Journal of Engineering and Applied Sciences 4 (5-6): 324-334, 2009
ISSN: 1816-949X

Technical Feasibility of a Micro Hydro Installation

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Abstract: The purpose of this study is to analyze the technical feasibility of a micro hydro installation and the principles of extracting electricity from a water source and the types of hydroelectric schemes used. This continued with the investigation into an understanding of the technology and the components required completing a hydroelectric system, these included the various types of turbine, mechanical plant and civil works. By performing this literature review, it was made clear what information and components would be required and how the overall performance could be calculated.

Key words: Analyze, technical, feasibility, hydroelectric, scheme, turbine

INTRODUCTION

Hydropower is derived from the potential energy available from water due to the height difference between its storage level and the tail water to which it is discharged. Power is generated by mechanical conversion of the energy into electricity through a turbine, at a usually high efficiency rate. Depending on the volume of water discharged and height of fall (or head), hydropower can be large or small (Manohar and Adeyanju, 2009).

The conversion of kinetic energy into mechanical energy is not a new idea. As far back as 2000 years ago, wooden waterwheels were used to convert kinetic energy into mechanical energy. The Egyptians and the Persians pioneered the waterwheel for the irrigation of the Nile and Euphrates Valleys, so water power may well have contributed to the evolution of the Fertile Crescent in the Mesopotamian region that has become known as one of the Cradles of Civilization. However, there is no one place, nor one time that one can select as the source of the idea of waterpower. It might be argued that this is due to the lack of documentary and archaeological evidence but it seems more likely that the developments occurred in parallel in different parts of the world. The Romans were responsible for the widespread adoption of the horizontal waterwheel with paddles and a vertical shaft, which often replaced animal or slave powered mills. They were very simple in construction, with no gearing and drove a set of millstones directly above the wheel, this type of mill spread as far as Scandinavia and the Shetlands, Western Scotland, Ireland and possibly Wales and became known as the Norse Mill or Grist Mill. Although, not as efficient as the vertical geared wheels, the horizontal wheel did acquire some refinements, such as the cupped paddles, which improved the efficiency of the transfer of energy from moving water to the wheel. This is an interesting pre-echo of the cupped blades of the Pelton Wheel turbine, a patent of Lester Pelton in 1860. The use of a horizontal wheel or runner with a vertical shaft survives in some of the most efficient water turbines in use today, the Francis Turbines. The vertical waterwheel was first used by the Egyptians before 100 BC and was well known to the Romans before the time Christ. Vitruvius, in 'De Architectura written around 15 BC, has a description that has all the hallmarks of an undershot vertical waterwheel. However, just as important as the change from a horizontal wheel to a vertical one is the use of a gearing system, so that the vertical plane of the wheel could be translated through 90° to the horizontal plane of the millstones. Also, by using 'step-up' gearing, the flexibility in the uses of waterpower was increased considerably. The waterwheel, a distant grandfather of the impulse turbine, played an important role in prompting engineers such as John Smeaton of England (1724-1792) to study and improve it until its efficiency had reached about 70 %. Engineers Zuppinger in 1846 and Schwamkrug in 1850 initiated development of a turbine using the same basic principles as the waterwheel. An important step away from the waterwheel was initiated at that time with the development of a waterspout or nozzle that directs a high velocity stream of water against blades set in a wheel. Along with this development and the description of an efficient waterwheel as stated by Poncelet in 1826, a group of engineers from California set out to develop an impulse turbine with efficiency higher than that of the waterwheel. Among this group was Lester A. Pelton (1829-1908), who was responsible for the development of a highly efficient impulse wheel that bears his name to this day. Eric Crewdson improved the already efficient Pelton wheel, or turbine, in 1920. This improvement led to the development of the Turgo wheel, which boasts even higher efficiency and simpler construction than either the Pelton wheel or the waterwheel. Nevertheless, impulse wheels have been upstaged in recent years by more complex and efficient reaction turbines. Reaction turbines also use water momentum, but pressure forces are added for increased torque. The Kaplan or propeller turbine, developed around the time that Lester Pelton was perfecting his impulse machine, has been a very popular machine throughout its history.

The Kaplan turbine's high efficiency under low pressures accounts for its growing popularity today because many installations have high flows but low heads. Other reaction turbines developed around the same time include the Francis turbine and other propeller machines. Hybrid impulse turbines, which circumvent some basic drawbacks of full impulse machines are known as cross-flow turbines. A.G.M. Mitchell patented the first cross-flow turbine in 1903. Professor Donat Banki also developed a cross-flow turbine in 1917 that bears his name today. Because these turbines are simple to build, they have been widely used in developing countries where both low cost and simple technology are imperative.

Hydro comes from the Greek word hydra, meaning water. Hydroelectric power is electricity produced by the movement of fresh water from rivers and lakes. At higher ground, water has stored gravitational energy that can be extracted by turbines as the water flows down stream. Gravity causes water to flow downwards and this downward motion of water contains kinetic energy that can be converted into mechanical energy and then from mechanical energy into electrical energy via hydroelectric power stations.

Head and flow: Hydraulic power can be obtained, where a flow of water falls from a higher plane to a lower plane. This could be in a stream running down a hillside, a river over a waterfall, a weir or from a reservoir discharge back in to a main outlet. The amount of power available from a hydro scheme depends on the head and the flow rate of the water.

