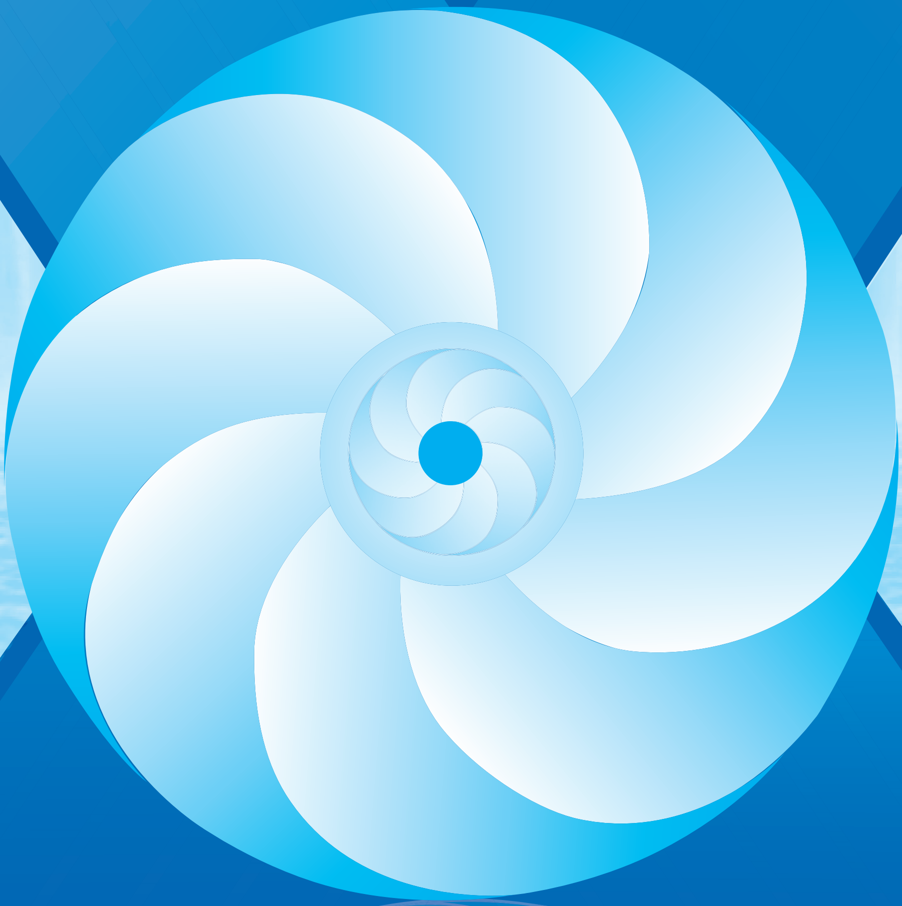
SMALL HYDRO POWER (SHP)
Module



Trainers Textbook

Study materials in Renewable Energy Areas for ITI students

Ministry of New and Renewable Energy
Government of India

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Small Hydro Power (SHP) Module

Ministry of New and Renewable Energy
Government of India

Prospective trade students

Welders, Plumbers, Sheet metal workers, Electricians Courses can be coupled with this course

Objective

At the end of this course students will be able to:

- Work in a Small Hydro Power plant
- Operate water mills
- Carry out maintenance of SHP and water mills

Duration: 12 hours

- SHP – 9 hours + 1 hour practical
- Water mills - 1 hour + 1 hour practical

Contents

Appendices

Unit 1. Introduction to Renewables

Time: 30 mins

Methodology: Lecture

1.1 Renewable Energy in the World and in India

Renewable energy is energy generated from natural resources—such as sunlight, wind, rain, tides, and geothermal heat—which are renewable (naturally replenished). In 2006, about 18 percent of the global final energy consumption came from renewable sources, with 13 percent coming from traditional biomass, such as wood-burning. Hydroelectricity was the next largest renewable source, providing 3 percent of global energy consumption and 15 percent of global electricity generation.

Wind power is growing at the rate of 30 percent annually, with a worldwide installed capacity of 1,21,000 megawatts (MW) in 2008. It is widely used in European countries and the United States. The annual manufacturing output of the photovoltaic industry reached 6,900 MW in 2008, and photovoltaic (PV) power stations are popular in Germany and Spain. Solar thermal power stations operate in the U.S.A and Spain, and the largest of these is the 354 MW SEGS power plant in the Mojave Desert. The world's largest geothermal power installation is The Geysers in California, with a rated capacity of 750 MW. Brazil has one of the largest renewable energy programme in the world, involving production of ethanol fuel from sugar cane, and ethanol now provides 18 percent of the country's automotive fuel.

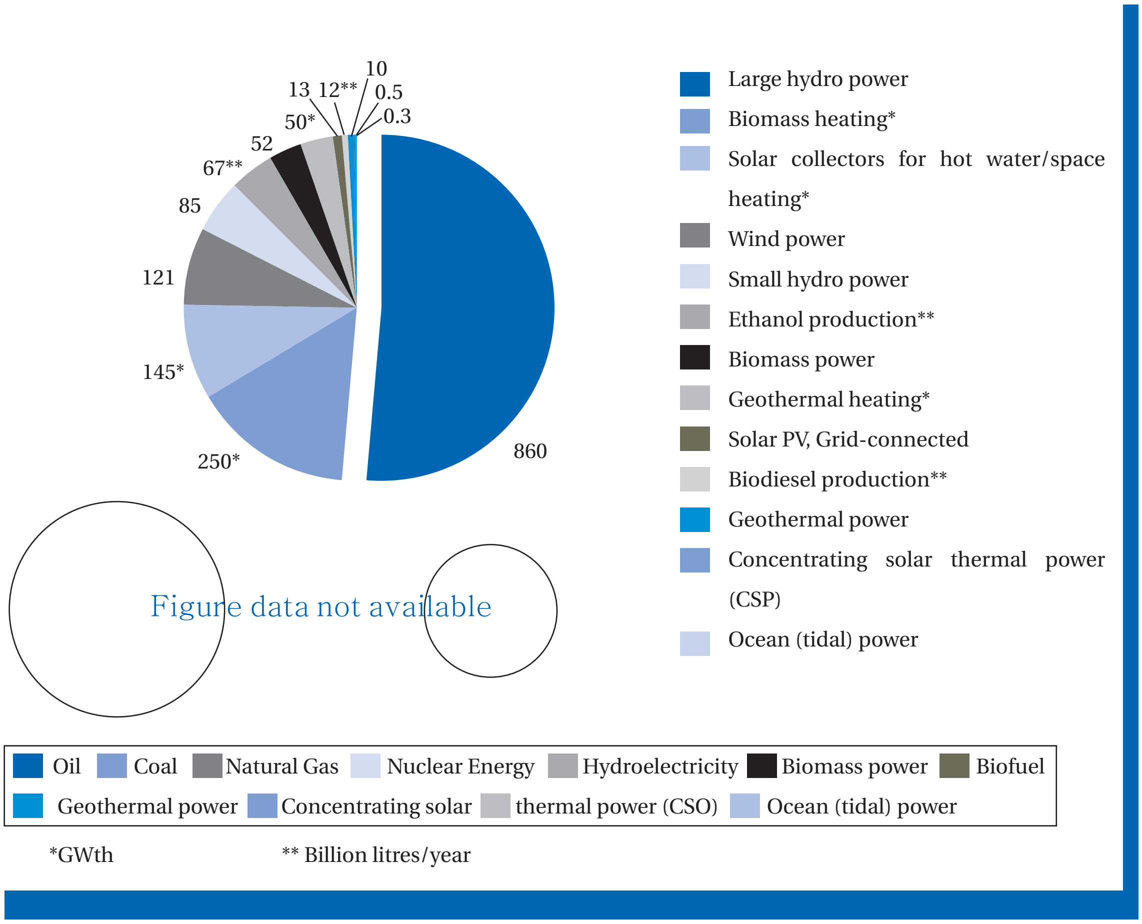
Ethanol fuel is also widely available in the USA. While most renewable energy projects and production are large-scale, renewable technologies are also suited to small off-grid applications, sometimes in rural and remote areas, where energy is often crucial for human development. Kenya has the world's highest household solar ownership rate with roughly 30,000 small (20–100 watt) solar power systems sold per year.

Some renewable-energy technologies are criticised for being intermittent or unsightly, yet the renewable-energy market continues to grow. Climate-change concerns, coupled with high oil prices, peak oil, and increasing government support, are driving increasing renewable-energy legislation, incentives and commercialisation. New government spending, regulation and policies should help the industry weather the 2009 economic crisis better than many other sectors.

With India's power needs projected to reach over 240,000 MW by 2012 – an increase of about 20,000 MW per year – it has become critically important to exploit other energy sources. As much as 18 percent of the additional grid interactive renewable power capacity that was commissioned during the first three years of the Tenth plan came from renewables.

The estimated potential in India for generation of power from wind, small hydro, and biomass is around 80,000 MW. Renewable power capacity is likely to double every five years or so in the future. By 2012 around 20,000 MW, which is 10 percent of the then installed capacity would be contributed by renewables. Sources estimate that about 7.5 billion dollars have so far been invested in the renewable power sector in India. About 90 percent of the investment has come from the private sector.

Figure 1.1 Renewable energy, end of 2008 (GW)



*GWth ** Billion litres/year

Source: REN21, Wikipedia.

1. 2 Hydro Power Generates Electricity

Of the renewable energy sources that generate electricity, hydro power is the one used most often. It is one of the oldest sources of energy and was used thousands of years ago, to turn a paddle wheel for the purpose of grinding grain.

How Hydro Power Works

It is important to understand the water cycle in order to understand hydro power. In the water cycle:

- Solar energy heats water on the surface, causing it to evaporate
- This water vapour condenses into clouds and falls back onto the surface as precipitation
- The water flows through rivers back into the oceans, where it can evaporate and begin the cycle all over again.

Mechanical energy is derived by directing, harnessing, or channelling moving water. The amount of available energy in moving water is determined by its flow or fall. Swiftly flowing water in a big river, like the Narmada or the Ganges, carries a great deal of energy in its flow. The same is the case with water descending rapidly from a very high point. In either instance, the water flows through a pipe, or penstock, then pushes against and turns the blades in a turbine, to spin a generator to produce electricity. In a run-of-the-river system, the force of the current applies the needed pressure, while in a storage system, water is accumulated in reservoirs created by dams, then released when the demand for electricity is high. Meanwhile, the reservoirs or lakes are used for boating and fishing, and often the rivers beyond the dams provide opportunities for whitewater rafting and kayaking.

1.3 Hydro Power and the Environment

Some people regard hydro power as the ideal fuel for electricity generation because unlike the nonrenewable fuels used to generate electricity, it is almost free, there are no waste products and hydro power

Figure 1.2 The water cycle

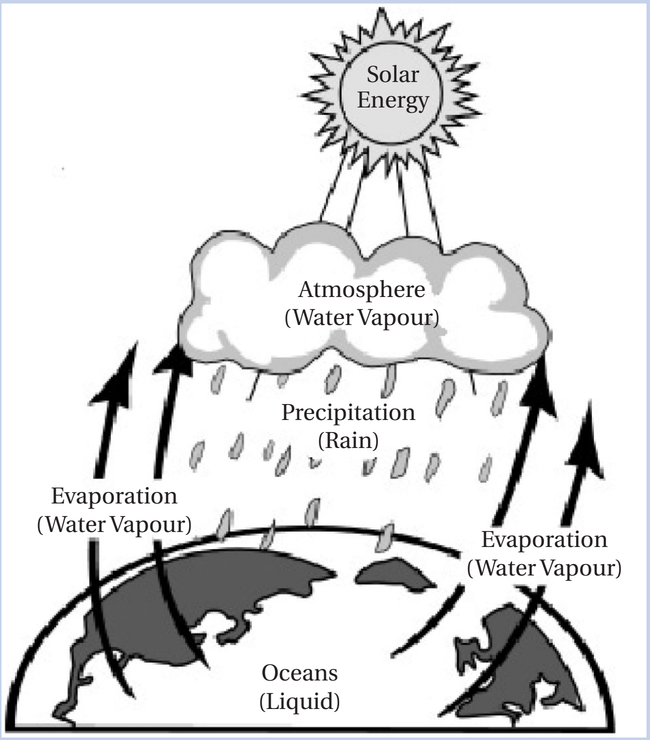
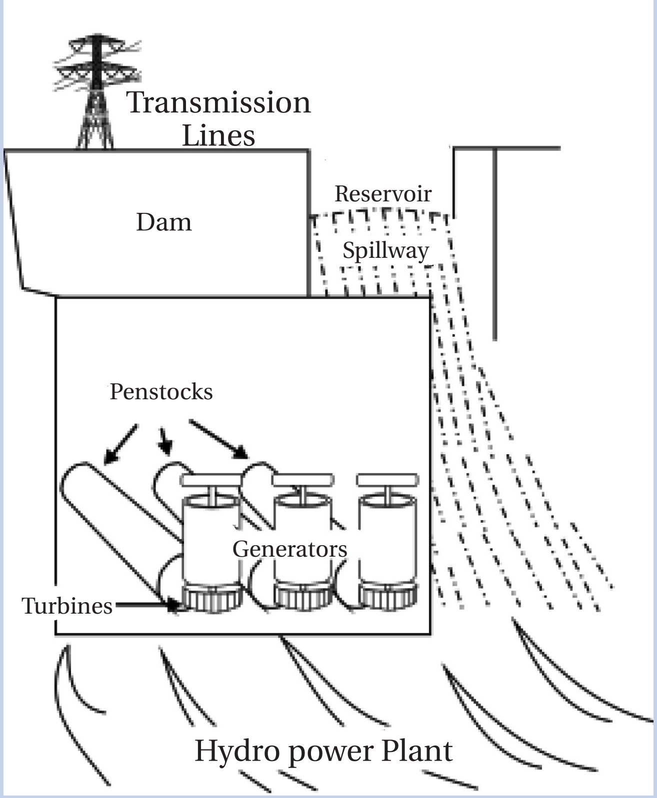


Figure 1.3 How Hydro Power Works



does not pollute the water or the air. However, it is criticised because it does change the environment by affecting natural habitats. For instance, the recent Narmada Valley Project created a mass movement that pressurised the Government of India to lower the height of the dam so that a smaller area would be submerged. However, in this part of our syllabus we are talking of Small Hydro Power projects that have minimum impact on the environment and the people around it.

Over 40 percent of India's population does not have access to electricity and providing electricity for 24 hours in rural areas is a major challenge. For this, the Indian government has envisioned several paths for its energy requirements, from nuclear to renewable overby Despite greening its energy requirements, the government has taken various paths, from bidding for foreign oil wells through diplomatic manoeuvring, to establishing fossil fuel thermal plants.

The National Electricity Policy envisages that the per capita availability of electricity will be increased to over 1,000 KW, by 2012. To achieve this, the government is expecting a total capacity addition of about 78,577 MW at the end of 2012, of which:

- 16,553 MW is expected from hydro
- 58,644 MW from thermal and
- 3,380 MW from nuclear.

Although India has significant potential for generation of power from non-conventional energy sources (1,83,000 MW) such as wind, small hydro, biomass and solar energy, the emphasis is still on thermal energy sources. India has at present a 7.5 percent overall electrical energy shortage and 11 percent shortage during peak hous.

1.4 Options for Hydro power

In the 2005 National Electricity Policy the objectives have been set as follows:

- provision for access to electricity for all households
- demand to be met by 2012, with no energy and peaking shortages
- adequate reserves to be made available and
- reliable and quality power supplies, at reasonable rates.

The Indian government considers hydro power as a renewable, economic, non-polluting and environmentally benign source of energy. The exploitable hydro-electric potential in terms of installed capacity, is estimated to be about 1,48,700 MW (See Table 1), out of which, a capacity of 30,164 MW (20.3 percent) has been developed so far and 13,616 MW (9.2 percent) of capacity is under construction. In addition, 6,782 MW in terms of installed capacity from small, mini and micro hydro schemes have been assessed. Also, 56 sites for pumped storage schemes with an aggregate installed capacity of 94,000 MW have been identified. The government expects to harness its full potential of hydro power by 2027, with a whopping investment of 5,000 billion rupees.

Table 1: India’s Hydro power potential

River Basin	Potential at 60 percent load factor (MW)	Probable capacity (MW)
Indus Basin	19,988	33,832
Brahmaputra Basin	34,920	66,065
Ganga Basin	10,715	20,710
Centrall India Basin	2,740	4,152
System	6,149	9,430
East Flowing River System	9,532	14,511
Total	84,044	1,48,700

India has the potential to nearly triple its hydroelectric output. Source: India Central Electricity Authority

1.5 Small Hydro-Power: A Viable Option

Small and mini hydel projects have the potential to provide energy in remote and hilly areas where extension of an electrical transmission grid system is uneconomical. Realising this fact, the Indian government is encouraging development of small hydro power (SHP) projects in the country. Since 1994 the role of the private sector for setting up of

Figure 1.4 Small 100 KW hydro power project in Himachal Pradesh

**Small 100 KW hydro power project in Himachal Pradesh (Photo: MNES)*

commercial SHP projects has been encouraged. So far, 14 States in India have announced policies for setting up commercial SHP projects through private sector participation. Over 760 sites of about 2,000 MW capacity have already been offered/allotted.

An estimated potential of about 15,000 MW of SHP projects exist in India. 4,233 potential sites with an aggregate capacity of 10,071 MW for projects up to 25 MW capacities have been identified. In the last 10-12 years, the capacity of Small Hydro projects up to 3 MW has increased 4 fold from 63 MW to 240 MW. 420 Small Hydro power projects up to 25 MW station capacity with an aggregate capacity, of an over 1,423 MW have been set up in the country and over 187 projects in this range with an aggregate capacity of 521 MW are under construction.

