloped towards the tailrace so that any spillage drains away.
- Large enough area to allow for all round access to turbine, generator and control equipment. If any mechanically-driven machinery such as grain mills are also housed or likely to be in the future, then the floor area should be increased accordingly.

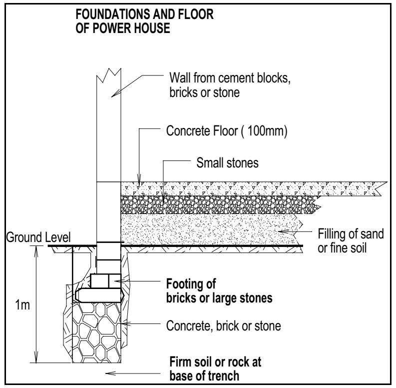

Figure 12-2 Recommended construction of foundations and floor

Walls:

- Should be at least 2m high at the lowest point and constructed to allow roof to be pitched.
- Should be thick enough to allow adequate protection from storms. Provision should be made for mounting control box, ballast equipment, capacitor box etc. Suitable methods are the use of wooden panels and built in shelving.

Windows:

- Essential to provide light and ventilation.
- Not facing the prevailing wind direction.
- Should be secured with wire mesh or wooden shutters to prevent unauthorised entry (not necessarily with glass.)
- Window area should be 1m^2 for every 10m^2 of floor space.

Door:

- The door to the powerhouse should open outwards for safety and should be lockable.
- It must be large enough to allow access for all equipment including possible future acquisitions.
- It should prevent entry of rainwater.

Tailrace:

- The tailrace should be lined with concrete to a depth of 100mm inside the powerhouse.
- The concrete lining should extend a minimum of 1m outside the powerhouse and must be leak proof in order to protect the powerhouse foundations.

Figure 12-3 Power house under construction, Nepal

Roof:

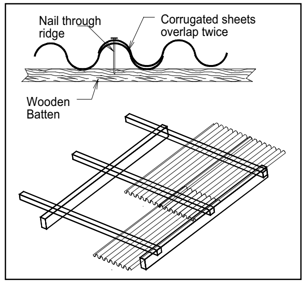

Figure 12-4 Suggested techniques for assembly of corrugated steel roof

- The roof must be watertight and pitched to improve drainage.
- It should preferably be made of a fire-proof material such as clay tile or corrugated steel and definitely be waterproof.
- It should extended beyond the walls to prevent water from entering the window spaces.
- Ventilation spaces should also be left under the eaves to allow circulation of air if the windows are closed.

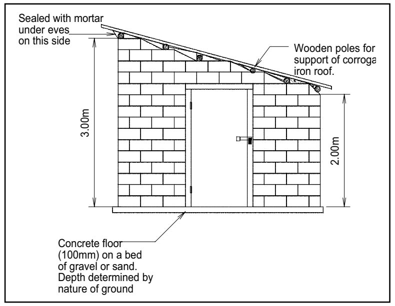

Figure 12-5 Recommended powerhouse construction methods

12.2 Layout

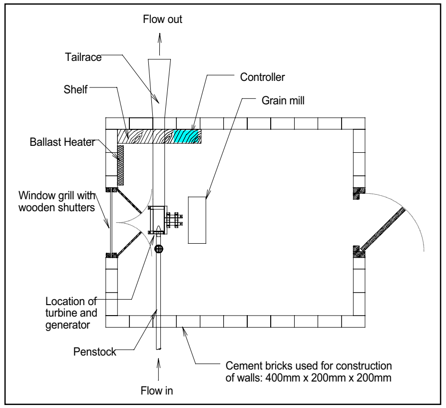

Figure 12-6 Suggested layout for powerhouse components

12.3 Planning the Installation.

1. Planning	2. Preparation	3. Construction and Assembly	4. Connection	5. Testing	6. Commissioning
Finalise the design particularly concerning the locations of the powerhouse, forebay or reservoir and intake	Order deliver and store materials and equipment at the site taking into account any late modifications	Lay the penstock pipe in position negotiating any difficult ground such as rocky outcrops or sunken areas	Connect penstock sections and join to flow control valve		
Make minor adjustments to design, and mark out positions of powerhouse, penstock and forebay or reservoir	Clear a path through the vegetation for the penstock digging a shallow channel if necessary	Position intake and dig canal if necessary. Otherwise lay pipe to forebay area which has been marked if forebay is required	Support penstock where necessary and cover particularly if made of PVC.		
Ensure that sufficient gradient exists for water to flow into forebay or reservoir from intake pipe or canal	Clear the site and construct the foundations for the powerhouse, allowing correct positioning of turbine and generator. Consider if earth connection is in base.	Assemble turbine and generator base frame on support structure and built supports for mechanically driven machinery	Line the forebay or reservoir as necessary with concrete or stone and cement and complete any building work at the intake	Check penstock and fittings for leaks	
	Make any final adjustments to positioning of forebay or reservoir and excavate	Construct the walls and roof of the powerhouse	Connect excitation capacitors, load controller, ballast and protection devices to generators	Test run turbine and generator to check for correct operation	Cover penstock with turf or soil
	Identify a suitable location for an earth connection near the powerhouse. (Unless earth is buried in the foundations)	Excavate and position the earth electrode. Attach a cable to powerhouse		Check correct operation of controller and ballast.	Train operators and managers
				Check operation of mechanical loads	Resolve any electrical problems with domestic connections.
Distribution System					
Check site plan including length and size of distribution cable required before delivery	Connect distribution cables together, erecting poles where necessary	Position domestic loads and load-limiters. Connect service cables to main distribution system.	Connect protection devices such as RCD(s) and lightning arrestors	Connect the distribution system to the load controller	Check operation of distribution system

Table 12-1 The installation has been divided into six phases to help the developer plan the order of activities. Work down the columns and then across the table, some activities can be carried out in parallel with others which will save time.

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13 SELECTING THE LOADS

The LOADS are the devices which are connected to a pico hydro system and which work as a result of the power generated by the turbine. They can be divided into **electrical** and **mechanical** loads.

13.1 Electrical loads

Electrical loads use the electricity produced by the generator. Many kinds of electrical loads can be used with a pico hydro system. A few common electrical loads are listed below. They have been divided into two groups: those that use a motor and those which do not. There are additional considerations when connecting motor driven loads to a pico hydro scheme. These are explained in Section 13.2.

Non-motor driven loads, for example:

- Lighting
- Battery chargers
- Radios
- Televisions

Motor driven loads, for example:

- Food processors and liquidisers
- Refrigerators
- Ventilation Fans
- Workshop tools (grinding wheels, drills, saws, planners, sanders)

The type and number of electrical loads that can be connected depends on the amount of electricity being generated. The following sections discuss the technical considerations for each type of load more carefully.

Lighting

Lighting is often the primary use of the electricity that is generated from a pico hydro system. The provision of electric lighting in an unelectrified rural community can improve the quality of life by a large margin. There are three types of electric lighting which are most commonly used for domestic purposes.

Incandescent lighting. Light bulbs of this type use a filament made of wire that heats up and gives off light when a suitable current is passed through.

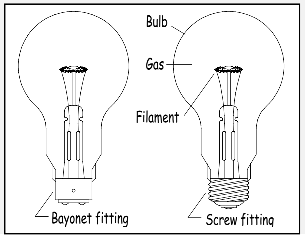


Figure 13-1 Incandescent lamps

Incandescent light bulbs are commonly used because they are cheap and easily available. However, they have quite a short lifetime and make inefficient use of the electricity. The problem is that only 8 to 12 % of the electrical energy is converted to light. The rest escapes as heat. Although there are a few lighting applications which use this waste heat such as chicken hatcheries, in most cases light bulbs of this type are a highly inefficient way of using the electricity which has been generated. In addition, constant heating and cooling of the filament eventually causes it to burn out and then the bulb has to be replaced.

Tubular Fluorescent Lighting. This type of lamp has electrodes at either end of the tube. These release small particles called electrons which cause ultraviolet light to be produced from the argon gas that is held inside. UV light is converted into visible light by a fluorescent coating on the inside of the glass.

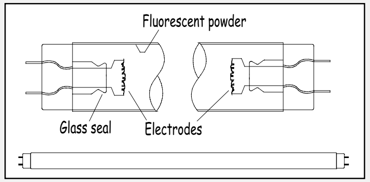
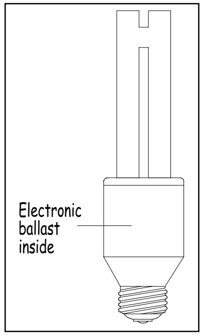


Figure 13-2 Tube lights

Tube lights require an electrical circuit called a ballast in order to control the electric current flowing through the lamp and to give a high voltage at the electrodes. An inductive ballast (a coil of wire on an iron core) was commonly used up until recently when electronic ballast's were developed. Electronic ballast's can operate at a higher frequency and this helps to improve the performance and increase the life of the lamp.

Compact Fluorescent Lamps (CFL's)-
These have been developed more recently and are already widely available. They work in the same way as fluorescent tubes except that the tube is narrower and folded over several times. The electronic or inductive ballast is usually contained in the base of the lamp. The design allows the lamp to be fitted to a conventional socket, with either a bayonet (BS) or Edison screw (ES) fitting. You can usually tell if an inductive ballast is fitted as the lamps are heavier.



Reliability of Fluorescent Lamps
Electronic circuitry in fluorescent lamps makes them sensitive to the quality of the electricity supply. If the voltage and frequency vary by large amounts then it is possible that the lamps will be less reliable and have a shorter life. Otherwise their life should be at least 5 to 10 times longer than an ordinary light bulb. It is therefore important that the voltage and frequency are kept near their rated values.

The rated value of voltage and frequency is the value that the device has been designed for. This is written on the side of the bulb.

The life of a ballast (and hence the lamp for CFL's because the ballast cannot be replaced separately) will be reduced if the frequency is less than the rated value (50 or 60 Hz) or if the voltage is higher than the rated value (110V, 120V, 220V etc.). Both these conditions cause the amount of current drawn to increase and will therefore have an adverse effect on the life of the windings or circuitry because of over-heating. Small rises in frequency or reductions in the rated voltage will probably be tolerated.

The lifetime of CFL's and tubes is also reduced if they are switched on and off many times. This makes them unsuitable for places where a light is only required for a short period e.g. a cupboard or a toilet.

Power Factor Correction of Fluorescent Lamps.
The term 'power factor' is explained in Appendix A on Electricity. Power factor correction means to adjust the power factor of the system nearer to one. The power factor already has a value of one for incandescent lamps so no correction is required. For fluorescent lamps which contain inductive ballast's, the power factor can be as low as 0.5. This has two impacts on a scheme where large numbers of the lamps (50+) are connected:

1. Power losses in the cable increase due to large amounts of reactive power which are drawn.
2. Low load power factor causes the generator frequency to rise and could cause de-excitation of the windings of the induction generator. This would cause the generator to stop working until some of the lamps are disconnected.

Power factor can be improved by connecting capacitors across the inductive loads. The amount of capacitance required will depend on the number of fluorescent lamps which are connected. Ideally each house with fluorescent lamps should have its own capacitors. Larger capacitors cost less per micro Farad (μF) than smaller ones so it is wise to power-factor correct all the lamps in one house with a single capacitor. Metalised polypropylene lighting capacitors that are available in size from 4μF are ideal for power factor correction of small lighting loads.

Although it is difficult to estimate the size of the inductive loads on a system until it is built, the approximate amount of power factor correction required should be estimated at the initial planning stages and priced in to the scheme costs.

Figure 13-3 Metalised Polypropylene Lighting Capacitors for power factor correction of fluorescent lamps

Example Capacitance required for power factor correction of inductive loads

A pico hydro scheme has 100 houses connected to a 2.5 kW generator. In each house there is a 20 W fluorescent tube. The power factor of these tubes (according to manufacturers' information) is 0.5. If the scheme operates at 220V and 50 Hz :

a) What value of capacitance should be connected to each tube to bring the power factor up to a value of 1?

b) If the capacitance is considerably cheaper when purchased in larger units and each house has four 20W fluorescent tubes, what size of capacitor should be chosen to correct the complete domestic lighting circuit?

a) How much current does each fluorescent tube require?

$$I = \frac{Power}{V \times \cos\phi}$$

$$I = \frac{20}{220 \times 0.5} = 0.182A$$

What capacitance is required to power factor correct given this current value?

$$C = \frac{I \times \sin\phi}{6.3 \times V \times f}$$

C = Capacitance required (Farads)
I = Current rating of device (Amps)
cos ϕ = Power factor
V = nominal voltage (Volts)
f = frequency (Hertz)

$$C = \frac{0.182 \times 0.87}{6.3 \times 220 \times 50} = 2.27\mu F$$

To fully power factor correct this fluorescent lamp, a capacitance of 2 micro-Farads (μF) should be connected across the supply. Under correction of the power factor is recommend when the precise value of capacitance for full power factor correction is not available (see note.)

b) In order to power factor correct four lamps per house then the capacitance required is 4 x 2.27 = 9.08 μF. Two 4μF capacitors connected in parallel across one of the lamps is the best solution in this case. If capacitors of only one or two sizes are available, then connect to the appropriate number of lamps to bring the power factor to 1. Always connect capacitors directly across the inductive load, otherwise there will be too much capacitance connected when other lamps are switched off.

Note: Do not over correct the power factor. This will reduce the supply frequency and increase the current in the wiring.

Voltage Rating of Capacitors
The price of capacitors depends on the voltage rating as well as their size. (i.e. the number of micro farads) The voltage rating of capacitors should be at least that of the loads to which they are connected. Capacitors with higher voltage rating than the load will have a longer lifetime. For small loads such as lights, which are used intermittently and for short periods, it is best to choose capacitors with the same voltage rating (i.e. 220V) as these will be the cheapest option. For power factor correction of larger loads such as motors it is worth spending more on capacitors with a higher voltage rating. For example, capacitors rated at 415V would be a good choice for a 220V motor.
Advantages and disadvantages of the three types of lamps are compared in Table 13-1.

	Advantages	**Disadvantages**
Incandescent lamps	✓ Low cost, widely available therefore easy to replace. ✓ Not damaged by low voltage operation ✓ Power factor of 1	× Low efficiency, made worse if the voltage falls. Therefore, not the best choice when the power available is limited. × Short life-span (750-1000 hours)
Fluorescent Tubes (ordinary type)	✓ Relatively Low cost ✓ Widely available ✓ Good efficiency so a good choice for village lighting using pico hydro ✓ Long life-span (5000-8000 hours)	× Require different socket (can also be an advantage, see below*) × Larger than other types of lamp for the same output. × Must be disposed of carefully as contains mercury vapour. × A separate ballast is required. This will require periodic replacement in addition to the tube. × May require power factor correction. × Not suited to frequent on/off switching.
Compact Fluorescent Lamps (CFL's)	✓ Very good efficiency and are a good choice for a scheme where the voltage and frequency are correctly controlled. ✓ Fit into standard sockets ✓ Ballast is usually contained in the lamp. ✓ Very long life-span (8000-10000 hours)	× Initial cost is more than previous types although prices are falling. × More sensitive to variations in the supply which can affect lifetime and performance. × Require careful disposal (contain mercury vapour). × May require power factor correction × Not suited to frequent on/off switching.