The head is the height difference between the inlet to the hydro turbine and its outlet (Fig. 1). The gross head is the maximum vertical drop available to the water from the top of the fall to the water level below. The actual head seen by a turbine is and away from the turbine and is therefore called the net head. The flow rate (Q) in the water source is the volume of water passing per second. This can be shown by the Eq. 1:

$$\text{Energy released} = mgH$$

Fig. 1: Head and flow description

Where:
m = Mass of water
g = Gravity
H = Gross head or vertical distance

Power and energy: The mass of the water is its density (ρ) multiplied by its volume (V) so that the equation changes to:

$$\text{Energy released} = V\rho gH$$

The water enters the turbine at a rate Q ($m^3\ sec^{-1}$) and be can be expressed in terms of power:

$$\text{Gross power} = \rho QgH \text{ Watts}$$

Where:
ρ = 1000 kg m^{-3}
g = 9.81 m sec^{-2}
Q = Volumetric flow rate $m^3\ sec^{-1}$
H = Gross head in meters

However, the power produced by the turbine cannot equal the gross power because of losses such as friction in pipe work and conversion machinery i.e., turbines and generators. A hydro turbine can have between 80% to over 90% hydraulic efficiency, although this will reduce with size. A typical micro hydro system (<100 kW) will tend to be 60-80% efficient. Therefore,

$$\text{Net power} = \eta\rho QgH \text{ Watts}$$

Where:
η = Hydraulic efficiency of turbine
ρ = 1000 kg m^{-3}
Q = Volumetric flow rate $m^3\ sec^{-1}$
g = 9.81 m sec^{-2}
H = Gross head in meters

Hydropower classification: Hydroelectric power schemes can be banded into 5 broad categories, these being:

- Large hydro power plant produces >50 MW of total capacity
- Medium hydro power plant produces 20-50 MW of total capacity

- Small hydro plant produces 5-20 MW of total capacity
- Mini hydro plant produces 1-5 MW of total capacity
- Micro hydro plant produces 1000 kW or less of total capacity

It must be noted that size designation does vary among different countries and the point is that hydro power plants come in all sizes (Gulliver and Arndt, 1991).

Main components of a scheme: A typical hydropower plant includes a dam, reservoir, penstocks (pipes), a powerhouse and an electrical power substation, as seen in Fig. 2. The dam stores water and creates the head diverted via the intake to the headrace, down to the head pond or forebay tank. A penstock or pressure pipe carries the water from the reservoir to turbines inside the powerhouse; the water rotates the turbines, which drive generators that produce electricity. After leaving the turbine, the water is discharged down a tailrace into the river or stream. Hydropower uses a well-established and reliable technology and can deliver very high efficiencies.

Types of hydro schemes: The three main types of hydroelectric scheme are Run-of-the-River, Diversion or Canal and Storage. Most hydropower plants are conventional in design, meaning they use one way water flow to generate electricity.

A run-of-the-river scheme: This utilizes the use of a dam as shown in Fig. 3, usually in the form of a weir, which does not stop the flow of the river and is used as an overflow, but diverts some of the flow through a trash screen to remove larger debris. After the flow passes through the trash screen, it enters the penstock (a pipeline) towards the turbine. Run-of-the-river hydroelectric plants use little, if any stored water to provide water flow through the turbines. Although, some plants store a day or week's worth of water, weather changes especially seasonal changes cause run-of-river plants to perience significant fluctuations in power output.

A diversion or canal system: This is where the water is diverted from its original river or stream towards the turbine, through the use of a long penstock or an open feeder canal, called a leat. The flow in the river or stream channel is altered considerably.

A storage scheme: This utilizes impoundment of water upstream of the power plant using a dam or the use of an existing lake or loch, which allows the complete control over the flow of water downstream. An important factor to this type of scheme is that it uses extensive civil works and that any dam or reservoir storing over 25,000 m^3 has to comply with the Reservoirs Act 1975. Storage plants have enough storage capacity to offset seasonal fluctuations in water flow and provide a constant supply of electricity throughout the year. Large dams can store several years worth of water.

In contrast to conventional hydropower plants, Pumped Storage (Fig. 4) plants re-use water. Water is passed through it, by storing it in catchment areas below the station and then pumping it back up to the higher catchment dams above the station in a closed circuit arrangement. During off-peak hours (periods of low energy demand), some of the water is pumped into an upper reservoir and re-used during periods of peak demand. When pumping is required, a reversal of roles