The Ministry of New and Renewable Energy Source (MNRES) provides various incentives like soft loans for setting up of SHP projects up to 25 MW capacity in the commercial sector, renovation and modernisation of SHP projects, setting up of portable micro hydel sets, development/upgradation of water mills, detailed survey and investigation, detailed project report preparation, interest subsidy for commercial projects, capital subsidy for SHP projects in the North-Eastern region, and implementation of UNDP/GEF Hilly Hydro project. India has a reasonably well-established manufacturing base for the full range and type of small hydro equipment. There are currently eight manufacturers within India in the field of small hydro manufacturing, supplying various types of turbines, generators, control equipment, etc.

Asian Development Bank(ADB) has begun its engagement in producing hydro-power in Uttarakhand in India with 4 SHPs (4-10 MW). However, the Manila based regional development bank believes that India's vast hydro power potential can contribute to the country's energy security in an environmentally sustainable and socially responsible manner. The report of ADB (Hydro power Development in India, 2007) provides an assessment of the hydro power development potential in India and highlights how hydro power can meet the country's goal of providing power for all by 2012. In all probability, the World Bank would like to assist in the construction of hydro power structures and the ADB will lay the transmission lines from the projects to the grid.

As major rivers transcend international boundaries in South Asia, India has taken up regional (mostly bilateral) co-operation on harnessing the hydro-power potential of international river systems. At present, India has the co-operation of Bhutan, Nepal and Myanmar on hydro-power.

Unit 2. Small Hydro Power – Basic Working Principles

Time: 15 minutes

Methodology: Presentation, lecture

2.1 What is Micro Hydro power?

Micro Hydro power (from hydro meaning water and micro meaning small scale) refers to electrical energy that comes from the force of moving water used to power a household or a small village.

The fall and flow of water is part of a continuous natural cycle. The sun draws up moisture from the oceans and rivers and the moisture then condenses into clouds in the atmosphere. This moisture falls as rain or snow, replenishing the oceans and rivers. Gravity moves the water from high ground to low ground. The force of moving water can be extremely powerful, as anyone who has experienced whitewater rafting knows! Micro Hydro power harnesses some of this power to create electricity.

Hydro power is a renewable energy source because it is replenished by snow and rainfall. As long as the rain falls, we won't run out of this energy source.

Small Hydro power Site

The site that is chosen for SHP is usually rivers or streams. It is called a run-of-the river system. For a SHP site, two types of information are needed. First, the flood flow or the expected maximum water level is needed to size a spillway (if any), to locate turbines and generators above the highest expected water level and to design diversion structures or canals. Second, the statistical distribution of monthly stream flow volumes (flow duration curve) is needed to estimate the reliability of the site for the production of a given amount of electrical power and to size a turbine.

2.2 How Does Micro Hydro power Work?

Hydro power plants capture the energy of falling water to generate electricity. A turbine converts the energy of falling water into mechanical energy. Then an alternator converts the mechanical energy from the turbine into electrical energy. The amount of electricity a hydro power plant produces is a combination of two factors:

1. **How far the water falls (Head):** Generally, the distance the water falls depends on the steepness of the terrain the water is moving across, or the height of the dam the water is stored behind. The farther the water falls, the more power it has. In fact, the power of falling water is 'directly proportional' to the distance it falls. In other words, water falling twice as far has twice as much energy. It is important to note we are only talking about the vertical distance the water falls – the distance the water travels horizontally is consequential only in calculating the expense of the system and friction losses. 'Head' is usually measured in 'feet'.

2. **Volume of water falling (Flow):** More water falling through the turbine will produce more power. The amount of water available depends on the volume of water at the source. Power is also 'directly proportional' to river flow or flow volume.

A river, with twice the amount of flowing water as another river, can produce twice as much energy. Flow volume is usually measured in 'gallons per minute', or GPM.

For Micro Hydro systems, this translates into two categories of turbines:

For high head and low flow volume sites, impulse turbines are the most efficient choice. The power produced by an impulse turbine comes entirely from the momentum of the water hitting the turbine runners. This water creates a direct push or 'impulse' on the blades, and thus such turbines are called 'impulse turbines'.

For low head and high flow volume sites, a reaction turbine is the best choice. The reaction turbine, as the name implies, is turned by reactive force rather than a direct push or impulse. The turbine blades turn in reaction to the pressure of the water falling on them. Reaction turbines can operate on heads as low as 2 feet, but require much higher flow rates than an impulse turbine.

Unit 3. Working of an SHP

Time: 45 mins

Method: Presentation, lecture

3.1 Main parts of an SHP

An SHP plant generates electricity or mechanical power by converting the power available in the flowing water of rivers, canals and streams. The objective of a hydro power scheme is to convert the potential energy of a mass of water flowing in a stream with a certain fall, called 'head', into electric energy at the lower end of the scheme, where the powerhouse is located. (Figure 1a). The power of the scheme is proportional to the flow and to the head. A well designed SHP system can blend in with its surroundings and have minimal negative environmental impacts. SHP schemes are mainly run-of-the river, with little or no reservoir impoundment.

Figure 3.1: Small Hydro power model

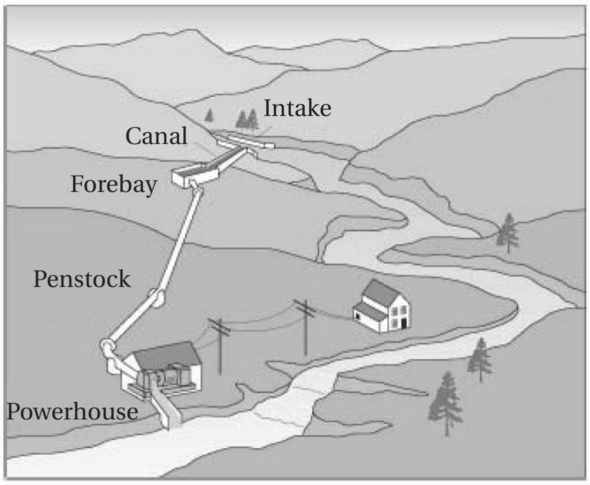
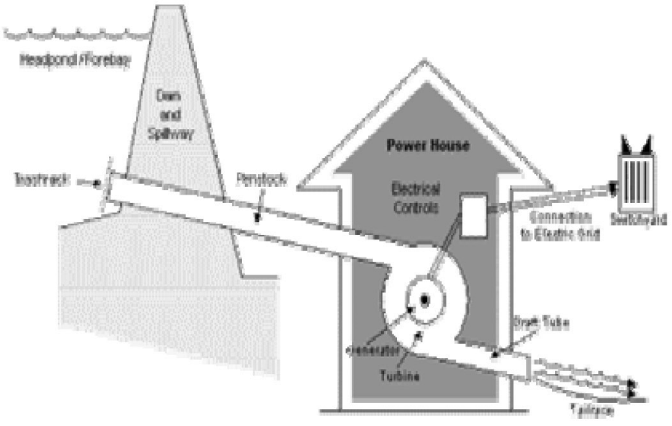


Figure 3.2: Cross-section of an SHP



For run-of-the river systems, a portion of river water is diverted to a water conveyance which delivers the water to a turbine. The moving water rotates the turbine, which spins a shaft. The motion of the shaft can be used for mechanical processes such as pumping water or it can be used to power an alternator or generator to generate electricity.

Small hydro power is not simply a reduced version of a large hydro plant. Specific equipments are necessary to meet fundamental requirements with regard to simplicity, high-energy output and maximum reliability. Figure 3.1 and 3.2 shows the major components of an SHP scheme.

3.2 Weir and Intake

An SHP must extract water from the river in a reliable and controllable way. A weir can be used to raise the water level and ensure a constant supply to the intake. Sometimes, a weir is not built because the natural features of the river are used. The following are required for an intake:

- The desired flow must be diverted,
- The peak flow of the river must be able to pass the weir and intake without causing damage to them,
- Minimum maintenance and repairs as for as possible,
- It must prevent large quantities of loose material from entering the canal,
- It should have the possibility for more piled up sediments.

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3.3 Canal

The canal conducts water from the intake to the forebay tank. The length of the canal depends on the local conditions. In one case, a long canal combined with a short penstock can be cheaper or necessary while in other cases, the combination of a short canal with a long penstock is better suited. The canals are sealed with cement, clay or polythene sheets to reduce friction and prevent leakages. The size and shape of a canal is a compromise between cost and reduced head. The following are incorporated in a canal:

- **Settling basin** – these are basins which allow particles and sediments, which have come from the river flow, and which will settle on the basin floor. The deposits are periodically flushed.
- **Spillways** – these divert excess flow at certain points along the canal. The excess flow can be due to floods.

3.4 Forebay tank

The forebay tank forms the connection between the canal and the penstock. The main purpose is to allow the particles to settle down, before the water enters the penstock.

3.5 Penstock

In front of the penstock, a trashrack (Figure 3.2) is installed to prevent large particles from entering the penstock. Penstock is a pipe which conveys water under pressure from the forebay tank to the turbine. Usually unplastified polyvinyl chloride (uPVC) is used to make penstock pipes. uPVC can reduce a lot of friction in the pipe, it is cheap and it can withstand pressure when compared to other materials that can be used to make penstock pipes. Appendix 1 shows the comparison between uPVC and other materials that can be used to make pipes.

Pipes are generally made and supplied in standard lengths and have to be joined together on site. There are several ways to join the pipe; flanged, spigot and socket, mechanical and welded. Expansion joints are used to compensate for maximum possible change in length.

Penstock pipes can be either buried or surface mounted. This depends on the nature of the terrain and environment considerations. Buried pipelines should be 0.75 m below the surface so that vehicles do not damage it. However, one disadvantage can be, that if leaks occur in the pipes, it would be difficult to detect and rectify. When pipes are run above ground, anchors or thrust blocks are needed to counteract the forces which can cause undesired pipeline movement.

The pressure rating of the penstock is critical because the pipe wall must be thick enough to withstand the maximum water pressure. This pressure depends on the head; the higher the head the greater will be the pressure.

3.6 Powerhouse and trailrace

Powerhouse is a building that contains the turbine generator and the control units. Although the powerhouse can be a simple structure, its foundation must be solid. The trailrace is a channel that allows the water to flow back to the stream, after it has passed through the turbine. (Figure 3.2)

Unit 4. Electrical and Mechanical Equipment in a Small Hydro Power Plant

Time: 2 hours

Methodology: Presentation, lecture, demonstration

The Powerhouse:

In a small hydro power scheme the role of the powerhouse is to protect the electromechanical equipment that converts the potential energy of water into electricity from the weather. The number, type and power of the turbo-generators, their configuration, the scheme head and the geomorphology of the site determine the shape and size of the building.

As shown in figures 4.1 and 4.2, the following equipment will be displayed in the powerhouse:

- Inlet gate or valve
- Turbine
- Speed increaser (if needed)
- Generator
- Control system
- Condenser, switchgear
- Protection systems
- DC emergency supply
- Power and current transformers etc.,

Fig. 4.1 is a schematic view of an integral intake indoor powerhouse suitable for low 'head' schemes. The substructure is part of the weir and embodies the power intake with its trashrack, the vertical axis Kaplan turbine coupled to the generator, the draft tube and the trailrace. The control equipment and the outlet transformers are located in the generator forebay.

4.1 Turbines

A turbine unit consists of a runner connected to a shaft that converts the potential energy in falling water into mechanical or shaft power. The turbine is connected either directly to the generator or is connected by means of gears or belts and pulleys, depending on the speed required for the generator. The choice of turbines depends mainly on the head and the design flow for the SHP installation. All turbines have power-speed characteristics.

Figure 4.1: Schematic view of a powerhouse - low head

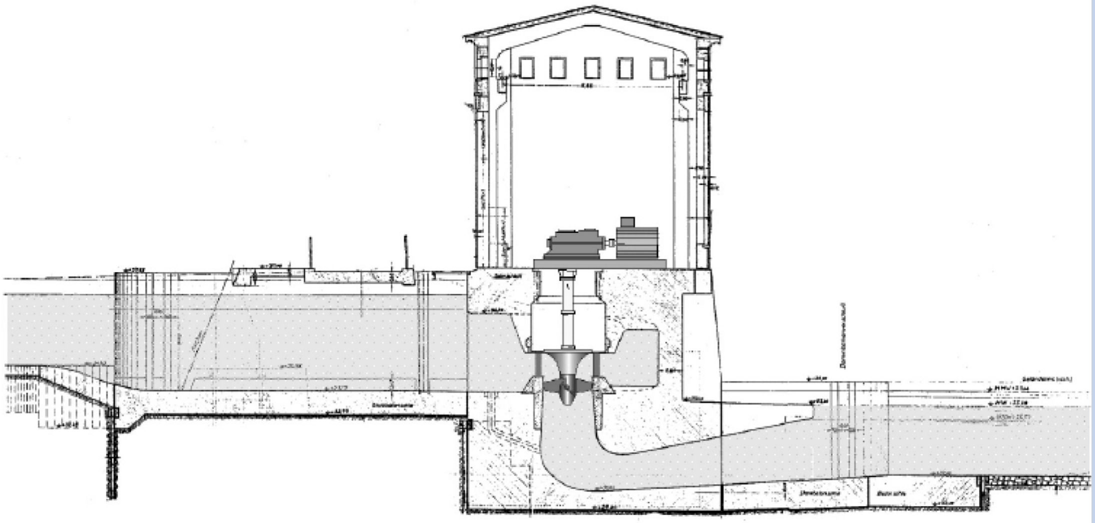
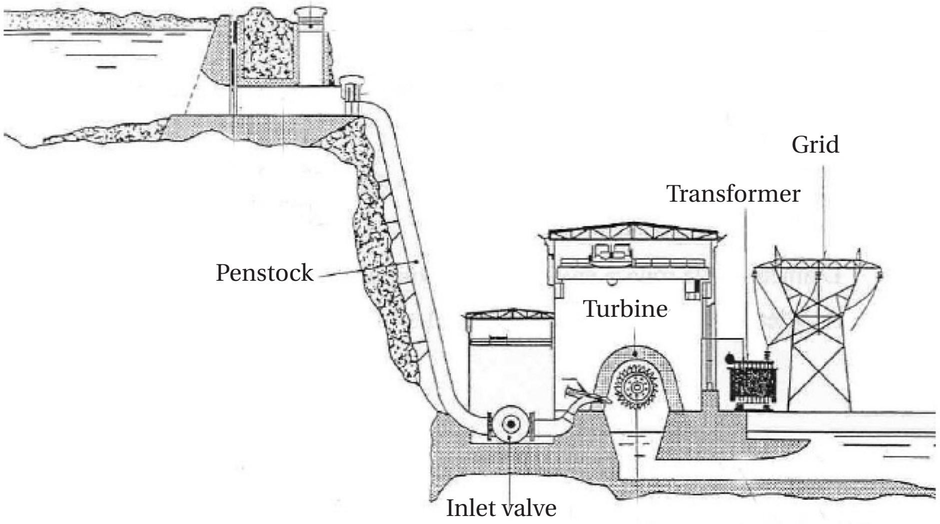


Figure 4.2: Schematic view of a powerhouse - high and medium heads



They perform most efficiently at a particular speed, head and flow combination. There are two types of turbines impulse and reaction. Table 2 shows which turbine is used for what kind of head.

4.1.1 Impulse turbines (high head, low flow)

Do you remember playing with toy pinwheels as a child? They are a good illustration of the principles behind an impulse turbine. When you blow on the rim of the pinwheel, it spins rapidly. The harder you blow, the faster it turns. The impulse turbine operates

Table 2: Groups of water turbines

Turbine	High head (more than 100 m)	Medium head (20-100 m)	Low head
(5-20 m)	Ultra low 'head' (less than 5 m)		
Impulse	Pelton		
Turgo	Cross-flow		
Turgo			
Multi-jet pelton	Cross-flow		
Multi-jet pelton	Waterwheel		
Reaction	-	Francis	
Pump-as-turbine	Propeller		
Kaplan	Propeller		
Kaplan			

on the same principle, except that it uses the kinetic energy from the water as it leaves the nozzle rather than the kinetic energy of air. In a system using an impulse turbine, water is diverted upstream from the turbine into a pipeline. The water travels through this pipeline to a nozzle, which constricts the flow to a narrow jet of water. The energy to rotate an impulse turbine is derived from the kinetic energy of the water flowing through the nozzles. The term 'impulse' means that the force that turns the turbine comes from the impact of the water on the turbine runner. This causes the attached alternator to turn, and thus the mechanical work of the water is changed into electrical power.

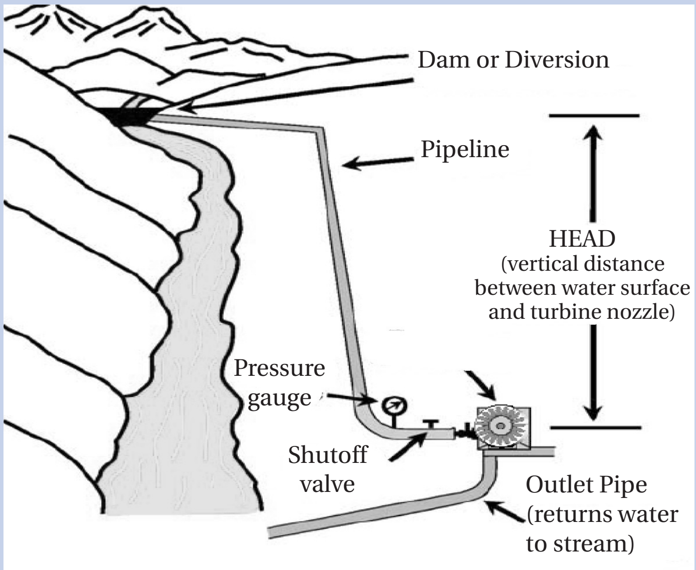
Most sites with a head of at least 25 feet now use impulse turbines. These turbines are very simple and relatively inexpensive. As the stream flow varies, water flow to the turbine can be easily controlled by changing nozzle sizes or by using adjustable nozzles.

