Chapter 6
Plant Components and Technology Options

A micro- or mini- hydropower scheme can be broken down into components in order to understand how the overall system operates. The following is a description of the various components. Section 6.1 deals with the water flow from the intake to the tailrace, followed by descriptions of turbines, governors/load controllers, and then generators. The chapter concludes with a discussion about quality and cost trade-offs as the relative advantages and disadvantages of locally manufactured machinery versus imported equipment are compared. As mentioned earlier also, it is beyond the scope of this manual to provide detailed and technical descriptions of the components here. The main purpose is to familiarise the readers with the essentials of the technology. Some excellent literature already exists on this subject (e.g., Harvey 1993).

6.1: Civil Works

Figure 6.1 shows the various components of the intake system and the water flow route. These components are given below.

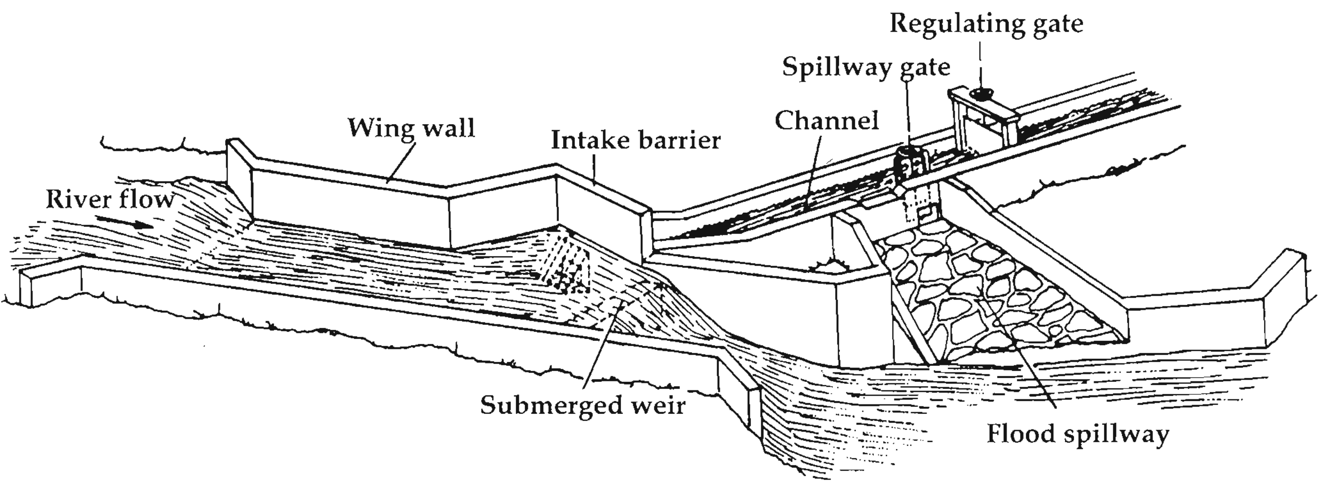
- Diversion weir
- Intake mouth
- Regulating gates
- Spillways
- Spillway drains
- Silt basin
- Channel
- Forebay tank
- Channel crossings
- Penstock
- Penstock supports
- Penstock anchors

6.1.1: Weir and Intake

An MMHP scheme must extract water at a fairly constant rate from the river in a reliable and controllable way. The water flowing in the channel must be regulated during the high and low flow conditions. Sometimes it is possible to avoid the expense of building weirs, using, instead, the natural features of the river. A natural permanent pool in the river may provide the same function as a weir, which acts as a barrier to the flow along the normal stream and diverts adequate flow into the power channel through the intake or the mouth.

Many variations in intake and weir design are possible, from simple boulders placed every dry season, which may get washed away during the monsoon, to expensive concrete or gabion structures. An example of a simple intake is shown in Figure 6.1

Figure 6.1 Example of an Intake Structure



6.1.2: Headrace

The headrace (or power channel) carries water from the intake and desilting basin to the forebay tank at the head of the penstock pipe. Various designs are possible to suit the type of the route or a part of it, including:

- simple earth excavation, no seal or lining;
- earth excavation with clay lining or stabilised soil lining;
- masonry lining or concrete channels; and
- flumes or aqueducts made from galvanised steel sheets, wood, pipes cut in half to form troughs, and plastic pipes.

6.1.3: Desilting Basins

The water drawn from the river and fed to the turbine will carry a suspension of small particles of solid matter. This 'silt load' will be composed of hard abrasive materials, such as sand, and will cause expensive damage and rapid wear to the turbine runners. To remove this material the water flow must be slowed down in desilting basins so that the silt particles settle on the basin floor where the deposits can be periodically flushed out. Figures 6.2 and 6.3 show simple designs for the desilting basins.

Usually, one or two desilting basins are provided to settle and remove the harmful solid particles. One desilting basin is provided a short distance after the intake and another some distance before the forebay. For short channels one basin may be enough.

6.1.4: Forebay Tank

The forebay tank is located at the end of the headrace. Water slows down here for a short time (depending on the size of the tank) to allow any entrapped air to escape and any silt collected in the headrace to settle out. The forebay also controls the flow into the penstock, ensuring that it enters smoothly without turbulence. Usually reinforced concrete or lime masonry is used for the forebay construction.

