Intelligent Energy Europe

SMART –

Strategies to Promote Small Scale
Hydro Electricity Production in Europe

D 4.4 Report on the feasibility analysis for most technically acceptable locations

DISCLAIMER

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1.1 Introduction

After 1970's, crude oil prices increased because of the oil crisis and the people's growing ecological sensitivity as well as the corresponding authority's incentives caused small hydropower emerge as an important source of renewable energy. Attractive policies of few countries (notably Germany) have boosted the small hydro sector in recent years.

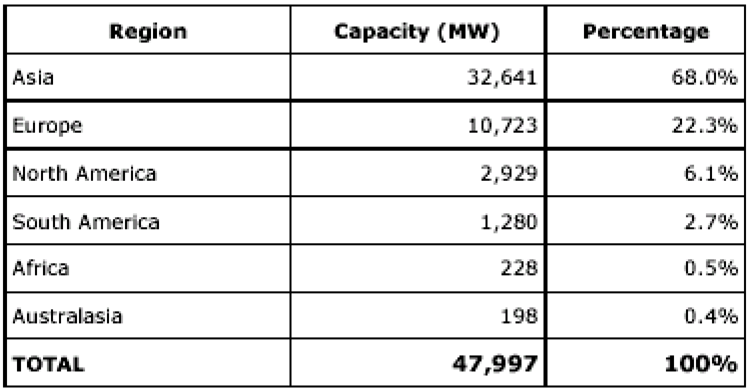
Small hydro is an ancient source of renewable energy and, in the light of CO_2 reduction targets and funding incentives, is currently being considered for installation in locations where sustainable water resources exist. Energy demands are increasing on a global scale. The energy demands from developing countries are set to rise exponentially. This places significant pressure on the earth's finite resources while producing increased CO_2 emissions.

Water is a natural resource which has been used to generate power, in one form or another, for centuries. In its simplest form hydro power was used to grind grain, provide shaft power for textile plants, sawmills and other manufacturing operations. These small hydro power sites could be found in many locations throughout Europe and North America.

The development of centrally-generated electric power eventually reduced the requirement for small hydro sites. These developments fuelled a growth in large scale hydro-electric schemes where dams were constructed to store water and generate, in many cases, mega-watts of power.

The trend is shifting in hydro electricity developments, with installations now reflecting small scale developments similar to the ones of centuries past. Small hydro turbines with high efficiencies have aided the move back towards small distributed sites.

Access to electricity is one of the keys to development because it provides light, heat and power used in production and communication. The contribution of small hydropower plants (SHP), defined as hydropower projects having a capacity below 10 MW, to the worldwide electrical capacity was about 2% of the total capacity amounting to 48 GW as shown in Figure 1. In the global small hydropower sector, China is the leader representing more than half of the world's small hydro capacity with 31,200 MW of installed capacity in 2005.



Region	Capacity (MW)	Percentage
Asia	32,641	68.0%
Europe	10,723	22.3%
North America	2,929	6.1%
South America	1,280	2.7%
Africa	228	0.5%
Australasia	198	0.4%
TOTAL	**47,997**	**100%**

Figure 1 Instaled capacity of SHP by continent

Figure 2 presents development of total installed SHP capacity in EU and world during the past three decades, while Figure 3 presents European SHP production.

TOTAL INSTALLED SHP CAPACITY

	1980	1985	1990	1995	2000	2005	2010
EU total installed capacity (MW)	5900	6700	7700	9000	9600	10300	11000
World total installed capacity (MW)	19000	21000	24000	27900	37000	46000	55000
EU total installed capacity (% of world installed cap.)	31.05	31.90	32.08	32.26	25.99	22.39	20

Figure 2 Development of total installed SHP capacity in EU and world

Figure 3 European SHP production

There is no international consensus on the definition of the term *"small"* hydro which, depending on local definitions can range in size from a few kilowatts to 50 megawatts or more of rated power output, as it is presented on Figure 4. Internationally, *"small"* hydro power plant capacities typically range in size from 1 (5) MW to 10 (15 or 50) MW. Projects in range 100 kW to 1 (5) MW are sometimes referred to as *"mini"* hydro and projects less than 100 kW are referred to as "*micro*" hydro. The term *"pico-hydro"* has also been used for the very smallest of plants, in the range of 0.5 to 3 kW. *"Medium"* hydro power plant capacities typically range in size from 10 (15) MW to 100 MW, and *"large"* hydro power plant capacities typically range in size over 100 MW.

Pico-hydropower	From 0.5 to 3 kW
Micro-hydropower	< 100 kW
Mini-hydropower	From 100 kW to 1 (5) MW
Small hydropower	From 1 (5) MW to 10 (15 or 50) MW
Medium hydropower	From 10 (15 or 50) MW to 100MW
Large hydropower	> 100 MW

Figure 4 Commonly accepted thresholds for hydropower systems

“Small hydro” and “low head hydro” are not synonomous. Low head hydro is a term associated with a research and development programs which are designed to advance the technology for generating hydro power from sites with heads of less than 20 meters.

Several types of studies varying in scope, detail and intended client are performed to determine the desirability of implementation of hydropower proposals. This text has adopted the standard sequence of preconstruction studies commonly followed in practice. They are “reconnaissance” or “prefeasibility” (should a feasibility study be performed?), “feasibility” (should an investment commitment be made?), and “definite plan” (the collective group of studies that are performed between an implementation commitment and construction initiation that result in permit applications, preparation of marketing agreements and financial arrangements, and definition of design parameters). The intention of the text is to aid in the execution of the reconnaissance and feasibility studies. A reconnaissance study is defined as …”a preliminary feasibility study designed to ascertain whether a feasibility study is warranted”, and feasibility study as … “an investigation performed to formulate a hydropower project and definitively assess its desirability for implementation”.

The reason underlying the major attention that is focused on small hydro is important in establishing the conceptual base for establishing a feasibility methodology. The character of small hydro is such that the marketable output will most often only be energy with little, if any, dependable capacity. This means the value of small hydropower will be primarily due to fuel and other operating cost savings and not due to offsetting the need for new power plants to supply capacity.

The feasibility of projects is expected to be quite sensitive to site specific conditions, e.g., the quantity of power produced will not likely support an extensive array of ancillary features such as long transmissions lines, access roads, or significant site preparation, etc. The nature of the market area load characteristics and present generating facilities servicing the load are critical elements in valuing power output. Areas served with major fossil fuel base plants or systems with high operating cost plants, operating at the margin will be more attractive for small hydro development. A significant issue of project feasibility is that investigation, design, construction management, administration and contingencies (the non-hardware elements of a project) are a major cost burden. Figure 5 schematically illustrates the cost elements in small hydro projects with high head, and Figure 6 the cost elements in small hydro projects with low head.

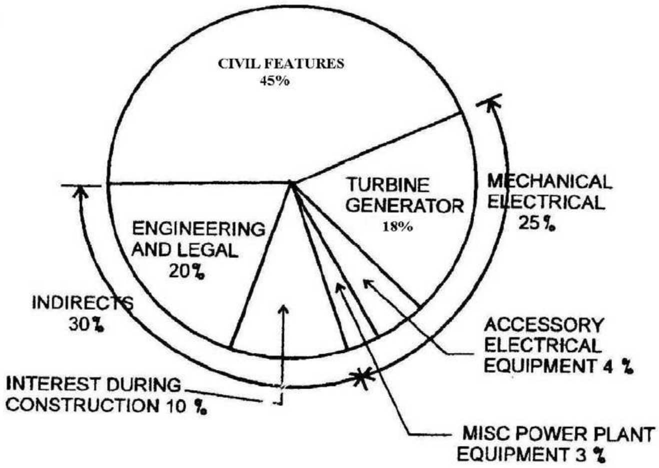


Figure 5 The cost elements in small hydro projects with high head

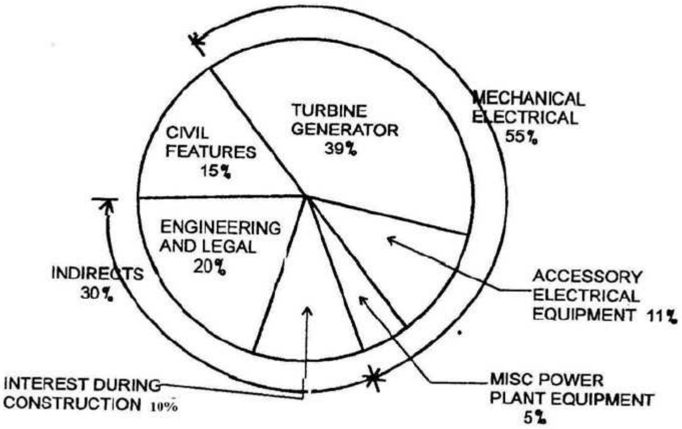


Figure 6 The cost elements in small hydro projects with low head

The development of small hydro power projects consist of three phases: prefeasibility study, feasibility study and implementation. Here in the focus is feasibility study, but because of completeness and the other two phases will be briefly presented. First, the single stages will be shown in general and then specifically for mini hydro power plants (to 1 MW).

For a better understanding of the prefeasibility study, feasibility study and implementation phase issues, in the text the next chapters are given: types of small hydro-power schemes, types of turbines, governors, hydro-electric generators and civil works.

1.2 Small hydro project development and operation phases

There are normally four phases for engineering work required to develop a hydro project:

1st - phase *Reconnaissance surveys and hydraulic studies* covers map studies; characterization of the drainage basins; preliminary estimates of flow and floods; a short site visit; preliminary layout; cost estimates based on experience and a final ranking of alternatives based on optimization of power potential and initial estimated cost.

2nd phase *Prefeasibility study* includes site mapping and geological investigations (with drilling and sampling); a reconnaissance for suitable borrow areas; a preliminary layout based on materials known to be available; preliminary selection of the main project characteristics; a cost estimate based on major quantities; and the identification of possible environmental impacts.

3rd phase *Feasibility study* includes the selected alternative with a major geographical investigation program; delineation and testing of all borrow pits; estimation of design and probable maximum floods; determination of power potential for a range of dam heights and installed capacities for project optimization; determination of the project design earthquake; design of all structures in sufficient detail; determination of the dewatering sequence and project schedule; optimization of the project layout, water levels and components; production of a detailed cost estimate; and finally, an economic and financial evaluation of the project along with a feasibility report.

4th phase *Implementation (System planning and project engineering)* includes final design of the transmission system; integration of the project into the power network; production of tender drawings and specifications; analysis of bids and detailed design of the project; production of detailed construction drawings and review of manufacturer's equipment drawings.