Common impulse turbines are the Pelton, Turgo, Cross flow and waterwheel or Chain turbines.

I. Pelton Turbine

This has a set of buckets on the periphery of a circular disc. It is turned by jets of

Figure 4.3: Impulse Turbine



Basic Components of an Impulse Turbine System - Notice how important the closed pipline is to producing the pressure (potential energy), which is translated into kinetic energy at turbine nozzle water that are discharged from one or more nozzles. The bucket is split into two halves so that the central area does not act as a dead spot incapable of defecting water away from the oncoming jet. (Figure 4.4) The cutaway on the lower lip allows the following bucket to move further before cutting off the jet, propelling the bucket ahead of it and also a permitting smoother entrance of the bucket into the jet.

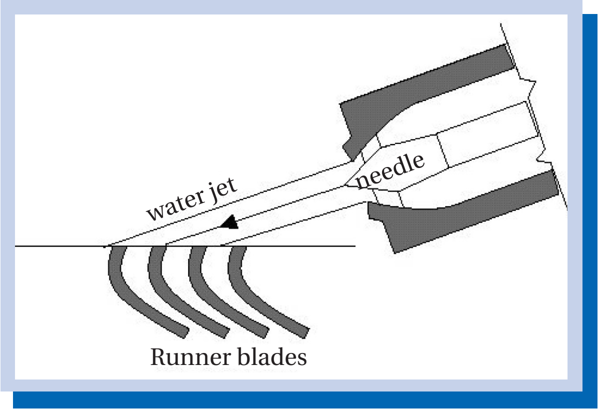
Figure 4.4: Pelton Turbine

The pelton turbine can be used efficiently if the number of jets are increased. This ensures that the rotational speed is increased, for a given flow.

II. Turgo Turbine

These are designed to have higher specific speed. The jets are aimed to strike the plane of the runner on one side and exit on the other. (Figure 4.5) With smaller faster spinning runners, it is more likely and to convert turgo turbines directly to the generator.

Figure 4.5: Turgo Turbine



III. Cross-flow Turbine

This has a drum-shaped runner consisting of two parallel discs connected together near their rims by a series of curved blades. (Figure 4.6)

IV. Waterwheel (Chain Turbine)

These are traditional means of converting useful energy from flowing and falling water into mechanical power. (Figure: 4.7)

Figure 4.6: Cross-flow Turbine

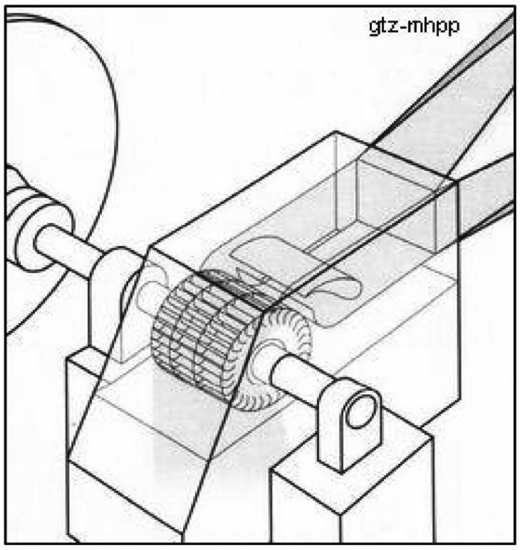
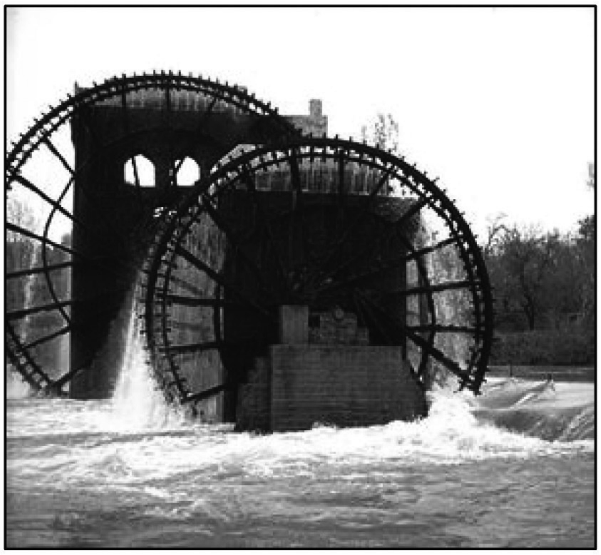


Figure 4.7 : Waterwheel



4.1.2 Reaction turbines (low head, high flow)

The reaction turbine, as the name implies, is turned by reactive force rather than by a direct push or impulse. In reaction turbines, there are no nozzles as such. Instead, the blades that project radially from the periphery of the runner are formed and mounted so that the space between the blades have in cross section, the shape of nozzles.

You can use a balloon to demonstrate the kickback or reaction force generated by the nozzle blades. Blow up the balloon and release it. The air will rush out through the opening and the balloon will shoot off in the opposite direction.

Newton's Third Law: For every action, there is an equal and opposite reaction.

When the balloon is filled with air, you have potential energy stored in the increased air pressure inside. When you let the air escape, it passes through the small opening. This represents a transformation from potential energy to kinetic energy. The force applied to the air to speed up the balloon is acted upon by a reaction in the opposite direction. This reactive force propels the balloon forward through the air.

You may think that the force that makes the balloon move forward comes from the jet of air blowing against the air in the room, but it is not so. It is the reaction of the force of the air as it passes through the opening that causes the balloon to move forward.

The reaction turbine has all the advantages of the impulse-type turbine, plus a slower operating speed and greater efficiency. However, the reaction turbine requires a much higher flow rate than the impulse turbine.

A reaction turbine runner, with the outer guide vanes guiding the water flow into the runner blades, which act as nozzles, Figure 4.8

Figure 4.8: Reaction Turbine runner

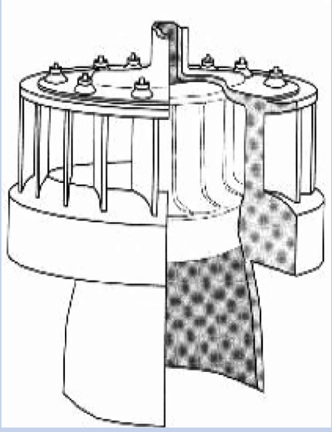


Figure 4.9 Reaction Turbine

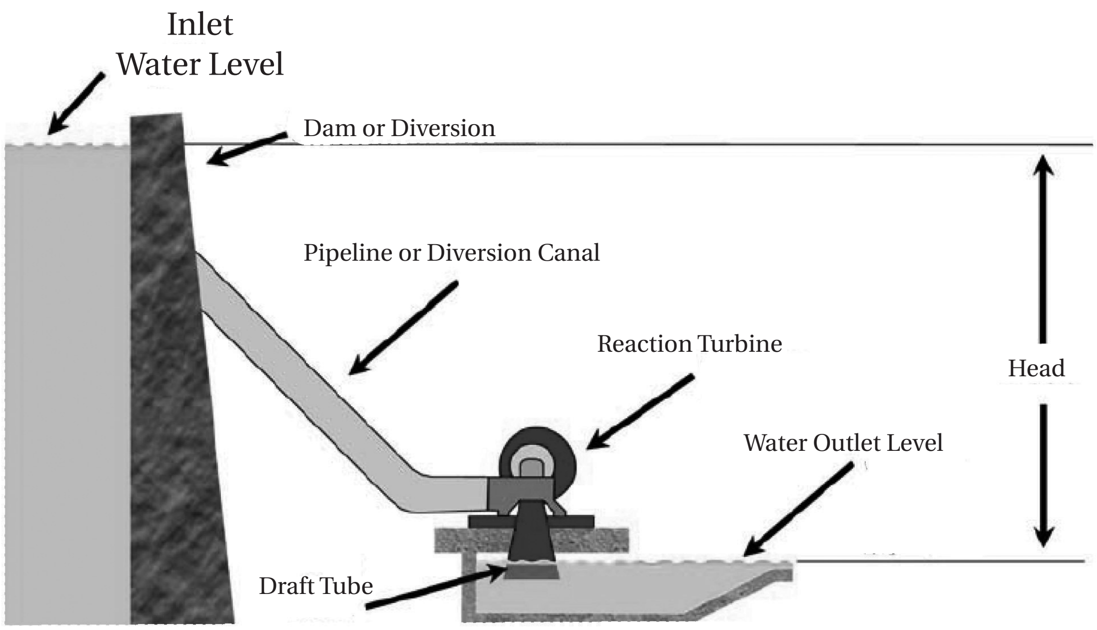


Diagram showing the components of a reaction turbine system with a combination diversion system. – figure 4.9

There are four types of Reaction turbines:

I. Francis Turbine

This is either volute cased or an open flume machine. The runner blades are profiled in a complex manner and direct the water so that it exits axially from the centre of the runner. In doing so, the water imparts most of its pressure energy to the runner before leaving the turbine via a draft tube.

II. Propeller Turbine

This consists of a propeller fitted inside a continuation of the penstock pipe. The turbine shaft passes out of the pipe at the point where the pipe changes direction. A propeller turbine is known as a fixed blade axial flow turbine because the pitch angle of the rotor cannot be changed.

III. Kaplan Turbine

This is a propeller type turbine with adjustable blades.

Figure 4.10 : Francis Turbine

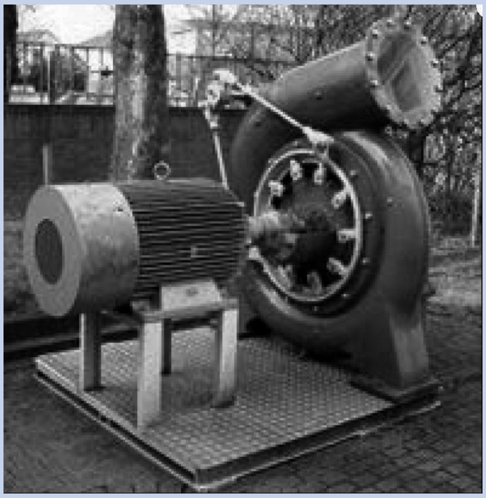
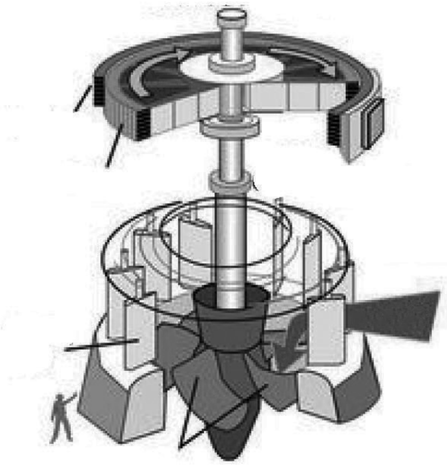


Figure 4.11 : Kaplan Turbine



IV. Reverse Pump Turbine

Centrifugal pumps can be used as turbines by passing water through them in reverse. Research is currently being done to enable the performance of pumps as turbines. The advantage is that it is low cost and spare parts are readily available.

Impulse turbines are usually cheaper than reaction turbines because there is no need for specialist pressure casing. Impulse turbines are generally more suitable for SHP applications as compared with reaction turbines because they have:

- Greater tolerance of sand and other particles in water
- Better access to working parts
- Easier to fabricate and maintain
- Better part-flow efficiency

One major disadvantage of impulse turbines is that they are mostly unsuitable for low head sites.

4.3 Drive Systems

The drive system transmits power from the turbine shaft to the generator shaft. It also has the function of changing the rotational speed from one shaft to the other, when the turbine speed is different to the required speed of the generator. The following can be considered for the SHP drive system:

- Direct drive
- Flat belt and pulley
- V or wedge belt and pulleys
- Chain and sprocket
- Gearbox

4.4 Generators

These convert the mechanical (rotational) energy produced by the turbine to electrical energy. The basic principle of generator operation is that voltage is induced in a coil of wire when the coil is moved in a magnetic field . Although most early hydroelectric systems were of the direct current (DC) variety to match early commercial electrical systems, nowadays, only three-phase alternating current (AC) generators are used in normal practice. Depending on the characteristics of the network supplied, the producer can choose between:

- **Synchronous generators:** They are equipped with a DC electric or permanent magnet excitation system (rotating or static) associated with a voltage regulator to control the output voltage before the generator is connected to the grid. They supply the reactive energy required by the power system when the generator is connected to the grid. Synchronous generators can run isolated from the grid and produce power since excitation is not grid-dependent
- **Asynchronous generators:** They are simple squirrel-cage induction motors with no possibility of voltage regulation and running at a speed directly related to system frequency. They draw their excitation current from the grid, absorbing reactive energy by their own magnetism. Adding a bank of capacitors can compensate for the absorbed reactive energy. They cannot generate when disconnected from the grid because are incapable of providing their own excitation current. However, they are used in very small stand-alone applications as a cheap solution when the required quality of the electricity supply is not very high.

Below 1 MW synchronous generators are more expensive than asynchronous generators and are used in power systems where the output of the generator represents a substantial proportion of the power system load. Asynchronous generators are cheaper and are used in stable grids where their output is an insignificant proportion of the power system load. The efficiency should be 95 percent for a 100 KW machine and can increase to 97 percent towards an output power of 1MW. Efficiencies of synchronous generators are slightly higher. In general, when the power exceeds some MVA, a synchronous generator is installed.

Recently, variable-speed constant-frequency systems (VSG), in which turbine speed is permitted to fluctuate widely, while the voltage and frequency are kept constant and undistorted, have become available. The frequency converter, which is used to connect the generator via a DC link to the grid, can even be "synchronised" to the grid before the generator starts rotating. This approach is often proposed as a means of improving performance and reducing cost. However no cost reduction can be achieved using propeller turbines, if only the runner regulation is replaced. It is also not possible to improve the energy production as compared to a double-regulated Kaplan turbine. There are, nevertheless, a number of cases, where variable speed operation seems to be a suitable solution, e.g. when the head varies significantly.

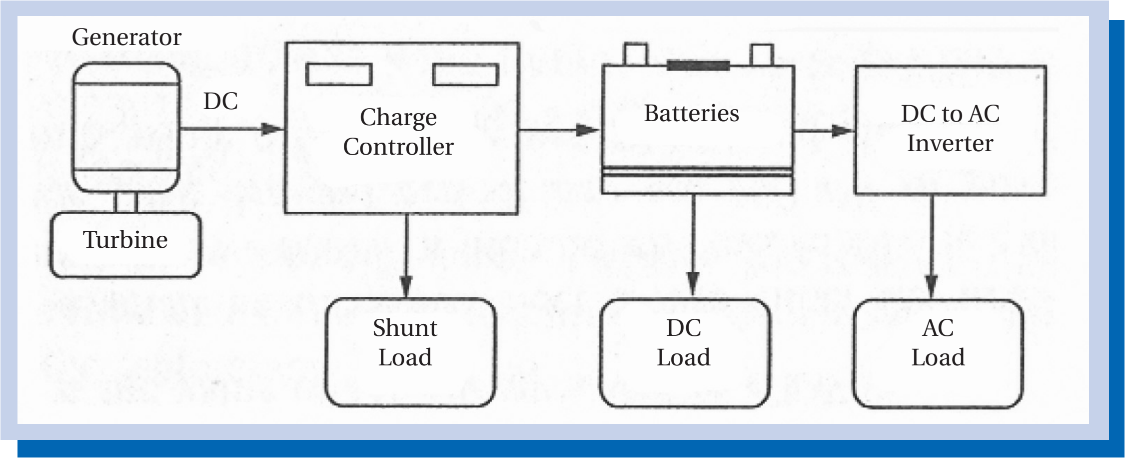
The operating voltage of the generator increases with power. The standard generation voltages of 400 V or 690 V allow for the use of standard distributor transformers as outlet transformers and the use of the generated current to feed into the plant power system. Generators of some MVA are usually designed for higher operating voltages up to some KV and connected to the grid using a customised transformer. In this case, an independent transformer HT/LT is necessary for the auxiliary power supply of the power plant.

Electrical power can be generated in either AC or DC. AC can be connected directly to household appliances and AC is much more economical for transmitting power to homes. DC can be used in two ways, either directly as DC or converted to AC through the use of an inverter. The main advantage of DC is ease of battery storage. Lead acid deep cycle batteries are usually used in SHP plants.

4.5 Controllers

SHP systems with lead acid batteries require protection from overcharge and overdischarge. Overcharge controllers redirect the power to an auxiliary or shunt load when the battery reaches a certain level. (Figure 4.12). This protects the generator from overspeed and overvoltage conditions. Overdischarge control involves disconnecting the load from the batteries when the voltage drops below a certain level.

Figure 4.12 : Electrical block diagram of a battery-based small hydro system.



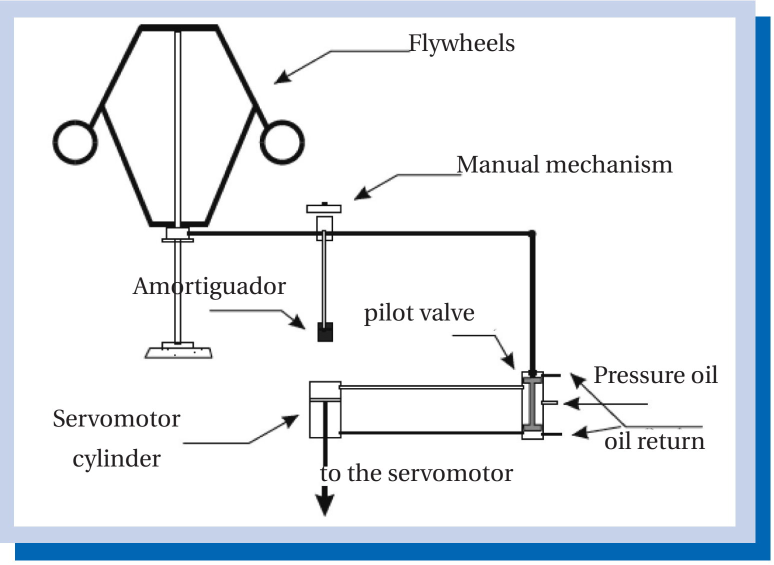
Over the last two decades, electronic load controllers (ELCs) have been developed that have increased the simplicity and reliability of the modern SHP system. An ELC is a solid state electronic device designed to regulate output power of SHP systems. Maintaining a near-constant load on the turbine generates stable voltage and frequency. The controller compensates for variation in the main load by automatically varying the amount of power dissipated in a resistive load, generally known as the ballast or dump load, in order to keep the total load on the generator and turbine constant. Water heaters are generally used as ballast loads. An ELC constantly senses and regulates the generated frequency. The frequency is directly proportional to the speed of the turbine. The major benefit of ELCs is that they have no moving parts, are reliable and virtually maintenance free.

