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.

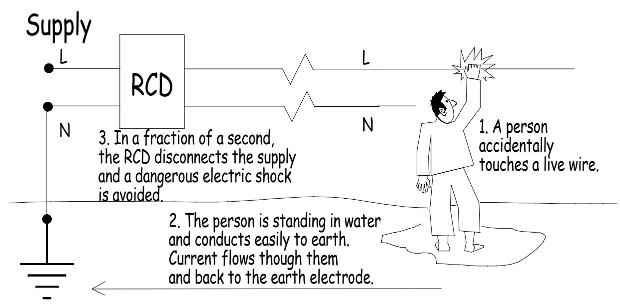


Figure 15-2 The danger of electric shock from a bare cable is reduced by fitting an RCD.

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.

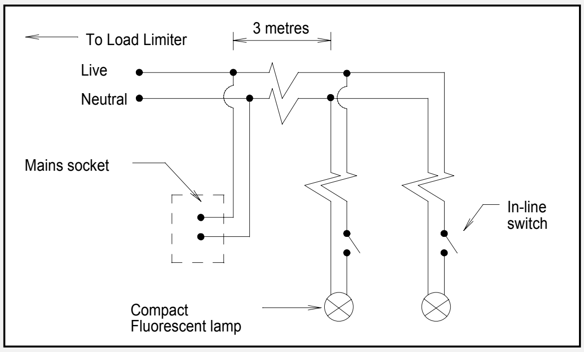


Figure 15-3 Circuit diagram of a typical wiring harness

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

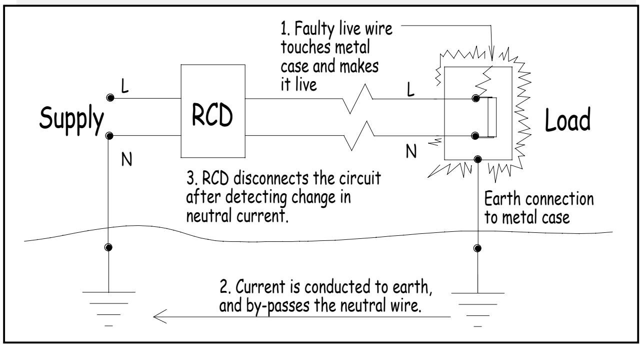


Figure 15-4 Protecting consumer loads using an RCD

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.

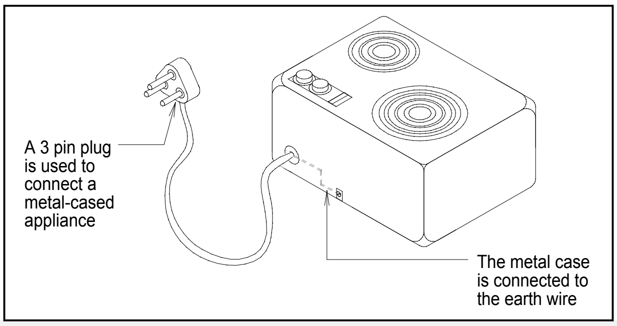


Figure 15-5 Metal-cased devices should be earthed

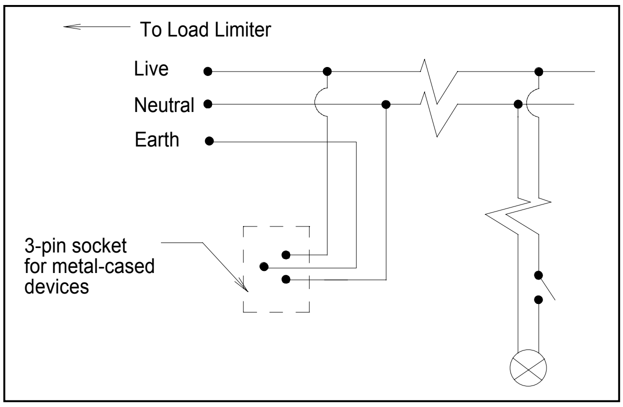


Figure 15-6 An earth connection must be provided if metal cased loads are likely to be connected.