The other two phases are related with financial aspect of the project and the maintenance of the plant.

5th phase *Financing* is often difficult for small hydro projects. Firstly a contract has to be obtained with a utility or organization which will purchase the produced electricity. With this contract in place the next step is to negotiate a bank loan or other source of financing. However, many banks lack knowledge of small hydro projects and have no experience with this type of loan. In recent years some banks have acquired the necessary experience and now routinely provide loans for small hydro.

6th phase *Ownership and maintenance*, where are some important factors for the effective operation of a small hydropower plant successfully depending on financial and management skills of the investor: realistic assessment of project costs and benefits, personal and corporate financial strength, knowledgeable financial institution, design with special attention of operation and maintenance requirements and professional maintenance plan to minimize expense and downtime.

However, for small hydro, the engineering work is often reduced to three phases in order to reduce total cost by combining the work involved in the first two phases described below and decreasing the level of detail. Three distinct phases exist for the assessment of small hydro which includes a desktop *prefeasibility study (including reconnaissance surveys)*; *feasibility study*; and an *implementation phase*.

The prefeasibility phase is the concept stage which defines at a high-level the capacity, demand estimation and community suitability. Assessing the water resource and obtaining all available existing data and information is critical in assessing the certainty of the energy production potential.

The *feasibility assessment* is a technical and commercial analysis which will allow the owner to decide whether to proceed with implementation of the scheme. The feasibility study assessment should consider as a minimum, a site inspection; hydrological modelling; field investigations; hydropower assessment; social and environmental issues; preliminary design; costing and financial analysis.

This text provides technical data and procedural guidance for the systematic appraisal of the viability of potential small hydropower additions and focuses upon the concepts, technology, and economic and financial issues unique to these additions. The contribution, designed to aid in the performance of prefeasibility studies i.e. reconnaissance studies (should a feasibility study be performed?) and feasibility studies (should an investment commitment be made?), was developed for use by public agencies (state and local), public and private utilities, and private investors.

The text includes data and discussions on the topical subjects of cost escalation in economic and financial analysis, feature component selection for reconnaissance and feasibility levels of study, and time, cost, and resources required to perform the investigations.

1.3 Types of small hydro-power schemes

Nearly a quarter of the energy from the sun that reaches the Earth’s surface causes water from the seas, lakes and ponds to evaporate. A proportion of this energy is used to make water vapour rise, against the gravitational pull of the Earth into the atmosphere, where it eventually condenses to form rain or snow. When it rains in the hills or snows in the mountains, some of the solar energy input remains stored. Therefore water at any height above sea level represents stored ‘gravitational’ energy.

Hydro energy is naturally dissipated by eddies and currents as the water runs downhill in streams and rivers until it reaches the sea. The greater the volume of water stored and the higher up it is, then the more available energy it contains. For example, water stored behind a dam in a reservoir contains considerable ‘potential’ energy. To capture this energy in a controlled form, some or all of the water in a natural waterway can be diverted into a pipe. It can then be directed as a stream of water under pressure onto a water wheel or turbine wheel. The water striking the blades causes the wheel (or turbine) to turn and create mechanical energy.

The hydro electric plants work by converting the kinetic energy from water falling into electric energy. This is achieved from water powering a turbine, and using the rotation movement to transfer energy through a shaft to an electric generator.

The Figure 7 illustrates a typical small hydro scheme on a medium or high head.

The scheme can be summarised as follows:

- Water is taken from the river by diverting it through an intake at a weir.
- In medium or high-head installations water may first be carried horizontally to the forebay tank by a small canal or ‘leat’.
- Before descending to the turbine, the water passes through a settling tank or “forebay”in which the water is slowed down sufficiently for suspended particles to settle out.
- The forebay is usually protected by a rack of metal bars (a trash rack) which filters out water-borne debris.
- A pressure pipe, or “penstock”, conveys the water from the forebay to the turbine, which is enclosed in the powerhouse together with the generator and control equipment.

- After leaving the turbine, the water discharges down a “tailrace” canal back into the river.

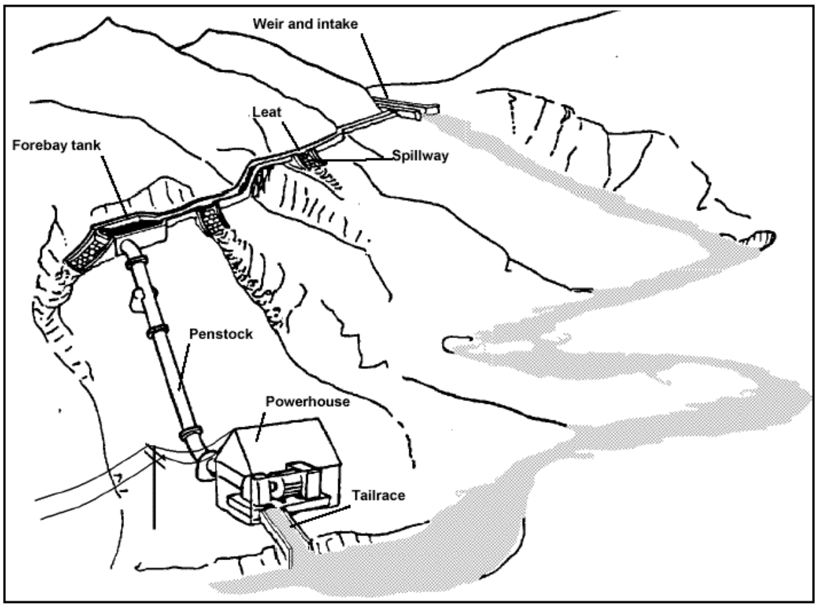


Figure 7 Illustration of a micro hydroelectric system

In practice, sites that are suitable for small-scale hydro schemes vary greatly. They include mountainous locations where there are fast-flowing mountain streams and lowland areas with wide rivers. In some cases development would involve the refurbishment of a historic water power site. In others it would require an entirely new construction. Figure 8 illustrates the four most common layouts for a mini hydro scheme. A variation on the canal-and-penstock layout for medium and high-head schemes is to use only a penstock, and omit the use of a canal. This would be applicable where the terrain would make canal construction difficult, or in an environmentally-sensitive location where the scheme needs to be hidden and a buried penstock is the only acceptable solution.

For low head schemes, there are two typical layouts. Where the project is a redevelopment of an old scheme, there will often be a canal still in existence drawing water to an old powerhouse or watermill. It may make sense to re-use this canal, although in some cases this may have been sized for a lower flow than would be cost-effective for a new scheme. In this case, a barrage development may be possible on the same site.

With a barrage development, the turbine(s) are constructed as part of the weir or immediately adjacent to it, so that almost no approach canal or pipe-work is required.

A final option for the location of new mini-hydro turbines is on the exit flow from water-treatment plants or sewage works.

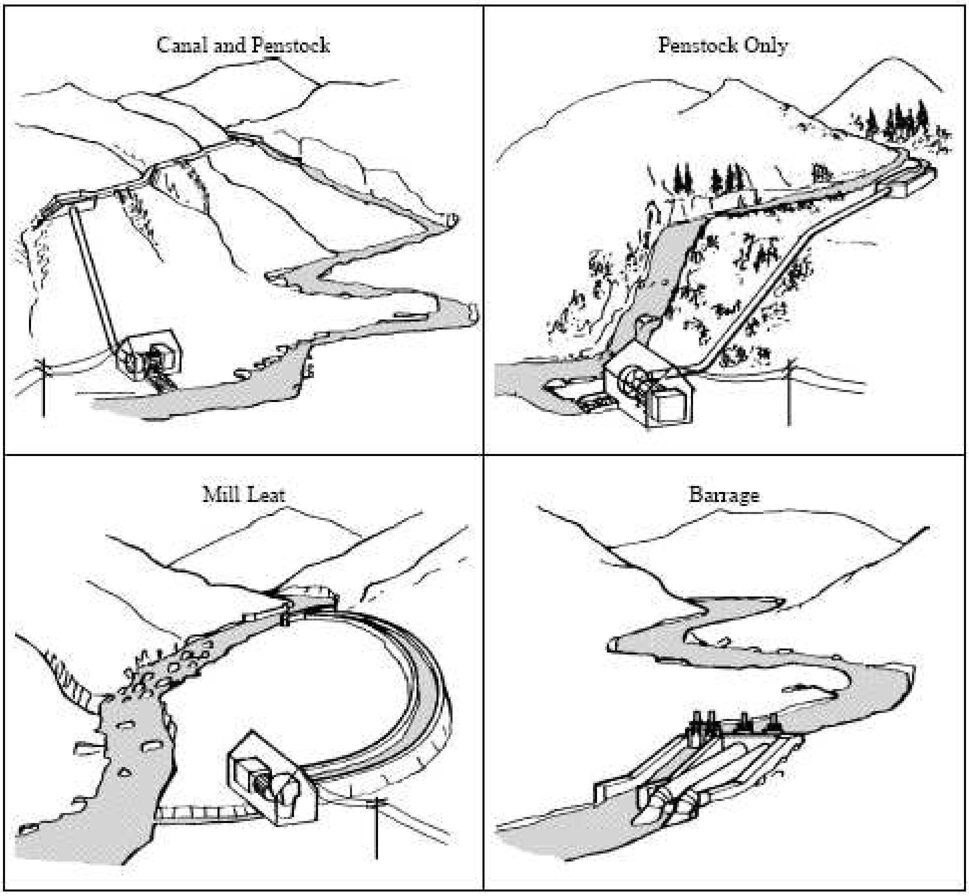


Figure 8 Most common layouts for a mini hydro scheme

1.3.1 Run of river

The first hydro facilities were known as run of river schemes. The schemes do not include any significant water storage, and therefore make use of whatever water is lowing in the river. When streams and rivers have low flow, run of river schemes are unable to generate power. A typical run of river scheme involves either a low level diversion weir (a small dam) or a stream bed intake, and are usually located on swift flowing streams. A low level diversion weir raises the water level in the river sufficiently to enable an intake structure to be located on the side of the river. The intake consists of a trash screen and submerged opening with an intake gate. An alternative arrangement is to have a streambed intake where the water drops through a screened inlet duct that has been installed flush with the bottom of the riverbed. A streambed intake will allow rocks and gravel to enter which means the design must include a screen to flush out the debris in the system. Water from the intake is normally taken through a pipe (penstock) downhill to a power house constructed downstream of the intake and as at low a level as possible to gain the maximum head of the turbine. Figure 9 presents run of river scheme.