4.6 Speed Governors

A speed governor is a combination of devices and mechanisms, which detect speed deviation and convert it into a change in servomotor position. A speed-sensing element detects the deviation from the set point; this deviation signal is converted and amplified to excite an actuator, hydraulic or electric, that controls the water flow to the turbine. In a Francis turbine, where there is a reduction in water flow,you need to rotate the wicket-gates. For this, a powerful governor is required to overcome the hydraulic and frictional forces and to maintain the wicket-gates in a partially closed position or to close them completely.

Several types of governors are available, varying from old fashioned purely mechanical to mechanical-hydraulic to electrical-hydraulic and mechanical-electrical. The purely mechanical governor is used with fairly small turbines, because its control valve is easy to operate and does not require a big effort. These governors use a flyball mass mechanism driven by the turbine shaft. The output from this device - the flyball axis descends or ascends according to the turbine speed - directly drives the valve located at the entrance to the turbine.

Figure 4.13 Speed governor



4.7 Speed Increasers

When the turbine and the generator operate at the same speed and can be placed so that their shafts are in line, direct coupling is the right solution; virtually no power losses are incurred and maintenance is minimal. Turbine manufactures recommend the type of coupling to be used, either rigid or flexible although a flexible, coupling that can tolerate certain misalignment, is usually recommended.

In many instances, particularly in low head schemes, turbines run at less than 400 rpm, requiring a speed increaser to meet the 750-1000 rpm of standard alternators. In the range of powers contemplated in small hydro schemes, this solution is often more economical than the use of a custom made alternator.

Nowadays, alternator manufacturers also propose low speed machines that allow direct coupling.

4.7.1 Types of speed increaser

Speed increasers according to the gears used in their construction are classified as:

- Parallel shaft using helical gears set on parallel axis and are especially attractive for medium power applications. Figure 4.14 shows a vertical configuration, coupled to a vertical Kaplan turbine.
- Bevel gears commonly limited to low power applications using spiral bevel gears for a 90 Degree drive. Figure 4.15 shows a two-phased speed increaser. The first is a parallel gearbox and the second a bevel gear drive.
- Belt speed increaser, that is commonly used for small power applications, offers maintenance facilities (see figure 4.16).

***Fig 4.14 Parallel shaft speed increaser**

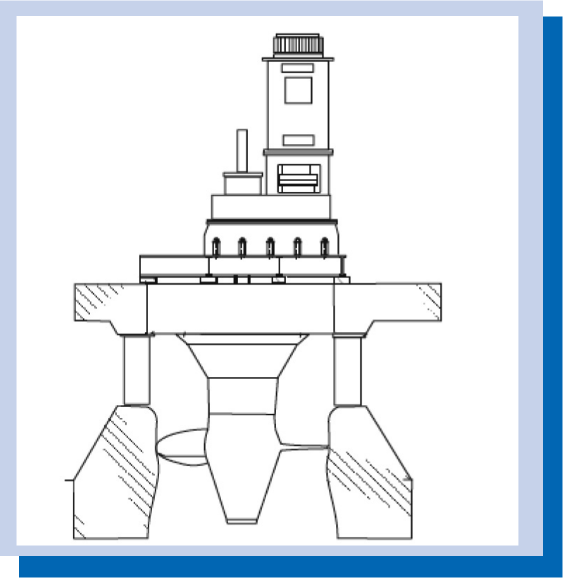


***Fig 4.15 Bevel gear speed increaser**

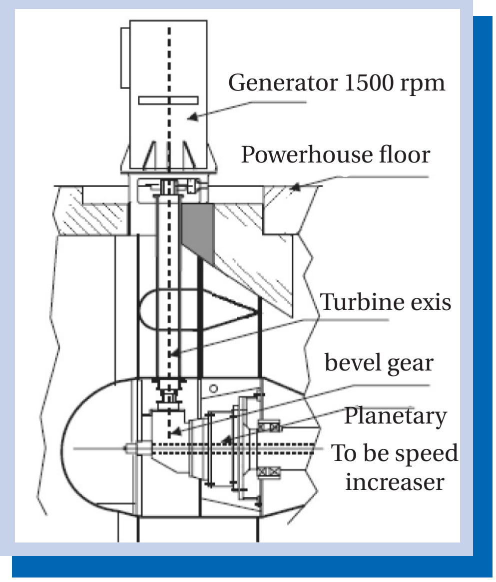
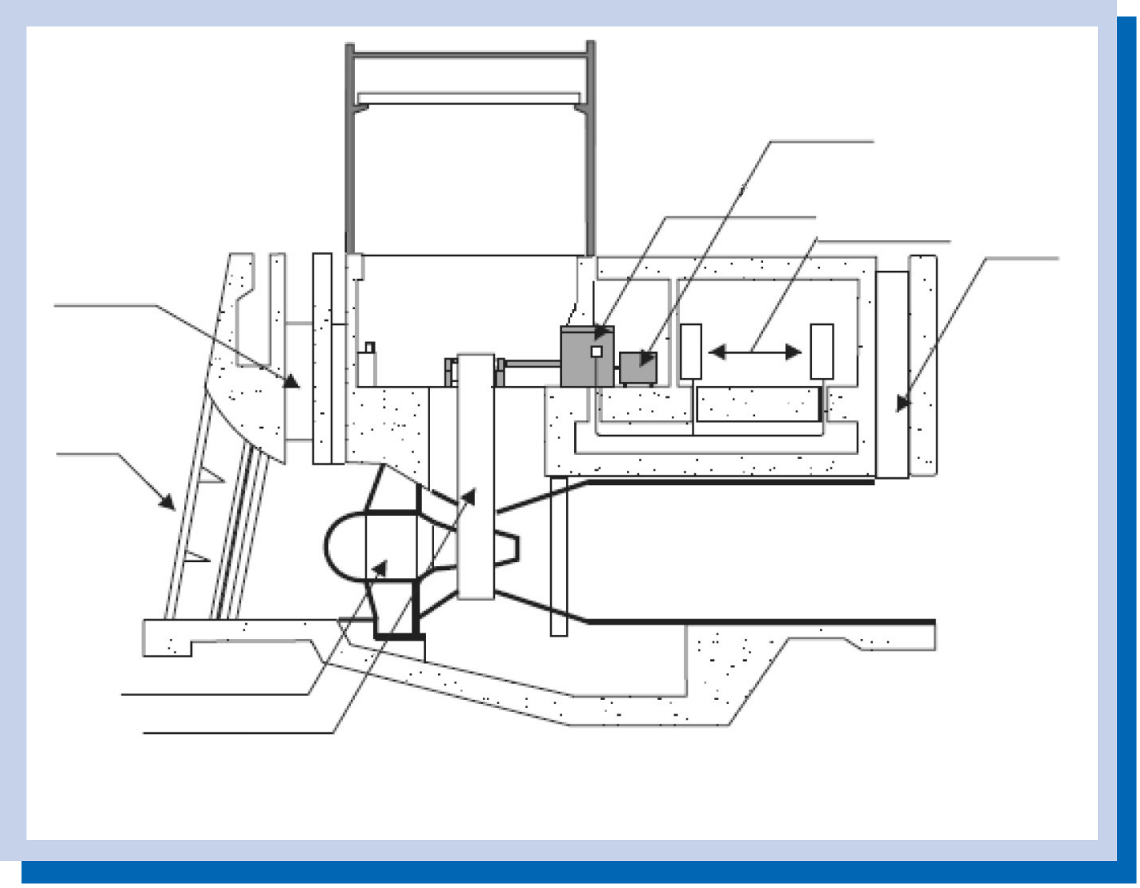


***Fig 4.16 Belt speed Increaser**



*(*Guide on How to Develop a Small Hydro power Plant ESHA 2004)*

Good lubrication is essential, to ensure the required level of reliability. It is very important that the quality, volume, viscosity and temperature of the oil always stay within specifications. A double lubrication system with two pumps and two oil filters would contribute to the system reliability.

Speed increasers are designed according to international standards (AGMA 2001, B88 or DIN 3990) using very conservative design criteria. These criteria conflict with the need to reduce costs, but no cost savings are possible or recommended without a thorough analysis of the fatigue strains, and a careful shaving of the heat treated gears, a satisfactory stress relieving of the welded boxes, all of which are essential to ensure the durability of a speed increaser. Metallurgical factors including knowledge of the respective advantages and disadvantages of hard casing or nitriding of gears are also essential to optimise the speed increaser.

Selection of journal bearings is also crucial under 1 MW. The use of roller bearings is usual Nowadays, manufacturers begin to use such technology for turbines upto 5 MW. The other possibility is to use hydrodynamic lubricated bearings that present the following advantages:

- The life of the roller bearings is limited by fatigue whereas the hydrodynamic bearings have a practically unlimited life.
- Hydrodynamic bearings permit a certain oil contamination, whereas roller bearings do not.

4.7.2 Speed increaser maintenance

At least 70 percent of speed increaser malfunctioning is due to the poor quality or the lack of lubricant oil. Frequently the oil filters clog or water enters the lubrication circuit. Maintenance should be scheduled, either based on predetermined periods of time or –better still by periodic analysis of the lubricant to check that it meets specifications.

Speed increasers substantially increase the noise in the powerhouse and require careful maintenance as their friction losses can exceed 2 percent of the outlet power, so other alternatives have been investigated, as for instance the use of low speed generators.

4.8 Switchgear Equipment

In many countries, the electricity supply regulations place a statutory obligation on the electric utilities to maintain the safety and quality of electricity supply within defined limits. The independent producer must operate his plant in such a way that the utility is able to fulfil its obligations. Therefore, various associated electrical devices are required inside the powerhouse for the safety and protection of the equipment.

Switchgear must be installed to control the generators and to interface them with the grid or with an isolated load. It must provide protection for the generators, main transformer and station service transformer. The generator breaker, either air, magnetic or vacuum operated, is used to connect or disconnect the generator from the power grid. Instrument transformers, both power transformers (PTs) and current transformers (CTs) are used to transform high voltages and currents down to more manageable levels for metering. The generator control equipment is used to control the generator voltage, power factor and circuit breakers.

4.9 Automatic Control

Small hydro schemes are normally unattended and operated through an automatic control system. Not all power plants are alike therefor it is almost impossible to determine the extent of automation that should be included in a given system, though some requirements are of general application:

a) The system must include the necessary relays and devices to detect malfunctioning of a serious nature and then act to bring the unit or the entire plant to a safe de-energised condition.
b) Relevant operational data of the plant should be collected and made readily available

so that operating decisions can be taken and stored in a database, for later evaluation of plant performance.

c) An intelligent control system should be included to allow for full plant operation in an unattended environment.
d) It should be possible to access the control system from a remote location and override any automatic decisions.
e) The system should be able to communicate with similar units, up and downstream, for the purpose of optimising operating procedures.
f) Fault anticipation constitutes an enhancement to the control system. Using an expert system fed with baseline operational data, it is possible to anticipate faults before they occur and take corrective action so that the fault does not occur.

The system must be configured by modules. They are an analogue-to-digital conversion module for measurement of etc., water level, wicket-gate position, blade angles, instantaneous power output, temperatures, etc., a digital-to-analogue converter module to drive hydraulic valves, chart recorders, etc. A counter module to count generated KWh pulses, rain gauge pulses, flow pulses, etc., and a “smart” telemetry module providing the interface for offsite communications via dial-up telephone lines, radio link or other communication technologies. This modular system approach is well suited to the widely varying requirements encountered in hydro power control, and permits both hardware and software to be standardised. Cost reduction can be realised through the use of a standard system and modular software allows for easy maintenance.

Automatic control systems can significantly reduce the cost of energy production by reducing maintenance and increasing reliability, while running the turbines more efficiently and producing more energy from the available water.

4.10 Ancillary Electrical Equipment

4.10.1 Plant service transformer

Electrical consumption including lighting and station mechanical auxiliaries may require from 1 to 3 percent of the plant capacity; the higher percentage applies to micro hydro (less than 500 KW). The service transformer must be designed to take these intermittent loads into account. If possible, two alternative supplies with automatic changeover should be used, to ensure service in an unattended plant.

4.10.2 DC control power supply

It is generally recommended that remotely controlled plants are equipped with an emergency 24 V DC back-up power supply from a battery in order to allow plant control for shutdown after a grid failure and communication with the system at any time. The ampere-hour capacity must be such, that on loss of charging current, full control is ensured for as long as it may be required to take corrective action.

4.11 Headwater and Tailwater Recorders

In a hydro plant, provisions should be made to record both the headwater and the tailwater. The simplest way is to fix securely in the stream, a board marked with metres and centimetres in the style of a levelling staff. However, someone must physically observe and record the measurements. In powerhouses provided with automatic control, the best solution is to use transducers connected to the computer via the data acquisition equipment.

Nowadays measuring units, a sensor, records the measurement variable and converts it into a signal that is transmitted to the processing unit. The measurement sensor must always be installed at the measurement site, where the level has to be measured. This is usually subject to rough environmental conditions and in areas which are difficult to access. The processing unit is usually separated and placed in a well protected environment that is easily accessible for operation and service.

4.12 Transmission/Distribution Network

The size and type of electric conductor cables required, depends on the amount of electrical power to be transmitted and the length of the power line. For most SHP systems, power lines are single phase. However, sometimes three phase power lines are used.

Unit 5. Measuring Head and Flow

Time: 2 hours

Methodology: Lecture, assignments

5.1 Developing Head Pressure

We've already defined 'head' as the vertical the distance water falls, once it enters our hydro system. This is probably the single most important factor in determining the amount of power your can generate from you potential hydro site, and thus we should delve a little further into how 'head' is measured and developed.

Determining Available Head and Flow

Measuring Head: Closed Diversion Systems

Selecting the Water Source Site

There may be several potential water source points, particularly if the water source is a river or stream. Each one will have a different elevation and linear distance from the hydro turbine. In selecting the best site, there are several factors to be considered. They are water availability, site access, topography of the site, elevation (potential static head), linear distance from the turbine, head pressure required for the turbine, and the volume of water required for the turbine. The best site will usually be the one that has the best cost-benefit ratio (the least cost per KWh of electricity produced). The site with the highest elevation may not be the best, as that site may also have the highest incremental cost of diverting and transporting the water to the turbine.

Measuring the Available Head

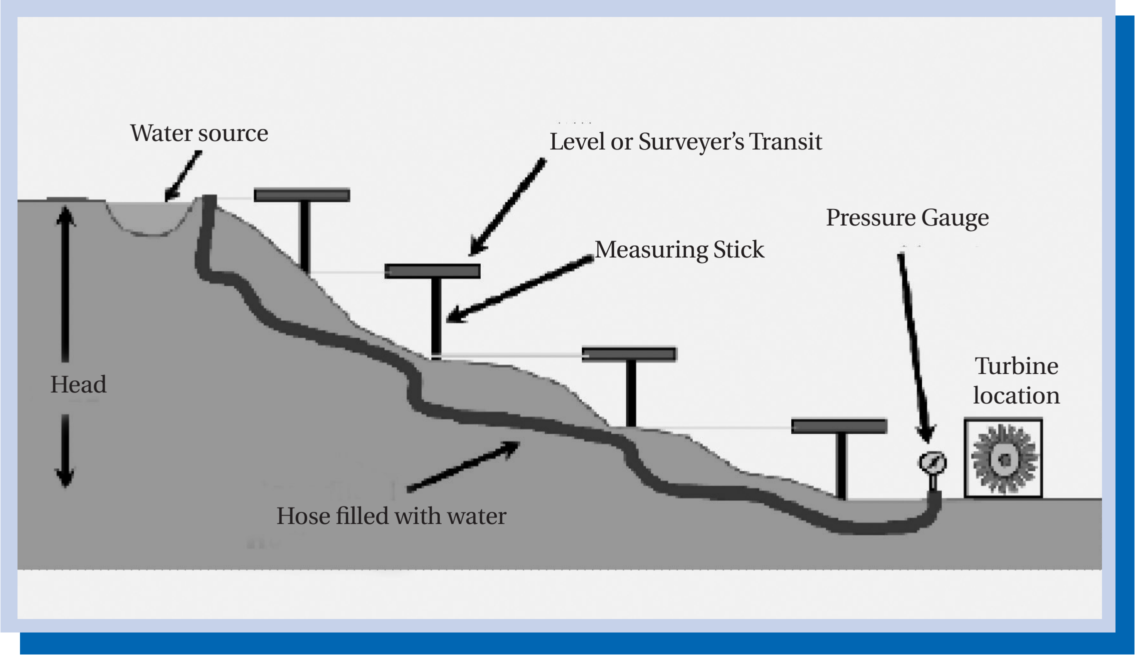
Head is a vertical distance. It's starting point is where the water begins to impact the pressure at the hydro turbine and it's ending point is where the water ceases to affect the pressure at the hydro turbine. With closed diversion systems, head is the change in elevation from the water surface at the inlet to the closed diversion system and the elevation at the turbine nozzle. Head is the most important factor in determining if your site is adequate for an impulse type turbine. There are a couple of commonly used methods of measuring head for a closed diversion system:

1. Use a transit or level and a measuring stick of known length to measure the vertical elevation change in successive steps down the slope. The cumulative total of the vertical measurements is the head in feet.