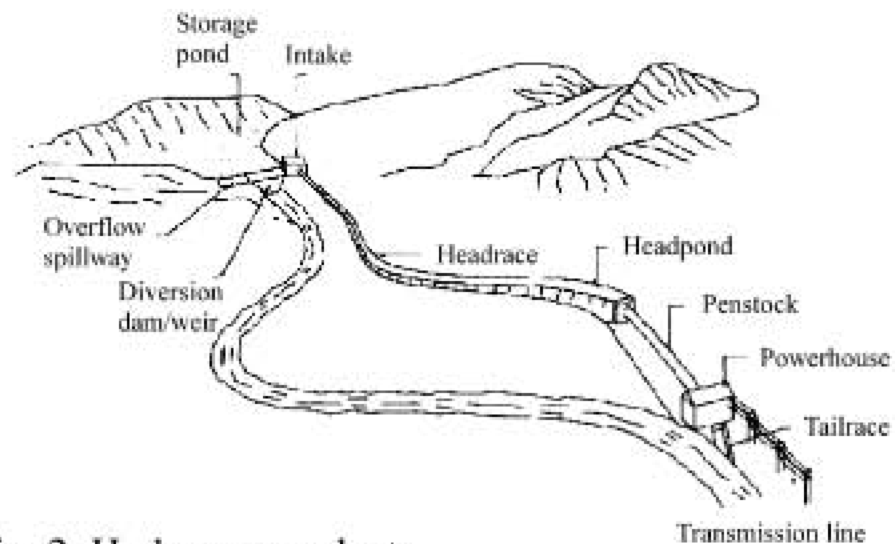

Fig. 2: Hydropower plants

Fig. 3: Long spruces dam 980MW

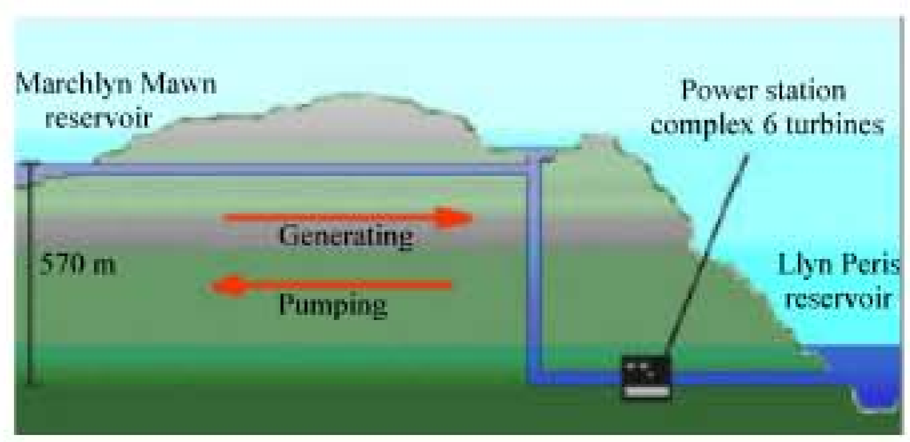

Fig. 4: Pumped storage

occurs. The generator becomes an electric motor, receiving electricity from a nearby power station and operates the turbine as a pump. The turbine receives energy instead of delivering it. However, in some pumped storage schemes there are two sets of equipment. One set is for generating and the other is for pumping. The use of pumped storage increases the total amount of power generated by the hydro power station, but this increase is not renewable. The pumps are run by non-renewable sources allowing excess electrical energy to be stored as the potential of energy of water raised to the height of the dam. The amount of renewable energy produced by the hydro power station remains the same.

Technology: Electrical and mechanical equipment characteristics are explained to aid further in the selection of specific waterpower devices. Modern hydro technology uses specially designed water turbines. Some turbines operate at low heads of <10 m. Water for a hydro-electric power station's turbines can come from a specially constructed dam set high up in a mountain range, or simply from a river close to ground level. As water sources vary, water turbines have been designed to suit the different locations. Largely head and quantity of water available at a particular site determine the design used. The purpose of a turbine is to converts energy in the form of falling water into rotating shaft power. The selection of the best turbine for any particular hydro site depends on the site characteristics, the dominant ones being the head and flow available. Selection also depends on the desired running speed of the generator or other device loading the turbine. Other considerations such as whether the turbine is expected to produce power under part-flow conditions also play an important role in the selection. All turbines have power-speed design characteristics, as they will tend to run more efficiently at a particular speed, head and flow combination.

Classification of turbines: Turbines can be classified as high head, medium head or low head machines. Turbines are grouped under the following two headings: impulse turbines and reaction turbines, as shown in the Table 1. The advantages of reaction turbines include: High efficiencies; excellent power output at low heads; numerous designs that provide easy tailoring to specific installations and the flexibility of choosing either horizontal or vertical installation. The disadvantages of reaction turbines include: efficiency at specified heads and discharges but inefficiency when these vary; the need for accuracy in installation design; the possibility that cavitation will occur; the potential that non-uniform forces will destroy

Table 1: Types of turbine

Turbines	High head	Medium head	Low head
Impulse	Pelton turgo Multi-jet pelton	Cross-flow/Banki Multi-jet pelton turgo	Cross-flow/Banki
Reaction		Francis	propeller kaplan

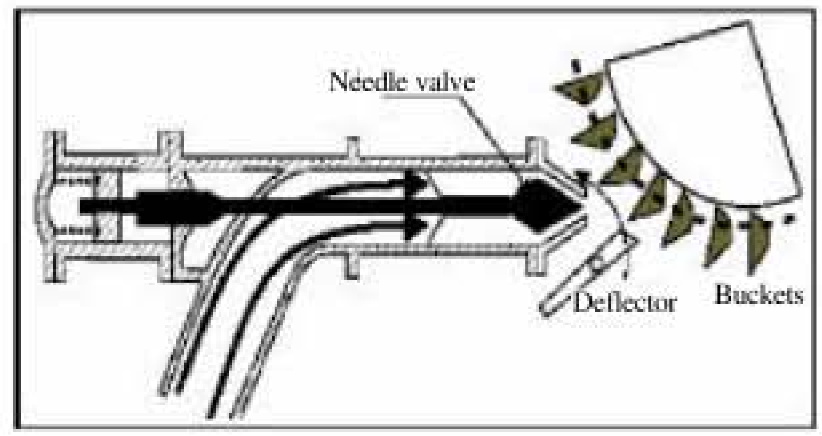

Fig. 5: Pelton turbine

the runner; very strict design tolerances; costly civil works and high manufacturing costs. The advantages of impulse turbines include: low water discharge requirements, the efficient use of high heads, small physical size yet high power output, high efficiencies, simple design, simple civil works, low maintenance, low cost and low labour input.

The disadvantages of impulse turbines include: poor power output under low heads; the possibility of increased wear and tear due to operation at high speed; very strict manufacturing specifications for other than crossflow and the complexity of regulating the speed of the turbine.

Impulse turbines: Impulse turbines derive their power from a jet stream striking a series of blades or buckets. A distinct feature of an impulse turbine runner is that it operates in air. The momentum of a high-speed water jet turns impulse turbines.

Pelton turbine: The Pelton wheel is probably the best known of the tangential flow impulse turbines. Invented by a Californian mining engineer, it has changed little in the last hundred years. It is efficient over a very wide range of flows but at lower heads the speed is a bit too low for convenient belt drives. The Pelton wheel is used where a small flow of water is available with a large head. It resembles the waterwheels used at water mills in the past.

The Pelton wheel has small buckets all around its rim. Water from the dam is discharged from one or more nozzles very high speed hitting the buckets, pushing the wheel around (Fig. 5). 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.

Having two or more jets enables a smaller runner to be used for a given flow and increases the rotational speed. The required power can still be attained and the part-flow efficiency is especially good because the wheel can be run on a reduced number of jets with each jet in use still receiving the optimum flow. Two Pelton wheels can be placed on the same shaft either side by side or on opposite sides of the generator. This configuration is unusual and would only be used if the number of jets per runner had already been maximized, but it allows the use of smaller diameter and hence faster rotating runners.

Turgo turbine: Eric Crewdson invented the Turgo impulse in 1920; it is used for heads of 12 m or more. The Turgo Impulse design allows a large water jet to be directed at an angled runner blade, usually approximately 20°, giving the turbine a higher specific speed and therefore a smaller physical size (Fig. 6). The rugged design is particularly suited to schemes having abrasive solids in suspension. Because power output from the turbine can be regulated using rapid acting deflectors without affecting the water flow, the Turgo Impulse Turbine has been applied on many irrigation and water treatment schemes where continuity of water flow is essential. It has several disadvantages. Firstly, it is difficult to fabricate since the buckets or vanes are more complex in shape and overlap, it also experiences axial loading on the runner that has to be quelled by a suitable bearing on the shaft, usually a roller bearing.