Figure 9 Run of river scheme

1.3.2 Dam based

Hydro schemes may also be based on the construction of a large dam to store water and to provide sufficient head for the turbine. These water storage schemes enable the power station to generate at times of peak power demand, and then allow the water level to rise again during off peak time. Schemes with large dams are better suited to larger, gently graded rivers. The advantage of this type of plant is that they have the capability to store the energy (water) and use it when necessary. Figure 10 presents dam based scheme.

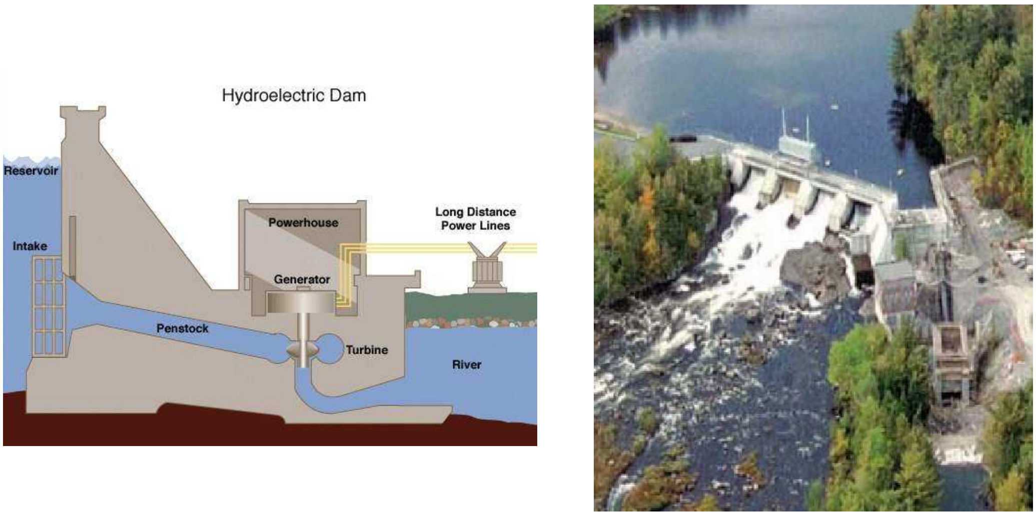


Figure 10 Dam based scheme

1.3.3 Pumped storage

Pumped storage plants utilise a reversible pumping turbine to store hydro energy during off-peak electricity hours by pumping water from a lower reservoir to an upper reservoir. This stored energy is then used to generate electricity during peak hours, when electricity is costly to produce, by distributing water from the upper to the lower reservoir. Figure 11 presents pumped storage scheme.

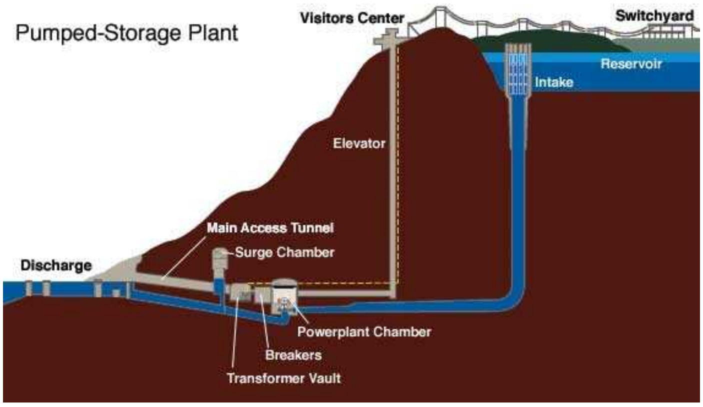


Figure 11 Pumped storage scheme

1.4 Types of turbines

Hydro turbines can be broadly categorized into either impulse or reaction turbines. Impulse turbines convert the kinetic energy of a jet of water in air into movement by striking buckets or blades. By comparison, the blades of a reaction turbine are totally immersed in the flow of water, and the angular as well as linear momentum of water is converted into shaft power. The types of turbines are discussed in more detail. Figure 12 presents turbine types while Figure 13 presents classification of impulse and reaction turbines with regard head.

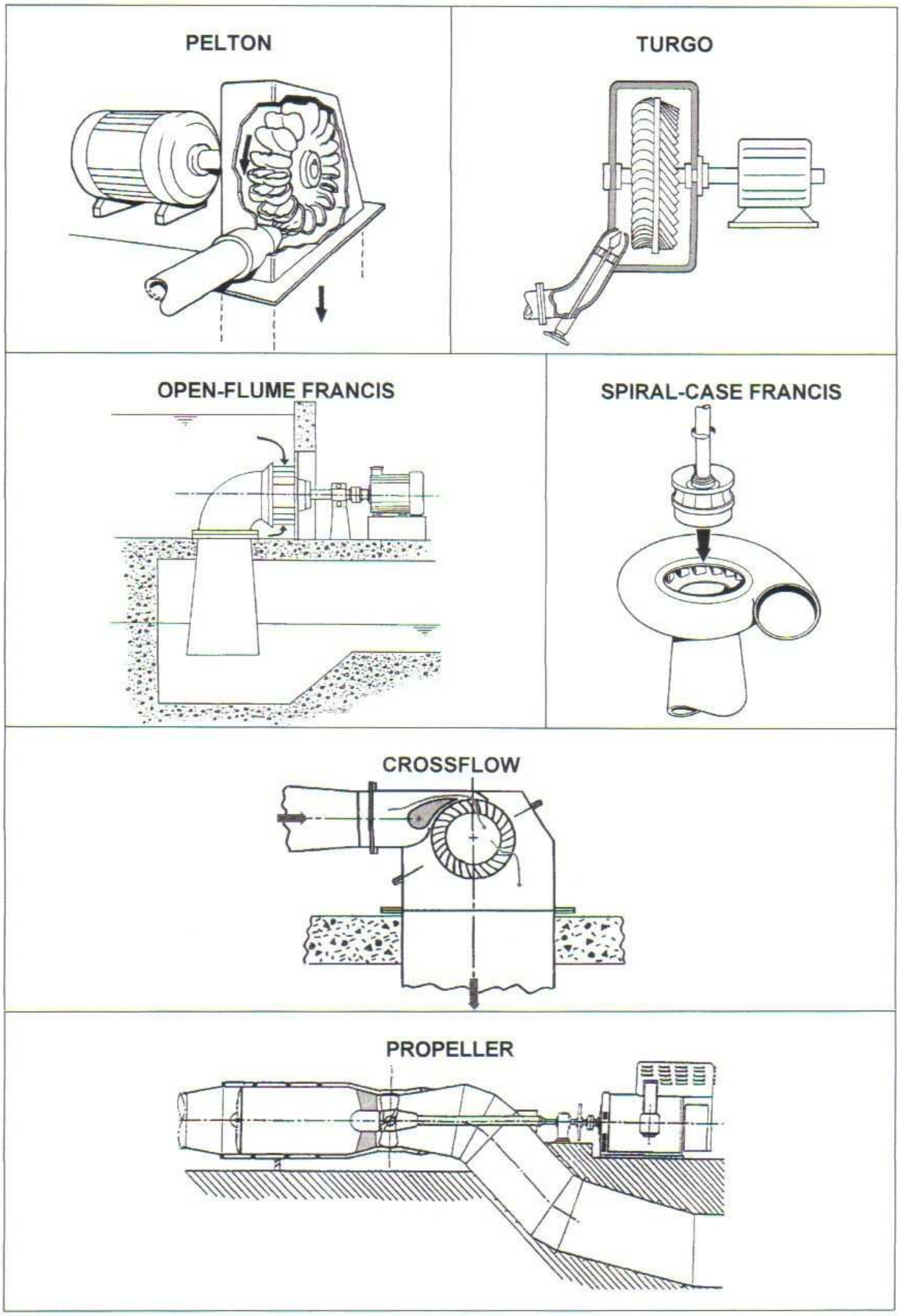
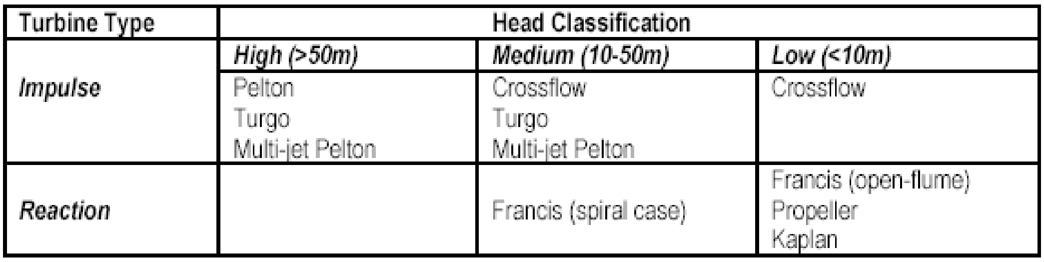


Figure 12 Turbine types



Turbine Type	**Head Classification**		
	High (>50m)	***Medium (10-50m)***	***Low (<10m)***
Impulse	Pelton Turgo Multi-jet Pelton	Crossflow Turgo Multi-jet Pelton	Crossflow
Reaction		Francis (spiral case)	Francis (open-flume) Propeller Kaplan

Figure 13 Classification of impulse and reaction turbines with regard head

1.4.1 Pelton turbines

The Pelton wheel was developed in California during the Gold rush days of the 1850s. The Pelton turbine consists of a set of specially shaped buckets mounted on a periphery of a circular disc. The disc is turned by jets of water, which are discharged from one or more nozzles, striking the buckets, Figure 14. The buckets are split into two halves so that the central area does not act as a dead spot incapable of deflecting water away from the oncoming jet. 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 permits a smoother entrance of the bucket into the jet. The Pelton bucket is designed to deflect the jet through 165 degrees (not 180 degrees which is the maximum angle possible without the return jet interfering with the following bucket for the oncoming jet).