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

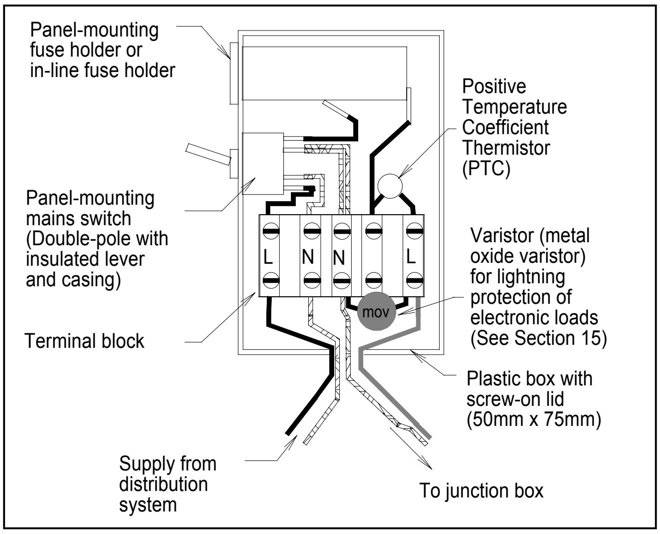


Figure 15-7 A load limiter should connect the service wire from the distribution system to the domestic wiring in the house. A PTC is used as a load limiter if less than 0.5 Amps is drawn.

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}).

$$\text{PTC } I_{nt} < \text{Fuse } I_{rated} < \text{PTC } I_{max}$$

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:

$$\text{Breaking Capacity} \geq 3.0 \times I_{op}$$

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. <u>This is not recommended</u> 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.

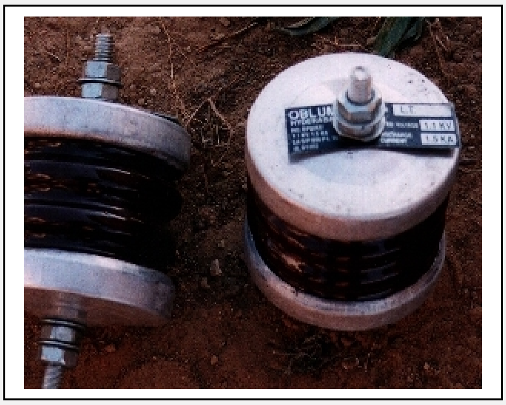


Figure 16-1 Spark gap lightning arrestors

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.

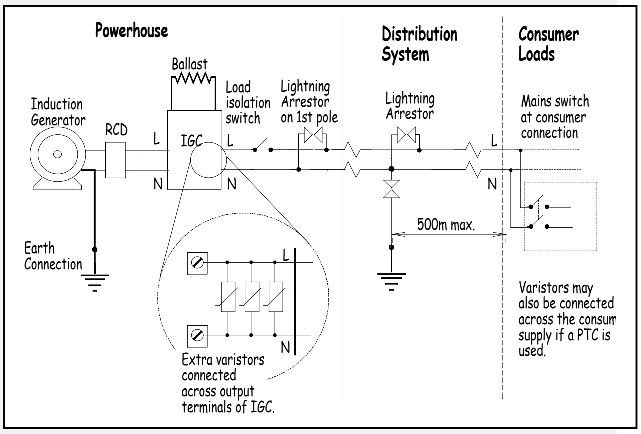


Figure 16-2 Connection of lightning arrestors to prevent damage to electrical equipment and reduce danger to electricity consumers

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 <u>and</u> 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.

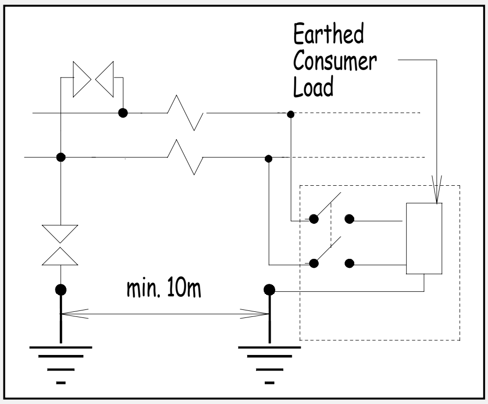


Figure 16-3 Ensure that the consumer earth electrode (if used) is at least ten metres from the neutral-earth arrestor electrode.