2. Assemble a temporary piping system (a series of connected garden hoses works well for this) and with a water pressure gauge, measure the static pressure (in pounds per square inch or PSI) at the lower end of the hose system, with the hose filled with water.

Convert the static pressure to vertical feet of head, using the formula 0.43 PSI = 1.0 foot of head. This method can also be done in successive steps to measure total head over a longer distance.

Figure 5.1: Determining head for a closed diversion system



This method is quite accurate.

Note: The expected error range of ± 50 ft on GPS altitude readings prevents GPS from being an accurate method for determining head.

Several methods exist for measurement of the available head. Some measurement methods are more suitable on low-head sites, but are too tedious and inaccurate on high-heads. If possible, it is wise to take several separate measurements of the head at each site. Always plan for enough time to allow on-site comparison of survey results. It is best not to leave the site before analysing the results, as any possible mistakes will be easier to check on site.

A further very important factor to be aware of is that the gross head is not strictly a constant but varies with the river flow. As the river fills up, the tailwater level often rises faster then the headwater level, thus reducing the total head available. Although this head variation is much less than the variation in flow, it can significantly affect the power available, especially in low-head schemes where every half metre is essential. To assess the available gross head accurately, headwater and tailwater levels need to be measured for the full range of river flows.

Dumpy Levels and Theodolite

The use of a dumpy level (or builder's level) is the conventional method for measuring head and should be used wherever time and funds allow. Such equipment should be used by experienced operators who are capable of checking the calibration of the device.

Dumpy levels are used with staffs to measure head in a series of stages. A dumpy level is a device that allows the operator to take sight on a staff held by a colleague, knowing that the line of sight is exactly horizontal. Stages are usually limited by the length of the staff to a height change of no more than 3 metres. A clear unobstructed view is needed, so wooded sites can be frustrated with this method.

Dumpy levels only allow a horizontal sight but theodolite can also measure vertical and horizontal angles, giving greater versatility and allowing faster work.

Sighting Meters

Hand-held sighting meters measure the angle of inclination of a slope (they are often called inclinometers or Abney levels). They can be accurate if used by an experienced person, but it is easy to make mistakes and double-checking is recommended. They are small and compact, and sometimes include range finders which save the trouble of measuring the linear distance. The error will depend on the skill of the user and will typically be between 2 and 10 percent.

Water-filled Tube and Pressure Gauge

It is probably the best of the simple methods available but it does have its pitfalls. The two sources or error which must be avoided are out of calibration gauges and air bubbles in the hose. To avoid the first error, you should recalibrate the gauge both before and after each major site survey. To avoid the second, you should use a clear plastic tube allowing you to see bubbles.

This method can be used on high-heads as well as low ones, but the choice of pressure gauge depends on the head to be measured.

Water filled Tube and Rod

This method is recommended for low-head sites. It is cheap, reasonably accurate and not prone to errors. In this case, if more bubbles are trapped in one rising section of the tubes than in the other, then the difference in the vertical height of the sets of bubbles will cause an equal difference in the head being measured, though this is usually insignificant. Two or three separate attempts must be made to ensure that your final results are consistent and reliable. In addition, the results can be cross-checked against measurements made by another method, for instance by water filled hose and pressure gauge.

Spirit Level and Plank

This method is identical in principle to the water filled tube and rod method. The difference is that a horizontal sighting is established not by water levels but by a carpenter's spirit level placed on a reliably straight plank of wood as described above. On gentle slopes the method is very slow, but on steep slopes it is useful. Mark one end of the plank and turn it at each reading, to cancel errors. The error is around 2 percent.

Maps

Large-scale maps are very useful for approximate head values but are not always available or totally reliable. For high-head sites (>100 m) 1:50,000 maps become useful and are almost always available.

Altimeters

These can be useful for high-head pre-feasibility studies. Surveying altimeters in experienced hands will give errors of as little as 3 percent in 100 metres. However, atmospheric pressure variations need to be allowed for; this method cannot be generally recommended except for approximate readings.

5.2 Measuring Head: Open Diversion Systems

Selecting the Water Source Site

Water source site selection and head calculation for open diversion systems requires a different approach. The minimum head requirements for reactive turbines and open diversion systems are much less than the requirements for impulse turbines and closed diversion systems, and they are much easier to attain.

All of the water source site selection criteria for closed diversion systems also apply to open diversion systems. However, the cost-benefit analysis for open diversion systems focuses on water volume instead of water pressure as the benefit.

Measuring the Available Head

With open diversion systems, you are not as concerned with high heads (high pressures) as with large volumes of water. The turbine (usually a reaction turbine) is submerged in the water at the end of the open diversion system.

With impulse turbines, the water exits the closed diversion system at the turbine so we are only dealing with the head prior to the turbine or pressure head. With reaction turbines, there can also be a closed system for the water exiting the turbine, creating a suction head.

The pressure head for open diversion systems is the vertical distance between the water surface above the turbine and the turbine impellers. This distance is usually less than ten feet and is easily measured. If a draft tube is used (see page 22), there is also suction head for these turbines. The suction head must also be measured. The total head is the pressure head (prior to the turbine) plus the suction head (after the turbine).

Measuring Flow

Note: The term ‘flow’ as used in conjunction with micro hydro represents volume, not speed. It is the volume of water, stated as cubic feet per second (ft3/s) or gallons per minute (GPM), that flows past a specific point in a specific amount of time.

Method 1:
The simplest way to measure flow is via a four-step process:

1) Measure the speed of the water (in feet per second)
2) Determine the cross-sectional area of the water source (in square feet) by measuring and multiplying the average water depth (in feet) X the average water width (in feet)
3) Calculate the flow (in cubic feet per second) by multiplying the water speed X the cross-sectional area.
4) Convert the flow in cubic feet per second to flow in gallons per minute by multiplying by the flow in ft3/s X 450.

Water Speed
Determining the water speed is easy. Pick a representative segment of river or stream close to the expected water diversion point. Place two stakes 50 feet apart along the bank, marking the upper and lower limits of this segment. Drop a ping-pong ball (or other lightweight, floating object) into the current opposite the upper stake. Time (a wrist watch with a second hand works great!) how long it takes for the ping-pong ball to travel the 50 feet.

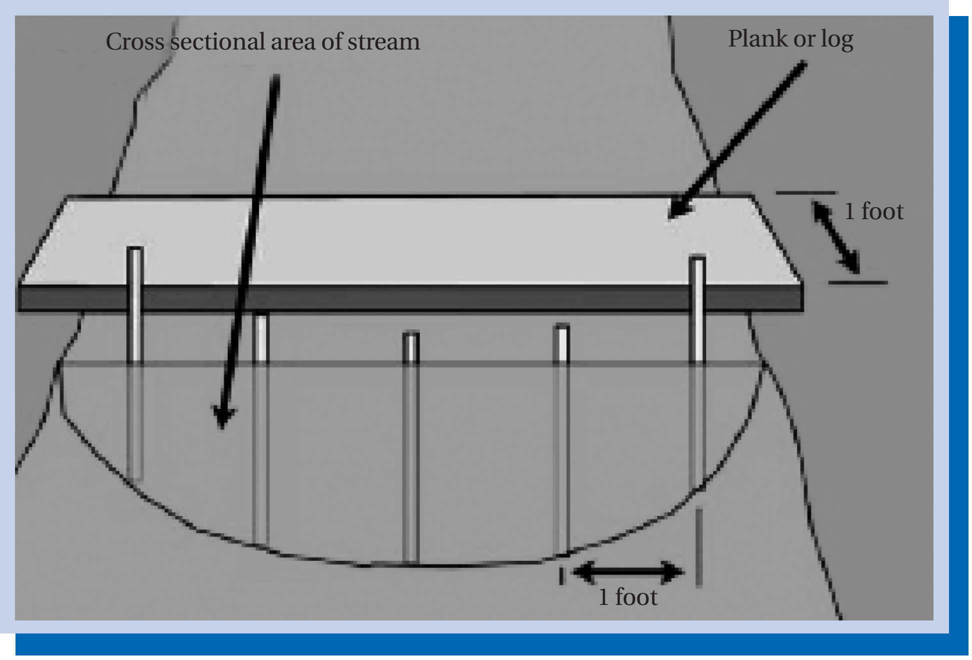
Take this measurement several times and calculate the average time (add all times and divide by the number of trials). This is the speed of the water through the segment at the surface. Not all water moves as fast as the surface because there is friction at the bottom and along the banks. To calculate the overall average speed of the water, multiply the surface speed X 0.80.

Cross-Sectional Area
Now we can measure and calculate the cross-sectional area of a ‘slice’ of the water. In the segment used above for determining water speed, select a spot that will provide a representative water depth and width for the 50 ft segment.

Measure and record the water depth at one foot increments along a cross section (water-edge to water-edge) of the river or stream at this spot. Laying a log or plank across the river or stream from which you can take these measurements is convenient.

You can also wade (or boat) across but take care that you are measuring the actual water depth and not the depth of water affected by your presence in the water. Calculate the average depth of the water (as explained above, during water speed).

Figure 5.2 Measuring flow by cross-sectional area method



Measure and record the width of the river or stream (in feet and from water-edge to water- edge). Multiply the average depth X the width. You now have the cross-sectional area (in square feet) of that slice' of the river or stream.

Calculating Flow

You can now use the following equation to calculate your flow.

Water Speed (ft/sec) X Cross Sectional Area (sq ft) = Flow (cu ft per second)

Flow (cubic feet per second) X 450 = Flow (gallons per minute)

Calculate the flow in cubic feet/second first by multiplying the average speed (in feet per second) X the cross-sectional area (in square feet). Then convert the flow from cubic feet per second to gallons per minute (GPM) by multiplying the cubic feet per second X 450.

Method 2:

Sometimes with small, intermittent or steeply dropping streams, it is difficult to accurately measure the average depth, width, and/or water speed. This is fairly common with water sources for impulse turbines, since they can operate with low water volumes. In these instances, it is possible to temporarily 'gather' the water by using sand bags, rocks, wood, etc., to create a temporary dam.

Insert a short length of pipe in the middle of this dam, preferably the same diameter of pipe that you later plan to use for your diversion system pipeline. The inlet to this pipe must be completely submerged in the water behind the temporary dam.

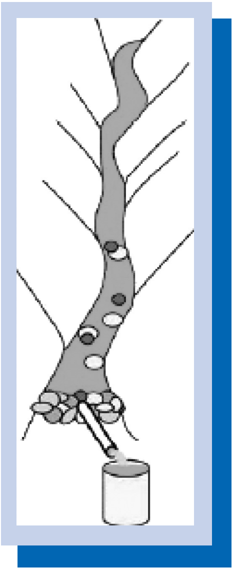


Figure 5.3 Measuring flow using methos 2

Fill a container of known volume (in gallons) with the water exiting the pipe, timing (in seconds) how long it takes to fill. As described in method 1, conduct this measurement several times and calculate the average. Using the 60 seconds = 1 minute relationship, calculate how many gallons would exit the pipe in one minute. You now have your flow in GPM.

Example:

The container holds 5.5 gallons

The average time to fill the container is 15 seconds

$$5.5 \text{ gallons X } \frac{60 \text{ seconds}}{15 \text{ seconds}} = 20 \text{ gallon/min(GPM)}$$

5.3 Seasonal Changes in Water Availability

When taking flow measurements for both closed and open diversion systems, evaluate any seasonal deviations in the source water level, such as low water during dry spells or flooding during monsoons and take these into account when determining the potential flow, diversion system size, and hydro turbine output.

Remember, though, that the requirement is to keep the pipe full or keep enough water in the diversion canal to supply the turbine. Any flow capacity at the water source that is in excess of the turbine requirement, even during dry spells and low water, is immaterial.

Unit 6. Generating Power

Time: 2.5 hours

Methodology: Lecture, presentation

6.1 Developing Head Pressure

You have seen many different ways to measure head at your hydro site, and a couple of the most common methods have been outlined. You'll find methods of determining the available flow volume of your hydro site as well.

In the following section, we will discuss how head is developed at a hydro site and how it is transferred into power.

Have you ever swum down to the bottom of a deep swimming pool and felt your ears pop? That's caused by water pressure which is created by the weight of the water above you. We measure water pressure in pounds per square inch (PSI). That to the weight in pounds of the water on a one-square-inch area.

A reaction turbine uses "pressure head" in the same way to produce electricity. If you substitute the diver in the picture for a submerged reaction turbine, you can imagine how the pressure of all that water falling through the turbine blades, creates the force to turn the blades and produce electricity. This 'pressure head' accounts for most of the power output of a reaction turbine.

In addition, many reaction turbines also have a water discharge tube called a 'draft tube', which can increase the head by producing a vacuum between the turbine runner blades and the level of the exit water. This is called the 'suction head' and can increase power output of the turbine by up to 20 percent, if it is set up properly. It is important that it is completely submerged in the tail water with no air leaks, maintaining a closed system and thus, the vacuum suction. With this system, the total head is a combination of the pressure head and the suction head.

Figure 6.1: Water Pressure exerts force on a diver

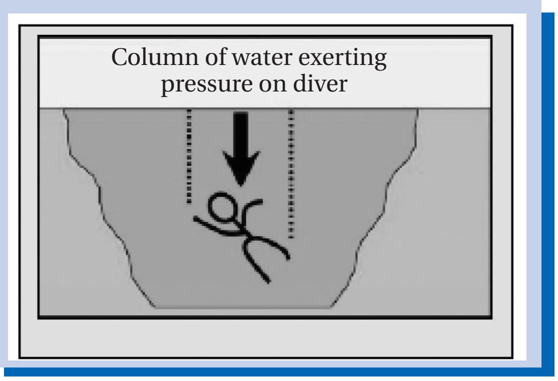


Figure 6.2: Pressure Head for a Reaction Turbine

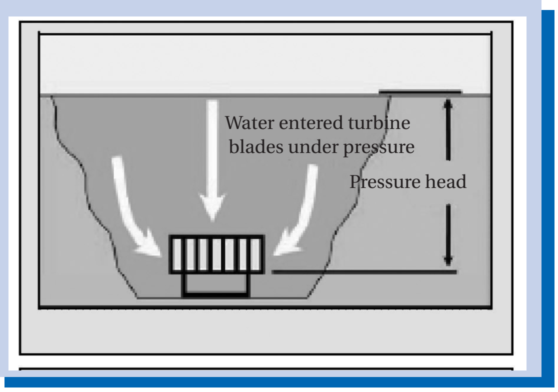
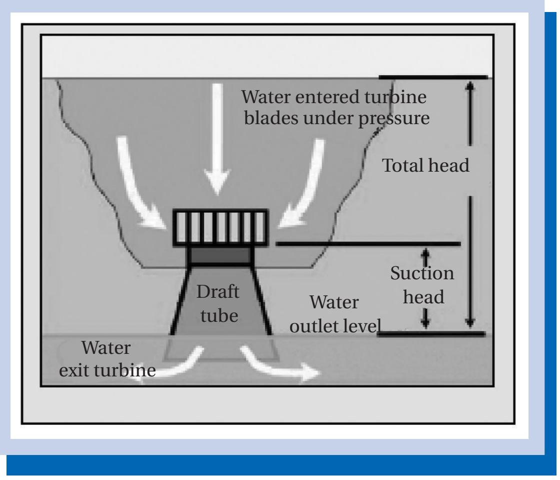


Figure 6.3: Suction Head for a Reaction Turbine



Another important characteristic of water is that it is essentially a non-compressible liquid. This means it exhibits the unique trait of transferring pressure horizontally when in a confined space (what we define as a closed system). This becomes very important in hydro systems where a pipeline is involved, which is always the case with impulse turbines and is occasionally used with reaction turbines as well. Water that enters a pipe exhibits the same pressure at the bottom as it would if the pipe were perfectly vertical, even if the pipe itself isn't. The best way to demonstrate this is with a picture.

As long as the water is not flowing through the pipeline, the pressure of the water at the lower end of the pipe is exactly the same as the water pressure at an equivalent level directly below the inlet. This is true no matter how long the pipe is. Since water is a non-compressible liquid it transfers the pressure horizontally along the pipe route for any distance without any loss of pressure.

This is called the "static pressure" (or "static head") of the water. If this system were completely frictionless, the pressure would remain the same when the water was flowing as well. However, there is friction between the water and the inner surface of the pipeline, causing the pressure to drop once the water is moving (called "friction loss"). The usable force of the water when it reaches the turbine is called the "dynamic pressure" (or "dynamic head"), and is calculated by subtracting the friction loss caused by the pipeline from the amount of static head.

The total length and diameter of the pipe you use becomes important in planning your system because you always want to minimize your friction losses. Impulse turbines are not submerged in the water, and thus the water exits the closed system when it exits the pipeline at the turbine nozzle. Hence there is no suction head and in an impulse turbine the total head is equal to the pressure head.

What we are beginning to see is that in a hydro system, it's not just important how much head and how much flow you have available in a theoretical sense, it's also really important to consider how you can get that water to your turbine location with as little loss as possible.

An analogy could be made with driving your car. Your car has a certain potential amount of power it can produce. But the amount of power you use at any given time has a lot to do with the road you are travelling on. A twisting, winding road will not allow you to move as fast as a straight one. A muddy road will not let you move as fast as nice smooth pavement. In the same way, it's not just the amount of power (from head) that you can theoretically get from your water source, it's also the 'road' you build to get your water to the turbine. We call this road a 'diversion system', and just as with a road, water prefers nice straight diversion systems without abrupt turns and smooth walls.