Crossflow turbine: The crossflow turbine actually had two inventors, firstly A.G.M. Michell, an Australian engineer who obtained a patent for it in 1903. The Hungarian Prof. Donat Banki later invented the turbine independently in Germany in 1919, while working with Ganz in Budapest, where it became known more widely between 1917 and 1919 through a series of publications as the "Banki Crossflow Turbine" or as it's sometimes called the "Mitchell Crossflow Turbine".

The present more widespread use of the cross-flow turbine is largely due to the efforts of the Ossberger Company in Weissenburg, Bavaria, contributing a number of original ideas to Mitchell's design, based on their own research work and world patents cover the various stages of this steady development. In the crossflow turbine the water, in the form of a sheet, is directed into the blades tangentially at about mid way on one side. The flow of water crosses through the empty centre of the turbine and exits just below the centre on the opposite side. Thus

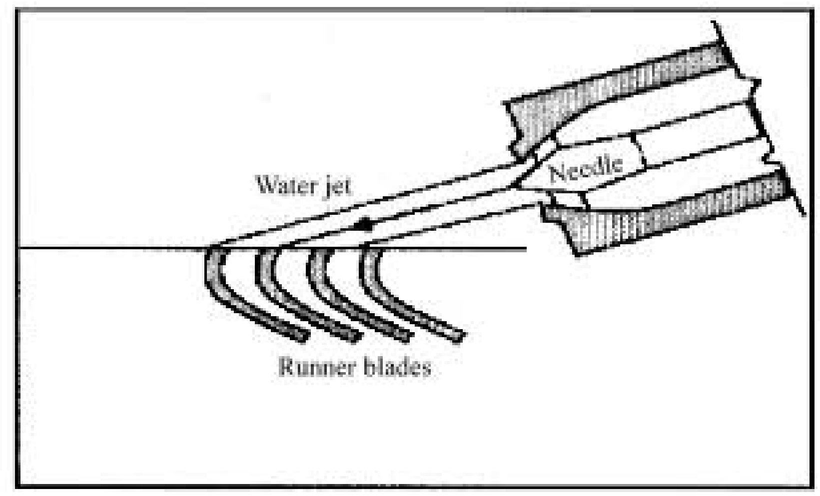

Fig. 6: Turgo turbine

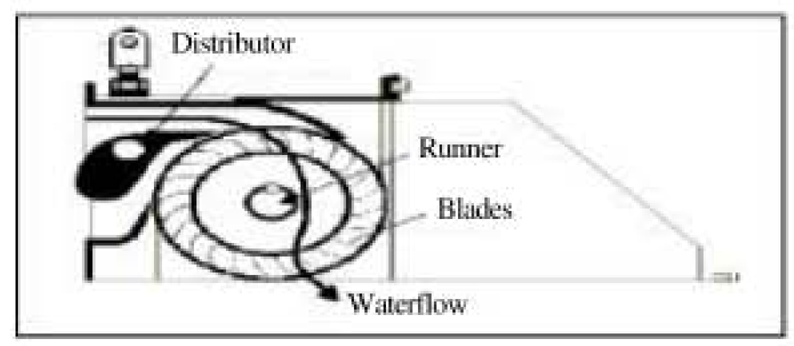

Fig. 7: Crossflow turbine

the water strikes blades on both sides of the runner (Fig. 7). It is claimed that the entry side contributes about 75% of the power extracted from the sheet of water and that the exit side contributes the remainder.

The main characteristic of the cross-flow turbine is that it uses a broad rectangular jet of water that travels through the turbine only once but travels across each runner blade twice, once in each direction. This machine is therefore a turbine with two velocity stages, the water filling only part of the runner at any one time. As far as energy utilization is concerned, the use of two velocity stages provides no immediate advantages. The arrangement represents, however a very skilful design, which removes the water in a simple manner, after it has passed through the runner without producing any backpressure.

The addition of a draft tube to the cross-flow turbine represents an idea implemented by Ossberger to enhance the turbine's performance. Ossberger use an air valve in the draft tube to help regulate the head by introducing air in the draft tube. Furthermore, this flow mechanism makes the turbine self-cleaning. During the first strike, suspensions and impurities, which reach the turbine are pressed against the blanket of the runner. During the second strike, after a half rotation these would then be washed out.

This mechanism contributes to the long functioning period and reliability of the turbine. They are generally built as multi-cell turbines, where the runner can be sectioned off to allow the smaller cell to utilize small water flows and the larger cell to use