Figure 6.2: Silt Basin at Channel Entry

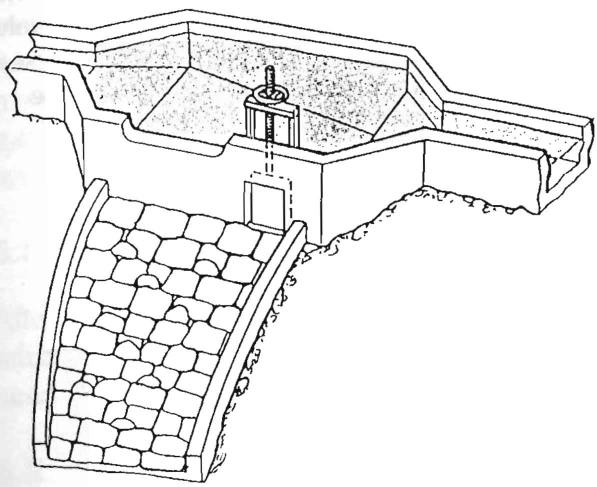
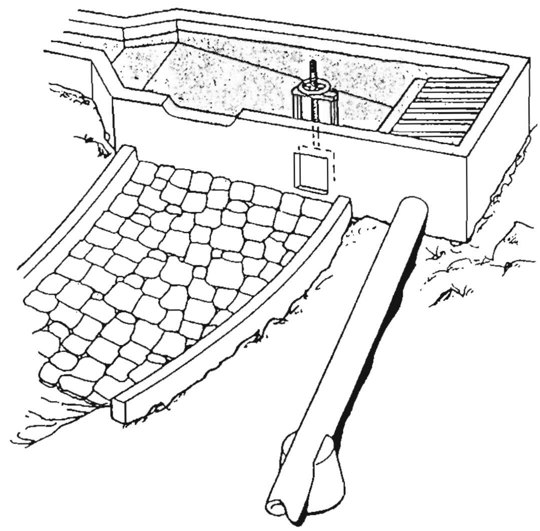


Figure 6.3: Forebay Basin



The design and construction of the forebay tank and desilting basin should be carried out according to the following principles.

- Within the limits of cost and size, the length and width must be sufficient to settle the silt particles.
- Design and construction should allow for easy flushing out of deposits undertaken at sufficiently frequent intervals.
- Water removed from the flushing exit must be led carefully away from the installation. This avoids erosion of the soil surrounding and supporting the basin and penstock foundations. A walled and paved surface, similar to that of a spillway drain, will do this.
- Flow turbulence, caused by introduction of sharp area changes or bends, and flow separation should be avoided.
- Sufficient capacity should be allowed for the collection of sediment.
- The depth of the forebay tank should be sufficient to avoid vortex formation.

Trash racks are also used at the mouth of the penstock to stop floating objects from entering the penstock.

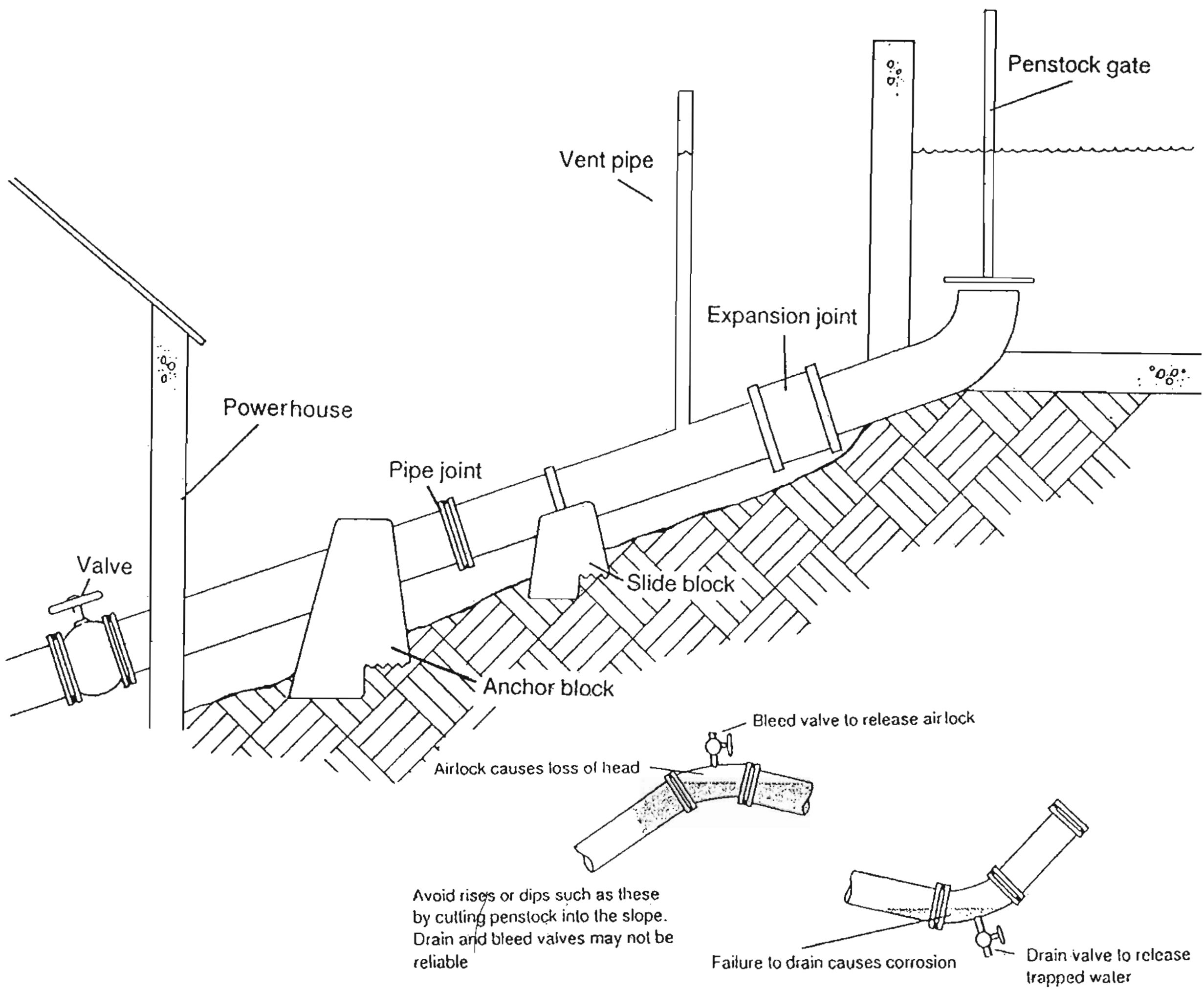
6.1.5: Penstock

The penstock is the pipe that conveys water from the forebay to the turbine, developing water pressure as it drops. The major components of the penstock assembly are shown in Figure 6.4.