6.2 ‘Pressure Head’ for an Impulse Turbine System

Hydro power is obtained from the potential and kinetic energy of water flowing from a height. The energy contained in the water is converted into electricity by using a turbine coupled to a generator. The hydro power potential of a site is dependant on the discharge and head of water. It is estimated by the following equation

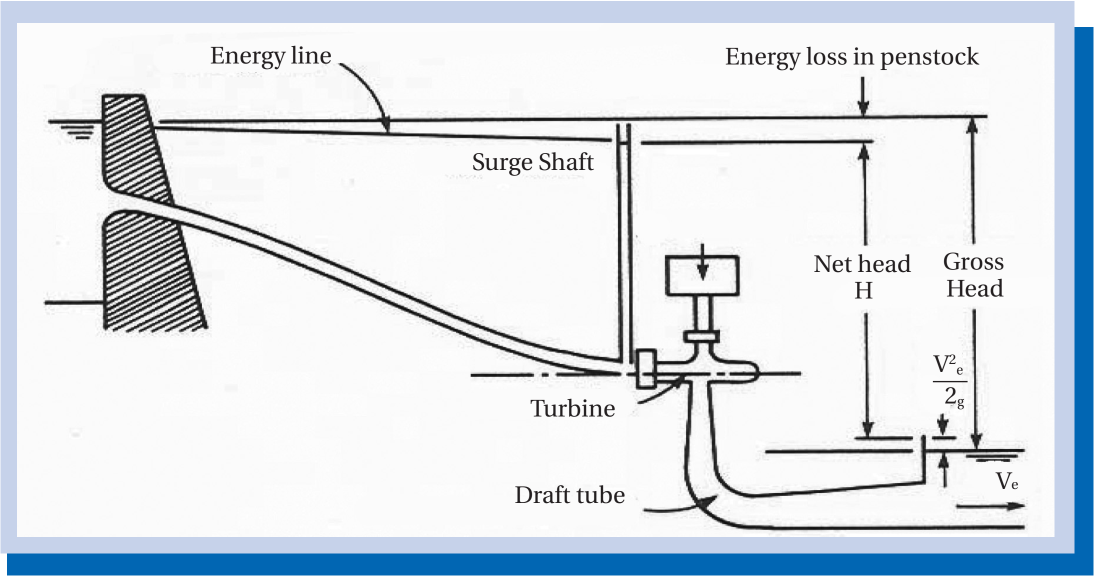
P (power in KW) $= Q \times H \times 9.81 \times \eta$, where

Q = discharge (rate of flow) in m^3/s;

H = Head (height) in metres; and

η = overall power generating system efficiency.

Figure 6.2: Components of a Small Hydropower Unit



A hydro power resource can be measured according to the amount of available power or energy per unit time. The power of a given situation is a function of head and rate of flow. (Figure 6.2)

The energy in a SHP starts out as potential energy by virtue of its height above the powerhouse. Water under pressure in the penstock is able to do work when released so there is energy associated with the pressure as well. The transformation of energy is from potential to pressure to kinetic energy. The total energy is the sum of the potential, pressure and kinetic in a run-of-the river system.

$$\text{Energy head per unit mass} \;=\; z + \underline{P} \;\; + \frac{v^2}{2_g} \qquad (1)$$

Where z – elevation from a reference height (m)

P – pressure ($Nm\text{-}^2$)
Y – specific weight ($Nm\text{-}^3$) (density of water 9.81)
V – average velocity ($ms\text{-}^1$)
G – gravitational acceleration (9.81ms-2)

Theoretically the power available from a site is proportional to the difference in elevation between the source and the turbine, called the head, H times the rate at which water flows from one end (height) to the other, Q. (11)

$$\text{Power} = \frac{\textit{Energy}}{\textit{Time}} = \frac{\textit{Weight}}{\textit{Volume}} \times \frac{\textit{Volume}}{\textit{Time}} \times \frac{\textit{Energy}}{\textit{Weight}} = y.Q.H.$$

The power delivered from the nozzle at the end of penstock is $P = y.Q.H_N$, where H_N is the net head (Gross head – head loss = $H_G - \Delta H$).

The power in kW from the nozzle is $P_i\ (KW) = y.Q.H_N/1000 = 9.81.Q.H_N$ (2)

From (2), one can see that the power in the hydro power system strongly depends on the net head and the flow-rate of water. SHP sites are characterised as high head or low head. The higher the head the better it is because then one would need less water (i.e. less flow-rate) to produce a given amount of power. This would mean that smaller and less expensive material could be used. A vertical drop of less than 0.6m will probably make a small hydroelectric system unfeasible. (13) This means that head less than 0.6 metres would produce less power and it would not be economical.

Net head is the gross head minus the head losses that occur when water flows from the intake to the turbines through canals and penstock. Water loses energy (head loss) as it flows through a pipe, fundamentally due to:

1. Friction against the wall.

The friction against the pipe wall depends on the wall material roughness and the velocity gradient which by near the wall. The friction in the pipe walls can be reduced by increasing the pipe diameter. However, increasing the diameter increases the cost, so a compromise should be reached between the cost and diameter.

2. Flow turbulence

Water flowing through a pipe system with bends, sudden contractions and enlargement of pipes, racks, valves and other accessories experiences in addition to the friction loss, a loss due to inner viscosity. This loss depends on the velocity and is expressed by an experimental K multiplied with the kinetic energy $\frac{V^2}{2g}$. (14) Water flow in a pipe bend, experiences an increase of pressure along the outer wall and a decrease of pressure along the inner wall. This pressure imbalance causes a secondary current. Both movements together (the longitudinal flow and the secondary current), produces a spiral flow at a length of around 100 metres is dissipated by viscous friction. The head loss produced depends on the radius of the bend and the diameter of the pipe.

The loss of head produced by water flowing through an open valve depends on the type and manufacture of the valve.

6.3 Example

Suppose a 0.1m diameter penstock delivers $0.009465m^3/s$ of water through an elevation change of 30 metres. The pressure in the pipe is 186kPa when it reaches the powerhouse. What fraction of the available head is lost in the pipe? What power is available for the turbine?

Solution:
From equation (1) Pressure head = $\frac{P}{\gamma} = \frac{186000}{1000kgm^{-3} \times 9.81} = 18.96m$

To find velocity head, velocity of water should be known. To calculate velocity, use Q=A.v where A is the cross-sectional area of the pipe.

$$\therefore v = \frac{Q}{A} = \frac{0.009465m^3/s}{\pi(0.05m)^2} = 1.21m/s$$

So, from equation (1) the velocity head = $\frac{v^2}{2g} = \frac{(1.21m/s)^2}{2 \times 9.81m/s^2} = 0.074m$

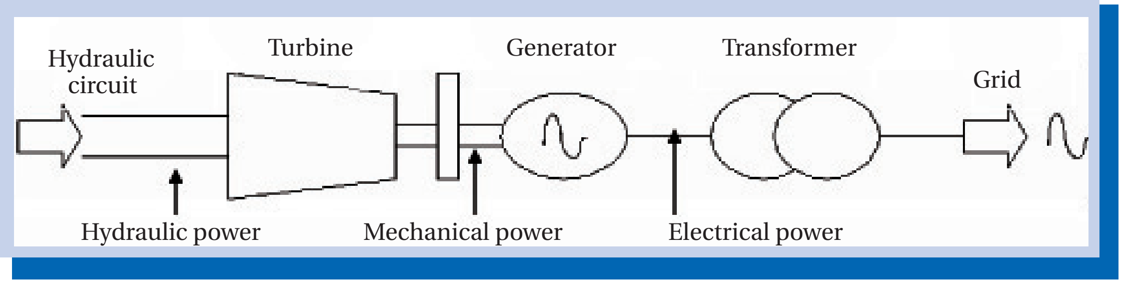
Total head left at the bottom of the penstock is the sum of the pressure and velocity head, 18.96m+0.074m = **19.03m**.

Since water was released from a height of 30m, the **head loss** is (30m – 19.03m) = **10.97m** or **36.5 percent**.

The power that is available to the turbine is:

$P = 9.81QH_N = 9.81 \text{ x } 0.0009465m^3/s\text{x}19.03 = 1.77kW.$

Figure 6.3: Power conversion scheme (15)



6.4 Efficiency of SHP

Figure 6.3 shows the power conversion scheme.

The final power (P_f) output from SHP is smaller than available hydraulic power (P_i)

$$P_f = \eta P_i$$

That is $P_f(KW) = (9.81).n.Q.H$ …………………………..(3)

Where η is the overall efficiency. This results from multiplication of partial efficiencies.

$$\eta = \eta_{turbine} . \eta_{generator} . \eta_{transformer}$$

$\eta_{turbine} \Rightarrow$ This depends on the type of turbine used.

$\eta_{generator} \Rightarrow$ This depends on the size of the generator.

$\eta_{transformer} \Rightarrow$ This depends on the size of the transformer.

6.5 Ideal Flow rate for Maximum Power

If the flow is too high, friction eats up too much of the power and power output drops. By slowing down the flow rate, friction losses are reduced but so is the power delivered.

Unit 7. Economics of using an SHP

Time: 1 hour

Methodology: Discussion, presentation

7.1 Advantages of an SHP

Some of the key advantages of SHP are:

- Environmental protection through CO_2 emission reduction – CO_2 emission is reduced because electricity production from SHP does not release CO_2 in the process
- Proven and reliable technology
- Improves the diversity of energy supplies – this is the one of many alternatives of producing electricity
- Grid stability
- Reduced land requirements – unlike in wind energy, where a fair bit of land is required to install a wind turbine
- Local and regional development – leads the community to be independent of fossil fuel
- Assists in the maintenance of river basins
- Technology suitable for rural electrification in developing countries
- High energy payback ratio

7.2 Shortcomings of an SHP

Some of the shortcomings are:

- SHP is a site specific technology and usually the site is faraway from the place where the electricity is required
- Run-of-the river plants experience significant fluctuations in output power

7.3 Environmental Impact of an SHP

Firstly, 1GWh of electricity produced by SHP allows to:

- Supply electricity for one year to 250 households in a developed country
- Save 220 tonnes of petrol
- Save 335 tonnes of coal
- Avoid the emission of 480 tonnes of carbon dioxide
- Supply electricity for one year to 450 households in a developing country

Secondly, because SHP is produced from run-of-the river systems, it doesn't disturb aquatic life. A general rule of thumb is to not divert more than 20 percent of the water flow of the river through the turbine and to return any diverted water back to the river just below the turbine.

7.4 SHP Economics and Costs

The capital required for small hydro plants depends on the effective head, the flow rate, geographical and geological features, the equipment (turbines, generators and others) and civil engineering works and continuity of water flow.

Sites with low heads and high flow require a greater capital outlay, as large turbine machinery are needed to handle larger flow of water. If, however, the system can have a dual purpose- such as power generation and flood control, power generation and irrigation, power generating and drinking water production-the payback period can be lowered.

The operation and maintenance cost including repairs and insurance can range from 1.5 to 5 percent of investment costs.

Unit 8. Water Mills

Time : 1 hour

Method: Presentation, discussion

8.1 Introduction to Water Mills

The idea of using energy in water and converting it into mechanical energy has been known to mankind for a long time. In ancient times, mechanical power was developed by passing flowing water through wheels and such wheels, known as water-wheels, were used in China, India, Egypt and later in Europe. Vertical shaft wooden water mills are generally used for grinding grains and are called *"gharats"*. These *gharats* operate under a head of 2 to 5 meters to produce on an average of 1.0 KW mechanical outputs.

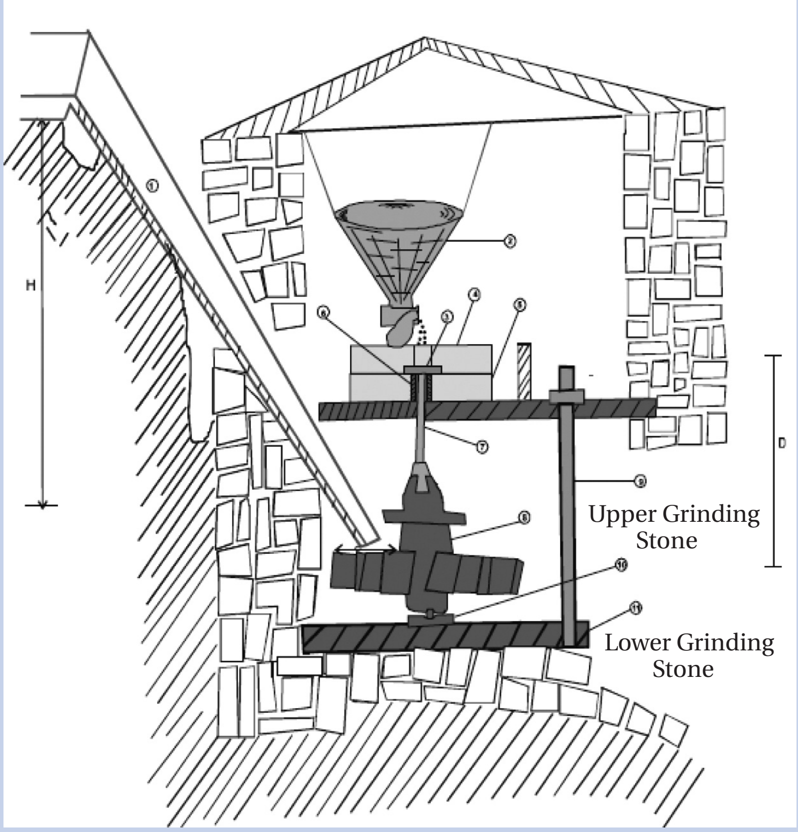
The *gharats* have a significant role in the utilisation of mechanical power from water streams, mainly for the purpose of grinding. The design of the traditional *gharat* is quite old and very little modification has been done over the years in the *gharat* designs. Traditional water mills for grinding are being widely used in the Himalayan regions and about 2.5 lacs traditional wooden water mills are still in use in Himalayan and sub-Himalayan regions. From Kashmir to Arunachal Pradesh, water mills are used for grinding cereals. By the input of technical enrichment, the efficiency of traditional water mills can be increased upto 3 times. The Alternate Hydro Energy Centre (AHEC), The Indian Institute of Technology Roorkee (IITR), have been involved in the development of water mills.

At water mill sites where sufficient head and water flow is available to develop 3 KW-10 power, a Multi Purpose Power Unit (MPPU) is considered to be appropriate. Based on the turbine technology, a new design with low cost fabrication technology has been developed by AHEC under UNDP-GEF Hilly Hydro Projects of the Ministry of New and Renewable Energy Sources (MNRES), Govt. of India. The developed system is capable of producing upto 10 KW of mechanical power for driving agro processing machines directly and for generating electricity, if connected with an alternator. The system is a Horizontal Shaft 'Open Cross Flow Turbine'.

8.2 Traditional Water mill

A traditional water mill consists of a wooden turbine with straight wooden blades, fitted at an incline to a thick vertical wooden shaft tapering at both ends. The water chute consists of an open channel, either made from wooden planks or carved from a large tree trunk. The chute is narrowed down toward the lower end to form a nozzle. The wooden shaft of the turbine is supported on a stone pivot through a steel pin and held in the sliding bearing at the top. The sliding bearing is a wooden bush fixed in the lower stationary grinding stone.

Figure 8.1: Traditional Water Mill



The top grinding wheel rests on the lower stone and is rotated by the turbine shaft through a straight slot coupling. The gap between the stone is adjusted by lifting the upper stone with the help of a lift mechanism.

Design of a Traditional Water Mill with different parts

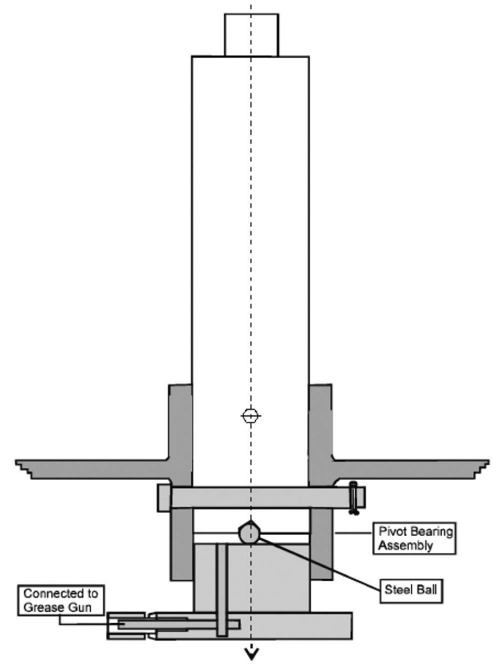
1. Flume
2. Hopper
3. Rynd/Cam
4. Upper Grinding Stone
5. Lower Grinding Stone
6. Upper Bearing/Bush
7. Shaft
8. Runner with Hub
9. Lifting Mechanism Lever
10. Bottom Bearing
11. Lifting Mechanism Bar

L Chute Length
H Head
C Runner Radius
D Shaft Length

Improved Water Mill

A vertical shaft water mill upto 3 KW mechanical output has been developed by AHEC under the Project sponsored by DST-TIFAC, the Govt. of India. The developed system is capable of providing an efficient and long life machine, which requires minimal maintenance and is useful for grinding cereals at a faster rate. The improved runner ensures the enhancement of efficiency by 3-5 times, over the traditional water mill. The improved runner is very easy to install and can be fitted with other parts of the existing water mills which are generally found in good condition The parts of the machines are very simple and are easy to understand by local people. The newly designed water mill consists of the following components:

Figure 8.2: Improved Water Mill



Runner

The diameter of the runner is about 750 mm having 16 blades. The complete runner is cast in single-piece and weighs about 50 kg.

Drive Shaft

A steel shaft of 50 mm diameter has been used as a drive shaft. The upper end of the shaft is cut in rectangular form to fit the rynd/cam for the upper stone attachment.

Bottom Bearing

A very simple bottom bearing which has a ball press fitted at the lower end of the shaft, which in turn rests on a piece of hard steel.

Wooden Bush

A simple oil soaked wooden bush made of hard wood is used in the upper stone hole to hold the shaft straight and aligned vertically.