Table 13-1: Different types of electric lighting compared

*A pico hydro scheme which provides lighting can become overloaded if CFL light bulbs fail and are then replaced by incandescent lamps (these are cheaper). An additional advantage of tube lighting is that there is less temptation to replace with incandescent bulbs since the sockets will also require changing to allow them to be connected.

Battery Charging

Battery chargers are useful in rural areas that are not grid -connected. Using hydro-power as a charging source, they can be left running for long periods and, depending on their design, may charge several batteries at the same time. Batteries can be used by people who live too far away to be connected directly to the generator. A battery allows the use of simple electrical loads and can be recharged when required for a small payment that is much less than the cost of disposable batteries.

Figure 13-4 Battery charging with hydro power (Peru)

Batteries store low-voltage dc electricity which is different from the higher voltage ac electricity which is produced by the generator. Two common types of rechargeable batteries, used for providing power to small electrical appliances in remote areas, are lead-acid and nickel-cadmium (Ni-Cad). Lead-acid batteries are used to provide 12V electricity in most motor vehicles and often used for lights, radios and TV's in rural homes because they have relatively high energy storage and are widely available. There are different types of lead-acid batteries. The older motor vehicle type, allow the electrolyte to be topped up with distilled water. Modern designs are maintenance free and sealed to prevent spillages. A more expensive type of lead acid battery is the deep-cycle battery. If available, these provide a more reliable and long lasting form of energy storage than motor vehicle batteries.

Nickel Cadmium batteries are more expensive per unit energy stored and used to power small electrical goods such as torches and radios. They give a smaller voltage than lead-acid batteries but are easier to handle and more reliable.

Battery chargers convert the electricity from AC to DC and prevent overcharging which is important to maintain the life and reliability.

Charging Lead-acid Batteries Safely

- Explosive gases are produced during the charging of vented lead-acid batteries so the presence of flames or sparks nearby is extremely dangerous and must be avoided.
- Charge batteries in a well ventilated area
- Use gloves and goggles when handling to avoid burns from sulphuric acid which forms the electrolyte. Wash any spillage's immediately with clean water.
- Even quite flat batteries can cause a fire if the terminals are accidentally shorted out with a cable or other metal conductor.
- Always disconnect the charger before disconnecting the batteries under charge.

Battery performance

Lead acid batteries should not be fully discharged as this damages them. Motor vehicle batteries are only intended for shallow discharging and ideally should not be discharged by more than 20% of their capacity. A small battery charge indicator (quite cheaply available in some countries) is useful to monitor this. Deep-cycle batteries can be discharged up to 80% of their capacity without damage.

The reliability of a battery reduces the more it is cycled (charged and discharged). Generally a new, good quality motor vehicle battery will fail after 200 cycles to 50% of its capacity. A suitable depth of discharge for a motor vehicle battery is therefore is 20%. This will prolong its useful life. Deep-cycle batteries can be cycled many more times, typically 1000-2000 times at 80% depth of discharge. This means that they will last many times longer than a motor vehicle battery even though they are more expensive initially.

Ni-Cad are the opposite to lead acid in that they perform better and last longer if fully discharged before re-charging. This is advantageous as no charge monitoring required and the natural tendency is to use batteries until they are fully discharged.

Battery Capacity

Capacity indicates how much energy a battery can store. A 60 amp-hour battery can deliver one amp for 60 hours or 20 amps for 3 hours. Multiply the amp-hours by the battery voltage to get Watt-hours.

Example

How long could a 12V 60Ah motor vehicle battery be used to power a black and white television which requires a 40W 12V DC supply before recharging if the maximum depth of discharge is 20%.

Answer:
Storage capacity of battery
= 12 x 60 = 720 Watt-hours.
Useful capacity before recharging =
=720 x 20% = 144 Watt-hours
Hours of TV viewing (40W TV)
= 144 / 40 = 3hrs 30mins

Emergency Lighting

A product sold for emergency lighting has recently become available in many countries. This is a tube light with a built in battery and charging unit. In areas where the grid is unreliable, these lights are popular because they can be used during power cuts and then plugged into the mains for recharging when the grid comes back online. They can also provide a useful lighting solution in rural areas and be charged when required from an induction generator. Since they are also portable, they remove the need for torches.

Figure 13-5 Example of emergency lighting sold in Kenya with 2 x 8W fluorescent tubes and plug for recharging (Cost = $35).

Radio and Television

After lighting, radios or televisions are probably the most common domestic loads. The main considerations when operating these loads from a pico hydro system or other isolated electricity supply are as follows:

- Operating at under-frequency or over-voltage is harmful. The life of internal components such as transformers will be shortened due to excess current.
- Small increases in frequency should not be harmful
- Protect expensive televisions with a separate voltage regulator.
- Operating from a DC supply such as batteries will not cause damage providing that electricity at the correct voltage is supplied and the TV or radio is designed to work with batteries.

13.2 Motor-driven loads

Many modern appliances are driven by electric motors. However, connecting motor driven loads to an isolated electricity supply requires additional considerations. The main differences between a motor and other common types of electrical load are that the current required can vary greatly:

- during motor starting, much more current is required than when the motor is running.
- the current required by a motor can vary during use depending on the load connected.

For example, a motor connected to a saw will draw more current when a plank of wood is being cut than when the saw blade is spinning freely. Alternatively, a motor driving a fan will draw a constant amount of current when the fan is running because the load on the fan does not change.

A number of undesirable things can happen if the wrong size of motor is used with a particular generator:

- the motor will not start and the generator de-excites.
- the supply voltage dips sharply when the motor is started. When the motor is running the voltage is lower than its rated value indicating that the scheme is overloaded.
- the MCB in the powerhouse may trip and disconnect the all the loads, if the machine which the motor is driving becomes jammed

Being unable to start the motor, or tripping the circuit breakers whenever the motor is in use, may cause frustration and disillusionment with the system. These problems can be minimised by careful planning.

13.3 How to avoid problems with motor starting

To avoid problems with motor starting, the following should be considered:

a) the **size of motor** which is connected to the generator
b) the **type of motor** which is connected
c) the **type of load** which is driven by the motor
d) the **length and size of cable** between the motor and generator.

a) Size of motor

Motors use much more power at starting than when running. Also when switched on they cause an initial drop in voltage which reduces their starting torque. If too large a motor is switched on , the starting torque will be insufficient to turn the shaft.

What is the largest motor that can be started using a pico hydro system?
Use this general rule to decide:
Max. Motor power = 10% of Generator power
For example, the largest motor that could be started and driven by an induction generator producing 2.5kW is: 10% of 2500W = <u>250W</u>

b) Type of motor

Universal motors are used in many small and hand-held appliances, such as electric drills. They are compact, available in smaller sizes than induction motors and easier to start. The type of motor that is used for most loads requiring more than about 200W is the **induction motor**. This is the same type that is used as a generator for the Pico Power Pack. Capacitors are often connected to help induction motors to start and to improve the power factor whilst running. The motors are then classified depending on which capacitors have been connected. The type of induction motor which is used, should consider the load that is being driven

Type of motor	**Characteristics**	**Suitable loads**
Capacitor start	High starting torque	Fridge compressors, mills,
Capacitor run	Good power factor/ low starting torque	Grinding wheels, drills, fans
Capacitor start and run	Best all round performance	Saws, planers,

c) Starting different types of loads

The type of load connected, affects how easy a motor is to start. The turning force (or torque) required, for example to start turning a mill is different from the force required to begin turning a fan. A high starting torque is needed to start the mill in order to overcome the friction of the grinding wheels.

For some types of machines that are easy to start, like fans, the motor power can be increased to 20% of the generator power. Machines that can be sized for 20% of the generator output include the following;

- Fans
- Grinding wheels (for tool sharpening)
- Electric drills

d) Position of the motor

The motor is likely to be one of the largest single loads in the distribution system. It is important the voltage is kept within the required range. If the motor is situated near to the generator then it will benefit from a higher voltage. This will reduce starting problems. If the motor is a long distance from the generator, the cable to connect it will be expensive and there will be a lower starting voltage.

13.4 Mechanical end-uses

In addition to supplying domestic electrical loads such as lighting, pico hydro-power can be put to good use during the daytime. The power can be used to make money and quickly repay the loan that was taken to help buy the equipment.

Many money-making activities which are useful to the community such as grain milling, need mechanical power. In areas that are serviced by a national electricity grid, the mechanical power is usually provided by electric motors. It is still possible to run some motors using the electricity generated with a pico hydro plant, but there are significant constraints on this as explained in the previous section.

Fortunately with pico hydro-power, there is also an opportunity to drive mechanical loads directly. The mechanical energy of the turbine runner can be transferred directly to the loads without conversion into electricity. This is usually achieved by means of pulleys and belts. The main advantage of using mechanical power directly is that much larger loads can be driven than would otherwise be possible with electrical motors. For a comparison of electrical and mechanical drives, look at Table 12.2.

If the mechanical power is used directly by linking the end-use machinery with pulleys and belts to the turbine, then it is possible to drive equipment requiring almost the full rated power of the turbine. A small efficiency loss occurs in the belt drive. This will be, at most, 10% of the power in the turbine shaft if the pulleys and belts are correctly sized and tensioned. This leaves 90% of the power to drive the load. Compare this with the maximum size of induction motor that ca n be driven, calculated on Page 13-6.

	Electrically Driven Machines	**Mechanically Driven Machines**
Ease of Starting	Difficult or not possible except for relatively small motors.	Excellent , since turbine torque is highest at zero speed.
Efficiency	low (50% of turbine power)	High (90% of turbine power)
Location	Very flexible	Very inflexible (must be located next to the turbine)
Maintenance and Repair	More complicated therefore maintenance and repair needs are greater	Simple to maintain and repair.
Cost	Cost may be lower than mechanical equivalent if device is mass-produced. The cost of cable and power factor correction must be included.	Pulleys, belts and tensioning equipment must be included. Locally produced machinery may be more expensive than mass-produced electrical appliances.

Table 13-2 Comparison of electrically and mechanically driven loads

Example : Calculate the mechanical power available to drive a load.

The power in the turbine shaft is 3.5 kW
The efficiency of the belt drive is 90%
Answer
90% of 3.5 = 3.5*0.9 = 3.15 kW
Power available = **3.15 kW**

Some examples of mechanical loads which are commonly driven by hydro-power are listed in Table 13-8. Typical power requirements and speeds for small loads (suitable for use with some pico hydro systems) have also been given. Before purchasing mechanical equipment, consult manufacturers' information and ensure that the power output of the turbine is sufficient. The choice of equipment will determine the pulleys and belts required. Read the next section carefully to make sure these are appropriately selected.

13.5 Pulleys and Belts

Pulley belt drives are used to link mechanical equipment to the turbine shaft where the equipment has a different operating speed to that of the turbine.

Note: Direct drive of mechanical loads

If the load can be directly driven from the generator shaft then no pulleys and belt are required. These are the considerations:

- Turbine speed must match the load speed
- Turbine must have the same centre point as the load. (Is it practical to position the load near the floor?)
- Disengaging the load from the turbine is more complicated.

Direct drive is practical with particular loads in certain circumstances (e.g. grinding wheels) but this is seldom the case.

Two types of pulley belt are commonly associated with hydro power schemes, the V-belt and the flat belt. V-belts are the most suitable for pico hydro. They are smaller, lighter, easier to install and maintain, and lower in cost compared with flat belts.

V-belt drives are an efficient and robust method of transmitting power between the turbine and other machinery. Wedge belts are a more modern version of the V-belt. They can transmit more power because they wedge themselves deeper in to the pulley and can therefore get more grip. The differences in size between the two types are illustrated in Figure 13-6

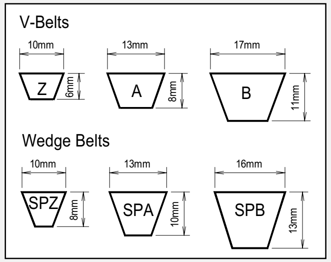


Figure 13-6 Cross-sections of different belt sizes

V-belts are named Z, A, B in increasing order of size and similarly wedge belts are named SPZ, SPA and SPB. V-belts and wedge belts of the same size range (Z and SPZ for example) can both be used on the same pulley. However, care must be taken not to confuse the two types. V-belts are generally much cheaper than wedge belts which can make them appear attractive to use when a spare is required. However, if a wedge belt is replaced with a V-belt then there is a strong possibility that the drive will no longer work because the belt will slip.

In order for pulleys and belts to function correctly and have a long lifetime, they must be carefully selected. The following questions must be answered to allow the correct pulley and belt combination to be selected:

- How much power does the load require?
- How fast does the turbine shaft run when driving the generator?
- What is the required running speed of the load shaft?
- What is the centre distance between the two shafts?
- How many hours per day will the load be in use?
- What is the diameter of the turbine shaft?
- What is the diameter of the machine shaft?

Speed Ratio

By choosing appropriate pulleys, the speed which one shaft spins can be different from the other. This is useful for a pico hydro system. The speed of the turbine may be around 1000 rpm (revolutions per minute), more commonly at 1500 rpm and sometimes even 3000 rpm. That is 50 complete turns in one second! Most machines connected to the turbine need a slower speed than this. A small flourmill for example, may require only 500 or 600 rpm. The difference in speed between the shafts is called the speed ratio. It is calculated as follows:

Speed ratio= turbine shaft rpm / load shaft rpm

The speed of the turbine shaft will depend on the site conditions and the type of generator used. Usually the manufacturer selects the operating speed. It is advantageous to use the generator and controller as an over-speed controller. If the mechanical load requires less power than is available from the turbine, the excess power will be delivered to the generator and controller. If the mechanical load requires all the turbine power then the speed will fall by about 10% as at this speed the generator will not excite and there will be no electrical load.

A speed reducing drive means that a small pulley is fitted to the generator shaft and a larger one to the mechanical load. This will mean that the larger pulley will turn more slowly so that the load, such as a mill, doesn't spin too fast. A speed increasing drive is the opposite way round: A large pulley drives a smaller one, making it spin faster. Certain types of saw, for example, may require a speed increasing drive.

A turbine shaft speed based on the number of generator poles should be used to calculate the speed ratio. The number of poles (usually 4 but sometimes 2, 6 or 8) can be found on the information plate on the side of the generator. 4 pole generators are most commonly used.

Number of Poles	**Approx. Head (m)**	**Design Speed of Turbine / Generator Shaft (rpm)**
2	>80m	3000
4	25 - 80	1500
6	<25	1000

Table 13-3 Generator shaft speeds and head range for direct drive

For more information about selection of design turbine shaft speed, please read the notes in Appendix B.

