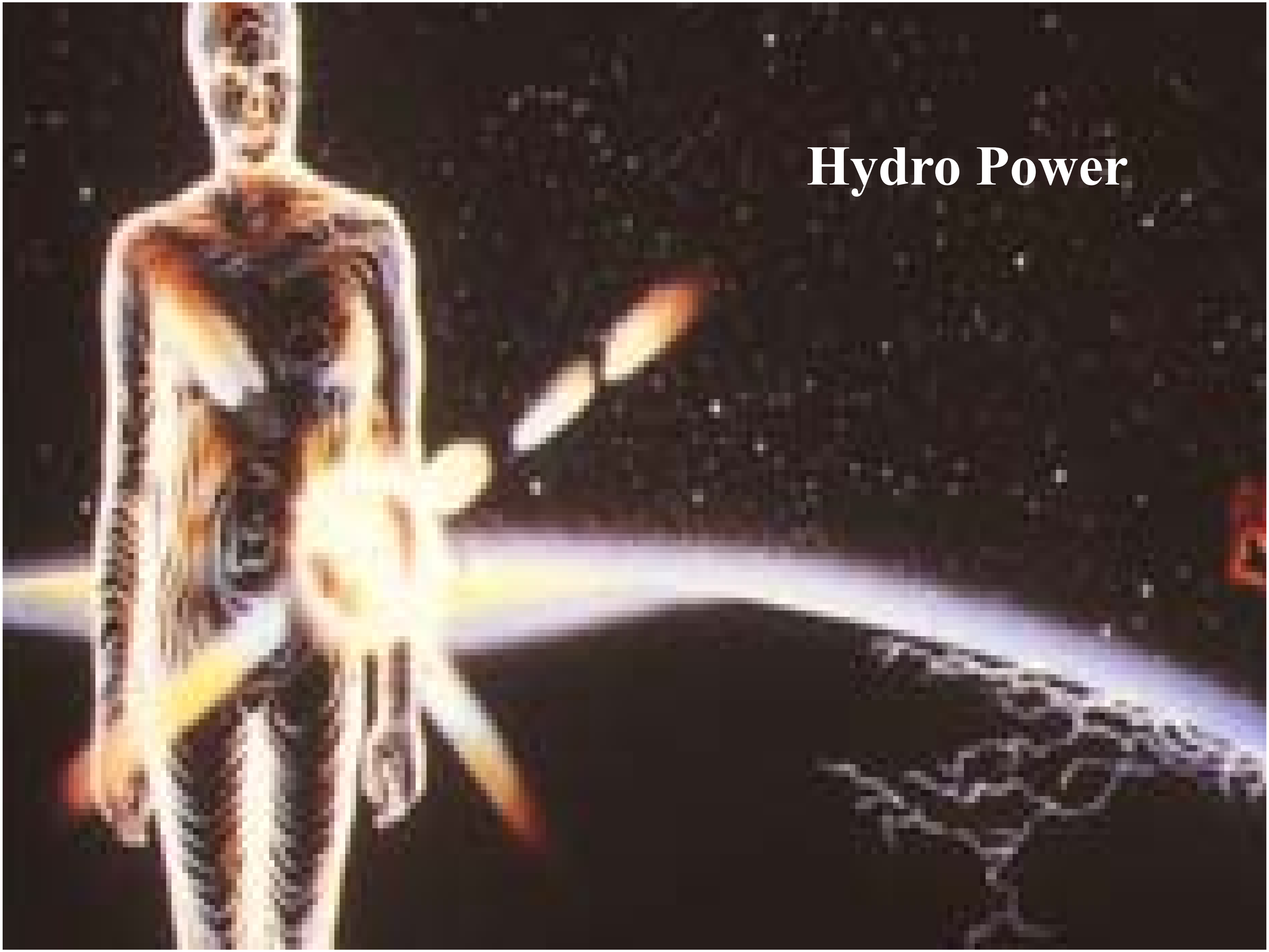
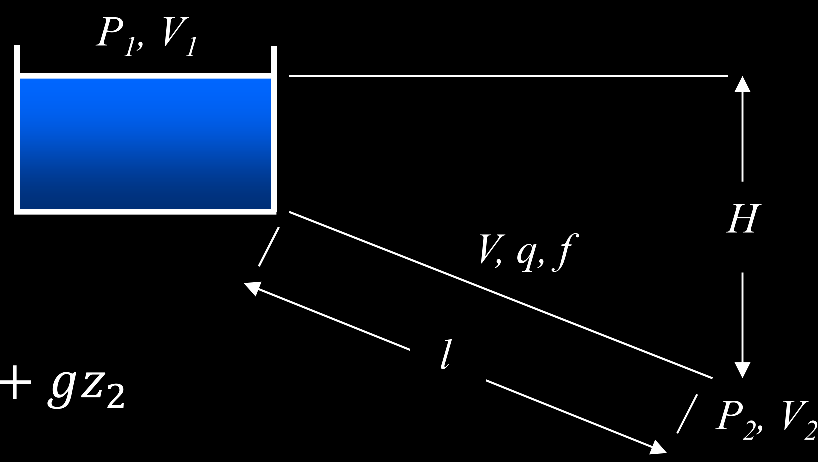