Rynd or Cam

Cam is used for revolving the upper stone over the bottom stone which to fitted with a driving shaft.

Upper Stone Lift Mechanism

The lift mechanism is a steel bar which has a rotating wheel at its upper end and pin at its lower end. The lower end is fitted to the cross bar with the help of the pin.

Figure 8.3: Picture of an improved runner, installed at a location in Uttarakhand

Grinding Stones

Existing grinding stones can be used for new installations as these are generally found in good condition.

Flume/Chute

The existing flume can be reused by providing the lining of G.I.

Feeding Mechanism

At existing sites, the feeding mechanism consists of a hopper with a vibrator and it can be reused.

8.3 Installation Process for the New Improved System

Step I : Ensure the Tools

To enable the installation of the improved system, well maintained and good quality tools are essential. First of all, check all the tools such as: hammer, sheet cutter, file, grease gun, hacksaw, plumb, screw driver, draw bar, spirit level, spanner, wood saw, chisels.

Step II : Dismantling of Traditional Water Mill Components

The components of a traditional water mill should be dismantled in order to fit the improved components.

Step III : Fitting of Bottom Bearing

To ensure the shaft alignment in a proper vertical position with respect to the cross bar over foot bearing at the lower end and the upper grinding stone at the upper end, a centre mark should be made on the cross bar. Taking this mark as the centre of the bottom bearing spindle, the plate of the bearing is fixed by putting nails on the cross bar.

Step IV : Shaft Fixing with Runner

After placing the runner over the bottom bearing from the downstream side, place the shaft through the hole of the lower grinding stone from the upstream side. After the alignment of the shaft with the runner, put the pin through the holes of the runner hub and the shaft in order to fit the runner with the shaft. Now put the wooden bush inside the hole of the lower grinding stone over the shaft.

Figure 8.4: Removing the old components

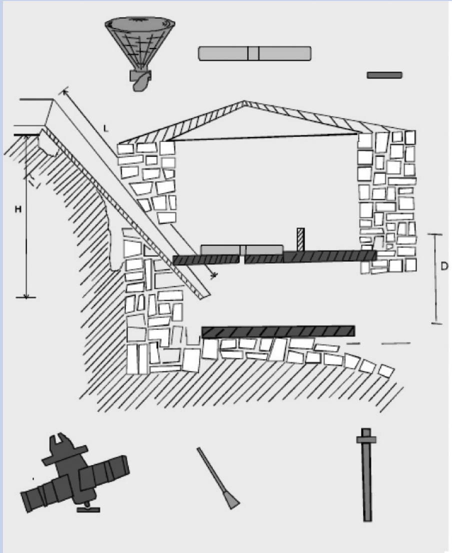
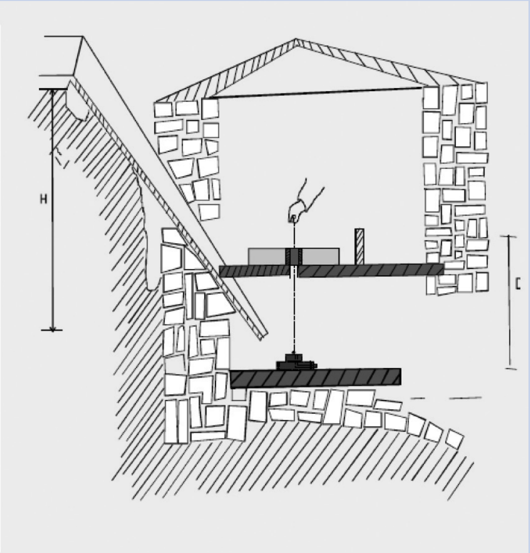


Figure 8.4: Installing the new components



Step V : Fitting the Remaining Components

After fitting the runner with the shaft, fix the rynd at the upper end of the shaft and place the upper grinding stone over the lower grinding stone. Fix all the remaining components.

Step VI : Alignment of the Water Jet

Alignment of the chute is one of the essential requirements of water mill installation. In case of the new runner, the water jet must strike 3 blades on the inside of the runner. The water flow is from inside to the outside direction, as the runner is 'outward' flow type.

8.4 Operation

Correct operation of the system is beneficial in many ways. Managers and operators must be fully familiar with the equipment, its functions a operational procedures. Technical specifications must also be known and properly recorded in the Operations & Maintenance Manual provided by the installer.

The following checks should be made during starting, stopping and running of the unit.

At any stage, if a problem is noticed say, an unusual sound, the unit should be stopped and the problem rectified before starting or running the unit.

(a) Follow the specified procedure for cleaning up the civil works as applicable.
(b) Visually inspect all components (e.g. bottom bearing, runner, shaft, pin, bush, stones, hopper, lift mechanism and vibrator etc.,)
(c) Ensure that the jet of water is aimed properly at the runner blades.
(d) Keep sufficient gap between the stones to rotate the upper stone smoothly in the beginning.
(e) Increase the discharge slowly, so that the stone along with the wheel, picks up speed.
(f) According to the quality of flour that is required, adjust the gap between the stones and operate the lift mechanism.

8.5 Maintenance

Maintenance of Chute Inlet

For a smooth flow from the power channel to the chute, the joint should be maintained properly.

Maintenance of Water Chute

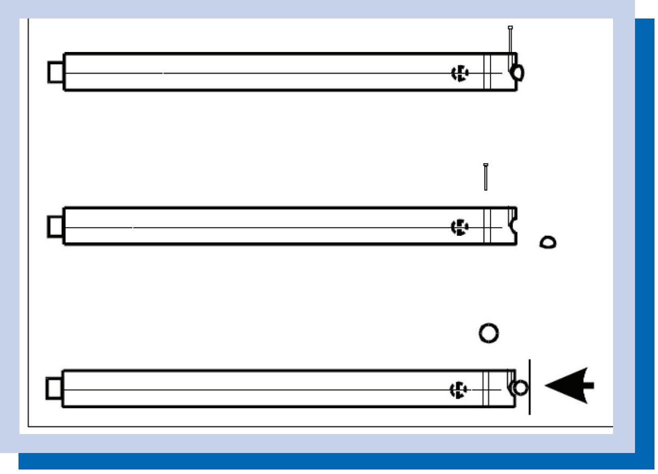
With use, the surface of the water chute gets worn out and the surface in contact with the water becomes rough, causing loss of head due to friction. Try to make this surface smooth by maintaining it properly.

Bottom Bearing Ball

Sometimes, the alignment of the shaft gets disturbed, due to the thrust of the water jet through the chute. This misalignment results in wobbling in the runner. This may damage the foot bearing and the hub of the runner. It is suggested to the owner/operator that he should check the alignment of the shaft regularly, and if there is any misalignment, then find out what the cause is and get it rectified it immediately.

Alignment of the Shaft

Figure 8.6: Alignment of the Shaft



The bottom bearing ball fitted with the shaft revolves over the foot bearing spindle. This ball gets worn out, over a period of time. The ball should be replaced a new one. However, the life of the ball may be increased by providing proper lubrication. The wner/operator must ensure the lubrication before starting the system.

There is a hole embedded at the end of the shaft. By striking the nail with a hammering device, the ball inside the hole in the shaft is drawn outside. For inserting the new ball in the given hole of the shaft, the wooden batten is stroked on the outer surface of the shaft. The procedure for of replacing the ball is shown below.

Stones Dressing

Dressing of stones is very important to increase the output of the water mill. It is necessary to made the grooving on the stones scientifically. Grooves should be maintained proper, and from time to time.

For the maintenance of the unit the following points should be noted.

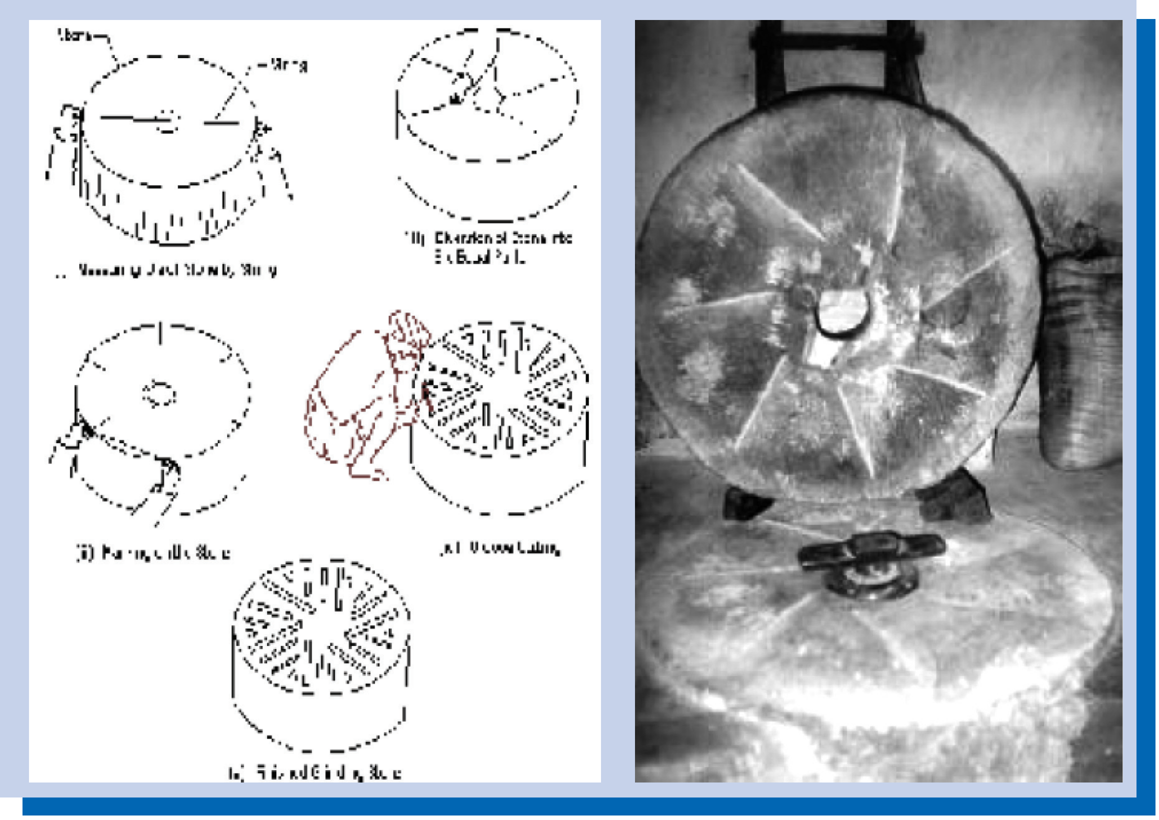
Before starting

(a) Clean the trash racks at the intake, desilting basin and forebay.
(b) Check whether sufficient water is flowing -through the headrace.
(c) If not, the plant load should be reduced accordingly or it should not be started at all.
(d) Flush the forebay and desilting basin during the monsoons (every other day if the debris quantity of is little).

During operation

(a) Check the temperatures and vibration level of the housings/casings of the bearings of the turbine and generator.

Figure 8.6:



(b) Check the leakage from valves, turbine housing, or base frame.

(c) If the leakage from any location is excessive, repairs should be organised straight away and in due course as the situation demands.

Good and timely preventive maintenance would almost always help to reduce the number of breakdowns and increase the life and productivity of the equipment.

A check list and schedule (as given here) for routine maintenance should be maintained.

Item	Daily	Weekly	Monthly	Observations/Action Taken
Power				
Foreign objects in channel		✓		
Correct flow level in channel	✓			
Leakage from channel		✓		
Flume				
Leakage in Flume	✓			
Alignment of nozzle	✓			
Upper Grinding Stone				
Condition of grooves/dressing		✓		
Lower Grinding Stone				
Condition of grooves/dressing		✓		

Rynd				
Fitting with upper stone	✓			
Fitting with coupling of gearbox	✓			
Bush				
Clearance over shaft		✓		
Fitting with lower stone		✓		
Shaft				
Alignment with stone		✓		
Alignment with runner		✓		
Alignment with bottom bearning		✓		
Runner				
Condition of blades		✓		
Fitting of hub with shaft through pin		✓		
Bottom Bearing				
Greasing/oiling	✓			
Surface of ball		✓		
Surface of spindle		✓		
Hopper				
Mounting of hopper		✓		
Wall surface of hopper		✓		
Vibrator				
Tightening with hopper		✓		
Contact with upper stone	✓			

8.6 Impacts of Water Mill Upgrades

8.6.1 On Water milling community

Improved revenue and position

The increased processing capacity of improved water mills has helped the owner to process more, by attracting more customers from distant villages, which has resulted in increased, income. Income has also been high due to the willingness of customers to pay more service charges for efficient processing. The pay back period for the additional investment made on the water mill upgradation is about 4 years. The improved water mill owners now have a respectable status in the village and for them the enterprise is considered as one of the prestigious ones. There has been upliftment of the social status of the owners. The upgradation also has resulted in increased inflow of ground flour to the familes of the water mill operators, which is given as a fee for grinding work. In some cases, millers are able to sell in the local market, additional flour obtained.

Variety of end-use possibilities
Although the upgraded water mill has potential for many end use applications, the main application of the improved mill at present is mainly limited to grinding and hulling only. Attempts are being made to extend the end usage applications for oil expelling, spice grinding, juice extraction, alternator, wool carding and welding.

Ease of Maintenance
The mill owners had to replace the wooden runner every 2 years while the improved mill runner can be used for more than 10 years. The owners had to tighten the wooden blades of the runner every 2 to 3 days. In improved mills, only the repair of the pin bearing is required every 3-2 months.

8.6.2 Larger Hill Communities

Time of grinding
Because of increased processing capacity of the upgraded mills, the processing/waiting time of the village customers has been reduced drastically. The time thus saved is utilised in fodder/fuelwood collection, household sanitation, childcare etc.

Quality of processed grain
The flour from improved mills is finer than that of from the traditional mills. The quality is also better than that of the diesel mills, as the rotational speed in diesel mills is much more (about 700 rPM) than that of the upgraded mill, which in turn, deteriorates the taste and quality of the ground flour due to generation of more heat.

Environment
The improved mill has reduced installation of diesel mills to some extent and the consumption of diesel oil, subsequently reducing the money outflow from local village communities. As compared to diesel mills and any other micro-hydro scheme, the improved mill installation has very negligible environmental effects.

Socio-economic development
The village information centre powered by upgraded water mills will provide basic computing facilities including internet connectivity for the local community. People will have accessibility to a wide range of information on education, health, employment, finances through software, information kits, CDs, and the internet. Through the local browser, the local community will be able to produce the local content, and access the internet without language barriers. The information centre will disseminate of information obtained from the internet among the local community for development requirements. The idle time of the water millers will be utilised for developmental activities of the community as a whole, and also help in building capacity of the youth and the unemployed, in terms of computer literacy and employment generation.

Employment and income generation
Local blacksmiths, carpenters and technicians will get more job opportunities as their technical capabilities are enhanced and the market for water mill upgrades develop.

8.7 Future Perspectives

Some of the future directions that are being pursued by the programme partners include:

- Involvement of rural banking and finance institutions in the hills to financ water mill upgrades to spread upgradation opportunities to economically weaker sections of society
- Involvement of local technical training institutions and local polytechniques in capacity building programmes, so as to create sustainable local training capability
- Involvement of the local metalworking and blacksmiths community in providing maintenance and replacement service to the upgraded water mills
- There is need of continuous and adoptive action research to make it more appropriate and versatile for wider acceptance of the technology. There is ample scope for wider end use application of the technology in terms of rural electrification, water lifting for irrigation and many other uses
- More district-level water miller associations need to be encouraged to spread the water milling movement to the north-west and north eastern parts of the Indian Himalayas

8.8 Conclusions

The following conclusions can be drawn as a result of upgradation of traditional water mills:

- The upgradation of traditional hydro power systems in the Himalayan and sub-Himalayan regions in the India has good potential to revive water milling activity and generate income in the Himalayas spanning several countries in the region, from Afghanistan to Myanmar. The improved versions of the water mill has helped in reviving water milling activity in the region.
- The technical solutions need to be combined with business skills at the local level, there should be more local participation and capacity building to sustain and build-up on the efforts.

Appendix 1: Developing your Hydro Site

This list forms only a basic framework that many be followed; many of these steps are interchangeable.

1. Determine the available head and flow you have available as your potential
2. Determine your household power requirements
3. Determine whether you will use a stand alone hydro system or a hybrid system
4. Consider the other elements you want to include in your electrical system
5. Determine what sort of turbine fits your available head, flow, and power requirements
6. Design your diversion system – open or closed

Appendix 2: Types of Diversion Systems (Open and Closed)

Example of a raised open diversion canal

diagram of the main elements in an open diversion system:

In this case, the useable head is the elevation difference between the level of the river water and the level of the water in the open diversion canal at the turbine location.

The "Diversion System" refers to the means that you use to "divert" water from the source and transport it to your turbine. There are various methods for diverting and transporting the water, but diversion systems can be grouped into two basic types – "open" and "closed" systems.

Matching the correct type of diversion system to a particular style of micro-hydro turbine is critical to the optimal performance of the turbine. In general, impulse turbines (which produce power primarily from head pressure) will utilise a closed diversion system. Reaction turbines (which produce power primarily from water volume) will normally work best with an open diversion system.

Whether a "Diversion System" is classified as "open" or "closed" depends on the point in the diversion system at which gravitational forces directly impact the water.

In a "closed" diversion system (such as a pipe), the system is sealed and water is isolated from direct gravitational forces while in the pipe. The water surface at the inlet to the pipe is the point at which gravity directly affects the water, and is, therefore, the starting elevation for the system head. Since the water exits the closed diversion system at the turbine, the turbine elevation becomes the ending elevation for calculating the system pressure head. Closed diversion systems work well for developing high pressure head with relatively low water flow volumes.