Minimum pulley diameter

A final consideration when selecting the pulleys is that particular sizes of induction motor specify minimum pulley diameters that can be connected. This is because a higher belt tension (and therefore a greater bearing load) is required for smaller pulleys. Common sizes of induction motor and the corresponding minimum pulley diameters are shown in the following table:

Induction motor frame size	**Common Power ratings (kW)**	**Minimum pulley diameter (mm)**	
		4 pole	**6 pole**
D80	0.37 / 0.55 / 0.75	71	71
D90S&L	0.75 / 1.10 / 1.50	71	71
D100L	1.50 / 2.20 / 3.00	71	71
D112M	2.20 / 4.00	90	71
D132S	3.00 / 5.50	90	85
D132M	4.00 / 5.50 / 7.50	112	95

Table 13-4 Minimum pulley diameters

Power per Belt

The amount of power that can be transferred depends on the thickness of the belt (whether it is an SPZ, SPA, Z or A for example) and also on the size of the smallest pulley. Larger pulleys transmit more power because there is more contact area with the belt and less chance of it slipping. Wedge belts can transmit more power than V-belts. The power that can be transmitted by one belt is shown for different sizes of pulley and belt in Table 13-5 and Table 13-6

Z	Rated Power (kW) per belt for small pulley of various pitch diameters (diameter in mm)						
rpm turbine shaft	**71**	**80**	**85**	**90**	**95**	**100**	**106**
1000	0.7	0.8	0.9	1.0	1.1	1.2	1.3
1500	0.9	1.1	1.3	1.4	1.5	1.7	1.8
3000	1.5	1.9	2.1	2.3	2.5	2.8	3.0

A	Rated Power (kW) per belt for small pulley of various pitch diameters (diameter in mm)						**B**
rpm turbine shaft	**90**	**100**	**112**	**125**	**132**	**140**	**140**
1000	1.1	1.4	1.8	2.1	2.3	2.6	2.9
1500	1.5	1.9	2.4	2.9	3.2	3.5	3.9
3000	2.3	3.0	3.8	4.6	5.0	5.5	5.3

Table 13-5 Power per belt tables for V-belt drives

SPZ	Rated Power (kW) per belt for small pulley of various pitch diameters (diameter in mm)						
rpm turbine shaft	**71**	**75**	**85**	**95**	**112**	**125**	**140**
1000	0.8	0.9	1.2	1.4	1.9	2.2	1.7
1500	1.1	1.3	1.6	2.0	2.7	3.2	3.7
3000	1.8	2.1	2.8	3.5	4.7	5.5	6.4

SPA	Rated Power (kW) per belt for small pulley of various pitch diameters (mm)						SPB
rpm turbine shaft	**90**	**100**	**112**	**125**	**132**	**140**	**140**
1000	1.4	1.8	2.3	2.9	3.2	3.5	4.1
1500	1.9	2.5	3.2	4.0	4.5	5.0	5.5
3000	2.9	4.0	4.7	6.7	7.4	8.2	8.5

Table 13-6 Power per belt tables for Wedge belt drives

Single-belt drives or multiple-belt drives

More than one wedge belt is often used to increase the power that can be transferred using a pulley of fixed diameter. However, for pico hydro applications it is recommended that only single-belt drives are used. This is for the following reasons:

- There is usually no cost saving with multiple belt systems at this power range.
- If more than one belt is required, then the belts must be very carefully 'matched' (i.e. be exactly the same size) If there is any difference in the size then this can cause one of the belts to fail more quickly.
- If one belt breaks, it is usually good practice to replace all the belts at the same time. A multiple belt system cannot be run if one or more or the belts is missing so multiple-belt systems have the same maintenance requirements and reliability as single-belts systems.
- Coupling and uncoupling of the turbine shaft from the mechanical load is more difficult with multiple belt systems.
- One belt simplifies the selection of the best pulley combination.

13.6 Procedure for choosing pulleys and belts:

STEP 1

Find the required pulley ratio:

Speed ratio= turbine shaft rpm / load shaft rpm

STEP 2

Look at 'Power per Belt' tables (Table 13-5 and Table 13-6). Select the minimum pulley diameter and belt type suitable to deliver the required power. (Check Table 13-4 to make sure that at least the minimum pulley size for the generator is used) The belt tables include a service factor of 1.1 assuming that the load will be in use for 10 hours a day or less. For further information on sizing, consult Appendix C.

STEP 3

Select another pulley from those available to give the speed ratio required to within ±10%. If it is not possible to obtain the correct ratio using the pulley sizes that are locally available, look at the power per belt tables again and make another selection, using the next pulley size up for the smallest pulley.

STEP 4

Calculate the required belt length using the approximate centre distance (see Figure 13-7) and diameters of the two pulleys.

$$\boxed{L = 2C + \frac{(D-d)^2}{4C} + 1.57(D+d)}$$

where:

L= pitch length of belt in mm

C= centre distance in mm

D= pitch diameter of large pulley in mm

d= pitch diameter of small pulley in mm

In order to determine the centre distance required for, available belt lengths and pulley combinations, use the following formula:

$$\boxed{\begin{array}{l} CentreDist. = A + \sqrt{A^2 - B} \\ where \\ A = \dfrac{L}{4} - 0.3925(D+d) \\ and \\ B = \dfrac{(D-d)^2}{8} \end{array}}$$

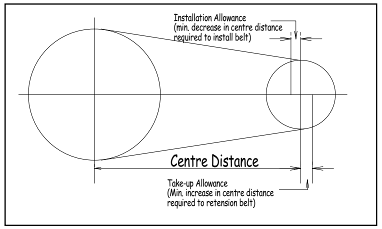


Figure 13-7 Measurement of centre distance

Example Selection of suitable belt drives

1) What is a suitable pulley and belt combination if the following is known?:

Power to be transmitted = **3.6 kW**

Speed of turbine shaft = **1500 rpm**

Speed required by load shaft = **550 rpm**

Approximate centre distance = **800mm**

Maximum Usage = **10 hrs per day**

Step 1 Pulley ratio = Turbine speed / load speed

= 1500 / 550

= 2.73:1

Step 2 Design Power = Load power + 10%

= 3.6 kW + 0.36 kW

= 4.0 kW

Step 3 Select belt and pulley from Table 13-5 and Table 13-6

The closest match to this power requirement is a SPA belt using a 125mm diameter pulley on the turbine shaft. The power per belt is 4.0 kW (at 1500 rpm).

Step 4 The diameter of the driven pulley can also be calculated: A ratio of 2.73 is required and the turbine shaft pulley is 125mm diameter

Pulley diameter required = 125 x 2.73 = 340mm

The nearest size to this is 315mm.

The ratio is now 315/125=2.52

This gives a load speed of 1500/2.52=595rpm

If this is acceptable then use this combination. If not then repeat the procedure using a different pulley size or different belt.

Step 5 What belt length is required for a centre distance of approximately 800mm?

$$\boxed{L = 2C + \frac{(D-d)^2}{4C} + 1.57(D+d)}$$

L= 2*800+(315-125)^2/4*800 + 1.57(315+125)

L= 2302. A belt of 2300mm will be a suitable length.

The new centre distance can now be calculated using a belt of 2300mm

$$\boxed{\begin{array}{l} CentreDist. = A + \sqrt{A^2 - B} \\ where \\ A = \dfrac{L}{4} - 0.3925(D+d) \\ and \\ B = \dfrac{(D-d)^2}{8} \end{array}}$$

New Centre distance = 799mm (A=402.3, B=4512.5)

2) What are the centre distance adjustments which are required for belt installation and re-tensioning?

Consulting Table 13-7for an SPA belt of length 2300mm:

a) For installation : a reduction of centre distance by at least 25mm should be possible.

b) A minimum take-up allowance of 40mm in addition to centre distance will allow the belt to be re-tensioned if it stretches.

Further Questions:

1) What combination of pulleys and belt would be suitable to transmit 2kW between the following turbine and load shaft:

Turbine shaft speed = 1500rpm Load shaft speed = 2000 rpm Usage for a maximum of 3 hours per day.

2) A SPZ belt of length 1500mm. Is this suitable for transferring a mechanical load of 1kW? The centre distance is approximately 600mm.

13.7 Belt tensioning and supporting fixtures

Correct tensioning of belt drive is important for reliability and efficiency. Under-tensioning creates slippage. This generates excessive heat that shortens the life of the belt. Over-tensioning also shortens belt life and increases the load on all the bearings. The life of the bearings will be reduced if the load on them is too high. Some means of adjusting the centre distance (the distance between centre of the two shafts) is required for installation of the belt and to adjust the tension. The tension can easily be measured using a spring balance. This procedure is described in Appendix C with methods for allowing the tension to be adjusted.

Belt Pitch Length (mm)	Installation Allowance (mm)			Take-up Allowance (mm)
	Z SPZ	A SPA	B SPB	
410 to 530	20			5
530 to 840	20	25	30	10
850 to 1160	20	25	30	15
1170 to 1500	20	25	30	20
1510 to 1830	20	25	30	25
1840 to 2170	20	25	30	30
2180 to 2830	20	25	30	40
2840 to 3500	20	25	30	50
3520 to 4160	20	25	30	60
4170 to 5140	20	25	30	70
5220 to 6150		25	30	65

Table 13-7 Installation and Take-up Allowances (see Figure 13-7)

Type of Machine	Speed (rpm)	Power required h.p.	kW
Milling			
200mm	600	3	2.2
225	550	4	3.0
280	550	6	4.2
Thresher 450mm dia. drum	1100	4-5	3.0-3.6
Woodworking			
Circular Saw dia. 200mm	2800	1	0.75
Band saw wheel dia. 300mm	------	1	0.75
Hand Feed Planer (surfacing only 600mm width of blade)	3000	1	0.75
Centre Lathe (Med. Duty, 160mm)	500-2000	0.5	0.375

Table 13-8 Examples of mechanical loads and their typical requirements

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14 THE DISTRIBUTION SYSTEM

Figure 14-1 Installation of a village distribution system (Kushadevi, Nepal)

14.1 Introduction

The distribution system is the name given to the cables, poles and associated equipment that deliver the electricity produced by the generator to the houses and other buildings where it is required.

The cost of a village distribution system is likely to be one of the largest costs of the whole pico hydro project. This cost can however, be minimised by careful design.

The methods described in this section are limited to the design and installation of single-phase AC distribution systems for village electrification. For further information about AC electricity, consult Appendix A.

For more detailed information on distribution systems consult the Mini-Grid Design Manual (ESMAP Technical Paper 007). This excellent reference is currently available free of cost from the World Bank.

The design of the distribution system needs to satisfy the following criteria:

- all the consumers who are to be included in the electrification scheme will receive a connection
- a voltage drop of 10 % or less will be maintained at the furthest point from the generator
- the distribution system will operate safely and reliably without presenting a danger to people.

14.2 Drawing a Plan

The first step in the design of the distribution system is to draw an accurate, scale plan of the area. The water source (stream) will be represented, in addition to the houses that will be connected to the generator.

It is important that this plan is drawn to scale. This means that the distances between each of the houses and the stream need to be measured accurately and drawn in the correct position. If this plan is wrong then it will be difficult to work out how much cable will be needed and where to route the cable.

The following steps enable the plan to be produced:

STEP 1

On a piece of paper, mark North, East, South and West.

STEP 2

Indicate with an arrow at the side of the paper the general direction uphill. If the village crosses a valley, draw two arrows pointing in different directions to show the opposite sides.

STEP 3

Draw the stream from which water for the hydro scheme will be taken.

STEP 4

Draw in carefully, any roads, footpaths, rivers, woods and other prominent landmarks.

STEP 5

Decide on the layout of the scheme (Page 6-1). Mark the proposed locations of the intake, the forebay or reservoir, penstock and the powerhouse. Write on the length of the penstock.

STEP 6

Mark the position of four houses that are going to be connected to the distribution system, choosing the ones that are furthest away from the generator. Choose one in each direction, North, East, South and West, if possible and use a compass. These are going to form the reference points for the system layout. Sometimes there are no houses in one or two directions from the generator. If this is the case, choose three or four houses that are both furthest away from the generator and from each other.

STEP 7

Number each of the reference houses 1,2,3,4. Then draw in all other houses that will be connected to the generator. Try and get their location on the plan as accurately as possible. Do not connect up the houses with lines representing cables at this stage.

STEP 8

Walk in as straight a line as possible from the proposed location of the powerhouse to each of the reference points in turn. Count the number of paces and calculate the exact distance in metres by first measuring the length of 20 normal paces. Mark these distances on the map and their compass bearings. Include the distance from the generator of any intermediate houses that lie on or very close to the path that is walked.

STEP 9

The map will be improved if the rough sketch is redrawn a couple of times. Try to get the relative positioning of the houses correct and estimate the distances between them. This map will be more valuable if care is taken to draw it accurately. Walk around the village several times, if necessary, and show your sketch to other people to get their opinion. Add as much detail as possible particularly about distances between the houses.

STEP 10

Draw the map out one more time, but this time draw it to scale. Spending time at this stage to plan carefully could save large amounts of money on cable. Draw in the penstock, powerhouse, and four reference houses.

STEP 11

Now add the other houses, carefully. Be sure to position each one in the correct position relative to the others.

STEP 12

Once the final copy of the map has been drawn in this way, it is time to consider the best method to connect the houses to the generator.
Note: Hand-held GPS (Global Positioning Systems) are becoming widely available at prices of about $200. These can make drawing the plan much easier.

14.3 Layout Patterns

Look at the following examples of distribution layouts and consider which is most like the layout of houses on the plan which you have drawn.

A: Houses grouped together with the generator some distance away

This is a very common situation with hydro-power schemes. Consider if it is possible to reposition the powerhouse using the suggestions in Section 6 so that the long distance to the village is reduced. Obviously the cost saving in cable will need to be balanced against the additional expense of extending the penstock or the canal to the forebay.

B Radial spread; central powerhouse with houses in all directions

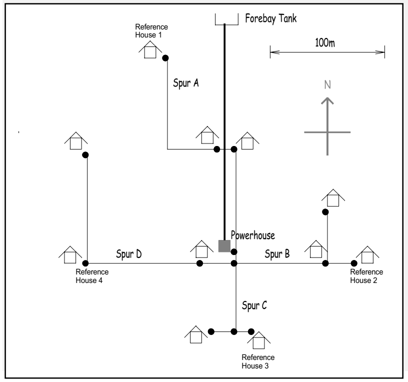


Figure 14-2 Radial spread distribution system

This is the most convenient arrangement. If the powerhouse is in the middle of the houses, then the distribution system can be kept as short as possible. Running cables to houses in different directions from the powerhouse also has the advantage that the network can be maintained and repaired more easily. Switches can be used to isolate the individual spurs. These can be located centrally in the powerhouse. MCB's are suitable for this purpose (see Section 0). The cable diameter required for the main distribution lines will be smaller because the total load current is divided amongst several spurs.

C: Random distribution in one or two directions

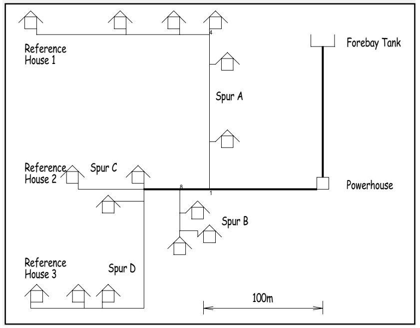


Figure 14-3 Distribution system in two directions

The shortest route to connect up all of the loads to the generator may be obvious on a small scheme. On larger schemes, carefully consider different routes for connecting the houses.

14.4 Selecting Cable for Village Electrification

The cable required to supply the houses with electricity, will be a significant part of the total scheme cost. It is therefore important that the most cost-effective cable is chosen.