Hydro Power

Power transmission



- From the free surface of the reservoir to the exit point at 2, with friction loss factor, f, an energy balance (J/kg) gives

$$\frac{P_1}{\rho} + \frac{V_1^{\,2}}{2} + gz_1 - \frac{4f.l}{d} \cdot \frac{\overline{V}^2}{2} = \frac{P_2}{\rho} + \frac{V_2^{\,2}}{2} + gz_2$$

- With z_2 as zero, the energy at 2 is

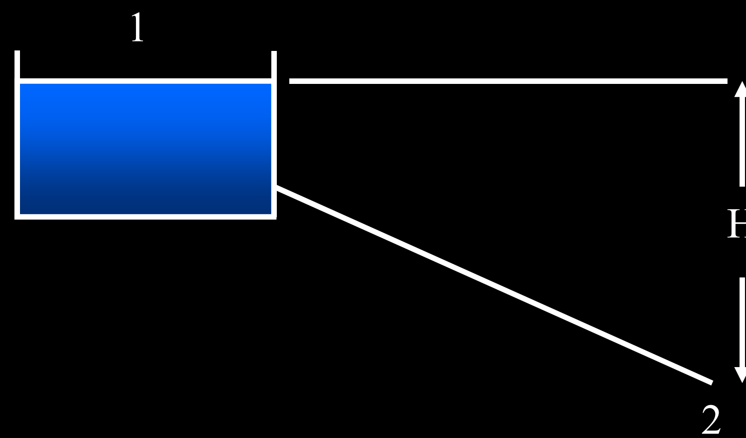
$$\frac{P_2}{\rho} + \frac{V_2^{\,2}}{2} = g(z_1 - z_2) - \frac{4f.l}{d} \cdot \frac{\overline{V}^2}{2}$$

and (with P_1 and V_1 zero) the power delivered (W) is

$$\rho Q \left[\frac{P_2}{\rho} + \frac{V_2^{\,2}}{2}\right] = \frac{\pi}{4}\rho d^2 \overline{V} \left[gH - \frac{4f.l}{d} \cdot \frac{\overline{V}^2}{2}\right] \quad Q - volume\ flowrate\ m^3/s$$

- If $\bar{V} = 0$ then power = 0; if $\bar{V}$ is very large then the term in the brackets will tend to zero. Between these conditions there is a value of $\bar{V}$ for which the power delivered at 2 is maximised.

Transmission efficiency



- For the condition of maximum power transmission:

$$\frac{\delta(Power)}{\delta\overline{V}} = 0$$

$$=> \quad \frac{\pi}{4}\rho d^2\left[gH - \frac{4f.l}{d}\cdot\frac{3\overline{V}^2}{2}\right] = 0$$

- The friction loss is given by

$$\frac{4f.l}{d}\cdot\frac{\overline{V}^2}{2} = \frac{1}{3}gH$$

- The transmission efficiency is defined as

$$\eta_{tr} = \frac{Energy\ delivered}{Energy\ available\ at\ source}$$

- At maximum power $\eta_{tr} = 2/3$; in general:

$$\eta_{tr} = \frac{gH - losses}{gH} = 1 - \frac{losses}{gH}$$

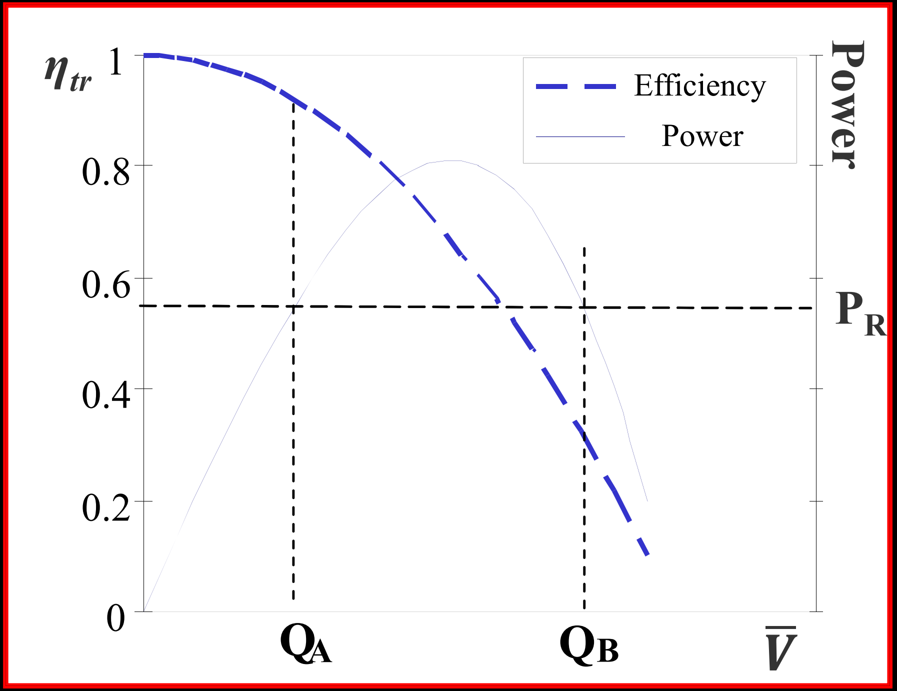
Final power output

- For any hydro-electric power plant, the final power output is

$$P = \eta_{O/A} \cdot \rho Q g H$$

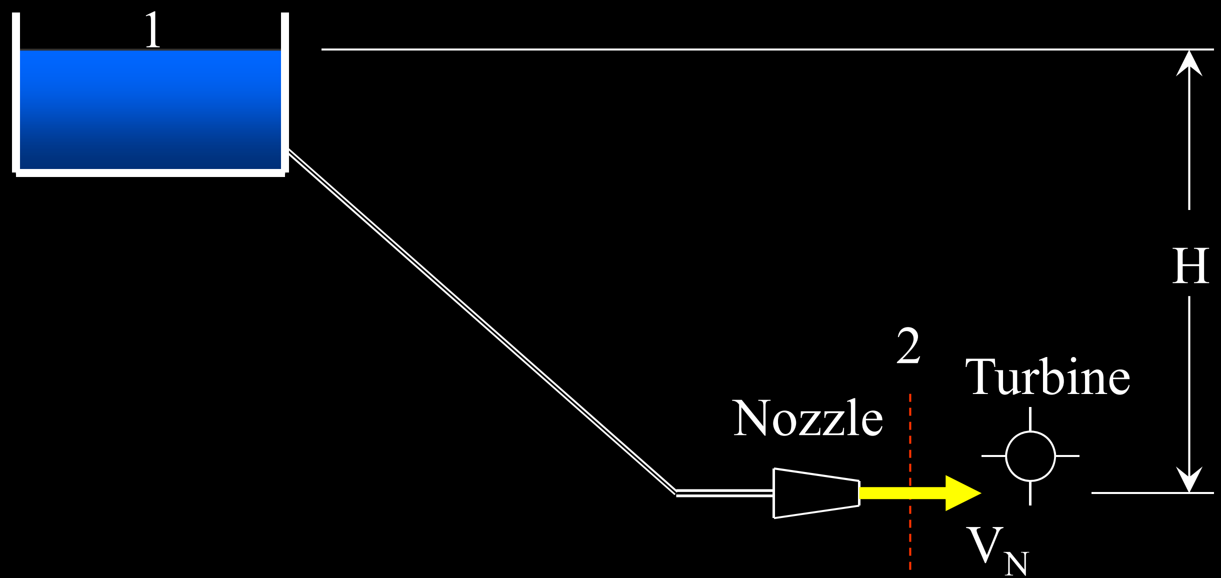
where $\eta_{O/A}$ is the overall efficiency, obtained by multiplying η_{tr}, the transmission efficiency, η_{turb}, the turbine hydraulic efficiency and η_{gen}, the generator efficiency.

- Graph shows power and transmission efficiency against volume flow rate.

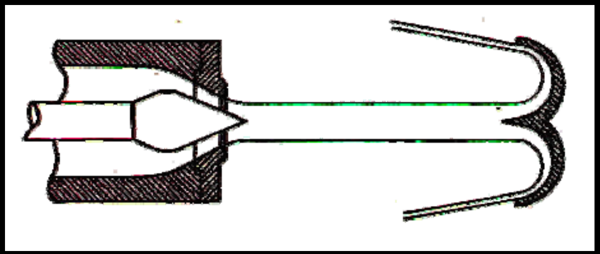


- Hydro-electric power plant do not normally operate at maximum power rating but at a lower power, P_R.
- A smaller flow rate, Q_A, is chosen.
- η_{tr} can exceed 90%.

Lay-out for an impulse turbine



- The energy reaches the turbine in purely kinetic form; the pressure around the turbine is atmospheric.
- An adjustable nozzle is used, such as the SPEAR VALVE shown here.
- The turbine blades are shaped to extract as much energy as possible.