In an "open" diversion system (such as a canal), the water along the entire diversion system is directly exposed to gravity. In an "open" diversion system, then, the last point at which gravity directly impacts the water is the water surface directly above the turbine inlet. Hence, the starting elevation for the pressure head is often the water surface directly above the turbine. The ending point for the pressure head is the turbine impeller. "Open" diversion systems work well for supplying large volumes of water to the turbine with low friction losses. Some disadvantages of the "open" diversion systems are that initially they may involve more work to set up and, in cold climates, slow moving water is more subject to freezing.

Some reaction turbines (such as the Nautilus) may utilise a combination of open and closed diversion systems, with an open system leading to a closed system (such as a pipe). The open segment diverts a large volume of water close to the turbine site, while the closed portion allows development of the necessary pressure head for the turbine without the expense of long lengths of piping. In these combination systems, the starting elevation for the pressure head is the water surface at the point where the water enters the closed system.

Diagram of main elements in closed diversion systems:

In this case, the useable head is the elevation difference between the water level at the pipeline intake and the turbine nozzle, after friction losses are taken into account.

Now, a comment on static and dynamic pressures. In both instances we are talking about the pressure at the bottom of the column of water. Static pressure refers to the pressure when the water in the column is static, or not moving. Dynamic pressure refers to the available pressure when the water is moving, and is the static pressure less system Pressure losses are due to friction and turbulence. Since hydro turbines draw their power from moving water, dynamic pressure is the important pressure.

In “closed” diversion systems, there can be significant system pressure losses due to friction on the pipe inner wall, bends in the pipe, valves, etc., and turbulence due to incomplete filling of the pipe. Thus, in “closed” systems there can be a substantial difference between static and dynamic pressure. It is imperative that the “closed” diversion system be designed to optimise the dynamic pressure and that the dynamic pressure is calculated and utilised.

In open diversion systems, the larger system capacity and slower water speed tend to minimize system friction or turbulence losses. System friction and turbulence losses are still an issue but are less critical for open diversion systems since there is far less difference between static and dynamic pressure.

Optimising both the static and dynamic pressures are a cost-benefit analysis. The baseline is to meet the minimum turbine pressure and flow requirements. Beyond that minimum, the site and diversion system selections centre on achieving the best power-to-cost ratio.

Appendix 3: Choosing the Right Turbine

A graphical representation of the power output of the hydro turbines in our product line is shown below. Once you have determined your site's head, flow, and your household power requirements, you can use this graph to assist in determining which turbine suits your situation. It is important to note that this is a logarithmic graph and thus the scale is not linear. You can find the power output on a third axis at 45 degrees to the flow and head axis. Power generated from any hydro turbine is a function of the amount of head and flow available.

Appendix 4: Choosing the Pipe

Mild steel, uPVC and HDPE are the most common us used materials. In the table below, different materials are compared on their merits.

Material	Friction	Weight	Corrosion	Cost	Jointing	Pressure
Ductile iron.	****	*	****	**	****	****
Asbestos cement	***	****	****	***	***	*
Concrete	*	*	*****	***	***	*
Wood stave	***	***	****	**	****	***
GRP	*****	*****	***	*	****	*****
uPVC	*****	*****	****	****	****	*****
Mild steel	***	***	***	****	****	*****
HDPE	*****	*****	*****	**	**	*****

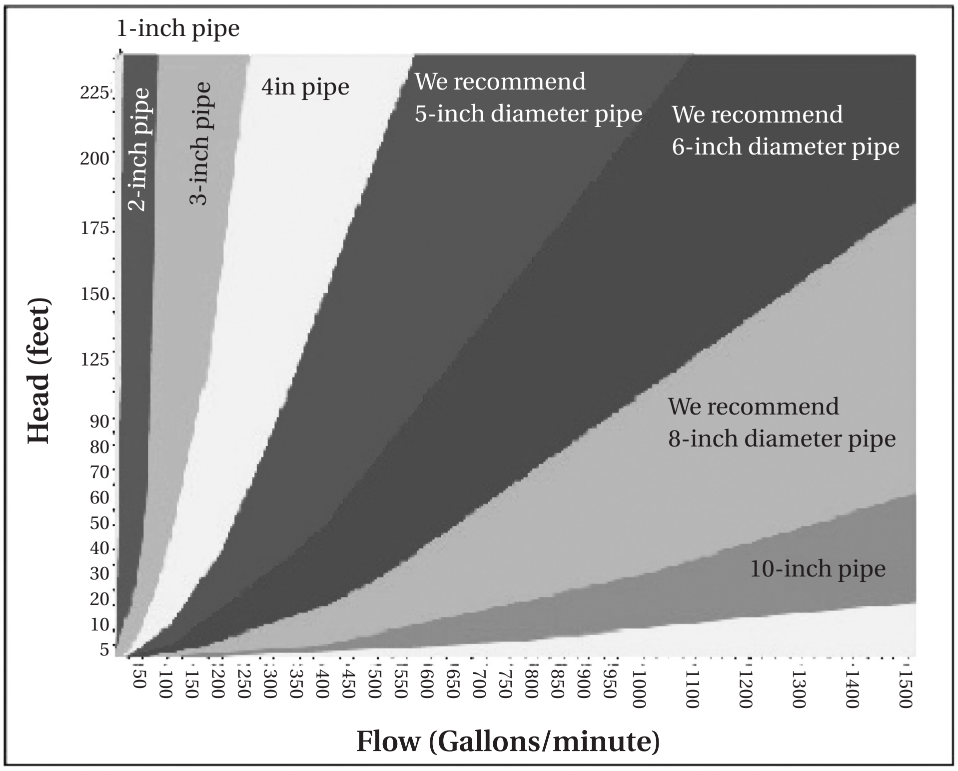
** = Poor ***** = excellent*

Source: Klunne.W, 2002

Choosing the Pipe in a "Closed" Diversion System

Once you have determined the water source inlet and measured the static head (vertical change in elevation) from the water source inlet to the turbine, measure the lineal distance for the path that the pipe for the diversion system will follow. You now want to select the optimal pipe diameter for your diversion system. The larger the pipe diameter, the less the friction loss will be. However, larger diameter pipes also cost more. You need to meet the hydro turbine's dynamic pressure and flow volume requirements. Beyond that, the optimal pipe diameter is the one that gives you the best cost-benefit ratio – the least cost per PSI of dynamic pressure. In the graph below we have provided a simple means of determining which pipe diameter to use, based on static head and flow information.

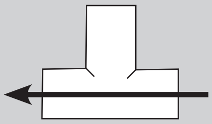
This graph is based on the assumption that your pipeline will have no turns or fittings with a radius greater than 22 degrees, and that it's overall length is under 500 ft. If you do have additional friction losses from these elements, you will need to size your pipeline larger than what is recommended here. Keep in mind that your flow must be adequate to keep the pipeline full even at low water levels to maintain a closed system and prevent cavitation and turbulence caused by air drawn into the system intake.

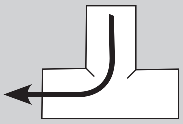


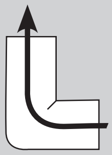
Source: Alaskan Inc

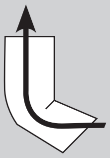
Appendix 5: Other Pipeline Friction Losses

Another major cause of head loss is in any fittings you might use. Avoid sharp corners in planning your pipeline, because sharp corners will cause turbulence and hence increase friction. The table below lists friction losses associated with various common plumbing fittings. It shows how many feet of pipeline length the fitting is equivalent to, in terms of friction loss. For example: A 'T' in a 4-inch pipeline represents 22ft of head lost – OUCH! Your goal in planning your pipeline is to keep it as straight as possible. Bends and curves should be less than 22 degrees. This is best accomplished with smooth, flexible hose sections making gradual curves where necessary or by carefully heating and bending straight pipe sections to your needs.









Pipe Diameter	Tee-Run	Tee-Branch	90^{0} Ell	45^{O}Ell
½	1.0 feet	4.0 feet	1.5 feet	0.8 feet
¾	1.4 feet	5.0 feet	2.0 feet	1.0 feet
1	1.7 feet	6.0 feet	2.3 feet	1.4 feet
1¼	2.3 feet	7.0 feet	4.0 feet	1.8 feet
1½	2.7 feet	8.0 feet	4.0 feet	2.0 feet
2	4.3 feet	12.0 feet	6.0 feet	2.5 feet
2½	5.1 feet	15.0 feet	8.0 feet	3.0 feet
3	6.3 feet	16.0 feet	8.0 feet	4.0 feet
3½	7.3 feet	19.0 feet	10.0 feet	4.5 feet
4	8.3 feet	22.0 feet	12.0 feet	5.0 feet

Some other sources of potential head loss to be aware of:

- Trash-rack/screen – clogged or poorly designed
- Pipe inlet – clogged inlet or inlet not properly submerged
- Valves – use gate, butterfly, or ball valves only in hydro systems as they allow unobstructed flow when open
- Size transitions in pipeline diameter, both increase or decrease
- Poorly sealed joints which allow air to be sucked into the pipeline

Appendix 6: Planning an Open Diversion Canal

There are many factors in planning a diversion canal and it is not the intention of this appendix to delve into it in great detail. Instead, we are presenting a brief overview of the important elements and considerations in planning the route and components of your diversion canal.

Important factors:

- Flowing water in the river will always carry silt and sand particles, which can be very abrasive to the turbine. Although it is impossible to eliminate these particles entirely, including a silt settling basin in your design will help to greatly reduce the amount of these particles reaching your turbine. This will significantly increase the life of your turbine runner.
- It is important to remember that while a hydro installation is designed to handle constant flow, rivers are variable in their flow rates throughout the year. Therefore it is important to create a diversion weir or dam to maintain channel flow at low water.
- The intake structure should be high enough to prevent excess water from entering your channel, and a spillway should be in place to allow excess water in the channel to escape.
- The channel should always be planned with flooding in mind. Floodwaters can cause a lot of damage to a poorly planned diversion channel. It is worthwhile to research past flooding records before beginning construction.
- Another factor demanding attention is the potentially destructive effect of turbulence in the flow of water through the channel. This can be erosive and lead to silt build up. It also allows particles to remain suspended in the water.
- Remember that since the power delivered by the turbine is strongly influenced by the head of water at the entry to the turbine, the channel should not drop any more than necessary along its length. The higher the level of the channel, the slower the water moves through it, allowing silt particles to drop out and reducing turbulence. The ideal water speed at the turbine is less than ½ foot per second.

Appendix 7: Conversion Factors

1 US gallon = 0.8327 Imperial gallons; 231.0 in3 (cubic inches); .1337 ft3 (cubic feet); 3.785 litres

8.34 lbs ; .00378 m3 (cubic metres)

1cu. ft. = 7.48 US gallons

1 ft3/s = 448.83 US gallons; 646,317 US gallons per 24 hours

1 inch = 25.4 millimetres; 2.54 centimetres

1 foot = 0.3048 metres

1 mile = 1.609 kilometres

1 centimetre = 0.3937 inches

1 metre = 39.37 inches

1 kilometre = 3281 feet

1 foot of head = 0.43 psi of pressure

Appendix 8: Formulae & Conversion Factors

Electrical Formulae:

Ohm's Law: R = V/I

Resistance (Ohms) =

Voltage (Volts)/Current (amps)

Power (watts) = volts x amps

1 horsepower = 746 watts

1 kilowatt = 1000 watts

1 kilowatt = 1.341 horsepower

Geometry Equations and Constants:

= 3.1416

Circumference of a circle = x diameter

Area of a circle = x (radius)2

Volume of a sphere = 0.5235 x (diameter)3

Volume of a cylinder = area of base x height

Pipes:

Doubling the diameter of a pipe increases its volume 4 times

Volume of water in a full pipe = II (inside pipe diameter)2 x length

Hydro and Physics Equations:

Newton's 3rd Law: For every action, there is an equal and opposite reaction

For a Hydro Turbine:

Net Head x Flow / 10 = Output Power

Flow = speed x cross-sectional area

Average stream speed = 80 percent of surface speed

Appendix 9: Basic Hydro Power Terminology

Buckets: In an impulse turbine, the buckets are attached to the turbine runner and used to 'catch' the water. The force of the water hitting the buckets turns the turbine runner and generates power.

Cavitation: Air bubbles in a closed hydro system, greatly reducing efficiency.

Cubic feet per second (cfs): A unit of measurement for flow. Flow equals the volume of water (cubic feet) passing through an area in a given time period (per second). 1 cfs is equal to 7.48 gallons per second.

Diversion (water): Redirects water from its natural course. There are two types of diversion systems: open diversions such as a ditch or canal, and closed diversions such as a pipeline.

Diversion Load: An electrical load to which excess energy from the hydro turbine can be diverted once the battery bank is fully charged. This is a necessary component of a hydro system, and requires a stable load such as a heating element.

Draught Tube: Used in reaction turbine systems, a draught tube is a flared cylindrical tube below the turbine runner, which maintains a closed system between the runner and the tail water. The draught tube recovers additional kinetic energy in the water, leaving the runner in the form of a 'suction head'.

Dynamic Pressure: The pressure in a pipeline when the water is flowing. This is equal to the static pressure minus pressure losses due to friction, turbulence or cavitation in the pipeline or fittings.

Flow: Flow is the volume of water passing through an area in a given time period. Flow is measured in gallons per minute (GPM) or cubic feet per second (cfs)

Flume: Conducts the water to the turbine

Forebay: A closed tank which acts as a settling basin and feeds water into the penstock.

Francis Turbine: A type of reaction turbine, a Francis turbine has a runner with nine or more fixed vanes. The water enters the turbine in a radial direction with respect to the shaft, and is discharged in an axial direction (90 degrees change). Francis turbines will operate from 4 feet to 2,000 feet of head and can be as large as 800 megawatts.

Guide Vanes: Used in reaction turbines to change water direction by 90 degrees, thus causing the water to whirl and enter all buckets of the turbine runner simultaneously.

This increases turbine efficiency.

Head: The total vertical distance influencing the water pressure at the turbine. The amount of energy potentially available in a hydro system is proportional to the head.

Head Losses: Factors which reduce the effective head, caused by anything that obstructs or limits the ready flow of water. Examples include roughness of the inner pipeline wall, and fittings which change the direction of the flow of water or increase the pipeline diameter.

Hydrology: The science dealing with the waters of the earth – their distribution and movement on the surface and underground; and also, the cycle involving evaporation and precipitation.

Impulse Turbine: The power produced by an impulse turbine comes entirely from the momentum of the water hitting the turbine runner. Impulse turbines are usually most efficient for high head micro-hydro systems (above 20 feet). Common impulse turbines include the Pelton and Turgo turbines.

Intake: The point at which water is diverted from the river to the turbine via either a closed pipeline or an open diversion channel. A trash screen and a settling tank are often set just in front of the intake to prevent debris and excess sand or silt from reaching the turbine.

Kinetic Energy: Energy due to motion. Water in motion has kinetic energy, which is being converted to electrical energy in a hydro power system.

Micro-hydro power: Hydro power installations with a power output of less than 100KW

Potential Energy: Energy that is in a stored form. Batteries store potential electrical energy. Water behind a dam also has potential energy, because the water is stored for future power production.

Pelton Turbine: A Pelton turbine is a type of impulse turbine that has one or more jets of water hitting the buckets of a runner. This runner looks much like a miniature water wheel. Pelton turbines are used for high-head sites (20 feet to 6,000 feet) and can be as large as 200 megawatts. It is a very efficient turbine and often used in high head micro-hydro applications.

Penstock: A closed pipeline through which the water flows to the turbine.

Propeller Turbine: A propeller turbine is a type of reaction turbine that has a runner with three to six fixed blades, like a boat propeller. Water passes through the runner and drives the blades. Propeller turbines can operate from 2 feet to 300 feet of head and can be as large as 100 megawatts.

Reaction Turbine: The reaction turbine, as the name implies, is turned by reactive force rather than by a direct push or impulse. The turbine blades turn in "reaction" to the pressure of the water falling on them. Reaction turbines can operate on heads as low as 2 feet, but require much higher flow rates than an impulse turbine.

Run-of-the-River: A hydro system which does not stop the river flow, but instead diverts part of the flow into a channel or pipeline to the turbine

Runner: A wheel to which buckets are attached in an impulse turbine. Looks similar to a miniature water wheel.

Scroll Case: A device used in a reaction turbine system that conducts the water from the penstock around the turbine vanes. This increases the efficiency by ensuring that the water enters the runner at a 90 degree angle, thus imparting the maximum force to the runner.

Static Pressure: The pressure produced by an unmoving column of water. This pressure is caused only by the vertical height of the water column and is unaffected by any horizontal displacement of water. Therefore, a pipeline where the inlet is 10 ft above the outlet has the same static pressure at the outlet regardless of whether the pipe is 10 feet long or 1000 feet long.

Suction Head: Additional energy reclaimed in the draught tube of a reaction turbine after the water leaves the turbine blades. While the inlet pressure head can be thought of as "pushing" the water through the turbine, the suction head can be thought of as "pulling" the water through the turbine. Generally, 80 percent of the power produced comes from pressure head and 20 percent from ths suction head.

Tail Race: Channel or pipe carrying the water from the turbine outlet back to the stream in any hydro system.

Trash Screen: A series of bars or mesh just before the system inlet designed to stop wood and debris from entering and choking or damaging the turbine.

Turgo Turbine: Variation on the Pelton turbine with differently shaped buckets which are tilted in such a way to allow for removing water from the system very efficiently after it hits the runner. Therefore a larger diameter water jet can be used which allows for greater power production. The Turgo runner is more difficult to manufacture and therefore, costs more than a similar diameter Pelton runner.

Watershed: The region draining into a river, river system or body of water; the total land area, regardless of size, above a given point on a waterway that contributes runoff water to the flow at that point; all the land that serves as drainage for a specific stream or river.

Weir: A low dam over which a river flows, but when water is in short supply nearly all of it can be redirected to the turbine or waterwheel