The penstock constitutes a major expense in the total MHP budget. It is therefore worthwhile optimising the penstock design to minimise both lifetime running costs and initial purchase costs. To ensure low maintenance costs, care should be taken to place the penstock anchors and supports on stable slopes and on a firm foundation.

There should be no danger of erosion/landslides from storm runoff on the slopes, and there should be safe access for repair and maintenance jobs (such as repainting).

Figure 6.4: Components of the Penstock Assembly. Penstocks should be laid in such a way as to prevent airlocks forming inside them. These airlocks act as obstructions in the penstock and cause a pressure drop across them. If the danger of airlocks exists, because the ground rises and the penstock cannot be cut in, an air bleed valve should be fitted as shown. Similarly, water drain valves may be needed. The use of valves should be avoided since, after some years, they can become unreliable.



The following materials are commonly used for the penstocks of MHP schemes, depending upon the design pressure, importance of friction losses, weight and transportation facilities, soil type, weather, corrosion, etc.

- Mild steel
- Unplasticised polyvinyl chloride (uPVC)
- High-density polyethylene (HDPE)
- Medium-density polyethylene (MDPE)

The penstock can be above ground or buried; the latter provides greater protection to the penstock but complicates maintenance. In larger schemes a tunnel can also be used.

6.1.6: *Powerhouse*

The powerhouse is where the electro-mechanical components (generator, control equipment, and turbine) are located. It provides shelter for this equipment and for the operators. It should be dry, clean, and well ventilated and should have sufficient free space to allow maintenance and repair work to be carried out inside the powerhouse. The space requirements will be much greater if agro-processing is also to be carried out within the powerhouse

6.1.7: *Tailrace*

After leaving the turbine, having given up its energy to the turbine/generator set, the water returns to the river via the tailrace. This is usually a channel similar in construction to the headrace. This water can also be used for irrigation purposes in certain locations.

6.2: MMHP Turbines

A turbine converts energy in the form of falling water into rotating shaft power. The selection of a suitable turbine for any particular MMHP site depends on the site characteristics; the dominant factors being the available head and the power required. Selection also depends on the speed at which it is desired to run the generator or other devices powered by the turbine. Other considerations, such as whether or not the turbine will be expected to produce power under part-flow conditions, also play an important role in the selection. All turbines have distinct power-speed and efficiency-speed characteristics. For a particular head, they will tend to run most efficiently at a particular speed and require a particular flow rate. A turbine's correct design speed depends upon the power rating (size), the site head, and its type.

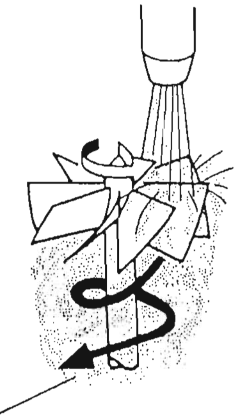
Often, the device that is driven by the turbine, e.g., an electrical generator, needs to be rotated at a speed greater than the optimum speed of a typical turbine. This leads to a need for speed increasing gears, or pulleys and belts, linking the turbine to the generator. In order to reduce costs and difficulties, it is preferable to minimise the speed-up ratio between the turbine and the generator.

Within the micro-hydropower range, we can crudely classify turbines as high, medium, or low-head machines, as shown in Table 6.2. The operating principle also divides the turbines into two groups; impulse or reaction.

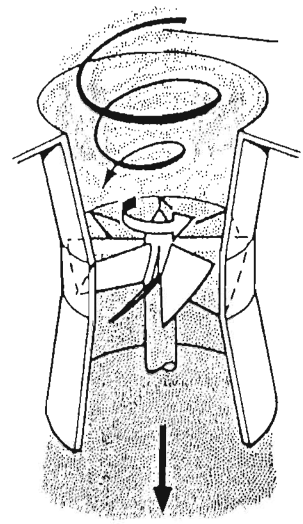
Table 6.2 : Groups of Impulse and Reaction Turbines

Turbine Group	Pressure Head		
	High	Medium	Low
Impulse	Pelton Turgo Multi-jet Pelton	Cross-flow (Mitchell/Banki) Turgo Multi-jet Pelton	
Reaction		Francis Pump-as-turbine (PAT)	Propeller Kaplan

Figure 6.5: Operating Principles of Turbines



a Impulse



b Reaction

In the case of an impulse turbine (Fig. 6.5a), pressure energy is first converted in a nozzle into the kinetic energy of a high-speed jet of water, which is then converted to rotational energy by runner blades that deflect the water and change its momentum. An impulse turbine needs a casing only to control splashing and give protection against accidents. Usually impulse turbines are cheaper than reaction turbines, because no specialist pressure casing and no carefully engineered clearances are needed.

In the case of a reaction turbine, the runner is fully immersed in water and is enclosed in a pressure casing (Fig. 6.5b). The runner blades are profiled so that pressure differences across them impose lift forces that cause the runner to rotate. The runner and the casing are carefully engineered so that the clearance between them is minimised.