Key issues

When selecting cable for village electrification projects, the key issues can be summarised as follows:

- **Cost**: Both the direct cost of the cable and the indirect cost of poles and fittings need consideration. The indirect costs are usually greater if non-insulated cable is used because the conductors have to be held under the correct tension to keep them spaced apart and insulators used so that they do not contact with the poles.
- **Voltage drop**: The voltage at the end of the cable will be different from that at the generator. This is mainly because the cable has a resistance. The resistance depends on the cable thickness and the type of conducting material from which the cable is made (e.g. copper or aluminium).
- **Lifetime / reliability**: The cable will be exposed to the weather throughout the year. Some of the factors which affect the life and reliability are diameter, conductor material, type of insulation and the number of strands which are wound together to make the complete cable. Stranded cable should always be chosen, the more strands the better.
- **Safety**: The safety of local people can be affected by the choice of cable. Cable with a tough insulation such as cross-linked polyethylene is safest. Pole design and correct tensioning also affects safety particularly when using non-insulated cables.
- **Security**: It is easier for people to make illegal connections to non-insulated cable.

Types of cable

The conducting material that the cable is made from is likely to be either copper or aluminium.

Copper Cable:

Copper cable is made of separate strands of wire. The number of strands and the thickness of each, determine the overall resistivity and cost. The number of strands vary but typical values for small cables are 3,7,16,24,30,32 and 50 strands. Different copper cables are identified by a numbering system. The first is the number of wire strands in the cable and the second is the gauge which gives a measure of the thickness of each strand. Cable number 7,16 for example, has seven wires of 16 gauge.

There are two common gauge systems: SWG (Standard Wire Gauge) and AWG (American Wire Gauge). They use different gauge systems for particular cross-sectional areas (CSA), so care should be taken to ensure that the two systems are not confused.

Hand drawn copper is better than the annealed (flexible) copper found in most equipment wire because it has approximately 60% more strength.

However, insulated annealed copper equipment wire has been used on many pico hydro schemes in Nepal because it is widely available in convenient sizes. The only reported problem has been where a small, three-stranded cable broke inside the insulation which made the fault difficult to locate. Firstly, it is recommended that cables with a larger number of strands are used to minimise this risk. Equipment wire is not designed to support its own weight over long spans. To prevent the cable from stretching a galvanised steel or iron support wire should be used around which the cable is wrapped. Most insulated copper cable has PVC insulation which is less weatherproof than the XLPE (Cross-linked Polyethylene) insulation which is commonly found on cables intended for outdoor use.

Note on PVC cable insulation

Some types of PVC cable insulation degrade in sunlight. Also it becomes brittle at sub-zero temperatures. If PVC coated cable is used for the distribution system, the operator should periodically check the cable for signs of degradation such as cracks in the insulation. If necessary, sections of the cable should then be replaced. Dark-coloured insulation usually degrades less than lighter colours.

Aluminium Cable:

1. **ACSR** Aluminium cable is commonly reinforced with galvanised steel. This is referred to as ACSR (Aluminium Cable Steel Reinforced). It is popular because of its relatively low cost and high strength. The aluminium cables are given names that correspond to a particular equivalent CSA of copper. This allows different cables to be compared in terms of their resistance.
2. **ABC**. Aerial Bundle Conductor is aluminium alloy cable with XLPE insulation. This is recommended where available as it is strong, highly resistant to sunlight and usually very cost-effective.
3. **Aluminium equipment wire** is also available in some areas. This is low cost but is not suitable for use as distribution cable because of its low strength.

14.5 Distribution Poles

Key issues

The important issues regarding selection of distribution poles are as follows:

- **Cost**: The cost of the poles may be quite substantial or very little and depends on whether local materials are suitable or if poles must be purchased and transported from further away.
- **Lifetime**: The materials used and how the poles are installed and maintained will affect how long they last.
- **Safety**: Safety depends on factors such as the material and method of installation as well as the pole height.
- **Weight**: Poles made from heavy materials such as concrete are difficult to transport and handle.

Poles can be a very expensive part of the distribution system, and as a consequence the cheapest option is often taken, even though this may prove to be more expensive in the long term due to the need for frequent replacement.

Wood is usually the preferred choice for poles, although reinforced concrete and steel are sometimes used where wood is scarce. Properly treated and maintained quality wood poles have a life of at least 40 years. However, poles made from unseasoned and untreated wood can fail in less than 12 months, particularly in hot and humid areas. Poles must be seasoned (dried) and treated. In dry climates, seasoning can be done by natural air circulation, but kiln drying or steam conditioning is required in humid climates. To properly treat poles, pressure or hot/cold soak methods are used to force creosote or other preservatives into the wood. Unfortunately these methods are not well suited for treating a small number of poles due their complexity and expense. A cheap approach is to paint or soak the lower portion of the pole using creosote or old engine oil, though this is much less effective than properly treating the complete pole.

An effective low-cost method with bamboo poles is to place the cut ends of freshly-felled bamboo in a container of preservative and to leave them in a sunny place for 4 – 5 days. Natural transpiration will cause the preservative to diffuse from the base of the bamboo to the leaves.For more information on poles and pole treatment consult the Mini-Grid Design Manual.

Sometimes, the main trunk of a living tree is used to support cables in rural areas. Only healthy, mature trees should be used and the foliage should be cleared to at least 1.5m in all directions around the cable. Also the lower branches should be removed to discourage children from climbing the tree. Regular checks should be made to ensure that further growth is not interfering with the cables. However, in lightning prone areas, live trees should not be used to support cables (see Section 16). A direct strike on a tree that has been used to support part of the distribution system will cause a large voltage to be conducted to the cables. This can result in significant damage to equipment and injury to people.

14.6 Installation of the Distribution System

Pole Installation

Distribution poles should be spaced between 25 metres and 40 metres apart.

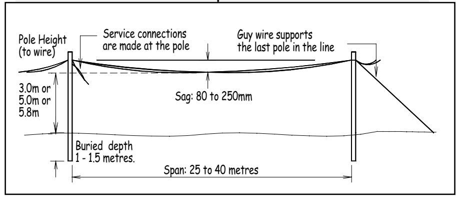


Figure 14-4 Required installation practice for distribution poles

The first and last poles in a line should be stayed with guy wire. Any poles on corners or bends should also be stayed. Minimum ground clearances should be according to national standards. If there are no standards available then the minimum ground clearance is 3.0m over open ground, 5.5m along motorable road and 5.8m across motorable road. The poles should be spaced approximately every 25m and at a maximum of 40m. Note different requirements for poles over 5 meters in Table 14-1. Since bamboo poles of appropriate diameter are unlikely to be available for poles which are 5 metres and above, hardwood poles should be used.

Ground clearance	3.0m	5.0m	5.8m
Min. pole dia.	100mm	125mm	125mm
Buried Length	1.0m	1.5m	1.5m
Maximum span	40m	35m	35m
Material options	Bamboo or hardwood	hardwood	hardwood

Table 14-1 Requirements for distribution poles

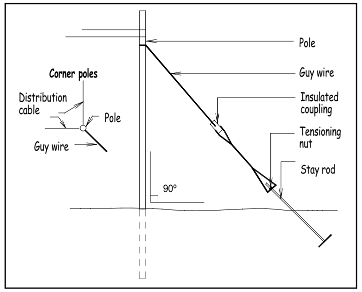


Figure 14-5 Use of guy wires to support poles and help tension cables

Cable installation

Sag: The distance between the poles determines the amount of sag that is required. The sag is not critical for insulated cables providing that a minimum sag of 80mm is allowed to prevent excessive tensioning. The maximum sag for insulated cables is 250mm.

For non-insulated conductors, it is important to measure the sag more carefully in order to prevent the risk of conductors making contact with each other especially during windy conditions. The requirements for sag of ASCR cables with various pole spans are presented in Table 14-2.

Cables expand in hot weather and therefore the sag is greater. When installing cables in cold weather, aim to achieve close to the minimum sag, and in hot weather aim for close to the maximum sag.

Span (m)	**20**	**25**	**30**	**35**	**40**
Min. sag (mm)	20	30	45	50	75
Max. sag (mm)	70	100	150	200	250

Table 14-2 Sag requirements for ACSR

Sighting method of sag measurement

A method of measuring the cable sag is to using straight wooden boards nailed to the poles as shown in Figure 14-6. The boards are fixed at the correct height for the cable sag and sighted from another pole one span back. The cable is tensioned until the sag is aligned with the boards as shown. One advantage of this method is that if the wooden boards are left in place, it is easy to determine if the cable sag increases over time, indicating if adjustments are required. This is likely, as cables will stretch over time with their own weight.

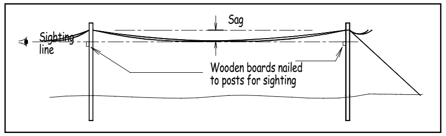


Figure 14-6 Sighting method of sag measurement

For long pole spans, a 'return wave' method can be used to obtain the correct sag. This is described in the Mini-Grid Design Manual (see Page 20-1).

Lengthening cables

The cable lengths can be joined by using crimp-type cable connectors and by twisting stranded cables together (see Figure 14-7)

Crimp type cable connectors, consist of a compressible metal tube (or splice) that slides over the ends of the conductors and is compressed (crimped) using a special tool. It is essential to use connectors that are specified for the diameter of cable used and to use a crimping tool suitable for the size and type of connector. If the correct connector and the right tool are used the connector should be able to support the full tension of the cable. The connectors are cheap, though for cables above 6mm^2 the tools are quite expensive.

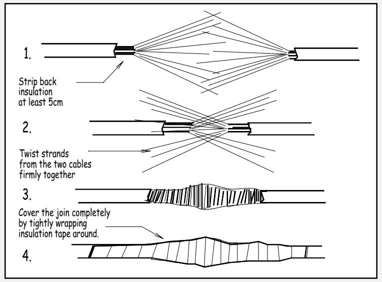


Figure 14-7 Twisting stranded cable

Insulated copper cables can be joined by twisting. However, the cable joins must never take the tension of the cable. Both cables should be wrapped around the pole or another fixture such as a bracket to prevent this. In this way, a loop of slack wire can be formed where a connection is made.

Identifying the live and the neutral can be a problem if conductor with the same colour insulation is used for both. If different coloured insulation is unavailable, use coloured insulating tape at the beginning and end of cable coils used for the live line. This will allow it to be easily identified during installation.

Connecting spurs to the main conductor

If a copper cable is to be connected to an aluminium cable, special bimetallic connectors are required that separate the conductors to prevent electrolytic attack on the aluminium conductor.

An alternative method of joining the cables is shown in Figure 14-8. If the distribution cable is insulated then the insulation must be carefully stripped back. Solder should be applied to the join using a soldering iron (preferably gas powered) and then the join should be re-insulated with tape.

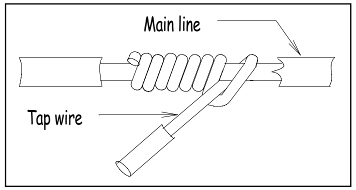


Figure 14-8 Suitable method of connecting tap wires to distribution cables

Service Connections

The service cable runs from the house to the main distribution line. A good, weather-resistant, electrical connection is required, between the distribution system and the service cables. The methods described for connecting spurs to the main line can be used for connecting the service cables.

A convenient and more rapid method of connecting the copper service cable to insulated copper conductor is to use a small, plastic connecting device called a 'tap splice' shown in Figure 14-9. These are available in sizes for various cable diameters between 0.5mm^2 and 6mm^2. They provide a low cost and safe alternative to splicing cables. Insulated cable need not be stripped back as an electrical contact with the conductor is made when the tap splice is clamped shut with pliers. It is essential to use tap splices of the correct size to minimise damage to the cables and ensure a good connection.

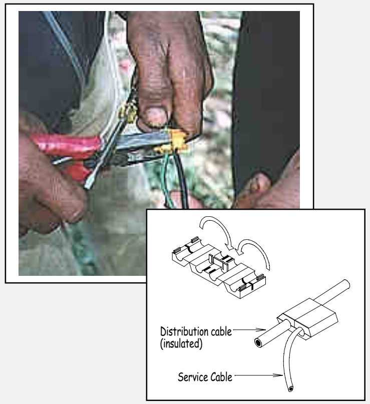


Figure 14-9 and Figure 14-10: Use of a tap splice to connect the service cable to an insulated distribution cable

14.7 Protection of the distribution system

Lightning

It is very important that consideration is given to protecting the distribution system from lightning. Even indirect strikes some distance away from the cables can cause very high voltages to be induced in the cable that can damage equipment. Consult Section 16.3 and incorporate the recommended measures at the initial stages of designing the distribution system.

Excess Current

The cables are protected from high currents (these could be caused by a short circuit) by either a Motor Protection Switch or MCB inside the controller in the powerhouse. The minimum cable sizes are determined by the current rating of this protection although cable sizes will usually be larger to minimise the volt drop (see Section 14.8). If several spurs begin at the powerhouse, it is preferable to connect an MCB for each spur so that the individual sections can be isolated if necessary. Additional MCBs may be required if the current carrying capacity of the smallest cables used at the ends of the distribution system are less than that of the existing MCBs.

Installation procedure for distribution system

Step 1: Using the guidelines for pole spacing and the map of the distribution system, work out how many poles will be required and where they should be positioned.

Step 2: Calculate how many poles will require supporting with guy wires (including corner poles, see Figure 14-5).

Step 3: Avoid routing distribution cable along exposed ridges where the risk of damage from wind and lightning strikes is greatest.

Step 4: Dig holes and lay out poles along intended route

Step 5: Erect all poles along chosen route except for those that will be supported by guy wires.

Step 6: Beginning at the powerhouse, and installing the thickest first, suspend the cable from each pole in turn. If non-insulated cable is used, ensure that cables are correctly fitted to insulators.

Step 7: Use people to pull the cable taught, achieving approximately the correct tension while attaching the cable to each pole.

Step 8: At the end of a run of poles, dig a hole and fix the end pole in position with a guy wire to support it.

Step 9: Measure the sag and adjust tension as required in order to set within the correct limits.

Step 10: When distribution system is complete, connect service cables. Leave a loop of slack cable where the cables enter the building. This prevents rainwater from running down the cable into the building.

14.8 Sizing the cables

The cables in a distribution system are likely to be different diameters in different places. This is because some parts of the system will carry more current than others parts and the cables will therefore need to be larger in diameter. It would be a waste of money to use large cables on branches of the distribution system where only a few houses with small loads are connected.

CSA of copper cable	Current capacity (Amps)
1.0 mm^2	17A
1.5 mm^2	22A
2.5 mm^2	30A
4.0 mm^2	40A
6.0 mm^2	51A

Table 14-3 Current carrying capacity of single core insulated copper cables in free air.

By calculating the **voltage drops** across the distribution system, it is possible to find the best sizes of cable to use.

Explanation of voltage drops:

The consumer voltage drop is the difference in voltage between the generator voltage and the voltage in a consumers house. This difference is due to the resistance and inductance of the cable through which the electric current flows. The volt drop due to inductance is usually small and for simplicity can be neglected, enabling the volt drop to be calculated using Ohms Law:

Volt (drop) = Current x Resistance (of cable)

A small volt drop is acceptable. If the voltage in a house is too low however, electrical loads that are connected (e.g. tube lights) will not work properly. An acceptable minimum voltage is 6% below the national voltage. For example, if the national voltage is 220V, for a 6% volt drop the consumer voltage would be:

$$220 - (0.06 \times 220) = 206.8 \text{ V}$$

At 207 V, electrical loads designed for 220V will still function normally. Houses that are furthest from the generator will have the largest volt drop because the current has to flow through more cable to reach them. Choose cables that ensure a minimum voltage of 6% below national voltage at the furthest houses. This keeps the distribution system cost to a minimum and ensures that voltages in other parts of the system are acceptable.