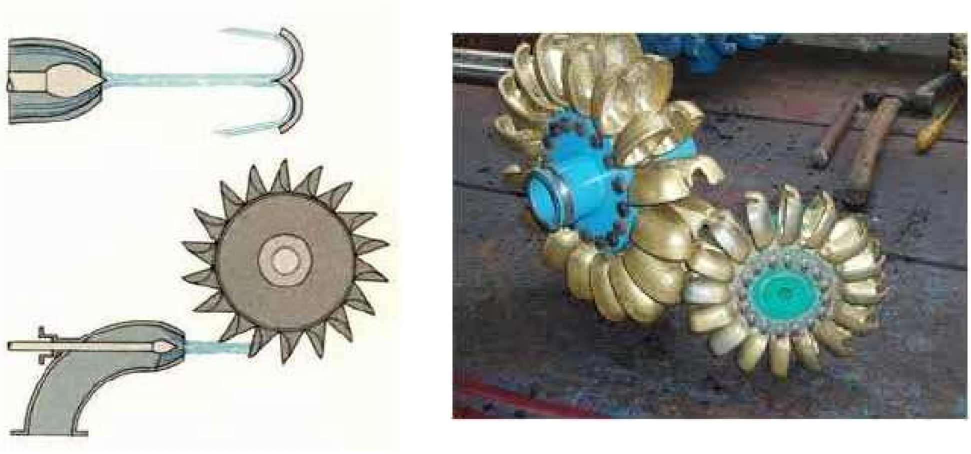


Figure 14 Pelton turbine

In large scale hydro Pelton turbines are normally only considered for heads above 150 m, but for micro-hydro applications Pelton turbines can used effectively at heads down to about 20 m. Pelton turbines are not used at lower heads because their rotational speed becomes very slow and the runner required is very large and unwieldy. This is an efficient process of extracting energy from the flow of water (90%) when there is a very high head available.

1.4.2 Turgo turbines

The Turgo turbine (Figure 15) is similar in design to a Pelton turbine, but was designed to have a higher specific speed. In this case, the jets are aimed to strike the plane of the runner on one side and exit on the other. Therefore the flow rate is not limited by the discharged fluid interfering with the incoming jet (as is the case with Pelton turbines). As a consequence, a Turgo turbine can have a smaller diameter runner than a Pelton for equivalent power. The Turgo is efficient over a wide range of speeds and shares the general characteristics of a Pelton turbine including the fact that it can be mounted either horizontally or vertically. A Turgo runner is more difficult to make than a Pelton and the vanes of the runner are more fragile than Pelton buckets. They require about the same heads as do the Peltons and they sometimes employ multi jets to allow them to accommodate more water flow.

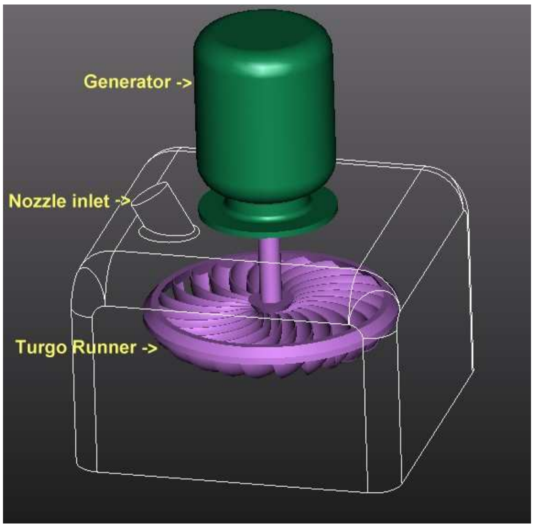


Figure 15 Turgo turbine

1.4.3 Crossflow turbines

A crossflow turbine has a drumshaped runner consisting of two parallel discs connected together near their rims by a series of curved blades. A cross flow turbine always has its runner shaft horizontal (unlike Pelton and Turgo turbines). In operation a rectangular nozzle directs the jet onto the full length of the runner. The water strikes the blades and imparts most of its kinetic energy. It then passes through the runner and strikes the blades again on exit (Figure 16) impacting a smaller amount of energy before leaving the turbine. At low flows, the water can be channelled through either two thirds or one third of the runner, thereby sustaining relatively high turbine efficiency.

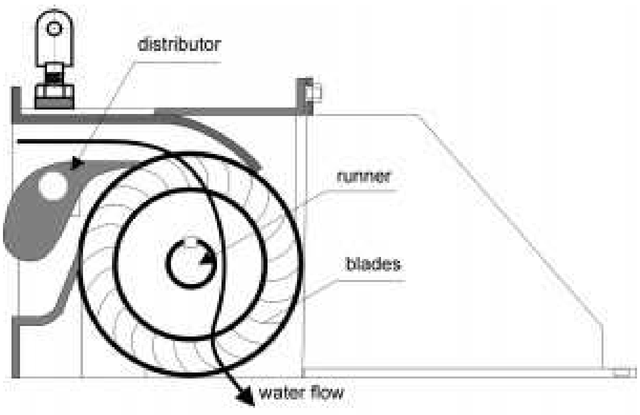


Figure 16 Crossflow turbine

1.4.4 Francis turbines

The Francis turbines (Figure 17) may be divided in two groups; horizontal and vertical shaft. In practice turbines with comparatively small dimensions are arranged with horizontal shaft, while larger turbines have vertical shaft. Francis turbines can either be volute-cased or open-flume machines. The spiral casing is tapered to distribute water uniformly around the entire perimeter of the runner and the guide vanes feed the water into the runner at the correct angle.

Figure 17 Francis turbine

The Francis turbine is generally fitted with adjustable guide vanes. 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. The Francis turbine has the widest range of application among the various types of turbines available. Highly flexible, it comes in a range of different sizes that can operate under heads ranging from around 20 to 500 meters.

1.4.5 *Propeller turbines*

The basic propeller turbine consists of a propeller, similar to a ship's propeller, fitted inside a continuation of the penstock tube (Figure 18). The turbine shaft passes out of the tube at the point where the tube changes direction. The propeller usually has three to six blades or swivel gates just upstream of the propeller. This kind of propeller turbine is known as a fixed blade axial flow turbine because the pitch angle of the rotor blades cannot be changed.

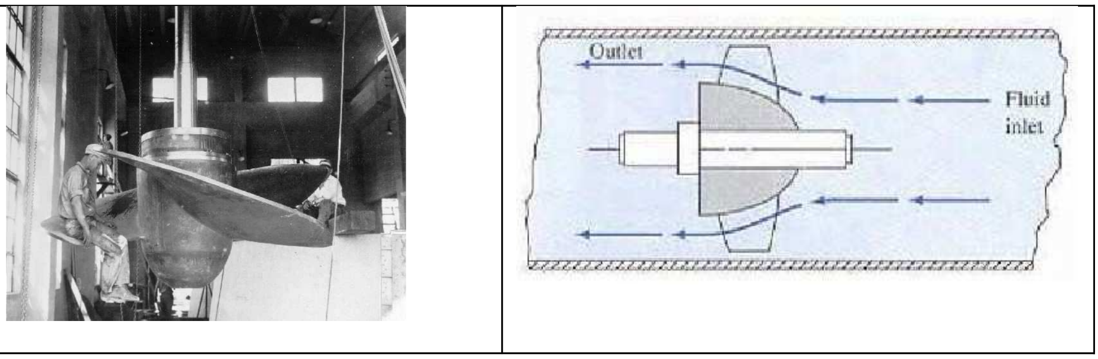


Figure 18 Propeller turbine

1.4.6 *Kaplan turbines*

Large scale hydro sites make use of more sophisticated versions of the propeller turbines. Varying the pitch of the propeller blades together with wicket gate adjustment enables to handle a great variation of flow very efficiently. Such turbines are known as variable pitch or Kaplan turbines (Figure 19). The Kaplan runner is a development of the early 20th century and can only be installed in the vertical orientation, Kaplan turbines have a high specific speed which means that direct coupling to the generator is possible but only at higher heads and lower flows. This means that a speed increase will be necessary on most applications.

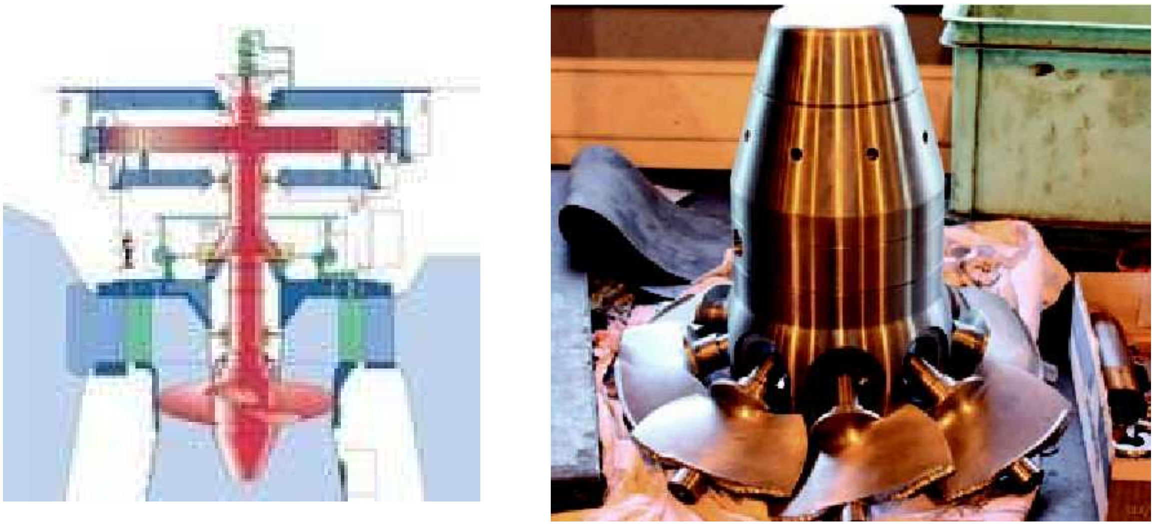


Figure 19 Kaplan turbine

1.4.7 Bulb turbines

Bulb turbines are named after the shape of their upstream watertight enclosures. The generator is accommodated within the enclosure and therefore submerged in the water passage (Figure 20). Suitable for low heads and large discharge/head variations, bulb-units have virtually replaced Kaplan turbines for very low heads sites. This is because the near straight design of the water passage improves the hydraulic characteristics of the flow, giving both size and cost reductions. The bulb turbines have been utilised however, more widely, in tidal power installations such as La Rance in France. For very low heads, generator speeds have to be increased by means of gears.

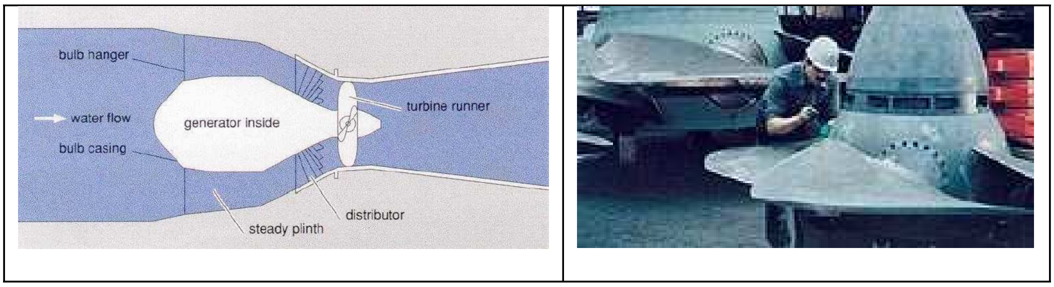


Figure 20 Bulb turbines

1.4.8 Turbine selection chart

The turbine selection chart below (Figure 21) permits the user to select turbines for a given flow rate (m^3/s) and head (m):

- The area within the blue line represents a Kaplan or Bulb turbine;
- The area within the red line represents a Francis turbine;
- The area within the green line represents a Pelton turbine;
- The area within the dark dashed line represents a Turgo turbine;

- The area within the black line represents a crossflow turbine.