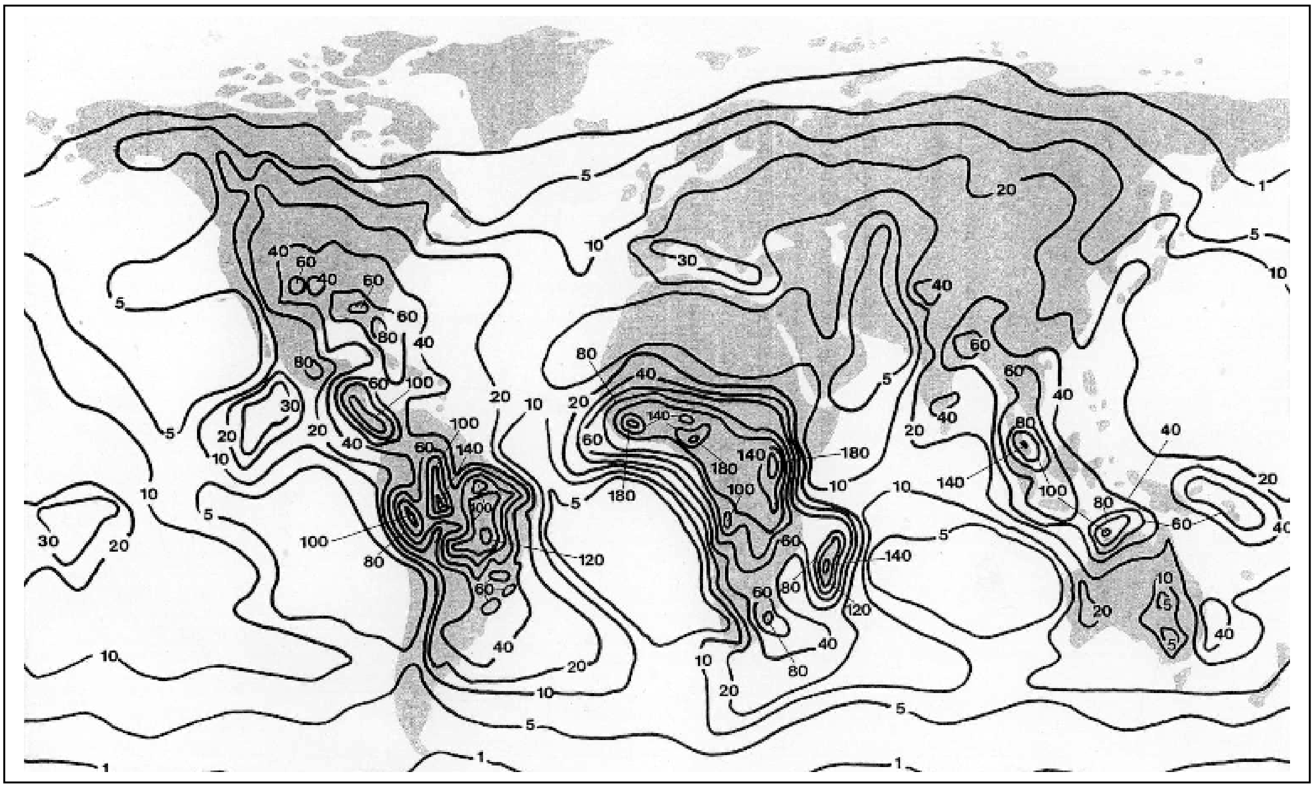


Figure 16-4 Map showing thunderstorm days per year throughout the world (based on World Meteorological records for 1955)

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 <u>before</u> 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.

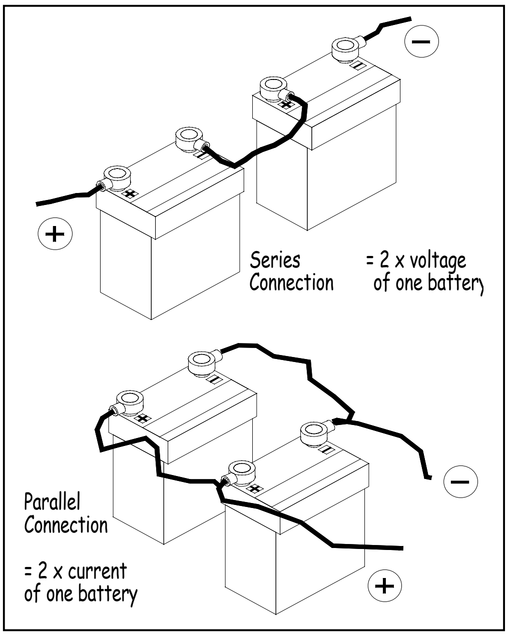


Figure 19-1 Series and parallel connection of batteries

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"

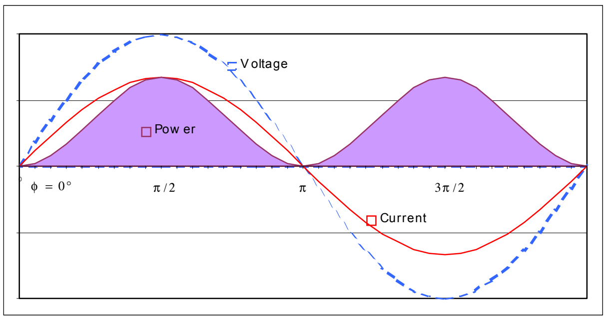


Figure 19-2 AC waveforms can be approximated to a sine wave. If the load is a pure resistor, then the current which flows is in phase with the generated voltage