Example: Calculating % volt drop:

Generator voltage = 220 Volts
Cable resistance = 0.0061 Ohms per metre
Length of distribution = 150 meters
Length of Cable = 300 metres
Load Current = 5 Amps

Volt drop = Current x Total resistance of cable
= 5 x (0.0061 x 300)
= 9.15 Volts
% volt drop
= 9.15/220 x 100
= 4.1%

Calculating the best size of cables for a distribution system increases in complexity, the more houses are connected. The best method is to treat each individual branch or spur separately. However, this is very time-consuming because of the number of separate calculations which must be made. Computer programmes allow this to be done much more rapidly.

Note: Save Money on Cable by Raising the Generator Voltage

If the voltage at the generator can be raised to the upper voltage limit (i.e. national voltage + 6%) then even greater savings in the cost of the distribution cable may be possible. The voltage range across the system is now +6% of the nominal value at the generator and -6% of the voltage at the terminals of the furthest house. A total volt drop across the cables of 12% is therefore possible. This means that a cable of smaller diameter can be used while still keeping the volt drop within acceptable limits.

Two manual approaches to sizing the distribution cable based on the volt drops are described below. Both methods make assumptions about the position of the loads. This helps to reduce the number of calculations that are necessary.

Cable type	**CSA strand mm^2**	**CSAcable mm^2**	**Ohms / 1km**	**Cost: US$/m**
Insulated Copper				
3,20	0.6567	1.9701	8.63	0.09
7,22	0.397	2.779	6.12	0.15
7,20	0.6567	4.5969	3.70	0.19
7,18	1.1675	8.1725	2.08	0.33
7,16	2.0755	14.528	1.17	0.69
Aluminium (ACSR) CSA in mm^2 copper equivalent				
Squirrel	-	13	1.31	0.16
Gopher	-	16	1.06	0.20
Weasel	-	20	0.85	0.24
Rabbit	-	30	0.57	0.37
Dog	-	55	0.31	0.67
Add US $0.11 per metre to ASCR for average cost of D irons and insulators (not required for insulated cable)				

Table 14-4 Sample of cable specification from Nepal

Method 1: Consumer loads clustered together at the end of the distribution cables

This method will tend to oversize the cable because the current is slightly overestimated. The cable is therefore likely to be more expensive than necessary. However, it is the most straightforward method for a rapid design of distribution system.

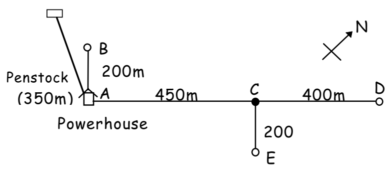


Figure 14-11 Distribution system with load "clusters" at the end of spurs

Consider the simple distribution system in Figure 14-11. The loads have been grouped together at B, D and E and the distances from the powerhouse A and from node C, have been carefully measured. All that remains is to size the cable for the distribution system to give the lowest acceptable voltage at B, D and E and therefore to minimise the cost.

What is the best cable to use if

- the load at each point (B,D and E) is 1kW single phase,
- the nominal voltage is 220V, and
- the power factor is 1 (for explanation of power factor, see Appendix A)

A-B

Current (I) flowing along A-B (using I=P/V)
1000/220 = 4.545Amps

a) Try 7,16 insulated copper cable. (see Table 14-4)
Total length of conductor required is 2 x 200m = 400m. Resistance (Ohms per metre) = 0.0012
Cable Resistance = length x resistance per metre
= 400 x 0.0012 = 0.48 Ohms
Cable Cost = 400 x 0.69 = US **$276**
Voltage Drop = I x R = 0.48 x 4.545 = **2.18V**
% Volt Drop = (2.18/220)*100 = 1%.

Since we are aiming for a total drop of 12% of the nominal value (see Note, P.14-8), this cable can clearly be reduced in diameter

b) Try 7,22 insulated copper cable (see Table 14-4)
Cable Resistance = 400 x 0.0061 = 2.44 Ohms
Cable Cost = 400 x 0.15 = US **$60**
Voltage Drop = 2.44 x 4.545 = 11.08V
Percentage volt drop is 5% which is still within the acceptable limits. Reducing the cable more than this becomes impractical because the cable strength will not normally be sufficient.

A-C
Although no load is directly attached to C the cable must be sized separately since the currents flowing are different from C-D and C-E. The voltage drop A-C must be added to the Voltage drop of C-D and C-E. The value at the end of the line must not exceed 12%.

a) Try 7,22 insulated copper
Cable Resistance = 900 x 0.0061 = **5.49 Ohms**
Cable Cost = 900 x 0.15 = US **$135**
Line Current = Load Connected / Nominal Voltage
= 2000 / 220 = **9.09 A**
Voltage Drop = 5.49 x 9.09 = **50 V**
Percentage voltage drop = 22.7% so cable diameter must be larger.

b) Try Squirrel ACSR (see Table 14-4)
Cable Resistance = 900 x 0.0013 = **1.17 Ohms**
Cable Cost = 900 x 0.16 = US **$144**
Line Current = Load Connected / Nominal Voltage
= 2000 / 220 = **9.09 A**
Voltage Drop = 1.17 x 9.09 = **10.63 V**
Percentage voltage drop = (17.2/220)*100 = 4.8 % must be added to voltage drop C-D and C-E

C-D Try 7,20 insulated copper (see Table 14-4)
Cable Resistance = 800 x 0.0037 = **2.96 Ohms**
Cable Cost = 800 x 0.19 = US **$152**
Line Current = Load Connected / Nominal Voltage
= 1000 / 220 = **4.54 A**
Voltage Drop = 2.96 x 4.545 = **13.45 V**
% voltage drop = (13.45/220)*100 = **6.1 %**
Total Voltage Drop A-D = 4.8 + 6.1 = **10.9 %**

C-E Same as A-B (1kW load and 200m long)
Voltage drop = **5%**
Cost of cable = US **$60**
Total Voltage Drop A-E = 5.0 + 6.1 = **11.1%**

Cost Comparison
The cost of this distribution system is compared.
1) Using all 7,16 insulated copper = (200 + 200 + 450 + 400)*2 = 2500 x 0.69
= US **$1725**
2) Using all 'squirrel' ACSR= 2500 x 0.16 + 1250 x 0.11 (0.11 = cost of D irons and insulator per meter along the section i.e. half the cable length)
= US **$537.50**
3) Using mixed conductors as calculated above:
A-B = US $60 (Cu)
A-C = US $144 + 450 x 0.11= US $193.50(ACSR)
C-D = US $152 (Cu)
C-E = US $60 (Cu)
Total for 3) = US **$465.50**

Clearly if the loads change, recalculation is required based on the new current value along each section. Although this process can be time consuming, particularly for more complex distribution systems, careful planning at an early stage will be rewarded with potentially significant savings in cost.

Method 2: Equally Spaced Consumer Loads

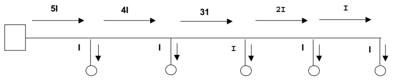


Figure 14-12 Equally spaced consumers

The second method of voltage drop calculation assumes that the loads connected to a particular branch of the distribution system are equally spaced along its length. This is slightly more complicated than the method shown above but is likely to give a more accurate picture of the expected voltage drop.

The current I, is assumed to be constant for each house. It is calculated by dividing the total available power (assuming a 6% power loss in the distribution system) by the nominal voltage and then by the total number of houses. Each house is assumed to have an identical load and to be spaced equally along a particular section of distribution line, as shown in Figure 14-12 The total voltage drop at the end of the line can be calculated as follows:

Vdrop = (5+4+3+2+1) I.R1

Where, R1 = cable length (i.e. 2 x distance between houses) x cable resistance per metre

Re-analysing the previous example in this way, and assuming that each 1kW load is actually 10 houses evenly spaced, and that the cable is used as calculated in Option 3 above (mixed conductors) then the voltage drops are as follows:

I= 100/220 = 0.4545
A-B : R1 = 2x200/10 x 0.0061 = 0.244

Vdrop = (10+9+8+...+1) x 0.4545 x 0.244
= 6.1V = **2.8%**

A-C : Same as before as no loads are connected in this section.
Vdrop = 1.17 x 9.09
= 10.63 V = **4.8 %**

C-D : R1 = 2x400/10 x 0.0037 = 0.296

Vdrop = (10+9+8+...+1) x 0.4545 x 0.296
= 7.4V = **3.3%**

C-E R1 = 2x200/10 x 0.0061 = 0.244

Vdrop = (10+9+8+...+1) x 0.4545 x 0.2.44
= 6.1V = **2.8%**

Reassessment of the cable requirements will be possible based on the above voltage drops which are much less than those calculated by the previous method.

Note: An Excel spreadsheet has been created to allow accurate design of village distribution systems with greater ease. Please contact the editorial address via email for a copy.
(Email address: phillip.maher@ntu.ac.uk)

14.9 Design of a distribution system to supply a workshop

This section has been included to illustrate the approach to sizing and connecting motor loads to a small induction generator. The example used is for a workshop but the principles can be applied to other types of motor loads connected to a distribution system.

Example

A particular village has a pico hydro site with the potential to produce 4.4kW of electrical power. The intention is to use the electricity for evening lighting. Some members of the community are also very interested in constructing a workshop to produce wooden furniture. This could potentially be very useful as it would provide a daytime load and add to the income generated from the pico hydro scheme.

The carpenters would ideally like to be able to use the following machines
- band saw
- plane
- lathe
- circular saw
- pillar drill
- hand drill
- grinding wheel

The community is aware that the mechanical power produced by the turbine is greater than the electrical power and it would be useful if the workshop machines could be driven directly using belt drives. Unfortunately the sides of the valley are steep and the flat area for building the powerhouse near the river is limited. In addition, access with timber for sawing into planks would be difficult if the workshop was in the same building. A flat area of land 200m uphill from the proposed generator site has been identified which would make a good location for the workshop. However, this will mean using workshop machines that are driven by electric motors.

The carpenters would like to know the following:

1) Which of the machines listed above could be operated?
2) What would be the cost of a distribution cable from the generator to the workshop?
3) What other considerations are important?

Answer

1) Which machines can be used?

All the machines that are listed can be run using the power supplied by the pico hydro generator if they are selected carefully. Small, workshop tools are usually powered by single-phase motors. A single-phase supply is the simplest to generate and will therefore be the most appropriate to transmit the electricity from the generator to the workshop. Before sizing the supply cable, research the available workshop machines that run on single-phase power.

Electric motors up to a certain size only can be connected to small induction generators (see Section 13.3). It is important to know what the starting current requirements are for these machines so that the generator is not overloaded. Generally, non- of these machines are under load when first switched on. They will only be used when the normal operating speed has been reached. For this reason, they can be classed as low-starting torque loads and sized up to 20% of the supply capacity.

Supply capacity = generator capacity – power loss in distribution cable.

Assume that the power loss is 6% and then size the cable to deliver the power with no more than 6% volt drop.

Supply capacity = 4.4kW – 6% = 4.1kW

So, the largest motor which can be connected in to the workshop to power one of the machines listed is

20% x 4.1kW = 820W

For example, machines that have induction motors up to 1 horse power (750W) can be operated successfully using this generator.

Hand held power tools usually do not use induction motors and can often be sized up to 25% or more of the supply capacity. This would enable a 1kW hand-held drill for example, to be connected in the workshop.

2) What is the cost of a suitable distribution cable?

The distribution cable required is 200m in length. All of the load is at the end of the cable and a maximum voltage drop of 6% is permissible.

Assume that all the power produced by the generator, may be consumed by loads in the workshop. The motors are small in relation to the generator but their power factors are uncertain. Calculate the maximum current that the generator can supply at the rated voltage and use this to size the cable.

Maximum generator current (@240V)
= 4400 / 240 = 18.3Amps

The length of cable is 200m x 2 (phase and neutral) = 400m

From Table 14-4, and selecting Squirrel cable (smallest ASCR), calculate volt drop:

Cable Resistance = 400 x 0.0013 = 0.52 Ohms

Voltage Drop = 0.52 x 18,3 = 9.5 V

Percentage voltage drop = (9.5/240)*100 = 4 %

Cable Cost = 400 x 0.16 + 200 x 0.11
($0.11 = average cost of D-irons and insulators per metre of cable)
= US **$86**

3) What additional considerations are there?

Additional considerations are as follows:

- Do not purchase the workshop machines until the turbine and generator are installed and the electrical output is checked.
- Do not start the machines simultaneously as the combined power requirement may exceed the generator capacity and trip the overload protection in the powerhouse. The motors should be started on after another, waiting for one motor to reach its running speed before starting the next.
- Power factor correct the motors as explained in Section 13.3.
- Each machine should be connected to the supply through a circuit breaker. This will protect the motor windings from high currents. Motor start MCB's should be specified and rated slightly higher than the normal rated current of the motor. Adjustable protective motor switches can also be used (see Figure 9-13). These allow the tripping current to be adjusted to the precise current rating of the motor for maximum overload protection. Use Table 14-5 as a guide for 240V supplies. Circuit breakers are not normally used for hand-held tools. These are protected by a consumer unit with a suitably rated MCB and a fused plug.

Motor size	Amp range of MCB (240V)
1/3 HP (250W)	2 – 4 Amps
½ HP (375W)	2 – 4 Amps
2/3 HP (500W)	2 – 4 Amps
¾ HP (560W)	4 – 6 Amps
1 HP (750W)	4 – 6 Amps

Table 14-5 Protective motor switch ratings for different machine sizes

15 DOMESTIC WIRING

Figure 15-1 Installation of domestic wiring circuit (Nepal)

15.1 Main Issues

The main considerations for house wiring are:

- Consumer safety
- Reliability
- Versatility in terms of positioning
- Limiting the size of the connected load
- Keeping the cost low
- Ease of installation

Safety

The greatest risk to consumer safety is from electric shocks and fires. These risks are minimised as follows:

1) Connect an **RCD**
2) Provide an **isolation switch** for each house
3) **Earth** all metal cased electrical devices
4) Use correctly-sized **double-insulated cable** and a **wiring harness** for house wiring
5) Make sure there is **no exposed wiring**
6) Position **sockets out of reach** of small children
7) Use a **suitably sized fuse or MCB to protect all wiring**.
8) **Give advice** about electrical safety and position a **danger notice** on the load limiter
9) Don't allow hot light bulbs and cookers to touch materials that burn easily.

Consumer protection using an RCD

The risk of a dangerous electric shock by a person accidentally coming into contact with a bare cable is minimised by the use of an RCD. RCD's must be used on all pico hydro schemes. Ideally each household should have its own RCD. However RCD's are expensive and therefore it is usual to share an RCD between several households or on small schemes just to have an RCD in the powerhouse. The level of protection is just as high with just an RCD in the powerhouse, though it is more inconvenient as a fault in one house trips the supply to all houses. This is explained in Figure 15-2. This device cannot however, remove the danger of a serious shock if someone touches both conductors at the same time. Local people should therefore be warned about the dangers of touching the cable, particularly when non-insulated cable is used for distribution.