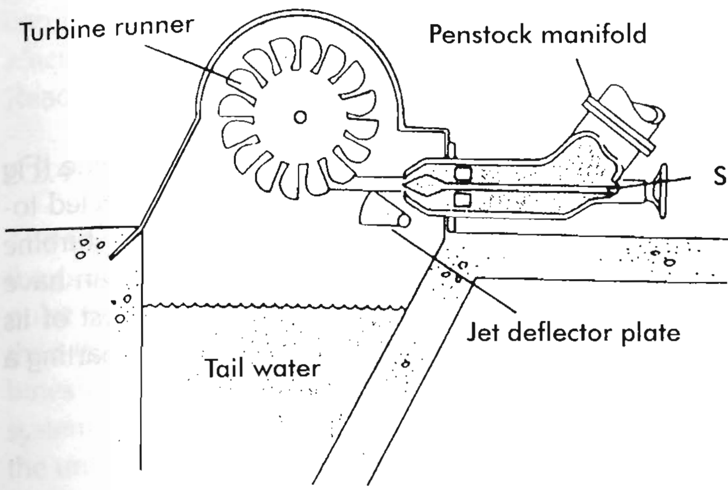
6.2.1: Pelton Turbines

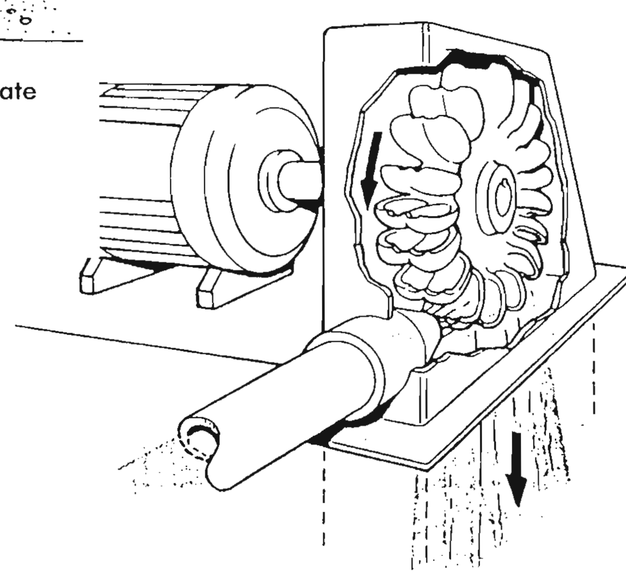
A Pelton turbine has one or more nozzles discharging jets of water which strike a series of buckets mounted on the periphery of a circular disc (Fig 6.6). In large hydropower installations, Pelton turbines are normally only considered for gross heads above 150 metres. For MHP applications, however, Pelton turbines can be used at much lower heads. For instance, a small diameter Pelton rotating at high speed can be used to produce one kW on a head of less than 20 metres.

Seasonal variations of flow over the course of a year can be handled in two ways. In the case of a single jet Pelton, it is possible to divide the yearly flow variation with two, three, or more parts and make a nozzle for each flow. The turbine operator can then fit the appropriate nozzle for each season. It requires some skill to judge when to change the nozzle and which one to fit.

If a multi-jet turbine has shut-off valves fitted on each of its jets, it can be run at different flow rates by simply altering the number of jets impinging on the runner.

Figure 6.6: The Single-Jet Pelton Wheel. Spear valves are not essential components. They can be replaced by various nozzle sizes, or a variable number of jets.





6.2.2: Turgo Turbines

The Turgo turbine is an impulse type similar to a Pelton turbine (Fig. 6.7). However, the jet is designed to strike the plane of the runner at an angle (typically 20°). In this turbine, water enters the runner through one side and exits through the other. As a consequence, the flow that a Turgo runner can accept is not limited by spent water interfering with the incoming jet (as is the case with Pelton turbines). Hence, a Turgo turbine can have a smaller diameter runner than a Pelton for an equivalent amount of power, and it runs at a higher rpm. Like the Pelton, the Turgo is efficient over a wide range of speeds and needs no seals with glands around the shaft. It also shares the general characteristics of impulse turbines listed for the Pelton.