Figure 22 presents a similar selection chart for mini hydro power plants.

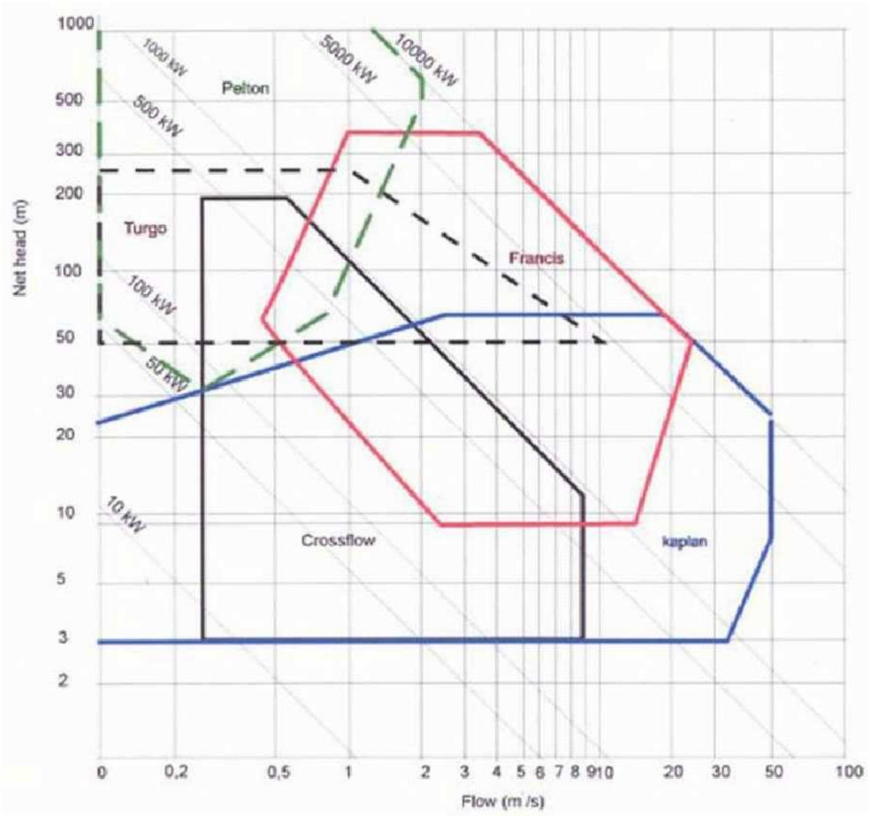


Figure 21 Turbine selection chart

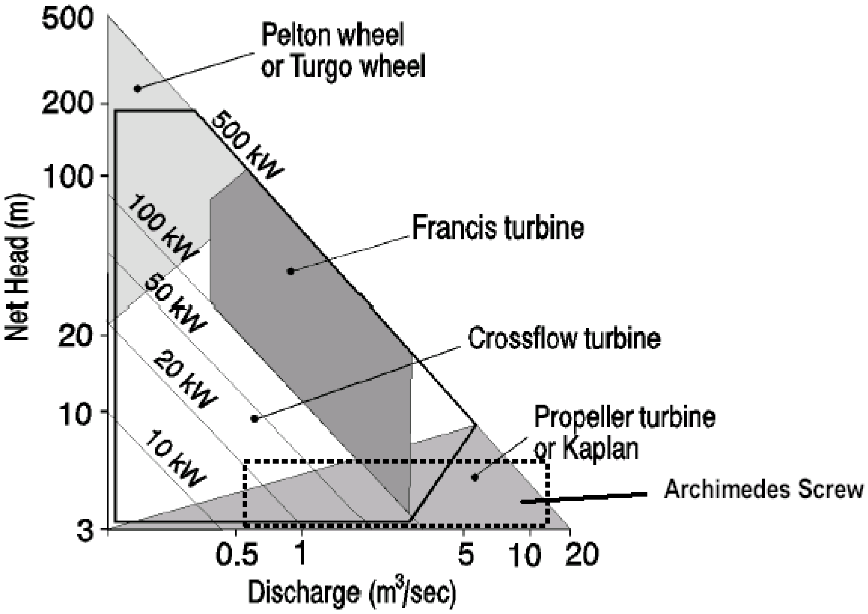


Figure 22 Selection chart for mini hydro power plants

1.4.9 *Turbine efficiency*

A significant factor in the comparison of different turbine types is their relative efficiencies both at their design point and at reduced flows. Typical efficiency curves are shown in Figure 23.

An important point to note is that the Pelton and Kaplan turbines retain very high efficiencies when running below design flow; in contrast the efficiency of the cross-flow and Francis turbines falls away more sharply if run at below half their normal flow. Most fixed-pitch propeller turbines perform poorly except above 80% of full flow.

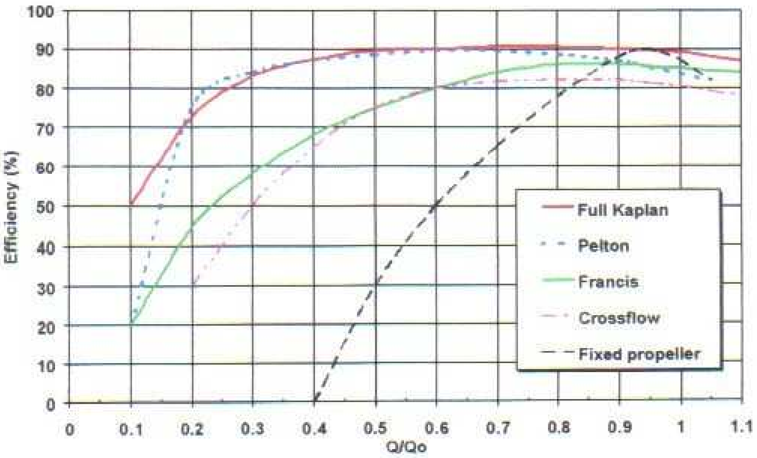


Figure 23 Typical efficiency curves for different turbine types

1.5 Governors

Turbine governors are equipment for rapid control and adjustment of the turbine power output and evening out deviations between power and the grid load. The governor system can be mechanical-hydraulic, electro-hydraulic, or digital hydraulic. The systems, regardless of type have the following three components:

- The controller, which is the unit used for control of the hydro installation;
- The servo system, which is an amplifier that carries out water, admission changes determined by the controller;
- The pressure oil supply system, which is used to supply oil to the servo system.

The turbine governors purpose is to keep the rotational speed of the turbine generator stable at any grid load and water flow in the turbine conduit. During load rejections or emergency stops the turbine water admission must be closed down according to acceptable limits of the rotational speed rise of the unit and the pressure rise in the water conduit.

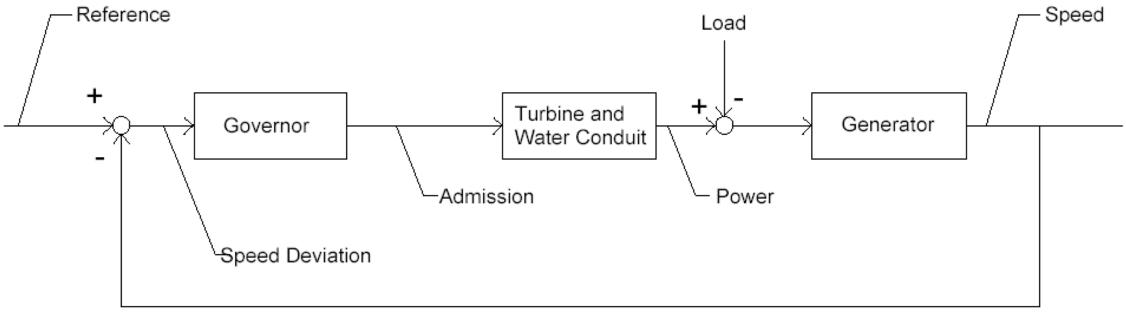


Figure 24 Governor function

Figure 24 shows the function of the governor. The input reference signal compared with the speed feedback signal. With a momentary change in the load a deviation between the generator power output and load occurs. The deviation causes the unit inertia masses either to accelerate or to decelerate. The output of this process is the speed, which is again compared with the reference.

1.6 Hydro-electric generators

1.6.1 Synchronous generators

A synchronous generator can be connected to a small hydro turbine and can operate either connected to the grid or as a stand-alone generator. The generator operates at a speed directly related to the frequency. However, when the small hydro turbine is connected to a synchronous generator, which is directly connected to the electric grid, a speed variation is not possible. If speed variation is not possible, system efficiency is reduced because the generator cannot adapt to a partial load. There are also safety issues with synchronous generators which include; voltage regulation, islanding, and speed and frequency control.

1.6.2 Induction generators

Induction generators rely on a connection to an outside source of power, i.e. the electricity network, to establish and control the rotating magnetic field. This makes this type of generator a safer option than other types of generators for connection to the grid. However, in the absence of grid connection it is possible for induction generators to generate power if it is connected to a sufficient source of capacitance reactance, such as capacitors. In this case very high voltages will be produced, causing a hazard to the equipment.

1.7 Civil works

1.7.1 Dams

Dams are classified according to their profile and building material, which is typically concrete, earth or rock. The civil works for a hydro electric scheme typically accounts for 60% of a plant's initial investment.

1.7.2 Concrete dams

Concrete dams can be divided into solid gravity, hollow gravity, and arch dams. The gravity dam relies on its own weight to resist hydraulic thrust. The hollow gravity dam contains about 35% of the concrete required for a solid dam, but is more expensive per unit volume. The arch dam, is designed for narrow valleys and distributes the hydraulic thrust to its abutments.

1.7.3 Rockfill and earthfill

Rockfill and earthfill dams usually have a core which is covered with loose rock or earthfill. Grass may even be grown on the earth fill. Water will seep in through the earth or rock fill, but should not seep into the core.