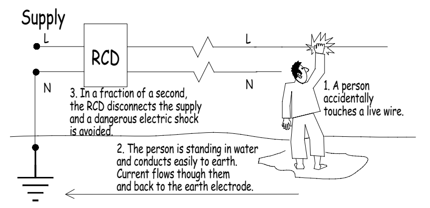


Figure 15-2 The danger of electric shock from a bare cable is reduced by fitting an RCD.

15.2 Wiring Harness

This is a "ready-to-install" domestic circuit. It is assembled by a trained person, is safe and reliable, and contains all the necessary components (load limiter, light bulb sockets, electrical sockets, etc.).

The use of wiring harnesses is particularly suitable for village electrification using pico hydro. Rural houses rarely require complicated domestic circuits. People who receive an electrical connection for the first time usually do not have many electrical appliances which to connect. In many cases the only devices used will be light bulbs and a radio or television. Consumers who use many loads will benefit more from a fixed wiring circuit as this is likely to be more cost-effective.

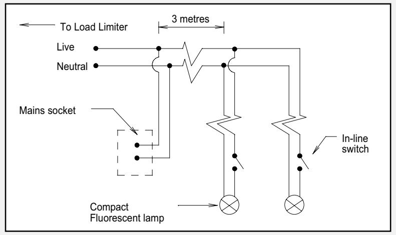


Figure 15-3 Circuit diagram of a typical wiring harness

Design of Wiring Harnesses

Flexibility: Many new consumers will want to change the position of their light bulbs after they are first installed. This is partly due to a lack of experience with electricity. If spare cable is provided and the sockets are already connected, then the lights can be positioned in a variety of ways without risk to the consumer. The harness is installed by strapping the cables securely to suitable wooden beams. Unused cable is coiled up and suspended out of the way. The amount of cable provided will depend on the size of the local houses.

Load connected: The number of plug and light bulb sockets connected to the harness will depend on the power that the consumer has subscribed to. A typical harness such as the one illustrated in Figure 15-3, has one plug socket and two light sockets. The connected load could be 2 CFL's lights (9W each) and a radio connected using the 2-pin socket (2W) giving a total of 20W. This load is used to determine the load limiter current rating (see Section 15.4).

Cable: The current rating of the cable used for wiring harnesses and all fixed domestic wiring, should be at least 40% higher than the current rating of the fuse or MCB protecting the house wiring (see Section 15.3 and 15.4). It should also be double insulated for additional consumer safety.

Consumer Earthing

There is no need for a consumer earth to be provided unless metal-cased appliances are likely to be used.

Consumer loads that have metal cases such as cookers, must have an earth connection. Then, if a wiring fault develops making the metal case live, the RCD will operate and disconnect the supply, protecting the user. Otherwise there is a risk of electric shock. This is explained in Figure 15-4

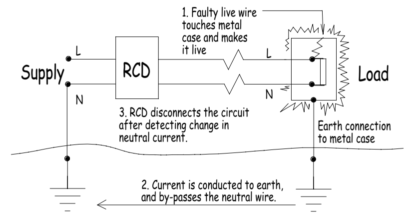


Figure 15-4 Protecting consumer loads using an RCD

If earthing is required, an electrode should be provided near to the consumer house. For information about earth electrodes, see Section 9.3. The earth cable from the electrode is connected to a spare section of the connection block in the service box and the cable junction box. The domestic cable should be of the twin and earth type. A 3-pin plug and socket is then used to connect the device to the supply. The earth wire should be connected internally to the metal case of the device.

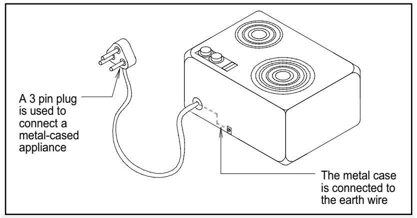


Figure 15-5 Metal-cased devices should be earthed

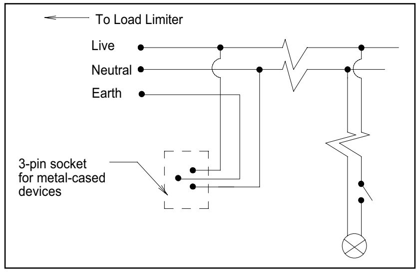


Figure 15-6 An earth connection must be provided if metal cased loads are likely to be connected.

15.3 The Load Limiter

Conventionally the consumer is charged for their electricity consumption by means of an electricity meter that records the number of kilowatt-hours drawn from the supply. This is not appropriate for pico hydro schemes as it does not prevent overloading of the small generator or encourage consumption of electricity during "off-peak" periods such as at night when electricity is still available and often goes to waste. A better option is a limited current connection, where the consumer pays a fixed monthly fee that allows them to draw a current up to a prescribed limit on a continuous basis. This prevents overloading and encourages 'off-peak' power consumption. A load-limiting device prevents the consumer drawing more current than they subscribe for by temporarily disconnecting them. Some types of load limiter reconnect automatically, others must be manually reset. The use of load limiters is strongly recommended for the following reasons:

- Load limiters are less expensive and more easily installed than electricity meters. Consumers cannot draw more power than they have subscribed to.
- The collection of revenue from the scheme is simplified if the tariff is a fixed amount each month.
- The total consumer load can be matched to the generator output. This means that the generator will not become overloaded and the system voltage and frequency will be maintained.
- Domestic wiring is automatically protected from high currents

The type of load limiter used, depends on the amount of current which is drawn:

If **less than 0.5 Amps** is drawn use a **PTC** (Positive Temperature Coefficient Thermistor)

If **more than 0.5 Amps** is drawn use an **MCB** or an **Electronic Current Cut-out (ECC)**.

If a PTC is used then a **fuse** and an **isolation switch** are also required. The fuse prevents the PTC from being damaged by high currents. The switch allows safe rewiring in the house and makes fault-finding easier.

15.4 Load limiter design

A low cost design of load limiter is shown in Figure 15-7

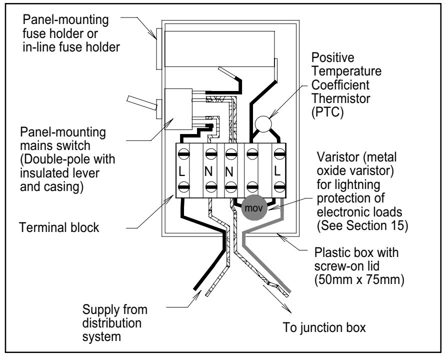


Figure 15-7 A load limiter should connect the service wire from the distribution system to the domestic wiring in the house. A PTC is used as a load limiter if less than 0.5 Amps is drawn.

Selection of PTC's

The PTC has a current level at or below which, it is guaranteed not to trip (I_{nt}). This is used to determine which PTC should be used to limit a particular load.

The switch allows safe rewiring of domestic circuits and increases the ease of fault detection by allowing the domestic circuit to be isolated easily from the supply. A fuse must be connected in series with the switch in the live and sized to protect the PTC from high currents that could cause it to fail.

A double-pole switch is used to ensure that both the live and neutral can be disconnected. A single-pole switch would make faults that caused the RCD to trip difficult to isolate because the neutral would still be connected. A double-pole switch also offers greater protection to loads from lightning strikes, provided that consumer disconnect their loads using the switch during storms. The current rating of the switch should be at least two times the rating of the fuse. The voltage rating must be greater than or equal to the generator voltage rating.

Selection of Fuses

There are five considerations for fuse selection to include in a load limiter of the design described.

1) The first consideration is the *current rating* (Fuse I_{rated}) The fuse must be designed to blow below the PTC maximum current (PTC I_{max}). The current rating must however be well above the guaranteed 'no trip' current of the PTC (I_{nt}).

PTC I_{nt} < Fuse I_{rated} < PTC I_{max}

2) The second consideration for fuse selection is the *breaking capacity*. This is the current at which there is a danger of the circuit reforming because of arcing across the fuse contacts. The breaking capacity must be greater than the highest continuous overload current that the generator is able to produce. The highest continuous current occurs when the generator is overloaded. This is typically twice its operating current (I_{op}). Size the fuse as follows, so that there is no danger of the breaking capacity being exceeded:

Breaking Capacity $\geq 3.0 \times I_{op}$

3) Fuses are available with glass and ceramic cases. The advantage with glass is that it is easy to identify whether the fuse wire is still intact. Ceramic fuses, however, have higher breaking capacity. A fuse with a glass case should preferably be selected, if available with sufficient current rating and breaking capacity.

4) The voltage rating of the fuse must be greater than or equal to the voltage rating of the generator (i.e.250V or 125V as necessary)

5) The final consideration is the size of fuse. This depends on the dimensions of the fuse holder. Ensure that new fuses are always identical to those being replaced.

6) Fuse Type: Fast-acting fuses should be selected as delay types are too slow to protect the PTC.

Note: Bypass prevention

Some form of protection is required to stop the load limiter from being bypassed. Suitable methods are using a seal or a small padlock on the service box to discourage tampering.

16 LIGHTNING PROTECTION OF PICO HYDRO SCHEMES

Lightning can cause death and injury and damage to buildings and equipment. Measures must be taken to minimise these risks, especially in areas of high lightning activity.

Risk Estimation

Weighting Factor A: Degree of Isolation	
Structure located in a large area of structures or trees of the same or greater height e.g. in a forest	0.4
Structure located in an area with few other structures or trees of similar height	1.0
Structure is completely isolated or exceeding at least twice the height of surrounding trees	2.0

Weighting Factor B: Type of Country	
Flat country at any level	0.3
Hill country	1.0
Mountain country between 300m and 900m	1.3
Mountain country above 900m	1.7

Try to identify on the map (Figure 16-4) the number of thunderstorm days per year in the region closest to you. Multiply by Weighting Factors A and B and use the following table to estimate the risk of lightning.

Risk Estimation by number of thunderstorm days per year	
High Risk	More than 100
Medium Risk	25 to 100
Low Risk	Less than 25

This is a very rough guide. To obtain an accurate estimate about the risk of lightning, talk to people from the community where the distribution system will be installed to find out if local lightning is frequent or rare.

This section deals with lightning protection from **direct** and **indirect strikes** on the distribution lines.

16.1 Direct Lightning Strikes

No equipment exists that provides full protection in the event of direct strikes. For this reason it is essential that the risk of direct strikes is reduced as much as possible by careful routing of the distribution system. The risk of direct strikes is reduced if the distribution is run through a large area of trees as there is a good chance that lightning will strike a tall tree some distance away rather than the cables themselves. When the number of trees is small, it is best to keep the distribution at least 10m away as the lightning may jump across from a tree which is struck. This is because cables provide a lower resistance path to earth.

Avoid routing the distribution along exposed ridges, particularly in lightning prone areas. If it is essential to do this, then use buried, armoured cable. Whenever possible, route the distribution in valleys.

Note on Overhead Ground Wires (OGW)
Some people have recommended the fitting of an overhead earthed wire, above the line and neutral conductors with the aim of conducting lightning discharges to earth. This is not recommended for low voltage distribution networks. The reason is that the lightning may jump between this wire and the line and/or neutral causing a dangerous voltage on these conductors. This approach only works on very high-voltage transmission systems due to the much larger air gap between the OGW and the conductors and frequent earthing of the OGW.

16.2 Indirect Lightning Strikes

An indirect strike is where lightning strikes close to the distribution line as this will induce high voltages in the cables. Whilst these voltages are not as high as the ones which can result from a direct strike, they are still dangerous, particularly for electronic equipment. Voltages are induced both between live and neutral and neutral and earth. The "line-to-neutral" voltage surge can be reduced by twisting the cables together if insulated conductors are used.

16.3 Lightning Arrestor Types

Spark-gap

The conventional lightning arrestor consists of a spark gap for the lightning to arc across and a series resistance to limit the flow of current after the voltage surge. They are generally slower acting than more modern arrestors and do not clamp the voltage at as low a value. They offer reasonable protection to electrical equipment such as wiring and motors but little protection to electronics. Prices are typically $10 to $20. Select the voltage rating so that the arrestor does not operate under normal voltage conditions but comes into operation if the voltage exceeds maximum setting of the over-voltage trip on the IGC (see Section 9.6). It is important the voltage rating is low enough to protect the generator but not so low that the arrestor is triggered by fluctuations in the generator voltage (for example, this can happen if the load is suddenly disconnected). The life of lightning arrestors can be shortened if they are triggered in this way.

Figure 16-1 Spark gap lightning arrestors

Varistors

Varistors have neither a spark gap or series resistance. They consist of two electrodes separated by a material that is a good insulator below a certain threshold voltage and which becomes an excellent conductor above the threshold. They are faster acting and usually clamp to lower voltages than spark-gap arrestors, therefore providing better protection for electronic equipment such as TVs, CFLs with electronic ballasts, and generator controllers. For low current ratings, they are very cheap (about $1) as they are mass-produced for use in domestic appliances. However, for the higher current ratings designed for use on overhead lines, they are expensive ($50 to $100) especially when compared to spark-gap devices.

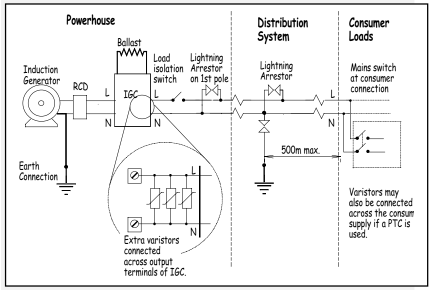


Figure 16-2 Connection of lightning arrestors to prevent damage to electrical equipment and reduce danger to electricity consumers

16.4 Protection of Powerhouse Equipment

A lightning arrestor is connected line-to-neutral on the first distribution pole immediately outside the powerhouse as shown in Figure 16-2. A single-pole load isolation switch is used instead of a double-pole one so that the neutral is earthed even when the load is isolated. This ensures that there is always a path to earth. Whenever possible during lightning storms, the distribution system should be disconnected using this switch and the generator shut down.

Protection of the IGC

A varistor is fitted (soldered) to the IGC circuit board to protect the more sensitive electronic components. It is recommended that in medium and high risk areas, additional varistors are fitted to provide extra protection. These should be connected in parallel across the output terminals as shown in Figure 16-2. Several devices connected in parallel allow greater current handling to reduce the voltage across the sensitive electronic components in the IGC.

The additional varistors should have a voltage rating at least 25% above the rated voltage of the distribution system. This will avoid them being damaged under normal operating conditions. However, their voltage rating should be less than the voltage rating of the soldered varistor. If they are damaged then they can easily be replaced on site as they are not soldered. For example, if a varistor with an AC voltage rating of 420V (usually the case) is already fitted to the IGC then additional lightning protection can be achieved by connecting devices with 320V rating.

16.5 Protection of Consumer Loads

It is difficult to specify the number of lightning arrestors required for a scheme as it depends on many factors, including the frequency of lightning, expense of replacing damaged appliances and the cost of the arrestors. Electrical guidelines for micro hydro in Nepal state that the maximum distance of a consumer from an arrestor is 500m and less in areas where the risk of lightning strikes is high. When selecting the precise location to protect a number of consumers, preference should be given to points in the system which are near to areas where lightning is more likely to strike.