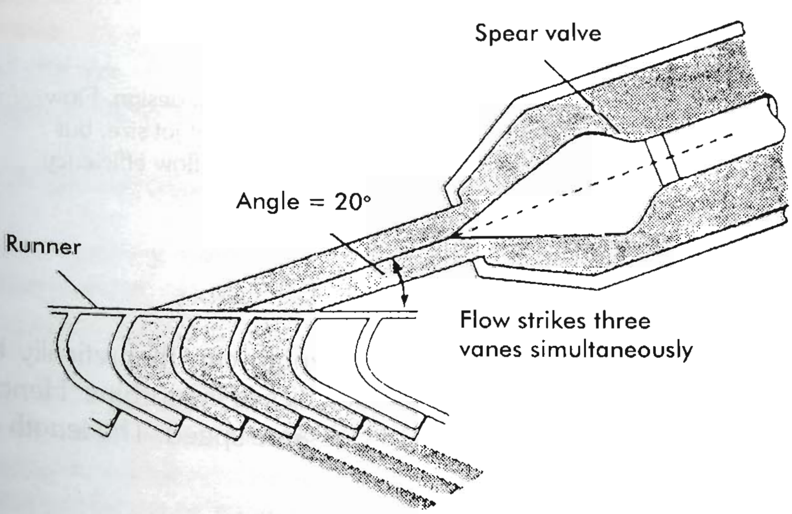


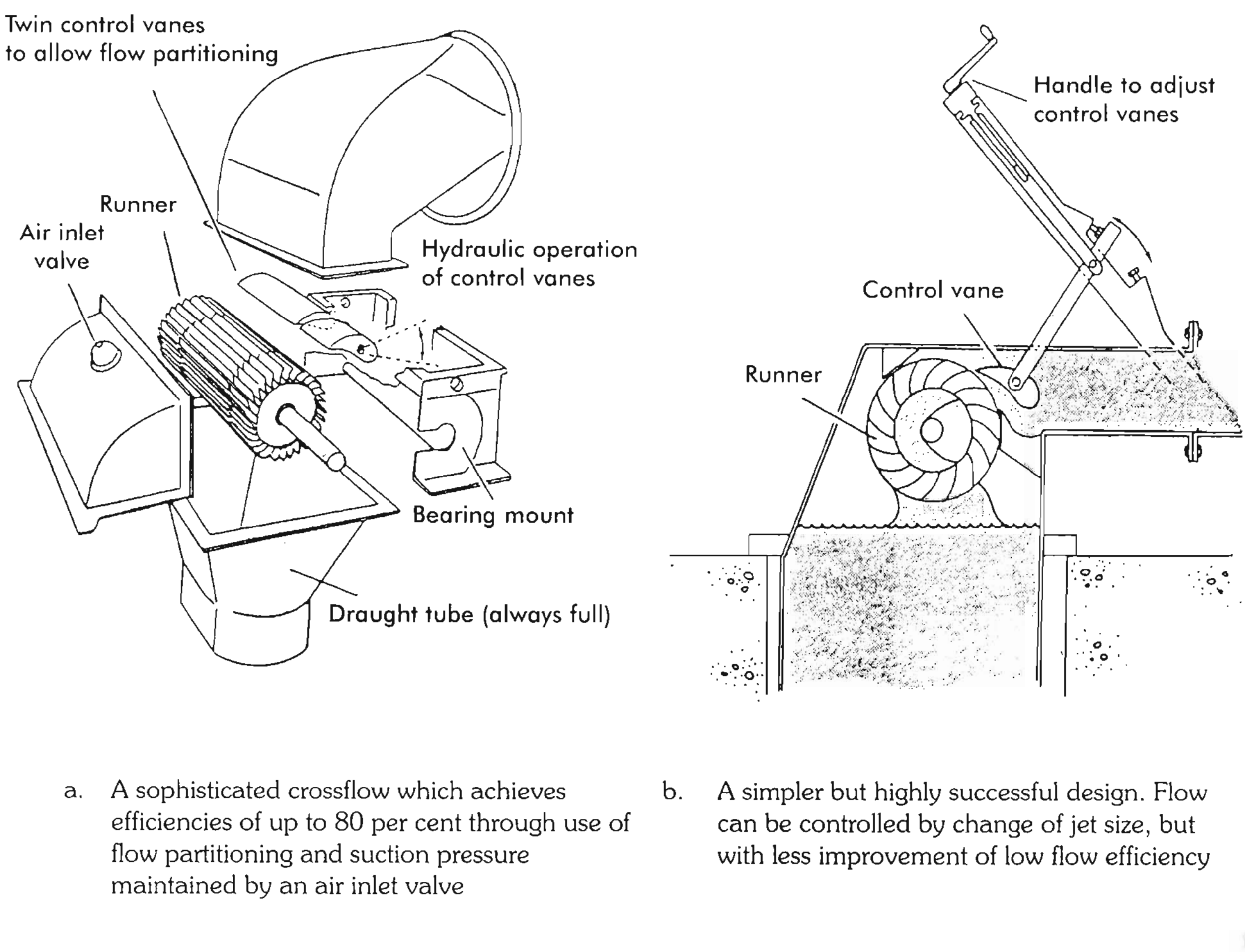
Figure 6.7: The Turgo Turbine. Although this is a compact turbine, the blade shape is complex and less suitable than the Pelton for local manufacture.

The Turgo does have certain disadvantages. Firstly, it is more difficult to fabricate than a Pelton, since the buckets (or vanes) are complex in shape, overlapping, and more fragile than Pelton buckets. Secondly, the Turgo experiences a substantial axial load on its runner which must be met by providing a suitable bearing on the end of the shaft.

6.2.3: Crossflow Turbines

Crossflows are also called Banki, Mitchell, or Ossberger turbines. A crossflow turbine (Fig 6.8) is comprised of a drum-shaped runner consisting of two parallel discs connected together near their rims by a series of curved blades. The runner shaft of a crossflow turbine is horizontal to the ground in all cases (unlike Pelton and Turgo turbines which can have horizontal or vertical orientation). The water strikes the blades and imparts most of its kinetic energy. It then passes through the runner and strikes the blades on exit, imparting a smaller amount of energy before leaving the turbine.

Figure 6.8: The Crossflow Turbine



a. A sophisticated crossflow which achieves efficiencies of up to 80 per cent through use of flow partitioning and suction pressure maintained by an air inlet valve

b. A simpler but highly successful design. Flow can be controlled by change of jet size, but with less improvement of low flow efficiency

Because of the symmetry of a crossflow turbine, the runner length can theoretically be increased to any value without changing the hydraulic characteristics of the turbine. Hence, doubling runner length merely doubles the power output at the same speed. The length of the runner is limited by the strength of the runner.

The crossflow turbine has three major attractions. Firstly, it is a design suitable for a wide range of heads and power rating. Secondly, it lends itself easily to simple fabrication techniques, a feature that is of interest in developing countries. The runner blades, for instance, can be fabricated by cutting a pipe lengthwise in strips. They also have a fairly horizontal efficiency curve at part-loads; although the overall efficiency is a little less than the Pelton or Reaction type turbines.

6.2.4: *Reaction Turbines*

The reaction turbines considered here are the Francis and the propeller. A special case of the propeller turbine is the Kaplan. In general, reaction turbines will rotate faster than impulse types, given the same head and flow conditions. The propeller will rotate even faster than the Francis. These high speeds have the very important implication that reaction turbines can often be directly coupled to an alternator without any speed-increasing drive system. Significant cost savings are made in eliminating the drive so that maintenance of the units becomes much simpler.

On the whole, reaction turbines need more sophisticated fabrication than impulse types, because they involve the use of larger, more intricately and precisely profiled blades. The extra expense involved is offset by greater efficiency and decreased cost if the turbine can be directly coupled to the generator without the need for a gearbox or pulleys and belts.

Fabrication constraints make these turbines less attractive to manufacture and use in the developing countries. Nevertheless, research is being undertaken to develop propeller machines that are simple to construct.

Figure 6.9 illustrates the Francis turbine. The runner blades are profiled in a complex manner, and the casing is scrolled to distribute water around the entire perimeter of the runner. In operation, water enters around the periphery of the runner, passes through the guide vanes and runner blades before exiting axially from the centre of the runner. The water imparts most of its 'pressure' energy to the runner and leaves the turbine via a draught tube.