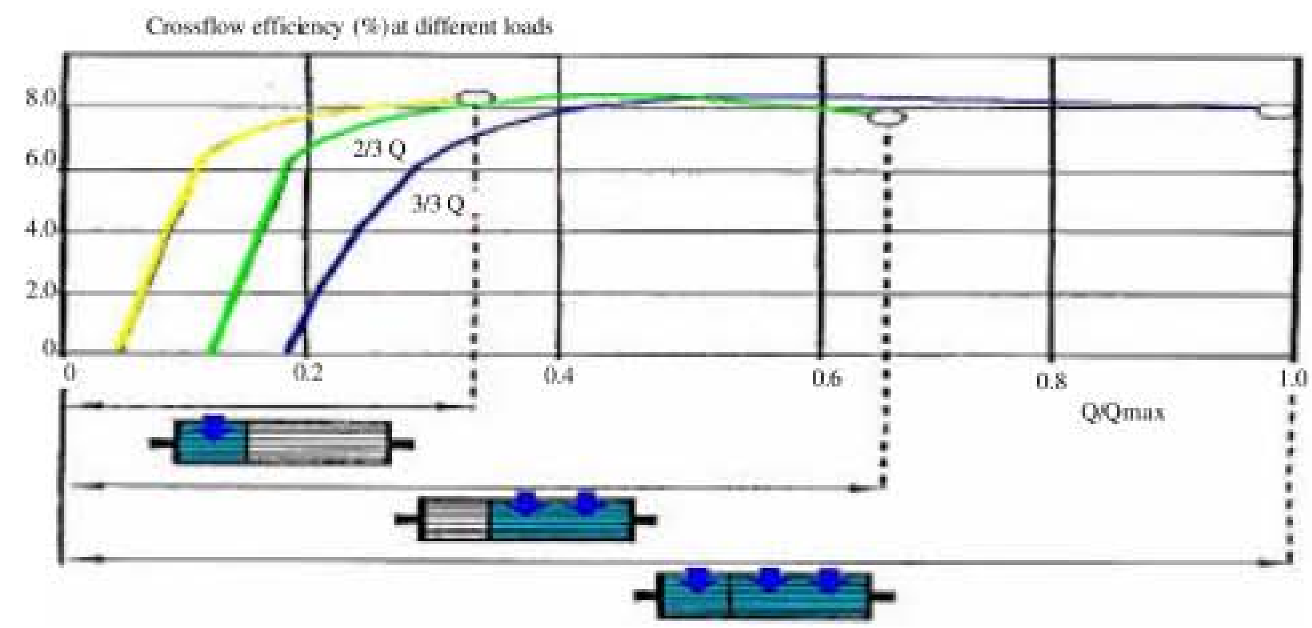

Fig. 8: Crossflow turbine operations

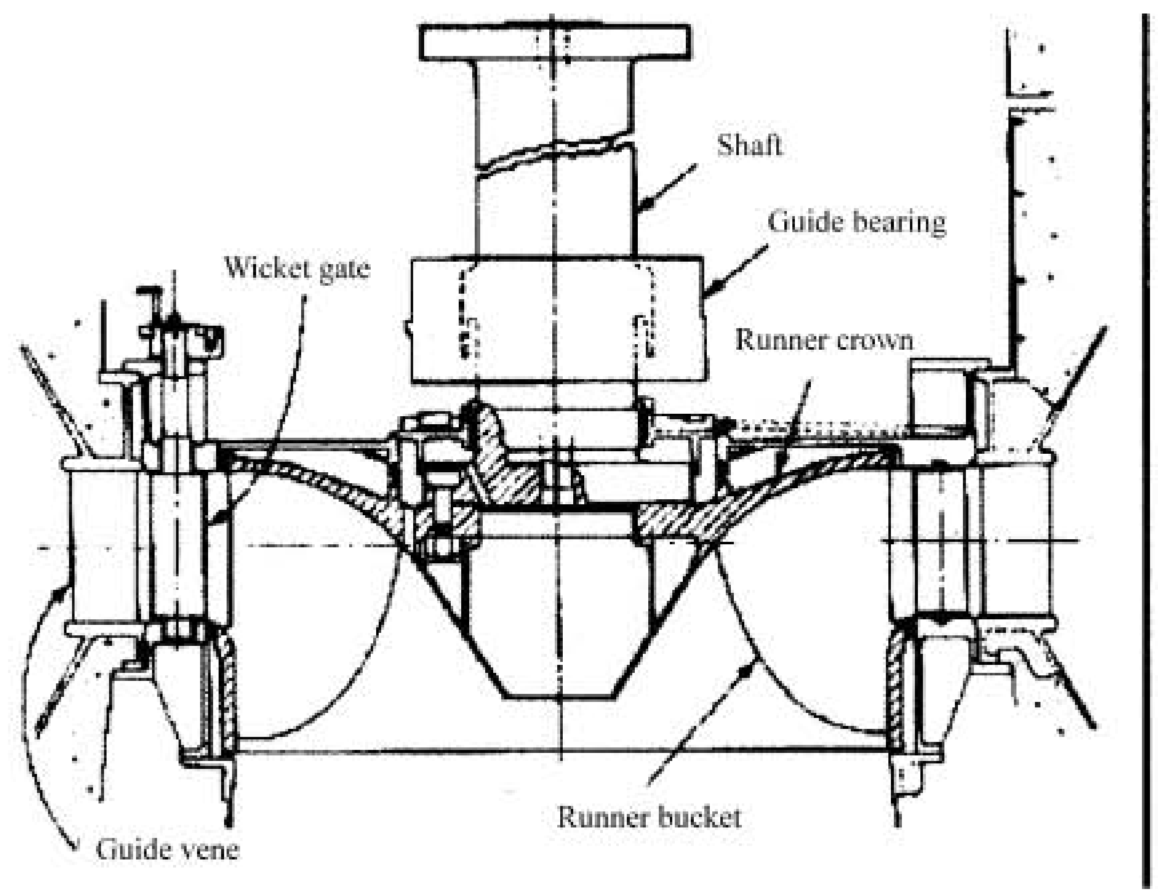

Fig. 9: Francis turbine

medium water flow and when both cells are opened together they utilize the full flow of the water (Fig. 8).

Reaction turbines: Reaction turbines use both velocity and pressure forces to produce power. Consequently, large surfaces over which these forces can act are needed. Also, flow direction as the water enters the turbine is important. They are distinguished from impulse type turbines by having a runner that always functions within a completely water filled casing.

Francis turbine: The Francis turbine is used, where a large flow and a high or medium head of water is involved. The Francis turbine is also similar to a waterwheel in that it looks like a spinning wheel with fixed blades in between two rims. This wheel is called a runner. A circle of guide vanes surrounds the runner and controls the amount of water driving it. Water is fed to the runner from all sides by these vanes causing it to spin. Francis turbines are radial flow reaction turbines, with fixed runner blades and adjustable guide vanes, used for medium heads. Francis turbines include a complex vane arrangement surrounding the turbine itself (also called the runner) which can be shown in Fig. 9. Water is introduced around the runner through these vanes and then falls through the runner, causing it to spin. Velocity force is applied through the vanes by causing the water to strike the blades of the runner at an angle. Pressure forces are much more subtle and difficult to explain and in general, the flowing water causes pressure forces. As the water flows across the blades, it causes a pressure drop on the back of the blades; this in turn induces a force on the front and along with velocity forces, causes torque. Francis turbines are usually designed specifically for their intended installation; with the complicated vane system, they are generally not used for micro hydropower applications. Because of their specialized design, Francis turbines are very efficient yet very costly.

Propeller turbine: Propeller type turbines are designed to operate, where a small head of water is involved. The basic propeller turbine consists of a propeller, similar to a ship's propeller, fitted inside a continuation of the penstock tube.