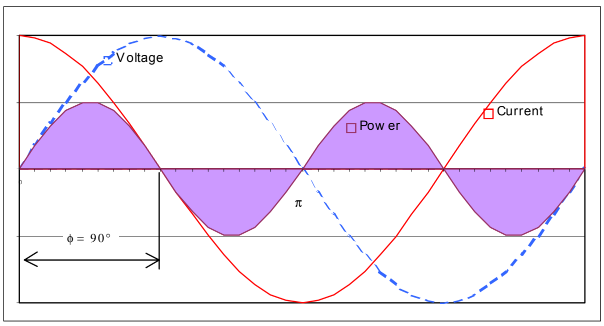


Figure 19-3 If the load is a pure capacitor, then the current leads the voltage by 90° and the average power consumed = 0 Watts

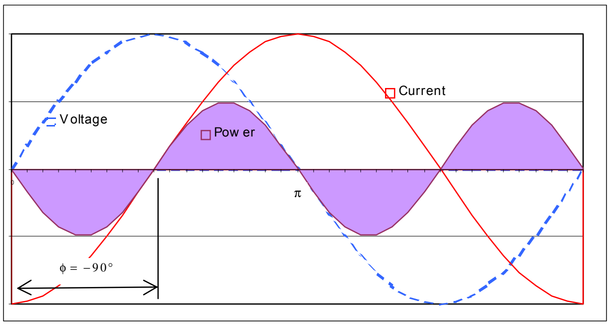


Figure 19-4 If the load is a pure inductor, then the current lags the voltage by 90°. The average power consumed is still = 0 Watts

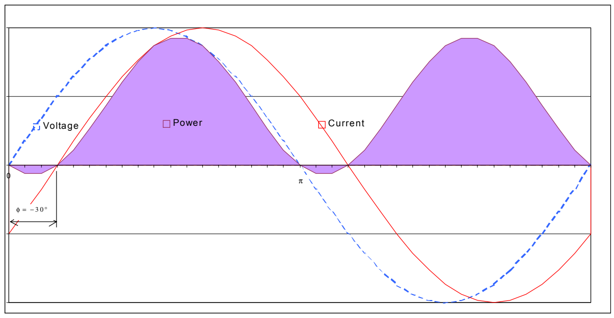


Figure 19-5 General circuits are combinations of resistance, capacitance and inductance. Here the current lags the voltage by 30° as the load is both resistive and inductive. The power factor (cosϕ) is close to 1 and the amount of reactive power consumed is small but must still be supplied by the generator.

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.

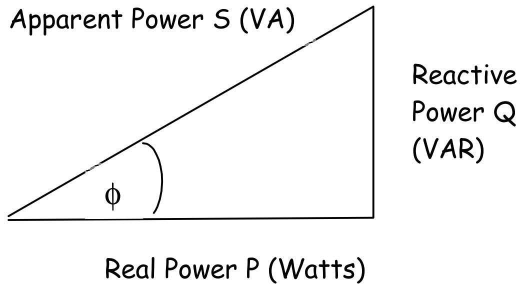
A power factor of 1.0 means that a load is purely resistive. No reactive power is used and real and apparent power have the same value. If the power factor is less than one, then the load is partly inductive. Power factors of some typical loads are given in the following table:

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

$$P = S \times \cos\phi$$

(Power factor = $\cos\phi$)

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

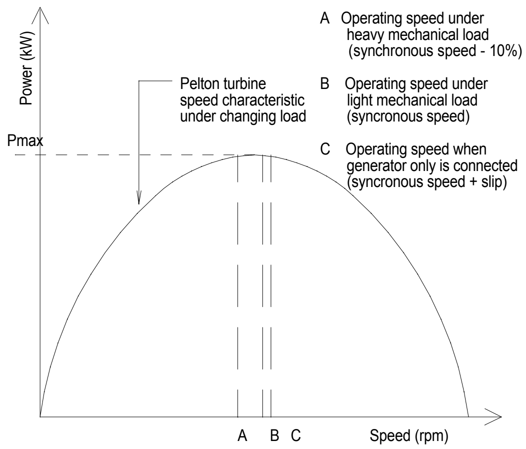


Figure 19-7 Ideal operating speeds of Pelton turbine under different load conditions

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

References:

1. Harvey, A. et al. 'Micro Hydro Design Manual,' Intermediate Technology Publications, 1993.

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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