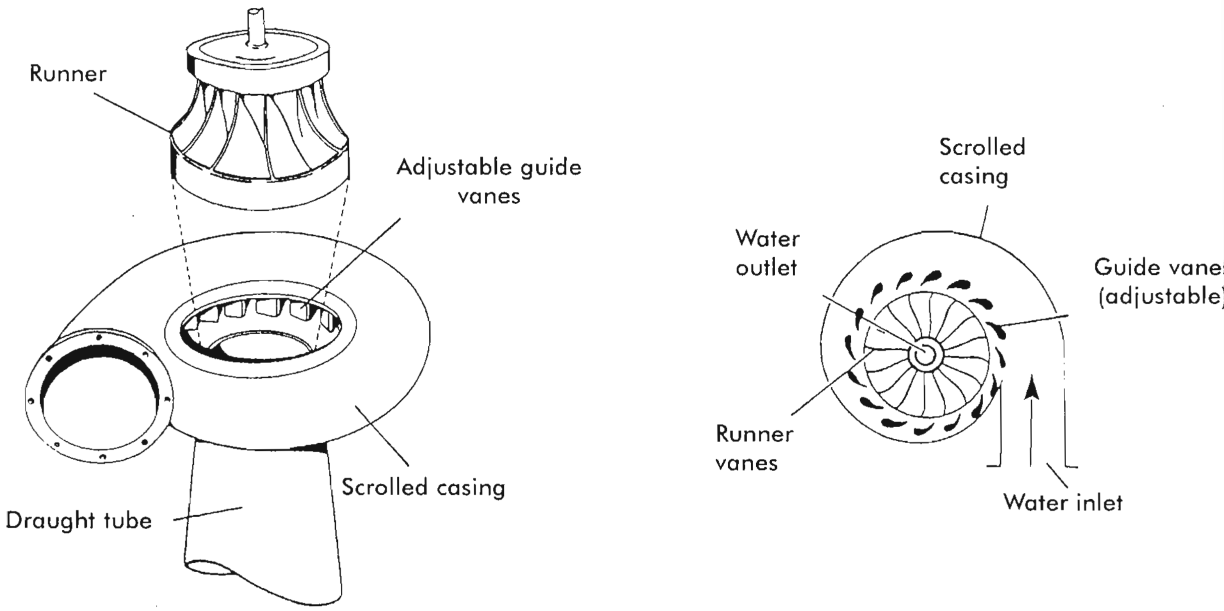
The basic propeller turbine consists of a propeller, similar to a ship's propeller, fitted inside a continuation of the penstock tube; its shaft taken out where the tube changes direction. Water flow is regulated by the use of swivelling gates ('wicket gates') just upstream of the propeller. The part flow efficiency characteristic tends to be poor. This kind of propeller turbine is known as a 'fixed-blade axial flow' turbine, since the geometry of the blade does not change. The Kaplan turbine is the same as a propeller turbine except that the pitch or angle of the blades can be changed.

6.3: Governing

Governors are used to control the speed of turbines. Some governing or control of the turbine speed is often required to ensure proper operation of the mechanical or electrical end-use machinery.

Electrical equipment is designed to operate at a specific voltage and frequency. Operation at frequencies and voltages other than the design values can cause serious damage. For example, an electric motor will run hot if the frequency is too low or may burn out rather than start if the voltage is too low. Some control of generator speed is therefore needed. As

Figure 6.9: The Francis Turbine. The complex blades, scroll casing shape, and the need for close tolerance cause this to be an expensive turbine. Guide vanes are rotated to change flow by a linkage mechanism.



the speed of the generator is determined by the turbine, the speed of the turbine must be regulated (kept constant).

6.3.1: Types of Governors

The approaches to governing may be classified in two categories: Mechanical & Electronic Load Controllers.

Mechanical Governors

A mechanical governor controls the turbine speed (hence the generator speed) by varying the flow of water to the turbine. It has a speed sensing device that sends a signal via high pressure oil that in turn controls valves or vanes that vary the flow of water to the turbine. Mechanical governors are complex, requiring quite a high level of skill to adjust and operate them. They should be designed to suit each system, including the penstock. Manufacturing requirements are quite sophisticated. Their main advantage is that only the required amount of water is used, making them very suitable for storage hydropower schemes.

Electronic Load Controllers (ELCs)

Load controllers were developed as a more robust and cheaper alternative to mechanical governors for MHP plants. The turbine/generator set runs at full power all the time. The power is consumed by various loads connected to the system which vary as they are connected or removed. This variable excess power is diverted to ballast heaters. By keeping a constant load on the generator, the output voltage and frequency are controlled. These ballast heaters can either be air or water heaters. In the case of water heaters, the hot water heated by this waste energy can sometimes be used.

This system is suitable for run-of-the-river type schemes where using the full flow is no problem. They are not so suitable for storage or reservoir systems. The load controller is simple to operate and maintain. Faulty components can be replaced and sent away for repairs, as they are light and compact.

Electronic load controllers are much cheaper than mechanical governors for micro- schemes. The ratio may be as high as 1:10 in favour of electronic load controllers.

6.4: Generators

6.4.1: DC - Generators

Low voltage, low power (12 V and 24 V at up to 2kW) direct current (dc) generators and associated low voltage equipment (lights, radios, televisions, motors, storage batteries, and so on) are readily and cheaply available for use in cars and trucks. The costs become comparatively high for larger-sized generators. It is, therefore, sensible to consider use of a low voltage, low power dc MHP system in the following circumstances.

- Where a small scheme (less than 2kW) is being considered and all the loads are very close to the generator, e.g., within 50 metres. Beyond this distance transmission losses are high.
- Where a battery-charging scheme is being considered, the MHP powered dc generator can be used to charge small batteries for customers who take them home to feed suitable small loads, e.g., radios and low wattage lights.

6.4.2: AC-generators

Except for the above-mentioned specialised cases, alternating current (ac) generators are used. There are two types of ac generator suitable for use in an MHP electricity supply scheme. These are synchronous generators (or 'alternators') and induction generators. Induction generators (in which an induction motor is used as a generator) are less common but are being used increasingly in smaller schemes. Their advantages are that they are easily and cheaply available, simply constructed and repaired, reliable, rugged, require little maintenance, and can withstand 100 per cent overspeed.

Induction generators are easily used when they are connected to an existing supply system (grid) and have been used in this way for many years. When used in a stand-alone application, such as an isolated MHP scheme, they need to be fitted with excitation capacitors. They can then be used to power single, fixed resistive loads, for instance a complete set of village lights, either all switched on, or all switched off. If fitted additionally with a voltage regulation system (or 'controller'), they can be used as all purpose ac supply generators.