When fitting arrestors, the neutral is normally earthed at the lightning arrestor to minimise the neutral to ground voltage surge, as this can cause the insulation to break down. **This is not achievable when an RCD is fitted in the powerhouse**, as earthing the neutral will cause the RCD to trip. However, the neutral can be earthed through an additional lightning arrestor, as shown in Figure 16-3.

Selection of Lightning Arrestors

The neutral-to-ground lighting arrestor can be a conventional spark-gap type, since it is only required to prevent insulation breakdown.

The selection of the line-to-neutral lightning arrestor depends on the type and value of the loads to be protected. Loads such as incandescent light bulbs, motors and heaters that do not contain electronics are reasonably well protected by spark-gap arrestors. However, loads that contain electronics, such as TV's, radios and CFL's are much more sensitive and require varistors for protection. The best protection is provided by pole mountable varistors with current rating of more than 50,000 Amps as these can withstand very high-energy discharges.

A cheaper alternative that works particularly well with PTC themistor load-limiters (see Figure 15-7) is to fit a disk-type varistor between line and neutral on the load side of the limiter and have a pole mounted spark-gap arrestor. In the event of lightning induced surge, the varistor will clamp the voltage in the house, with the additional voltage being dropped across the PTC. Once the voltage is high enough, the spark-gap arrestor will operate and conduct most of the current. Note that this puts extra stresses on the PTC. However, these are cheaper to replace than most domestic appliances.

During stormy weather, consumers should be encouraged to disconnect their supply via the mains switch at the entrance to their house. Note the use of a double pole switch at the consumer service entrance to isolate the live and the neutral (Section 14.4). This is the most secure method to prevent damage to delicate loads such as CFL's. Where the consumer premises require an earth, it is important that the consumer earth is separate from the earth to which the lightning arrestor is connected and preferably 10m or more away. This is because high currents to earth can result in dangerous voltage potentials close to the earth connection.

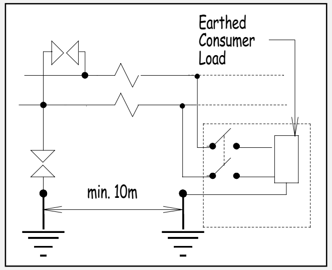


Figure 16-3 Ensure that the consumer earth electrode (if used) is at least ten metres from the neutral-earth arrestor electrode.

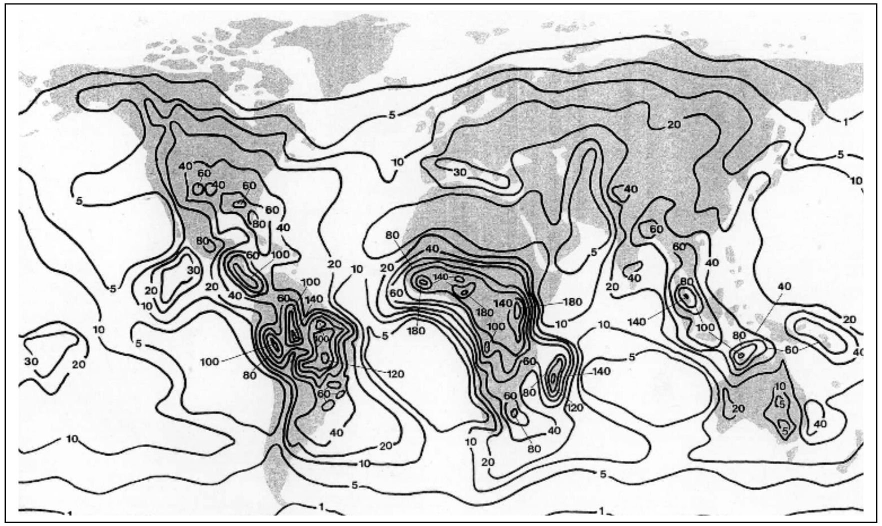


Figure 16-4 Map showing thunderstorm days per year throughout the world (based on World Meteorological records for 1955)

17 TESTING, COMMISSIONING AND OPERATION

17.1 Final Checks

Check the following before starting the turbine for the first time.

- The generator, motor protection switch and connecting cable have been correctly sized (Section 9.8)
- The generator, capacitors, controller, ballast, RCD, motor protection switch and earth-electrode have been connected according to Figure 9-7 and manufacturers instructions.
- All connections are tight and cable insulation has not be stripped back further than necessary (no bare cable should be exposed at connection blocks).
- The turbine and generator are free to rotate.
- Any moving parts such as pulleys and belts have safety guards to protect people in the powerhouse.
- The motor protection switch and RCD are switched on.
- The tailrace is free from obstruction
- The penstock joints are watertight and the penstock is anchored or buried.
- The penstock filter is free from debris.

17.2 Start-up

- Disconnect user loads connected to the distribution system using the mains switch located near the controller (Note: MCB and RCD should be in ON position).
- Open the gate valve near the nozzle slowly to about half full flow. Wait 60 seconds to allow any soil and air in the penstock to be flushed out.
- Turn off the valve and remove the turbine cover. Inspect the nozzle for any obstructions. If any are found, disconnect the nozzle to remove them.
- Replace the cover and slowly open the valve.
- The generator should excite and this will be indicated by a reading on the volt meter. This voltage should rise to approximately the same voltage as the generator.
- Check the ballast meter to ensure that the reading is greater than zero. This indicates that the controller and ballast are functioning. If no voltage is produce or the ballast meter reading is zero, refer to Section 18.
- Adjust the position of the nozzle plate to give the highest ballast reading.

17.3 Generator connection

There are two possible connections for the generator. Only one is acceptable. Continuous operation with the wrong connection is likely to damage the generator.

- Note the ballast reading when the valve is fully open.
- Close the valve and remove the cover on the generator terminal box when the generator has stopped rotating.
- Reverse the connections labelled “L” and “2C” (see Figure 9-7).
- Replace the cover, start the turbine by fully opening the valve.
- If the new ballast meter reading is greater than before then this is the correct connection. If not, restore the connections to their original position after closing the valve and waiting for the generator to stop.

Note: That with the correct connection the generator will run more quietly less hot.

17.4 Adjusting voltage and frequency.

- The voltage (indicated by the voltmeter) is set by the controller. Adjust the setting on the controller by following manufacturers instructions in order to obtain the required value.
- The frequency value should be 49 Hz to 52.5 Hz for a 50 Hz system (59 Hz to 63 Hz for a 60 Hz system).
- **Do not operate below the minimum frequency values given. The life of the generator and other devices connected will be reduced.**
- A frequency slightly above these ranges will not usually have a detrimental effect unless speed dependant motor loads such as pumps or fans are connected.

- To measure the frequency use a frequency meter or use a tachometer and calculate from the speed (generator shaft rpm’s) as follows:

Number of poles	Frequency (Hz)
2	Shaft speed / 63
4	Shaft speed / 31.5
6	Shaft speed / 21

- Calculating frequency from the speed is accurate to about 5%.
- The frequency can be adjusted by altering the amount of capacitors connected. Removing capacitors increases the frequency. Twice the amount of capacitance must be added or removed from the 2C as from C (see Figure 9-7).
- If the turbine will be operated over a range of flows, then check the frequency over the whole range and correct if necessary.

Note that changing the frequency will effect the power output as it will change the turbine efficiency and generator efficiency. The change is best observed by reading the ballast meter with no user loads connected.

17.5 Size of ballast load

The ballast meter should read between 40% and 100% when no user loads are connected.

- If below 40% then the ballast is too large and should be replaced by a smaller one. For example, some of the resistive elements (e.g. the cooking rings) can be disconnected.
- If 100% then check that all elements are heating up. If some elements are cold, check connections and, if possible, the resistance of the element.
- If all the elements are working and the reading is still 100%, increase the size of the ballast load without exceeding the maximum rating for the controller or generator.
- If this is not possible, then operate the turbine at reduced power output. Alternatively increase the capacity of the controller and/or the generator.

17.6 Commissioning the distribution system.

- Check all distribution poles and cables to ensure that they have been installed safely paying particular attention to ground clearance and cable sag.
- Check all house wiring has been safely installed and that consumers have been instructed about the dangers of electricity.
- If inductive loads such as tube lights or motors are connected, measure the frequency when these are operating. If frequency is too high then apply power factor correction to the significant inductive loads.

17.7 Operation

To start the generator:

- disconnect the consumer loads.
- open the flow control valve slowly until fully open or desired power output is achieved.
- connect consumer loads.
- If a large amount of power is being dissipated in the ballast, consider reducing the flow in order to reduce the temperature of the ballast and increase its life.

To stop the generator:

- disconnect the consumer loads
- slowly close the flow control valve until it is completely closed.

18 FAULT-FINDING

Problem	Possible Causes	Solution
No voltage/low power output	Insufficient turbine power	• Check water supply, nozzle and generator speed.
	Wiring fault	• Check wiring and MCB and RCD are switched on.
	Capacitor values incorrect	• Check capacitors are connected as shown in the wiring diagram. • Check capacitor values are correct for generator.
	Generator has lost residual magnetism	• Disconnect consumer load. When generator is stationary, connect a battery of 6V or more across any two generator terminals for one or two seconds. Re-start with no user load connected.
Over-voltage trip operates	Ballast loads not connected properly (ballast meter reads 100%)	• Check for loose or missing connections • Check that any switches in the ballast circuit are on. • Check that all ballast loads become hot. If not, measure resistance and replace if necessary.
	Generator output higher than IGC rating	• Operate turbine at reduced power output or replace IGC with one of higher rating
	Controller damaged and fails to deliver power to ballast (ballast meter does not operate or only over a limited range),	• Check whether fault is due to incorrect wiring of IGC. If not, then replace circuit board.
Ballast trip lamp lit	Ballast short circuited	• Check resistance between ballast leads and between each ballast lead and earth to test for short circuits. Repair or replace faulty wiring / ballast loads.
	Ballast load too large	• Check that the power rating of ballast is less than or equal to the power rating of the IGC.
Light bulbs flicker	Response speed of controller incorrect.	• Alter setting of response speed potentiometer on circuit board.
	Ballast load much greater than generator rating.	• Reduce capacity of ballast load.
	Uneven turbine output	• Check turbine for misalignment, damage or blockage. • Check for badly worn bearings.
Motor protection switch **operates**	Generator connection incorrect	• Check generator connections.
	Too much excitation current (motor protection switch operates even when turbine operating at reduced power output)	• Reduce the amount of capacitance connected.
	Too much load current (motor protection switch operates with turbine operating at full power output)	• Increase rating of motor protection switch and generator if necessary. • Operate turbine at reduce power output • Avoid overloading the generator
	Short circuit in distribution system	• Isolate sections of the distribution system until the fault is found. Alternatively measure the resistance at different sections to identify the fault.
RCD operates	Current leaking to ground either in powerhouse or elsewhere	• Disconnect consumer loads and restart to establish if the fault is in the powerhouse. If in powerhouse check wiring of earthed devices (e.g. controller casing) to locate earth fault. • If fault is elsewhere in the system, disconnect all earthed consumer loads • Check lightning arrestors for short to ground by temporarily disconnecting.
Individual house without power	Load limiter tripped	• disconnect all domestic loads and wait for 5 minutes. Reconnect less loads than before
	load limiter fuse blown	• check fuse.
	Wiring fault	• check service wire connection • check domestic wiring
Group of houses without power	Wiring fault	• check distribution cable connected to the houses for a fault
All houses without power (generator, controller and ballast working normally)	Wiring fault	• check wiring of main consumer switch in powerhouse • check first section of distribution cable for breaks .
		•

Further notes on fault finding:

1. Loss of Residual Magnetism

If consumer loads are left connected when an induction generator is stopped it is likely that the residual magnetism will be lost. This small magnetic field is required to build up the excitation currents and allow the induction generator to work at the voltage required. If excitation does not occur, then the voltage (and power) will be approximately zero when the turbine is rotating. If this is the case, then a dc power source such as a battery should be connected across any two of the generator terminals before starting the turbine. A 6V, 9V or 12V lead acid battery would be suitable for this or several large torch batteries connected in series and should be connected for 1-2 seconds only. Note: Care must be taken when using lead acid batteries not to short-circuit the terminals as the battery can explode!

2. Check for damaged capacitors

Ideally check the capacitor value with a capacitor meter. Otherwise the operation of capacitors can be verified with a multimeter - measure the resistance (should be high and increasing as capacitor is charged by meter battery) A low resistance indicates that the capacitor is damaged and it should be replaced.

19 APPENDICIES

Appendix A Basic Electricity

Voltage, Current, Power

Electricity is a very convenient form of energy. It can be generated in one place and then transported to where it is needed. At the flick of a switch, it can be made to do useful work such as create light, heat or run motors. The driving force that causes electricity to flow is called the voltage. The electricity flow itself is known as current. Electrical power is a combination of voltage and current. The power, measured in watts or kilowatts is used to describe the rate at which the energy is used.

Resistance

The amount of current which flows depends not only on the voltage which is driving but also on the resistance of the material through which it is passing. Materials such as copper have a low resistance allowing current to pass easily. These are called conductors. Materials that have a high resistance, such as most plastics, are called insulators.

AC and DC Electricity

Direct Current (dc) is the type of electricity that is stored in a battery. The current flows from positive (+) to negative (-) if the battery is connected to a load. Battery voltages vary. For example, they may be 1.5V, 6V, 9V or 12V. If two batteries are connected in a line (series), then the voltage is doubled. If both batteries are connected in parallel then the currents capability is doubled. Never short the terminals of a battery as they explode.

The time over which a particular current can be produced, also varies from battery to battery. For example, a sixty amp-hour (Ah) battery could produce one ampere of current for sixty hours or twenty amperes for three hours. Only batteries with identical voltage and amp-hour rating should be connected together in the same circuit. For more information about battery types, see Section 13.1.

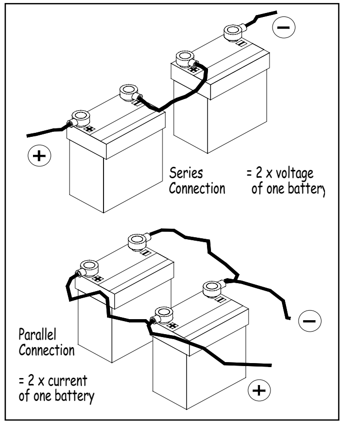


Figure 19-1 Series and parallel connection of batteries

Direct current at 12V can be produced using a car alternator. The maximum power however, is limited to about 500W.

Alternating current (ac) is used to describe electricity that is repeatedly changing direction. The rate at which this happens is called the frequency. Induction generators and synchronous generators produce ac electricity. One major advantage of ac is that the electricity can be generated at a much higher voltage, e.g. 120V or 220V than that of dc systems using batteries.

Higher generator voltage means that the current required to deliver a certain power is less. If the current is less then the power losses in cables are also less. This means that with ac, it is possible to transport electricity efficiently over long distances.

The following ac and dc system have been compared for a supply to five 40W light bulbs:

Alternating current system (ac)

1) Power required by load is 200W
2) Voltage is 220V ac

$$I = P/V$$
$$= 200/220$$
$$= 0.91 \text{ Amps}$$

Direct current system (dc)

1) Power required by load is 200W
2) Voltage is 12V dc

$$I = P/V$$
$$= 200/12$$
$$= 16.7 \text{ Amps}$$

High current means high losses in electric cables because of the cable resistance.