The turbine shaft passes out of the tube at the point where the tube changes direction. The propeller usually has three to six blades, three in the case of very low head units and the water flow is regulated by static blades or swivel gates (wicket 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. The part-flow efficiency of fixed-blade propeller turbines tends to be very poor. However, with some of these the angle (pitch) of the blades can be altered to suit the water flow. The Propeller turbine in its simplest form is like a ship's propeller running in a tube.

As the water flows through the propeller rotates. Special coatings are used for increased corrosion and abrasion resistance. For lowland and old mill sites the propeller turbine is ideally suited since it is compact and fast running even on low heads. The angle of the bend can be between 30 and 90° but standard layouts are either 45 or 90° (Fig. 10). A penstock can be used for higher heads up to 15 m and the turbine runner setting can be lowered to avoid cavitation by inserting a length of parallel tube between the bend and the turbine casting. Existing civil works associated with old mills, navigation locks or irrigation structures often lend themselves to the installation of this type of turbine. The Siphon layout is used for small turbines and axial-flow pumps, where the unit is installed over a wall.

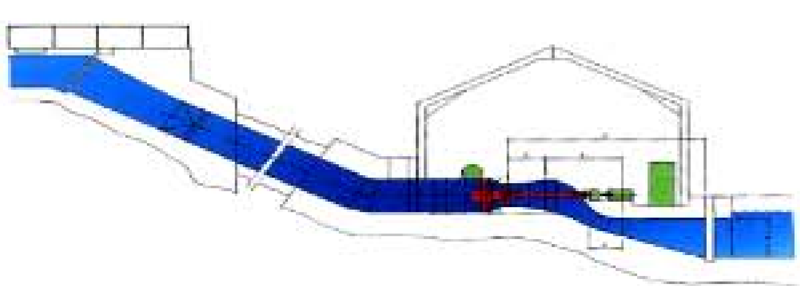

Fig. 10: Propeller turbine

Kaplan turbine: 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 reasonable efficiency to be maintained under part flow conditions. For good efficiency water needs to be given some swirl before entering the turbine runner, where the swirl is absorbed by the runner and the water that emerges flows straight into the draft tube. Methods for adding inlet swirl include the use of a set of guide vanes mounted upstream of the runner with water spiraling into the runner through them. Another method is to form a snail shell housing for the runner in which the water enters tangentially and is forced to spiral into the runner. Such turbines are known as variable pitch or Kaplan turbines. Water flows into the turbine casing and passes the runner blades through to the draft tube then to the tailrace (Fig. 11). Various configurations of Kaplan turbines exist and can be mounted horizontally, vertically or angled in the same way as propeller turbines. This type of turbine has a high efficiency over a wide range of heads and outputs and has a high specific speed (Simeons, 1980).

Turbine efficiency: A significant factor in the comparison of the various turbine types is their relative efficiencies both at their design and at reduced flows. Typical efficiency curves are shown in Fig. 12. An important note is that the Pelton and Kaplan turbines retain very high