1.7.4 Canals and channels

The canal conducts the water from the intake to the forebay tank. The length of the channel depends on local conditions. Most canals and channels are excavated to reduce friction and prevent leakage, channels are often sealed with cement, clay or polythene sheet. The size and shape of a channel are often a compromise between costs and reduced head. As water flows in the channel, it loses energy in the process of sliding past the walls and bed material. The rougher the material, the greater the friction loss and the higher the head drop needed between channel entry and exit.

1.7.5 Settling basin

The water drawn from the river and fed to the turbine will usually carry a suspension of small particles. The sediment will be composed of hard abrasive particles such as sand which can cause damage and rapid wear to turbine runners. To remove this material the water flow must be slowed down in settling basins so that the silt particles will settle on the basin floor. The deposit formed is then periodically flushed away.

1.7.6 Forebay tank

The forebay tank forms the connection between the channel and the penstock. The main purpose is to allow the last particles to settle down before the water enters the penstock. Depending on its size it can also serve as a reservoir to store water. A sluice will make it possible to close the entrance to the penstock. In front of the penstock a trashrack is normally installed to prevent large particles entering the penstock.

1.7.7 Penstock

The penstock is the pipe which conveys water under pressure from the forebay tank to the turbine. The penstock often constitutes a major expense in the total micro-hydro budget, as much as 40% is not uncommon in high head installations, and it is therefore worthwhile optimising the design. The trade-off is between head loss and capital cost. Head loss due to friction in the pipe decrease dramatically with increasing pipe diameter. Conversely, pipe costs increase steeply with diameter. Therefore a compromise between cost and performance is required.

1.8 Prefeasibility (reconnaissance) study

1.8.1 Generally

The execution of a feasibility study can be a significant investment in time and resources suggesting that a decision to proceed with a study should be based on a finding that a potentially viable project proposal will be forthcoming. The reconnaissance (prefeasibility) study is designed to reduce the potential chance of a subsequent unfavorable feasibility finding and maximize the potential for identifying and moving forward the attractive projects. The prefeasibility study is a relatively complete small scale feasibility study in which the issues expected to be important at the feasibility stage are raised. The finding of a prefeasibility study should be either a positive recommendation to proceed with a feasibility study which would include a study plan and method of accomplishment, or a recommendation to terminate further investigations.

1.8.1.1 Project formulation

The strategy for performing a prefeasibility study is first to perform a preliminary economic analysis and than identify and assess the issues that may be critical to implementation. The formulation of project features and determination of costs was determined to be a critical and major task. The recommended project formulation strategy is to select several installed capacities, say at 15%, 25% and 35% flow exceedance values, and carry these through the preliminary economic analysis. The procedures developed for performing the cost estimates for construction, site acquisition, operation and maintenance, and engineering and administration for the feasibility study were judged to be too detailed for a reconnaissance (prefeasibility) study. To facilitate reconnaissance estimates, the information for the feasibility analysis was consolidated into one chart and table. Figure 5 and Figure 6 provides a basis for estimating the major share of construction costs for items that are governed by capacity and head, e.g., turbine and generator, powerhouse, and supporting electrical/mechanical equipment. The figure was developed by studying the generator and powerhouse costs for variety of turbine types for a complete set of head/capacity values. Reconnaissance costs factors for penstock, tailrace, switchyard equipment, and transmission line is possible determine from literature. The user is cautioned that the least cost criteria governed so that site issues of space and configuration, and generation issues of performance ranges were not considered. The data, however, should be adequate for reconnaissance estimates. An additional allowance of up to 20% should be added to the cost determined to cover investment items that are not incorporated in the chart and table such as land acquisitions, access roads, and special control equipment.

Since reconnaissance cost estimates are also needed for the nonphysical works cost items, an allowance for unforeseen contingencies ranging from 10% to 20% be added to the sum of the construction cost, the value depending upon a judgement as to the uncertainties. Indirect costs of 25% are recommended to be added for investigation, management, engineering, and administration costs that are needed to implement the project and continue its service. Operation and maintenance costs can vary considerably depending on present staff resources of the project proponent, the site proximity to other sites, and the intended degree of on-site operation requirements. An annual value of 1.5% of total costs is suggested as a base value; however, the value used should not be less than a base value, and may range upwards of 4% if the project proponents can not efficiently integrate the plant into their work program.

1.8.1.2 Power values

The determination of value of power is an very important item. The power value needed is the value that the project proponent could reasonably expect to receive for the sale of the generated energy and that of the dependable capacity, if any exists.

1.8.1.3 Economic feasibility

Economic feasibility is positive when the benefits exceeds the costs. The text encourages adoption of the Internal Rate of Return method of characterizing project feasibility. The Internal Rate of Return is discount rate at which the benefits and costs are equal, e.g., the discount rate at which the benefit to cost ratio is unity. Use of the method avoids the need at the reconnaissance stage to adopt a discount rate and also provides an array of economic feasibility results. To perform the analysis several discount rates are selected and the total investment cost in annualized for each rate and added to the annual operation and maintenance cost to obtain the total annual cost. The benefit is computed on an annual basis by multiplying the yearly generation by the value of energy. A benefit to cost ratio is determined for each total annualized cost which is than plotted relative to its respective discount rate. A curve is drawn connecting the plotted points and the Internal Rate of Return is the discount rate where the curve intersects the line representing a benefit to cost ratio of unity (see example).

1.8.2 Specificity of mini hydro power project

The activities required during prefeasibility (reconnaissance) study of mini hydro power project proposed by Hydro Tasmania are given in the flowchart presented on Figure 25.

1.8.2.1 Review of Existing Documentation & Data Collection

As a first step to understanding the issues associated with developing hydropower, a review of relevant documentation is required to be undertaken. To be able to perform a desktop study of the hydropower development all relevant existing information relating to the scheme must be obtained, in particular, hydrological data, topographic data and geological data. Assessing the available water resource is a key part of the project, and the certainty of the energy production potential and price estimates relies on its accuracy.

Hydrological Data Review Measured hydrological flow data or stream gauging information located on the catchment in question should be utilised. The most accurate data would include the finest time series and the longest period of data. A minimum of 1 years daily flow data is required to make a preliminary assessment. Where no measuring site exists or hydrological data is limited, flow and rainfall information data for an adjacent (or similar) catchment maybe used, and adjusted for catchment area and average rainfall level. Given the similar nature of the topography, mean annual rainfall and catchment areas it would be expected that the flow duration curves for these catchments would be similar. This provides some uncertainty in the results, but will be sufficiently accurate for the purpose of a prefeasibility assessment. It is advisable to follow this up with site measurement once the project looks likely to be feasible.

Topographic Data Review In the absence of detailed information, topographic maps should be used for contour information and to determine catchment areas and land use. Contour information or aerial photographic maps with reasonable accuracy (1:25,000) should be obtained for determining levels and distances. Levels or spot height information will need to be verified by a detailed survey at the feasibility stage.

Geological Data Review An assessment of the regional geology by means of geological maps and review of existing reports should be made to assess the potential location and scheme arrangement. In particular consideration should be given to ground conditions, landslides, regional seismic activity and river sedimentation loads. These features may directly influence the design of penstocks and tunnels; the design of the intake structure to be able to cope with high sediment loads or the height of weirs associated with intake structures.

1.8.2.2 Preliminary demanda assessment

It is important to determine the ability of the generated electricity to be used within the region or the need to supply nearby loads (e.g. communities, industry) as this will influence the feasibility of the scheme. Assessment of historical and present electrical demand should be made based on the best available information. This will allow a typical load profile to be determined, which will show energy supplied and the historical trending, system losses and any variance with the expected system losses. Consideration of future maximum demand forecasts should be made by understanding if any firm plans exist to increase loads. (e.g. best knowledge of industrial and commercial developments).

1.8.2.3 Evaluate suitability of hydropower Vs alternative

It may be necessary to consider alternative energy generation compared to hydropower to determine the most economically and technically viable scheme. By assessing alternative options at a pre-feasibility level, a well-rounded opinion of the power generation available can be made. The energy generation options should be ranked by a project screening exercise, and selection criteria developed to determine the commissioning of a feasibility study. Capacity, demand estimation, community suitability and cost performance issues should be used for the optimisation and selection.