This type of stand-alone, self-excited induction generator is now being used increasingly in schemes of less than 50kW in size, as a result of the development, since 1985, of an inexpensive voltage and frequency controller; the induction generator controller (IGC).

In synchronous generators, the frequency generated is directly related to the shaft speed. Induction generators are known as asynchronous generators because the frequency generated, though dependent on shaft speed, is not directly proportional to it and changes slightly with load changes. Both types of generators may have the same stator (outer stationary part of the generator) design but they use quite different rotors.

6.4.3: Voltage Regulation

The output voltage of a simple synchronous generator falls very rapidly, as the load current it supplies increases. It is essential that the output voltage remains the same for all loads. An 'automatic voltage regulator' (AVR) controls the output voltage. For synchronous generators (up to 50 kVA), this is usually an electronic unit built into the machine. Older machines may have electro-mechanical AVRs.

The induction generator has poor voltage regulation. Even when driven at constant speed, its output voltage drops rapidly with increasing load. The voltage is much more dependent on the speed with which it is driven than the synchronous generator. The water turbine-driven induction generator can, however, be used to operate multiple fixed resistive loads, such as village lights, with only the addition of capacitors, if some voltage variation and de-excitation problems can be tolerated for the sake of very low costs. The development, in recent years, of a simple IGC, has overcome these problems and made the stand-alone induction generator an increasingly attractive proposition for MHP schemes. It combines the functions of both a load controller and an automatic voltage regulator.

6.4.4: Non-conventional Approaches to Load Control

If high-quality electrical supply is required for sensitive equipment, then one of the automatic controllers listed above must be used. However, where the quality of supply is not so critical, some compromise in performance may be justified, particularly with very small plants (less than 10kW). To achieve lower costs, technically less sophisticated approaches to controlling load and speed are possible.

In rural areas, electricity is a new commodity and loads build up gradually. Non-conventional approaches permit access to electricity with less cost and reduced sophistication. The simplest method of ensuring constant frequency and voltage is to have no switches in the circuit. Power is switched on by opening the valve to the turbine sufficiently wide to attain the nominal frequency and/or voltage. Closing the valve when power is no longer required switches off the electricity. In this approach, neither switches nor power outlets should be included in the system. Frequency may be accurate to only $\pm$ 10 per cent, but modern automatic voltage regulators permit good voltage stability.

One variation of this approach permits more than one constant load to be used. A two-way switch can be used so that switching off one load (e.g., lighting), when it is no longer needed, switches on a second load of similar magnitude (e.g., a water heater). In this manner, a constant load is maintained on the generator despite the use of several loads. Each switch must only control a few per cent of the load. There are numerous variations of this approach.

With the manual control approach, an operator is required to maintain a relatively constant frequency manually. This can be done by adjusting either the flow of water to the turbine, or the total load imposed on the generator.

It is not necessary for the operator to make adjustments continually during the operation of the plant. Small deviations from nominal frequencies and voltages have no adverse effect on the plant or the load.

6.5: Indigenous Design and Manufacture of MMHP Plants

6.5.1: Manufacturing MMHP Equipment in Developing Countries

One of the biggest advantages of micro-hydropower over alternative non-conventional sources of energy is that it lends itself to indigenous manufacture. Very rudimentary workshops can produce equipment of reasonable quality to serve millions of rural people, as is the case throughout the world today. This cannot be said to be true for Solar PV, or Wind.

In Nepal, the crossflow turbine alone provides milling services for oil expelling and rice hulling for close to 10 per cent of the population. It is clear that if the only crossflow turbines available on the market today were those from the Ossberger company in Germany, very few of the two million people served today would have access to water power. Nepal is also fortunate that it has traditional craftsmen who have introduced innovations on traditional water power technologies to produce products such as the Multi Purpose Power Unit (MPPU), the 'improved *ghatta*', and the 'Peltric' set (a small Pelton turbine directly mounted on the shaft of an induction generator). The major advantages of having indigenously designed and manufactured plants are briefly discussed below.

Low Cost

Turbines and other MMHP equipment (for schemes of up to 300kW) are being manufactured in a number of developing countries; and at very low cost. MHP plants, for example, in the micro- and mini-range, are being manufactured in these countries at rates of US$ 300 to 2,000 per kW. The costs in industrialised countries are much higher.

The lower costs of turbines manufactured in the developing countries may well be offset by lower life, less efficiency, and higher maintenance costs. However, for many investors in developing countries, the high prevailing interest rates will mean that schemes are only viable if they can be built at very low construction costs.

Access to Repair and Maintenance

An equally important advantage of manufacturing MMHP equipment locally is access to repair and maintenance. It is reported that the 36 isolated, small hydropower schemes of the Nepal Electricity Authority have equipment from 30 different countries! This makes it extremely expensive and difficult to keep spares and to find workshops that can reliably repair the equipment. The absence of repair facilities can result in extended periods of breakdown. This leads to loss in confidence on the part of entrepreneurs to invest in industries that could improve the load factor of the plant.

A not uncommon problem is trying to trace the international manufacturer of equipment some years after commissioning the powerplant and finding that the industry has closed down, been taken over by another, or has discontinued the particular line of production.

There are, however, a number of limitations to indigenous manufacturing also. These are detailed in the following passages.

Poor Performance of Equipment

In many developing countries, the small workshops which manufacture MMHP equipment are not used to rigorous standards of accuracy and quality. In some cases, this leads to bad workmanship, though this is not usually the case. In many cases, however, even with high quality work, it has been found that the equipment does not actually produce the amount of rated power. The problem stems from over-optimistic assumptions and there not being a regulatory mechanism to verify that the power quoted is actually produced; for example, a penalty to enforce compliance.

Lower Life of Equipment

In order to keep costs low, it is usual for manufacturers to manufacture MHP equipment for a life of between 10 and 15 years. This is not necessarily a problem, as the examples below demonstrate.