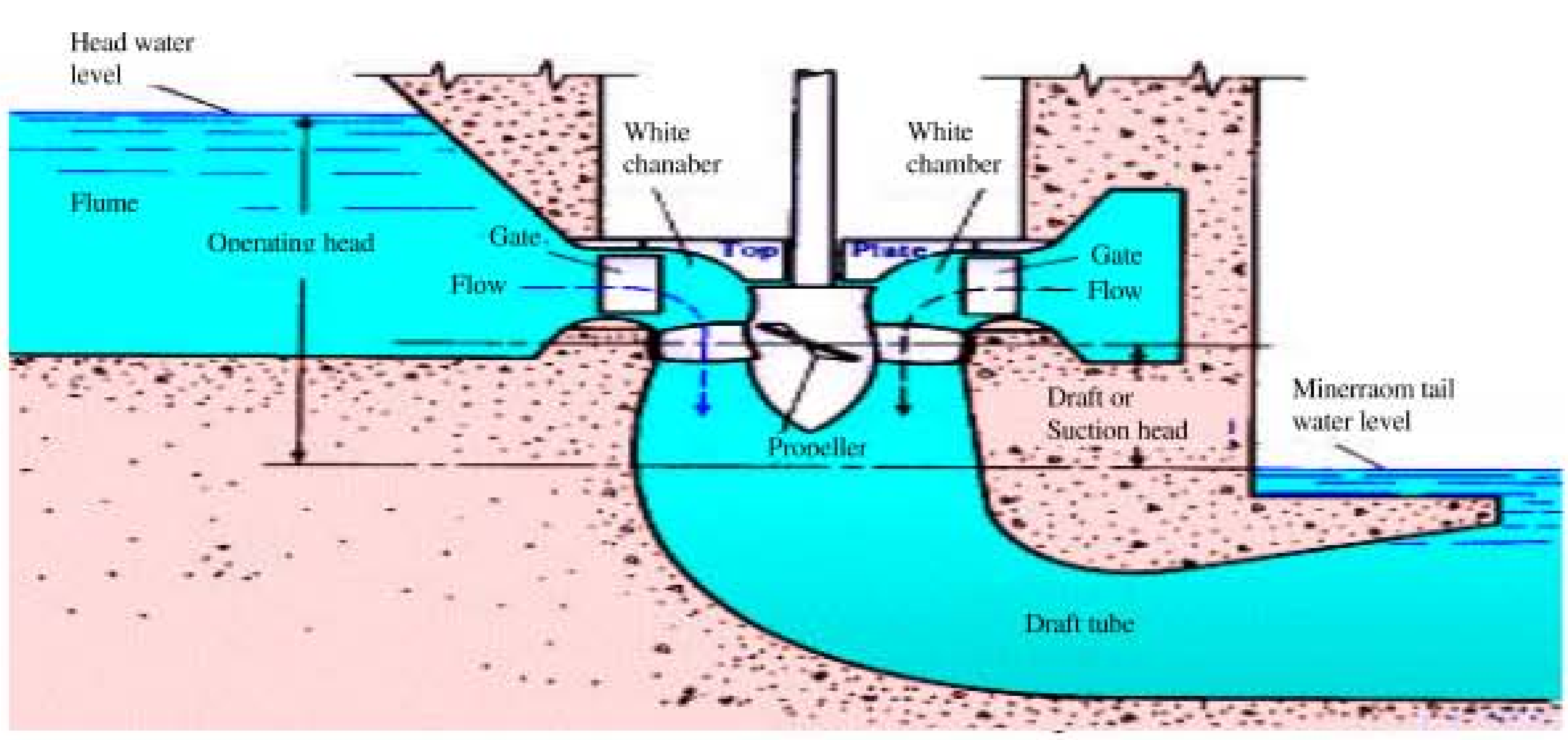

Fig. 11: Kalplan turbine

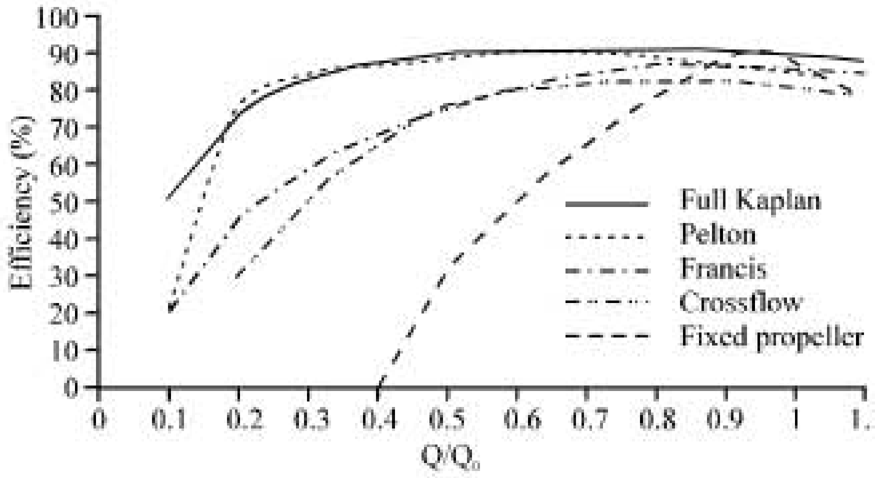

Fig. 12: Comparison of various types of turbines efficiency

Fig. 13: Governor

efficiencies when running below design flow; in contrast the efficiency of the Francis turbine falls away more sharply if run below half their normal flow, as does the Crossflow turbine, but the multi-celled Crossflow turbine retains a high efficiency but with a reduced output. Most fixed pitch propeller turbines perform poorly except above 80% of full flow.

The governors: The turbine usually drives the generator through either a gearbox, through a pulley and belt system, or directly using shock-absorbing brushes. The governor modulates the generator speed in order to control the electrical frequency of generation. The governor does this by detecting the change in the electrical load output of the generator and then altering the flow of water into the turbine using valves. They can be linked to a level switch situated in the storage reservoir so that the flow through the turbine is also dependent on the level and hence the water flows. Governors can either be mechanical (Fig. 13) or electrically operated (Harvey *et al*., 1993).

The generators: Generators can be either of a synchronous or asynchronous type. In a synchronous generator the frequency of the electricity produced is directly related (i.e., synchronous) with the rotational speed of the shaft. Therefore, at 50 Hz generation, the shaft rotates at a fixed sub multiple of 50 Hz, depending on the gearing ratio. This type of generator must be designed to withstand the high runaway speeds that can sometimes occur during hydroelectric turbine system faults. They often have to be specially designed, thus increasing their cost considerably. These generators come in single phase (for small systems) and three phase (for larger outputs) and the single phase type is more commonly known as an alternator (Victorov, 1986). Within induction generation or asynchronous generation a motor is used as a generator. This type of generator is simple in construction containing fewer parts, making it cheaper and more reliable than synchronous generators. It can withstand 200% runaway speeds without harm and has no brushes or other parts to require maintenance. In this type of generator power enters the grid when the speed of rotation has a frequency greater that that of the grid. This is called slip. Usually systems are designed for maximum power to be entering the grid at a slip of about 10%. Power is actually drawn from the grid to provide the magnetic field until running speed is achieved, when power is then produced (Victorov, 1986). When operating in conjunction with a large power grid, a standard single or three-phase motor may be used as a generator. Hydro power plants designed as asynchronous installations are usually more economical than synchronous generating sets. In the past, asynchronous plants were equipped with minimal equipment.

Civil works

The dams: Dams are classified into a number of different categories according to hydraulic design, use and materials comprising the structure (Elliott *et al*., 1997). Storage dams are constructed for irrigation, drinking water supply and hydroelectric power generation. Also such facilities are used in flood control and all dams must be designed to withstand the high water levels and surges of a 100 years flood occurrence and the amount of reservoir seepage that may be permitted. Diversion dams were traditionally built to provide head for diverting water flow into canals or pipelines. This dam has two classification types, overflow and non-overflow.

An Overflow dam is designed to allow the water to cascade over the crest of the dam, in a controlled manner, as to keep the reservoir behind the dam at a minimum level. Due to this the materials used in the construction of an overflow dam need to be of suitable resistance to water erosion, such as steel, concrete, masonry and in some cases even wood.

Non-overflow dams have spillways to prevent over the reservoir overflowing. This type of dam enlarges the choice of materials and designs that can be used, often utilizing composite structures, using rock and earth filling in their construction. In the construction of modern dams concrete is used extensively and concrete dams have two distinct types, the gravity and arch. The concrete gravity type is used mainly in the small-scale reservoirs, whereas the concrete arch is used predominantly in large-scale water impoundment. The arch style is easily recognized due to its dramatic shape and size. The most common dam construction within the UK is the earth fill dam, using cheap, readily available local materials that require minimum processing. The foundations required in earth fill dams are not as stringent as for other types of dams, (USDI, 1974) often using rock on the waterside and face side of the dam as an erosion barrier and to provide extra strength the structure. Due to the materials used, adequate spillways must be provided to prevent surges and overflows.

Rock fill dams use rock of all sizes to provide stability and an impervious membrane to provide water tightness (USDI, 1974). The membrane may be an upstream facing of impervious soil, like clay, a concrete slab or steel plates. Like the earth fill dams, rock fill dams are subject to damage or destruction by water erosion caused by overflow waters and so must be provided with suitable spillway capacity.