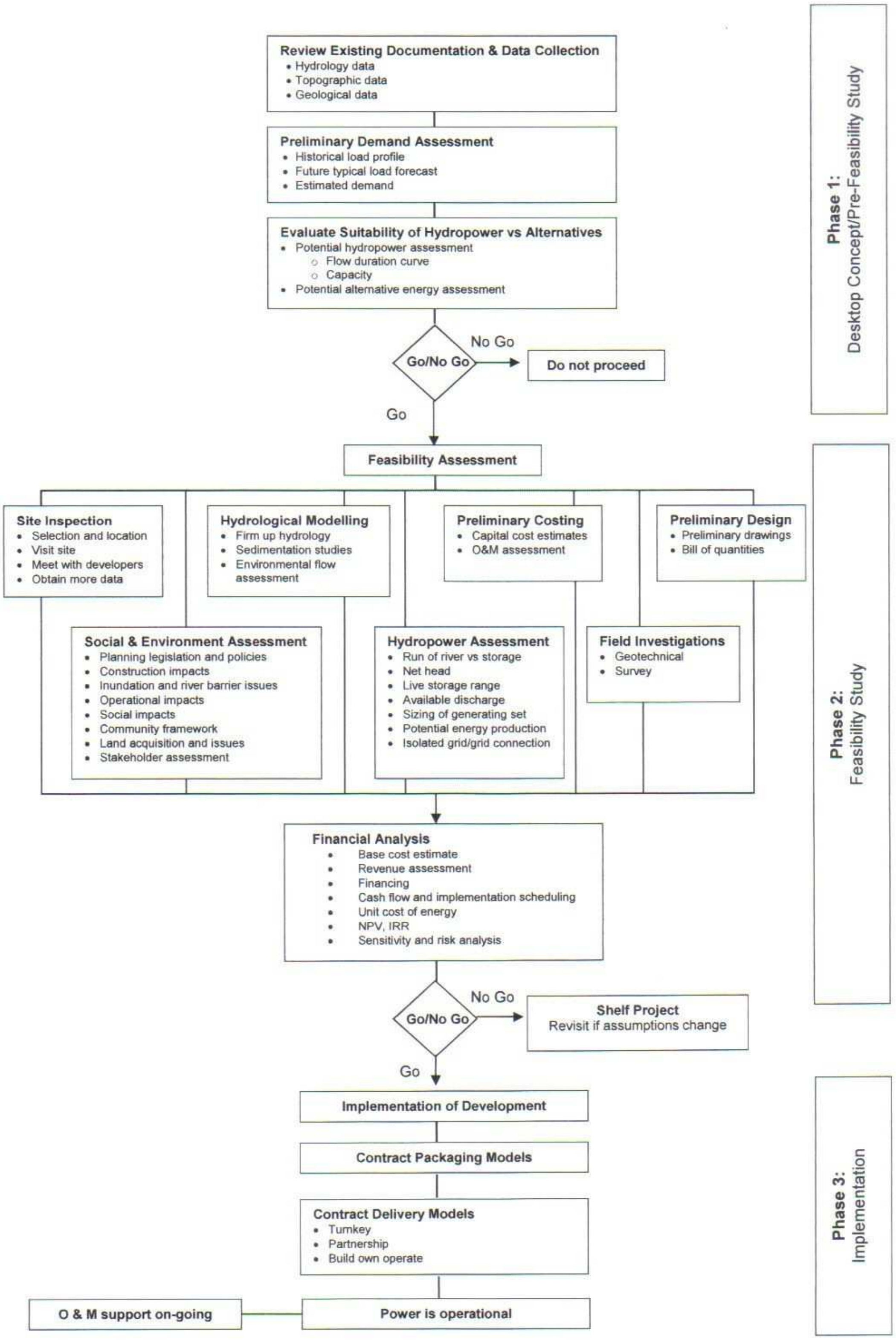


Figure 25 Assessment methodology for mini hydro power plants

1.9 Feasibility study

1.9.1 Generaly

The feasibility study is designed to formulate a viable small hydro project, develop an implementation strategy, and provide the basis for an implementation commitment. The addition of small hydropower generation to an existing facility is, with few exceptions, a single purpose project planning task. The significant legal, institutional, engineering, environmental, marketing, economic and financial aspects are to be identified, investigated, and definitively assessed in support of an investment decision. The objective is to formulate a power addition project that is economically attractive and consistent with modern concepts of resource planning and management. The findings of a feasibility study should be whether or not a commitment to implementation is warranted, and should the finding be positive, define the steps needed to assure implementation.

The selection of the installed capacity, the number of units, and the supporting ancillary physical works are the specific objective of project formulation. The target of small hydro project formulation is to develop one or more proposals that have the greatest economic value consistant with the array of constraints that modify the attractiveness of a purely economic formulation. Two issues were singled out for expanded discussion in the feasibility study section of the manual. They were refinement of alternatives and development of costs for both the economic and financial analysis.

1.9.1.1 Refinement of alternatives

The significant interacting factors in the formulation of a small hydro project are the nature of flow/head availability, the performance characteristics of the turbine equipment, and the powerhouse structure needed to accommodate the specific generating equipment. The amount of energy that can be generated is dependent upon the range of flow that can be passed through the turbine and upon the head variation. The range of flow that can be utilized is therefore a function of the installed capacity, type of turbine (operating range and efficiency characteristics), and number of units. Each of these variables affects the size and shape of the powerhouse.

A project formulation strategy that progresses through three progressive stages of feature sizing and selection is suggested. The first stage, essentially performance of a reconnaissance formulation is discussed previously, yields a preliminary estimate of the project installed capacity. The second stage incorporates machine performance characteristics in the formulation of several refined alternatives and yields a selection of the number and type of turbine units that thus consider site conditions and tradeoffs between unit performance and energy generated. The final stage concludes the project formulation by examining the performance of the more promising one or more alternatives in a sequential power routing analysis.

Hydrologic parameters play an important part in refinement of alternatives. Initially and during the first stage, and perhaps the second, flow-duration techniques are judged to be generally adequate. Duration curve analysis requires the use of a single value (weighted) for head and a single value (average) for efficiency. Refinement occurs with the use of a continuous record of stream flow and performance of sequential power routings. This procedure assures that important sequential issues of varying upstream and downstream water levels, machine performance, and flow passage by the site are properly incorporated in the analysis. The more complete simulation will trace the turbine performance and may result in slightly higher or lower power and energy output estimates. The array of refined project formulations are then subjected to full feasibility analysis.

1.9.1.2 Economic analysis cost consideration

In the manual, economic and financial analysis have been carefully defined as having distinctly different purposes, and consequently, distinctly different (although very much similar) cost data. Economic feasibility analysis compares economic costs with project economic benefits while financial feasibility analysis develops the specific cash flow and assesses financing and repayment issues. The economic comparison is properly made using a common value base, (e.g., dollar values as of the study year). Government policies have generally resulted in fixing price levels for valuing future costs and benefits in value terms as of the study date as well and the time frame commonly used for cost/benefit analysis begins the first year of project operation and extends through the project economic life. The alternative convention often adopted in the private sector is to state all project costs and benefits in dollar values as of the initial year of operation. Since small hydro project are expected to be implemented in short time frames, the time and year statement of dollar values should not be critical.

The inclusion of cost and value changes in economic feasibility analysis must be handled with care. In principle, a price level change economic analysis should forecast the change in value for all aspects of the feasibility assessment, both the cost side and its several components. The cost and benefit streams are then constructed from these forecasts and the feasibility assessment performed. The usual result of including cost and value escalation in project as small hydro (large initial cost followed by small O&M, and long stream of project benefits) is to make them appear more economically attractive, e.g., benefits grow with time while costs increase slightly based on O&M. The impetus for including value changes is the conviction that benefits will continue to rise knowing that some benefit elements are increasing more rapidly than the general inflation rate, e.g., fossil fuel costs. The argument is that ignoring these value shifts leads to incorrect decisions, (e.g., the project may appear infeasible when it should be found to be feasible) even though theoretically, inclusion of general price rise (inflation, not differential cost escalation) does not affect the feasibility determination.

The argument against including price level change and/or general cost escalation in economic feasibility analysis is that change in price forecasting is fraught with pitfalls that are both institutionally and technologically dependent. The resulting analysis thus often becomes suspect and a candidate for subjective manipulation, i.e., a means of justifying projects. If cost and value change analysis are adopted for the economic analysis, considerable care should be taken to rigorously observe the basic principles and to document the critical value change forecast.

1.9.1.3 Financial analysis cost considerations

Financial feasibility analysis develops, among other data, the specific cash flow characteristics (dollars in and out of the accounts) of the project. The need is to forecast the amount and timing of cash outflow and revenue income as accurately as possible. The cash flow analysis is usually constructed for the project implementation period, the first year of operation often being critical to project cash reserves. To perform the analysis, the construction costs are indexed to the actual date of contract award; interest during construction is added along with recurring costs (operations and maintenance) escalated based on increased costs to service again equipment and on anticipated general cost inflation; and the revenue stream is adjusted based on anticipated power sale contract provisions for payment of project power. If there were no cost inflation, no borrowing required, and if project revenues captured all project benefits exactly, the economic cost and benefit streams and the financial cost and revenue cash flow streams would be identical.

1.9.2 Specificity of mini hydro power project

The activities required during feasibility study of mini hydro power project proposed by Hydro Tasmania are given in the flowchart presented on Figure 25.

A feasibility study assesses in detail the technical and economic viability of a small hydropower development, and allows the client to determine whether to proceed with the implementation of the scheme. The approach to this phase should include confirmation of data to be accurate and a detailed assessment and optimisation of the costings. The essential components of a feasibility study are the next.

1.9.2.1 Site inspection

A site inspection should be carried out by a hydropower engineer for familiarisation of the environment and determination of any major impediments to the implementation of the scheme. The engineer should meet with client and operational representatives to obtain the best knowledge available and identify further data input requirements.

An assessment of the following should be made while visiting site:

- Existence of a suitable energy resource. i.e. consistent flow of water at a usable head;
- Existing infrastructure and condition, including operational considerations;
- Potential intake and powerhouse location;
- Potential access road routes and suitable construction and equipment installation;
- A nearby demand for electricity, or the prospect of a grid connection at reasonable cost;
- The social and environmental impact/benefits on the local area;
- Land ownership and/or the prospect of land acquisition or lease;

1.9.2.2 Hydrological modelling

Confirmation of accurate hydrology and detailed modelling should be made to confirm the flow duration curve. Long-term records of flow data and rainfall, together with an estimation of the compensation/environmental flow (if required) should be assessed. Assessment of seasonal variation and peak and off-peak demands need to be considered. A firm capacity of the scheme should be determined, based upon the 90th percentile flow. The hydrological modelling may need to consider sedimentation studies, especially concentration rates to assist with the design of the intake arrangement and location.

1.9.2.3 Field investigations

Dependent on the topographic data obtained in the prefeasibility study, it may be necessary to conduct a topographic survey to confirm the net head of the scheme. Survey of the potential location of the intake structure and powerhouse should be conducted, with spot heights recorded. This is particular important for low head schemes when a reasonable amount of confidence is required for the level of accuracy of the net head. Geotechnical boreholes will be required to finalize the location of the intake structure, powerhouse and associated infrastructure and to allow input into the final design drawings.

1.9.2.4 Hydropower assessment

Since the flow and head data has now been confirmed the potential annual energy generation can be properly assessed. Firstly the turbine and generator will need to be carefully selected and sized based upon the suitability of the flow and head range. Optimisation of the operating range of the turbine will need to be made, including the capacity factor of the scheme. There is clearly a balance to be stuck between choosing a larger, more expensive turbine which takes a high flow but operates at a low capacity factor, and selecting a smaller turbine which will generate less energy over the year, but will be utilised more of the time. i.e higher capacity factor. The capacity factor for most small hydro schemes would normally fall within the range of 50% to 70% in order to provide a satisfactory return on investment. Most turbines can operate over a range of flows (typically 30-40% of their rated flow) in order to increase their energy capture and sustain a reduced output during the drier months. The electricity generated by a scheme may be used at the point of generation or it may be exported via the distribution network.

The hydropower assessment must define the average annual energy output (river flows, hydraulic losses, operating head, turbine efficiencies and methods of calculations) (MWh/year) and the output of the scheme in terms of maximum potential power output (MW).

1.9.2.5 Social and environmental

There are a number of environmental and social considerations that need to be investigated as part of the feasibility study. It will include reviews and assessments of likely environmental impacts, broadly considering factors such as:

- Assessment of any planning legislation and policies for the area;
- Requirements for clearing native vegetation;
- Impacts on stream flow and fish migration;
- Inundation or river barrier issues:
  - Threatened terrestrial species in inundation zone,
  - Fish migration barriers – migratory species can be an issue if they are regarded as a threatened species, or locally important food source,
  - Operational impacts,
  - Community water supply,
  - Aquatic ecology health – environmental flows,
  - Hydropeaking issues – community safety, erosion potential,
  - Flood warning (gate operation if relevant, etc.),
  - Water quality in the reservoir,
  - Sedimentation of the reservoir and downstream;
- Construction impacts:
  - Traffic – road safety, noise, fuel spills,
  - Site runoff issues – siltation, construction noise, water quality,
  - Chemical/fuel spills,
  - Materials sourcing,
  - Water diversion issues;
- Social Impacts:
  - Potential for resettlement and relocation (to be avoided where possible),
  - Inundation of arable land,
  - Public safety,
  - Inundation of sacred sites/areas of cultural or historical value,
  - Stakeholder management.