As the raw materials for the equipment are usually imported, manufacturers in developing countries are not able to guarantee the longevity of their products even when their own work has been of a high quality. There are examples, in Nepal, in which an adequately sized shaft of a turbine has broken in two to the dismay of both the turbine manufacturer and the customer, and through no fault of the manufacturer.

6.5.2: Trade-offs between Low Cost, Long Life and Reliability

There is clearly a trade-off involved between the low cost of equipment and installations on the one hand, and reliability in performance and long life on the other. The discussion below attempts to use some examples to demonstrate how proper weightage can be given to the competing concerns.

Three examples are taken to illustrate the point.

Example A A high cost site using imported equipment with high quality civil works costing US$ 4,000 per kW installed and distributed. It has relatively low maintenance costs and achieves very high reliability and plant factor.

Example B A medium cost installation using locally manufactured, good quality equipment to the greatest extent possible has semi-permanent civil works and costs US$ 1,400 per kW. It has higher maintenance costs but maintains a high plant factor.

Example C A low cost installation that, using locally-manufactured equipment, uses temporary civil structures and costs as little as US$ 500 per kW. The scheme has fairly high maintenance costs, and relatively low reliability. The scheme will mainly be used for lighting; the low plant factor of 20 per cent results from the absence of a load controller, failure to limit the power used by the consumer, and very limited investment in engineering design for optimal matching between the various components of the installation.

These examples are based on real sites existing in Nepal and Pakistan. Assumptions have been made on the plant factor, operator costs, and maintenance costs but represent, as far as possible, the situation as it exists in the field.

Example A	
Size of plant:	400kW
Cost per kW:	US$ 4,000
Lifetime of plant:	40 years
Annual opert cost:	NRs 600,000
Annual maint cost:	1% of capital
Plant factor:	55%
Reliability:	98%

Example B	
Size of plant:	50kW
Cost per kW:	US$ 1,400
Lifetime of plant:	15 years
Annual opert cost:	NRs 80,000
Annual maint cost:	2% of capital
Plant factor:	55%
Reliability:	95%

Example C	
Size of plant:	100kW
Cost per kW:	US$ 500
Lifetime of plant:	15 years
Annual opert cost:	NRs 80,000
Annual maint cost:	3% of capital
Plant factor:	20%
Reliability:	85%

6.5.3: Putting a Cost to Trade-offs

Completing installations at a low cost per kW is important; however, it is the cost per kWh of energy produced and used by consumers that gives us the best indication of the cost-effectiveness of an MHP investment. Assuming the same rates of financing, for the cost per kWh to be low, the following conditions must prevail.

1) Installation costs per kW are low.
2) Energy use is high.
3) Operation and maintenance costs are low.
4) Breakdown of the equipment is infrequent.
5) The life of the equipment is long.

By producing clear costing for the above parameters, the cost of energy produced by a power plant can be provided by using the following procedure.

1) Annual Equivalent Installed Cost

The following annuity equation provides a simple way of converting the initial cost of installing a scheme into an annual cost. We can say that the initial outlay or capital cost is equivalent to a fixed sum outlay (A) each year for the life of the plant.

where,

A = annuity (fixed yearly outlay),
C = capital cost,
r = annual discount rate (fraction), and
n = predicted plant life (years).

2) Annual Cost of Operation

This includes the salary of the staff to keep the plant operating, to collect tariffs, and perform repairs. This will also involve any training the operators need to receive over the course of the year.

3) Annual Costs of Repair and Maintenance

Maintenance costs need to be taken into account for parts' replacement, civil works' repairs, and the input of outside specialists.

4) Total Annual Cost

The total annual cost is the sum of 1, 2, and 3 above.

5) Annual Energy Delivered to Consumers

The number of kilowatt hours of energy generated and, after deducting losses, delivered to the houses of the consumers, needs to be estimated.

6) The Cost of Energy Delivered

The cost of energy delivered is then computed by dividing the total annual cost by the annual energy delivered.

This procedure was followed for examples A, B, and C above in order to compute the resulting cost per kWh of energy produced.

Costs	Example A	Example B	Example C
Annual equivalent installed cost	Rs 6,000,800	Rs 384,300	Rs 274,500
Annual cost of operation	Rs 600,000	Rs 80,000	Rs 80,000
Annual cost of repair and maintenance	Rs 800,000	Rs 70,000	Rs 75,000
Total annual cost	Rs 7,400,800	Rs 534,300	Rs 429,500
Annual energy delivered	1,794,223kWh	217,412kWh	141,474kWh
	Rs 4.12	**Rs 2.46**	**Rs 3.04**

Methodology of Calculation

- In calculating the annual equivalent installed cost, a real discount rate of seven per cent was used. This is arrived at by deducting from the prevailing interest rate of 16.5 per cent (the market discount rate) an estimated inflation of nine per cent using the equation $1 + r = (1 + m)/(1 + f)$.

  These and other equations are discussed in more detail in the following Chapter (7).

- The total annual energy delivered is arrived at by multiplying the theoretical annual potential of the plant by the plant factor and then deducting five per cent losses in distribution from the powerhouse to the consumers.

6.5.4: Conclusions

These figures show that the medium initial-cost installation (example B) has the lowest cost per kWh (energy). The low-cost installation has the next lowest energy cost, while the high cost imported equipment installation has the most expensive energy. A significant influencing factor for the medium-cost installation is the good plant factor (that is assumed to be 55%). Variations in plant factor can alter the cost of energy quite significantly. The plant factor is affected by many factors other than equipment quality, e.g., types of loads and tarrif structure.

These figures do, however, suggest that good quality, locally-manufactured equipment with semi-permanent or permanent civil works will produce the lowest cost energy. If, on the other hand, the same plant factor was used (say 55%) in all three cases, while allowing for variation in the reliability, the following costs per kWh would be applicable; indicating that Example C would be the most cost effective option.

Example A	Rs 4.12/kWh
Example B	Rs 2.46/kWh
Example C	Rs 1.10/kWh