AC Waveforms

The AC voltage which is produced by a synchronous or induction generator has approximately the same shape as a sine wave. When a load is connected, the current will have a similar shape and the same period (period = time for one complete wave). The frequency is the number of complete waves in 1 second. For example, the complete wave shown in Figure 19-2 is repeated 50 times in one second if the frequency is 50 Hertz.

If the load is purely resistive (for example a heater or light-bulb), then the current then the current will alternate at exactly the time as the voltage. The current and voltage are said to be "in phase"

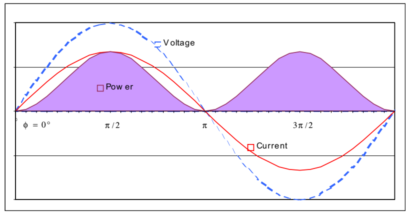


Figure 19-2 AC waveforms can be approximated to a sine wave. If the load is a pure resistor, then the current which flows is in phase with the generated voltage

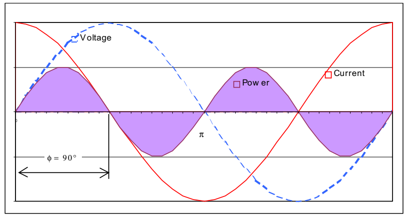


Figure 19-3 If the load is a pure capacitor, then the current leads the voltage by 90° and the average power consumed = 0 Watts

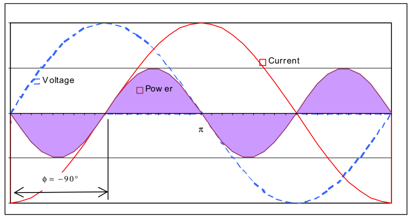


Figure 19-4 If the load is a pure inductor, then the current lags the voltage by 90°. The average power consumed is still = 0 Watts

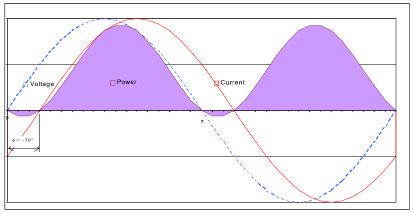


Figure 19-5 General circuits are combinations of resistance, capacitance and inductance. Here the current lags the voltage by 30° as the load is both resistive and inductive. The power factor (cosϕ) is close to 1 and the amount of reactive power consumed is small but must still be supplied by the generator.

Real and Apparent Power

The basic formula for power is current times voltage:

19.2 Power (apparent) = I x V

However, for ac circuits this is not the whole story as this is only the apparent power. To calculate the real power an additional factor is needed called the Power factor.
Using the Power factor (Pf) the real power can be calculated:

Power (real) = V x I x Power factor

Real power is measured in Watts (W) and apparent power in Volt-amps (VA).

The reason for this difference is that there are two types of electrical loads; resistive loads and reactive loads. With resistive loads the current is in phase with the voltage as shown in Figure 19-2 and in this case the power factor=1 and the real power equals the apparent power. Reactive loads may be either inductive or capacitive. Purely reactive loads draw current consume no net power as shown in Figure 19-3 and Figure 19-4 as for half a cycle the power dissipated is positive and for half a cycle it is negative. In these cases the power factor=0 and real power=0. The combination of resistive and reactive requirements of a particular circuit is referred to as the impedance. A leading power factor (p.f. > 1.0) indicates that a load is more capacitive than inductive. A lagging power factor (p.f.<1.0) indicates that the load is more inductive than capacitive.

When the power factor equals 1.0, then the net requirement for reactive power is zero and only resistive power is supplied. Power factor correction means to bring the power factor closer to one and reduce the reactive power consumption. In practice this usually means connecting capacitors in parallel with an inductive load to raise the power factor.

Since the reactive power does not show up on an electricity meter, domestic consumers are not normally charged for reactive power. However this extra reactive power must still be provided by the generator. So to prevent a pico hydro system from becoming overloaded, power factor correction is often an important consideration for the developer.

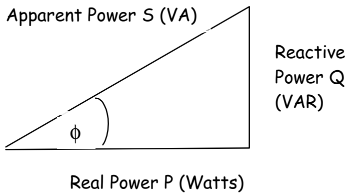
A power factor of 1.0 means that a load is purely resistive. No reactive power is used and real and apparent power have the same value. If the power factor is less than one, then the load is partly inductive. Power factors of some typical loads are given in the following table:

Load	Power factor
Incandescent lamp	1.0
Fluorescent lamps	0.5 - 0.7
Motors	0.2 - 0.95

Table 19-1 Variation of power factors for common loads

Power Triangle

The relationship between real and apparent power and power factor can be summarised in a "power triangle."



So

P= S x cosφ

(Power factor = cosφ)

and

$$S = \sqrt{P^2 \times Q^2}$$

Figure 19-6 Power triangle showing relationship between real and apparent power.

Power Factor Correction

Circuits which have a lagging power factor caused by inductive loads (see Figure 19-4) such as electric motors or fluorescent lamps, require a supply of reactive power. For small loads connected to the electricity grid, this does not present a problem as the reactive power can easily be supplied. However, this may not be the case with small stand-alone induction generators. Power factor correction is sometimes necessary in these situations to allow the most efficient use to be made out of the power available.

The term "power factor correction" means to increase a lagging power factor towards 1 so that the amount of reactive power required by a circuit is reduced (see Figure 19-5.). This can be achieved by connecting capacitors across the load. Capacitance causes the current to lead the voltage rather than lag behind. This can be understood by comparing Figure 19-3 and Figure 19-4. The net effect of this is that the total reactive power requirement of the circuit is reduced. Additional considerations are the availability and cost of suitable capacitors and how much capacitance to connect. These may determine to what extent the power factor can be corrected. However, it is important to avoid over-correction of the power factor. Selection of capacitors for power factor correction is explained in Section 13.1.

Appendix C Turbine Operating Speeds for Mechanical Loads

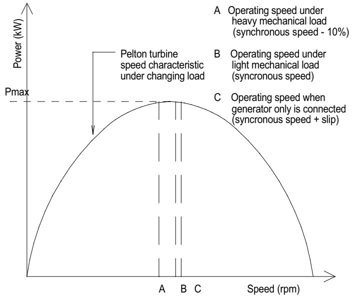


Figure 19-7 Ideal operating speeds of Pelton turbine under different load conditions

If the speed of the turbine for driving the mechanical load is carefully chosen, then it is possible to allow the induction generator to be used as a brake for the mechanical load thus regulating its speed. This reduces wear and has advantages during processes such as milling, for example, producing a more evenly ground flour. Any surplus power, not required by the mechanical load will be dissipated in the generator or ballast, preventing the load and turbine from over-speeding.

The operating speed of an induction generator is typically the synchronous speed +3%. This is the speed when electrical power is delivered to the controller and consumers. At about 10% below the synchronous speed, there is no net generation of electricity.

The use of an induction generator controller regulates the turbine speed under both varying mechanical and electrical load conditions. When the mechanical load is reduced causing the speed of the turbine to increase, the controller begins to divert the excess power to the ballast. This increases the load on the turbine and therefore is able to control its speed. The action is similar to a mechanical brake.

So what speed should be chosen as the design speed for the turbine shaft when sizing a pulley system for a mechanical drive?

A useful guideline is to use the synchronous speed of the motor. This will be slightly less than the operating speed when the generator is being driven (synchronous speed + 3% slip) This will mean that under normal conditions of operating the mechanical load electricity will not be generated, but the turbine will still be deliver maximum power. The synchronous speeds for 2 pole (3000rpm), 4 pole (1500rpm) and 6 pole (1000rpm) induction machines have been used in the "Power per Belt" tables (Table 13-5 and Table 13-6)

Appendix D: Additional Notes on Belt Sizing

The guidelines given in Sections 13.5 and 13.6 are sufficient for approximate matching of pulleys and belts to loads. However, the following two factors have not been taken into account in the "Power per Belt" tables.

1) Long belts can deliver more power than short ones.
2) A pulley ratio which is speed reducing (a small pulley is driving a larger one) can also deliver more power than a drive which has two pulleys of equal size.

Ratio	SPZ	SPA	SPB
1:1	>550	>760	>1050
2:1	>600	>850	>1150
3:1	>600	>850	>1200
4:1	>650	>900	>1260
5:1	>650	>950	>1260

Table 19-2 Add 5% to power per belt if Centre Distance (mm) is greater than the above value.

The pulley belt can be sized to a greater level of accuracy if Table 19-2 and Table 19-3 are used. For a belt which is longer than the values given in Table 19-2 (values in mm), 5% can be added to the power. For example, If an SPZ belt is used on a pulley system that has a ratio of up to 2:1, the power can be increased by 5% when the centre distance is greater than 600 mm.

rpm's of turbine shaft	SPZ	SPA	SPB
1000	0.15	0.39	0.81
1500	0.23	0.58	1.21
3000	0.46	1.17	2.42

Table 19-3 Additional kW per belt if Ratio is 1.95 or greater and turbine pulley smaller than the load pulley

If the pulley ratio is 1.95 (1.95:1) or greater, then the power can be increased by the amount shown in Table 19-3. For example, if an SPA belt is chosen and the turbine speed is around 1500 rpm, the power which that belt can deliver increases by 0.58 kW if the ratio is 1.95 or more.

20 USEFUL REFERENCES AND ADDRESSES

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2. Inversin, A. 'Mini Grid Design Manual,' ESMAP, World Bank, 2000.

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21 GLOSSARY

Abney level	a device used for measuring the incline of a slope; can be used to calculate the head
ac	**a**lternating **c**urrent; electric current which changes direction at frequent intervals .e.g. at 50Hz or 50 times per second
Altimeter	a device which uses air pressure to calculate difference in vertical height between two points
Ballast load	usually an electrical heating element which consumes any unused power produced by the generator
Battery	used for storing dc electricity; re-chargeable batteries (e.g. lead-acid, Nickel Cadmium) can be used to light houses which are too far from the generator to have a connection
Belt drive	system for transferring rotating mechanical power from one shaft to another using pulley wheels and belts
Bucket method	method of flow measurement using a bucket of known volume and a stopwatch
Canal	can be a practical and low cost method in some rural areas of transporting water to the forebay and reducing the length of penstock required
Capacitor	electronic device used to allow induction motors to work as generators; also used for power factor correction; capacitance is measured in micro Farads (µF)
CFL	**C**ompact **F**luorescent **L**amp; energy efficient light bulb requiring less power than other varieties
Current	the rate of flow of electrons through a circuit; measured in Amps
dc	**d**irect **c**urrent; electric current flowing in one direction
Demand survey	Assessment of the power requirements and ability to pay of a community
Distribution system	wiring system which connects houses to the generator
Distribution pole	supports for distribution cable
Domestic wiring	electrical system inside a house
Earth-fault	a wiring fault allowing current to leak to the ground
Efficiency	the word used to describe how ell the power is converted from one form to another; it is the ratio of the output power to the input power expressed as a percentage; the efficiency of a pico hydro system is usually about 45%.
Emergency lighting	tube light with rechargeable battery which can be switched on when the electricity supply fails
Energy storage	energy storage may be required if the flow of water cannot be guaranteed to be high enough throughout the year; batteries and reservoirs are examples of how energy can be stored
Flow	measurement of the quantity of water flowing past a point in one second; measured in metres per second or litres per second and used to calculate the hydraulic power
Forebay	structure which is sometimes used for pico hydro at the start of the penstock ensuring that the water is sufficiently deep
Frequency	the switching backwards and forwards of alternating current; measured in Hertz (cycles per second)
Fuse	electrical safety device which prevents damage to circuits or appliances caused by short circuits or overloading

Head	the vertical drop of a water in a stream or in the penstock; measured in metres
IGC	**I**nduction **G**enerator **C**ontroller – and electronic device used to keep the voltage and frequency steady
Incandescent lamp	simple lamp with a wire filament
Induction generator	source of ac electricity
Induction motor	electrical machine which can be used to drive mechanical loads
Intake	point where water enters the penstock
Lighting package	an electricity supply suitable for one lamp and possibly a radio
Lightning arrestor	a device which allows current surges caused by lighting strikes to be conducted away to ground
Load	a device which uses the power produced by the generator
Load control	a system to keep the amount of load on the generator constant
Load limiter	a device which prevents too much current being taken by a consumer
Low-pressure pipe	can be used as a cost-effective alternative to a canal to bring water to the mouth of the penstock
MCB	**M**iniature **C**ircuit **B**reaker; alternative safety device to the fuse with the advantage that it can be reset after tripping due to a short circuit or overloading
Meter	device which displays the level of generator voltage or ballast power
Motor Protection Switch	Safety device which disconnects if too much current is drawn. Unlike an MCB, which operates at only one current level, the tripping current can be selected from a range, e.g. 6 to 10 amps.
Over-voltage trip	protection circuit built into the IGC which automatically disconnects the supply to protect the consumer loads if the voltage rises too high
Pelton turbine	rotating wheel with buckets around the outside which absorb the power of a water jet and convert it into rotating mechanical power; most Pelton designs require a head of 20 metres or more to work efficiently
Peltric Set	design of pico hydro unit which is popular in Nepal
Penstock	pipe containing water under pressure: brings water from forebay to powerhouse
Pico hydro	hydro power with a maximum electrical output of 5kW
p.c.d.	**p**itch **c**ircle **d**iameter; diameter line around a Pelton turbine at the centre of jet interaction
PTC	**P**ositive **T**emperature **C**oefficient Thermistor; electronic device which can be used as a low-cost form of load limiting
Power	measurement of energy supply and demand; given in Watts(W) or Kilowatts(kW); may be hydraulic power, mechanical power or electrical power.
Power factor correction	reducing the reactive power requirements of loads such as induction motors and fluorescent lighting by connecting capacitors of certain value across the supply.
Powerhouse	building which contains the turbine, generator and any directly driven mechanical loads
RCD	**R**esidual **C**urrent **D**evice; used to disconnect the supply in the event of an earth fault
Reservoir	small scale energy storage; sometimes used during the dry season if flows are insufficient; water

	collected during the day so that the turbine can be run in the evening for lighting
Resistance	property of materials related to how well they conduct electric current e.g. plastic has a high resistance and is called and insulator, copper has a low resistance and is called a conductor; resistance is measured in ohms (Ω)
Salt Gulp	method of flow measurement by adding salt to the water and measuring the conductivity change
Stand-alone system	Electricity system which is not connected to the National Grid
Transformer	A device with allows the voltage of an ac circuit to be changed up or down by a fixed amount (e.g. 240v to 12v) Sometimes the distribution voltage is raised so that houses further than 1km from the generator can be connected. Higher voltage reduces losses in the cables.
Turbine nozzle	restricts the flow of water at the end of the penstock to produce a high velocity jet
Valve	device used to regulate the flow of water in the penstock. A gate valve is preferred
Voltage	measurement of "electrical pressure" which is required in order for current to flow around a circuit; measured in volts (v)
Voltage drop	loss of voltage across the distribution system because of the cable resistance. A voltage drop of up to ±6% is acceptable

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