Land issues and land compensation can be a major issue and will need to be carefully considered during the study and could be a deciding factor in a recommendation.

1.9.2.6 Preliminary design

The design of the scheme should be completed at a level adequate for costing and a bill of quantities to be determined. Hence, the design should be adequate for tendering purposes, and would include general arrangement and layout drawings.

Prominent aspects of the works can be categorised into:

- Civil works (intake and weir, intake channel, penstock, powerhouse, tailrace channel, site access, construction details);
- Generating equipment (turbine, generator, control system);
- Network connection design to allow assessment of the local power distribution and the community demand requirements.

Optimisation and design of the civil components (intake weir sizing; penstock sizing and lining; minimising access routes and penstock lengths) will need to be finalised. In any small hydro scheme, the electrical and mechanical components (ie. turbine, generator, control systems) determine the physical arrangement of the powerhouse. The floor levels, roof clearance, building footprint, substructure arrangement, pipework alignment and discharge arrangement are all dependent on the specific characteristics of the selected equipment. If possible, the designers will therefore need to work closely with the machinery suppliers, so that specific equipment parameters can be considered as the basis of the design.

1.9.2.7 Costing

The costing of the scheme should include the costs to implement the project and the operation and maintenance costs to allow its on-going operation. The capital cost estimate must be determined from drawings and a bill of quantities as determined during the design phase. It should be at an accuracy in the order of ±10%. Key capital cost items can be subdivided into:

- Cost of civil works;
- Cost of hydro-mechanical and electro-mechanical equipment;
- Cost of grid connection;
- Engineering and project management costs.

<u>*Capital Costs*</u> However, installed costs are only part of the overall life cycle costs, and the generating profile (i.e. what proportion of time the turbine will operate for at full output and when) as well as the ongoing maintenance, communications and electrical connections costs are core to the economics of small hydro projects.

The civil costs may include the intake, forebay tank and screen, the penstock or channel to carry the water to the turbine, the powerhouse and machinery foundations, the tailrace channel to return the water to the river, and access roads. The civil works are largely site specific. On high head site the major cost will be the penstock, on low head sites probably the water intake, screens and channel. The cost of penstocks or tunnels has a significant impact on the overall cost of the scheme. Therefore penstock and tunnel lengths should be kept as short as possible. The size of the powerhouse is generally proportional to the machine diameter, which is related to the square root of the flow volume.

Generally speaking, *machinery costs* for high head schemes are lower than for low head schemes of similar power. High head machines have to pass less water than low head machines for the same power output and are therefore smaller. They also run faster and thus can be connected directly to the generator without the complication of gearbox or belts.

The electrical system will involve the control panel and system, the wiring within the powerhouse, and a transformer if required, plus the cost of connection to the electricity. These costs are largely dependent on the maximum power output of the installation. The connection cost is set by the local electrical distribution company. A contingency of 20% of the construction cost was included in the final capital estimates for each project.

Engineering and Project Management Costs These costs encompass the engineering services to design and manage the installation, plus supervision costs for the project. This is likely to equate to approximate 10 to 15% of the total capital amount. Land acquisition costs must be considered and should be provided by the client where possible.

Operation & Maintenance Costs Operation and maintenance costs for small hydro turbines are low. Generally, in developed countries, the stations are unmanned and automatically controlled by water levels or from a central control room. Routine inspections are then required on a regular basis, and generally in conjunction with other routine inspections. Generally, operation and maintenance costs for a scheme may be up to 2% of the project capital cost.

1.9.2.8 Financial Assessment

A financial analysis will allow the economic viability of the project to be assessed. The analysis must consider the following parameters as part of its economic modelling:

- Base cost estimate;
- Revenue assessment – the value of energy based upon market analysis or
- demand capability. Include seasonal variation and peak/off-peak pricing;
- Financing strategy;
- Cash flow analysis and implementation schedule;
- Economic life – typically 40 years used.

The economic viability should be presented by means of the unit cost of energy (EURO/kWh), net present value and the internal rate of return. It is therefore likely that the client will have their own hurdle rate in which the project must provide a minimum return for it to be considered eligible for implementation. A sensitivity and risk analysis should be performed to test against the base case for various changes in capital cost, revenue price and annual energy production. The risk assessment should consider the project holistically including construction and operational considerations.

1.9.2.9 Criteria for decision

The feasibility study allows a detailed assessment of the technical and commercial viability of a scheme to be made. However the decision whether to implement the scheme will be up to the owner, especially if the scheme is economically marginal. The owner must fully understand their project and business drivers, as the decision to implement may consider intangible benefits.

An appropriate criterion for selection should consider:

- The scheme would need to be technically feasible, but of simple arrangement with appropriate risk mitigation and containment in place;
- Easy to implement;
- Robust;
- Cost effective/cheap;
- Environmentally and socially sound and sustainable.

1.10 Time, cost and resources for prefeasibility (reconnaissance) and feasibility studies

The time, costs and human resources required to perform prefeasibility (reconnaissance) and feasibility studies for small hydroelectric power plant additions varies depending on expected plant size, site conditions, specific scope and depth of study, and availability of information (basic data and prior studies). Analysis of The American Society of Civil Engineers guidelines in light of recent feasibility study experience suggest that feasibility study cost, noting the fairly specialized nature of several of the issues important to small hydro, should range from 1.5% to 3% of estimated construction cost. Prefeasibility studies, estimated as 10% of feasibility study costs, would therefore range from 0.15% to 0.3% of estimated construction costs. A prefeasibility study for a 1 MW plant might cost approximately about 10-15 man-days. Using 2.5% as conservative estimate for feasibility study costs, for a 1 MW plant might cost approximately about 80 to 110 man-days. The time required to perform the feasibility study could range from 60 days for the small, relatively simple power addition to upwards of 6 to 9 months for larger more complex projects.

The participating professionals for a feasibility study include civil, electrical and mechanical engineers, power economists and especially for private proponent projects, the services of financial specialists. Projects that significantly alter the flow regime or physical environment will likely need the services of water quality and fish and wild life specialists. The participating professionals for a reconnaissance study would likely include civil, mechanical and electrical engineer, and power economist for larger proposed projects. Reconnaissance investigations of smaller projects may require more versatility in fewer professional such as, experienced engineer and economist.

1.11 Implementation of development

The activities required during implementation of development of mini hydro power project proposed by Hydro Tasmania are given in the flowchart presented on Figure 25.

Small hydropower development is of relatively complex nature that requires careful consideration of the implementation process to ensure the development risk is effectively managed. The plant may be embedded within local communities, which will require appropriate operational considerations and constraints. Small hydro can often expose owners and developers to risks that far exceed the project’s direct commercial indices due to the scale of the projects and their interaction with existing water assets, electricity networks and control systems. While some schemes incorporate a degree of classic design, most are born out of reinvested experience in the design and construction of similar schemes. Often the adoption of arrangements to make use of existing structures and the careful consideration of operational flexibilities within the owner's constraints can make the difference to commercial and technical viability.

There are a number of development options, by means of contract packaging and delivery models which can be adopted for the implementation of small hydropower. Each model has its own level of risk and reward, which requires the developer to carefully consider the cost risk benefit of the development. Design and construction risks must therefore for carefully managed to ensure risks are understood and fully considered during construction and long-term operation.

1.11.1 Contract packaging models

The contract and commercial packaging for small hydro developments can be considered in a number of ways. Given the need to manage the commercial conditions and the implementation timeframes, it is important that the construction activities and procurement lead-times of equipment are fully understood. Typically the critical path items are the procurement of the turbine and generator.

The contract can be packaged into a number of broad categories, such as:

- Civil package;
- Civil and hydromechanical package;
- Electrical and mechanical package;
- Grid connection package.

The interface or separation points need to be clearly defined to ensure appropriate delivery of design and construction. The open tender process can involve extensive up-front engineering design and specification works to allow all tenderer's to compete on an equal basis, for a defined arrangement and scope of work. Innovation in design would be offered through an alternative or nonconforming tender, and in many cases this would prove successful in reducing the contract cost to allow the project to remain economically viable. Pre-tender consultancies can cost in the order of 10-20% of the value of the contract works for the smaller schemes, and while necessary to determine the feasibility of the scheme, may add limited value to the tender process in achieving the most economical arrangement.

Often, the most economical schemes will be one where the supplier nominates their preferred equipment and standards, and client requirements are then negotiated in. The supplier is in the best position to know the level and standard of equipment required to perform the task, and often tender specifications will only add to the expense of the equipment by specifying standards that may not be warranted by the size of the installation. Some level of specification is always required to define what will finally be delivered, performance criteria and standard of workmanship.

A more streamlined process for the procurement would be to obtain direct quotations from reputable machine suppliers. Usually a maximum of three quotations would be sought, in order to select the most suitable equipment supplier for the works, and that the intention of the design criteria is met. This would also include an interview process of the preferred supplier. Final tender pricing will be prepared based on the final design and outputs, including machine selection and pricing.

1.11.2 Contract delivery models

Since any hydro scheme requires a substantial upfront investment, it is clearly essential that the project is implemented correctly and with robust engineering and equipment. Generally, the delivery models for the implementation can be categorised into:

- Turnkey (engineer, procure, construct);
- Partnership (joint venture/alliance);
- Build own operate.

Turnkey The most common approach for implementing small hydro projects is the turnkey contract in which a single contractor takes the entire scheme from design to construction, which allows simplification of the management of the project. The contractor, who might be a civil engineering company or the turbine supplier, brings together a team of subcontractors and suppliers under a single contract, typically following a competitive tendering process. Since the main contractor takes the full risk, they have the opportunity to maximise the benefits and revenues.

Partnership Typically the owner enters into a partnership (alliance) arrangement with another developer and the two parties combine their capabilities to best suit the project. This model ensures that the project is delivered with shared risk and shared benefit.

Build own operate Under this model the owner sells all rights to the project, and a developer pays for the rights and usually pays an annual royalty for its ownership. Hence, the developer takes the responsibility of the full risk and benefits, in which the owner minimises their risk and benefit.

1.12 Literature

At writing of this chapter the next references were used:

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