Canals and channels: The canal or channel also called a 'leat' or 'lade' is a method of diverting the water from a river or stream to the intake of the turbine. Various types of canal that are in use these being:

- A simple earth unlined channel
- The earth excavation where the channel is lined and sealed using clay or cement slurry
- Masonry linings
- Concrete channels
- Flumes and aqueducts made from galvanized sheet steel, pipes or wood

Sealing is the application of a thin layer of material with no structural strength and serves only to reduce friction and leakage. Lining is any method of adding structural strength to the channel walls. Earth infill's are also used instead of aqueducts and these usually carry a pipeline across depressions in the terrain (Elliott *et al*., 1997).

Forebay tank or surge tank: A forebay tank is required for canal headrace schemes to spill surplus water and provide small balancing storage for the turbine on start-up and during rapid load changes. The diverted water from the stream or river may contain harmful abrasives such as sand and peat in suspension, which would cause extensive and expensive damage to the turbine plant. The use of a forebay limits the exposure of such suspensions to the turbine. The harmful particles are removed by flowing the water through a silt tank to allow the water and the contained particles to settle out. Larger materials entering the forebay, such as leaves, twigs, branches and other floating debris are stopped entering the pipeline intake to the turbine by using a trash screen. Trash screens come in all shapes and sizes with varying filter sizes. There are elaborate mechanical self-cleaning or simple galvanized screens, able to be hand cleaned during autumn months. Careful design of the forebay tank is essential to ensure the entrance to the penstock will always be fully submerged. The excess water exits over a spillway in the forebay, away from the pipeline area and is disposed to a watercourse.

Pipeline or penstock: The pipeline is probably the most expensive part of any hydroelectric development and is therefore prudent in putting some effort to minimize the length and cost. The pipeline itself must be able to tolerate sudden changes in water pressures and to resist adequately internal and external forces, such as the changing weather conditions for the sited area. Due to these factors pipelines are subject to British Standards classifications. Ductile cast iron, glass fiber, reinforced plastic and asbestos cement are subject to BS3601. In most cases, the pipeline or penstock is test to its maximum pressure when first installed (Simeons, 1980). As all materials have various advantages and disadvantages the choice of pipeline material is very important for a long and reliable working lifetime. Penstocks can be constructed from a variety of materials such as UPVC, Medium Density (MD) and High Density (HD), Polyethylene (PE), ductile iron, mild steel and concrete (Elliott *et al*., 1997). UPVC is widely used in micro-hydro because it is relatively cheap and is widely available in a variety of sizes from 25-500 mm in diameter. It is suitable for high pressure use, has good friction loss characteristics and is corrosion resistant but suffers from being fragile in the respect to low temperatures and damage from falling rocks or trees. Polyethylene pipes range in sizes from 25 mm-1 m in diameter and are very expensive. It is the most versatile of the materials as it is flexible and can be coiled, this making it very advantageous when used in underground pipelines. An alternative to polyethylene pipes is ductile iron, which is cheaper and quite a popular material in the construction of micro-hydro applications. Usually coated internally with cement, this reduces friction losses and gives better corrosion resistance. This practice does make the pipes heavy and cumbersome to install and are bolted together by a flexible seal or a flanged end plate. The use of mild steel is used for its cheapness and is easily available in a wide range of diameters and pipe wall thicknesses. It is resistant to external damage from falling rocks and trees, but when buried suffers from long term corrosion and needs to be protected by painting or some other form of anticorrosion coating to give an expected life of 15 years plus. Mild steel piping is heavy but can come in convenient lengths, easier for movement and is jointed either by welding or bolted flanges. Concrete penstocks have many disadvantages; these being that concrete cannot tolerate moderate pressures and are brittle causing easy fracturing. Movement and the laying of concrete pipes is difficult due to heavy weight and can be inadequately jointed due the rubber o-rings used, which require precise alignment for a tight seal.

Trash screens: The trash screen or a trash rack filter out river-borne debris before it reaches the turbine. It is an extremely important component of the whole scheme and can be one of the more expensive items. The large majority of operating problems and maintenance costs can be traced back to the screening system so investment in a robust design will pay for itself in the long run. The standard screening solution, which has been used since the days of waterwheels, is to place a rack of bars in front of the intake, with the bars spaced so that a rake can be used to drag the accumulated debris up to the top of the screen (Fig. 14). The screen is a hindrance to the flow and introduces a slight head loss. Therefore the bar-spacing should be the maximum that will still trap debris large enough to damage the turbine (Mikhailov *et al*., 1985).

Rakes (trash screen cleaners)

A robotic rake: These come in a variety of designs, but usually involve one or more rakes operated by a hydraulic ram. Some designs require only a single rake which can unattended operation of the equipment.

A rake-and-chain cleaner: A bar is moved up the screen by a chain drive at each end of a rake-and-chain-cleaner. The bar deposits the collected debris in a channel running the length of the screen. The channel can be flushed clean index along the screen; otherwise two or more rakes can operate side by side.

These systems are usually very robust, partly because they can keep their drive mechanisms out of the water at all times. Their main disadvantages are the visual presence of the equipment and the slightly greater health and safety risk posed by by a water supply (pumped if necessary), washing the debris towards a side spillway.

Fig. 14: A trash screen

The grab-and-lift cleaner: This is a robust alternative to the robotic rake, a single set of jaws indexes along the screen and lifts the material straight into a skip.

Coanda screens: These are applicable only for high and medium head schemes, require no raking because they utilize the Coanda effect to filter out and flush away debris and silt particles, allowing only clean water into the intake system. Precisely positioned, finely spaced horizontal stainless steel wires are built into a carefully profiled screen, which is mounted on the downstream face of the intake weir. Clean water is collected in a chamber below the screens, which is connected directly to the turbine penstock.

CONCLUSION

By this study, it was made clear what information and components would be required and how the overall performance could be calculated for hydroelectric power generation, the main concepts, classification bandings, components, types of hydroelectric schemes available, the technology used within the hydroelectric generating field, the various types of turbine, mechanical plant and civil work required to build a hydroelectric plant.

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