Impulse turbine: power characterisation

- Energy equation from 1 to 2, ignoring losses in the nozzle, is (as before)

$$\frac{P_1}{\rho} + \frac{{V_1}^2}{2} + gz_1 - \frac{4fl}{d} \cdot \frac{\overline{V}^2}{2} = \frac{P_2}{\rho} + \frac{{V_2}^2}{2} + gz_2$$

- Here P_1, V_1, P_2 and z_1 are zero, and so

$$gH = \frac{{V_N}^2}{2} + \frac{4fl}{d} \cdot \frac{\overline{V}^2}{2}$$

where the velocity of the water jet, V_N, is given by

$$V_N = C_v \sqrt{2\left[gH - \frac{4fl}{d} \cdot \frac{\overline{V}^2}{2}\right]}$$

where C_v accounts for losses in the nozzle.

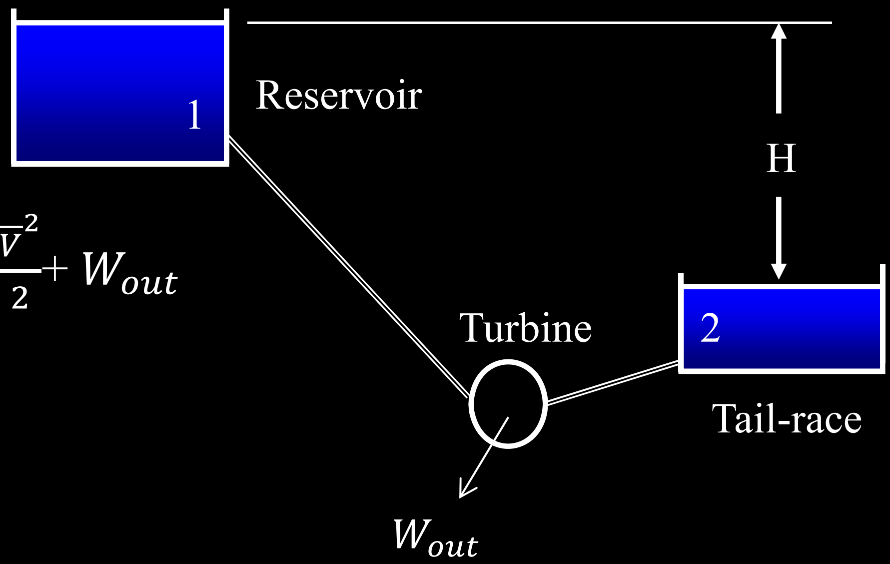
- The power delivered to the turbine in the water jet is

$$\rho Q \cdot \frac{{V_N}^2}{2} = \frac{\pi}{4}\rho d^2 \overline{V} {C_v}^2 \left(gH - \frac{4fl}{d} \cdot \frac{\overline{V}^2}{2}\right)$$

The same expression as before, with the addition of C_v^2, the transmission efficiency of the nozzle. η_{tr} for the pipe is as before.

Reaction turbine: power characterisation

- Turbine fully submerged; water experiences a large pressure drop as it passes through the turbine.
- The kinetic energy of the flow leaving the turbine is often reduced by fitting a diffuser or draft tube.
- The energy equation for flow from 1 to 2 is now



$$\frac{P_1}{\rho} + \frac{V_1^{\;2}}{2} + gz_1 = \frac{P_2}{\rho} + \frac{V_2^{\;2}}{2} + gz_2 + \frac{4f.l}{d} \cdot \frac{\overline{V}^2}{2} + W_{out}$$

- Here, P_1, V_1, P_2 and V_2 are all zero:

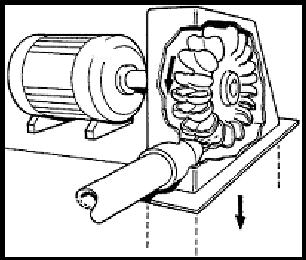
$$W_{out} = gH - \frac{4f.l}{d} \cdot \frac{\overline{V}^2}{2}$$

- The power delivered to the turbine is

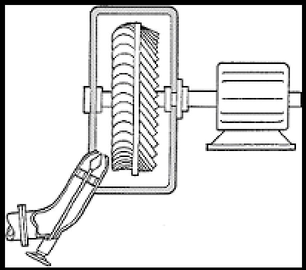
$$\rho Q\, W_{out} = \frac{\pi}{4}\rho d^2\overline{V}\left[gH - \frac{4f.l}{d} \cdot \frac{\overline{V}^2}{2}\right]$$

This is the same expression as the one derived earlier; the power delivered and transmission efficiency vary with flow rate as before.

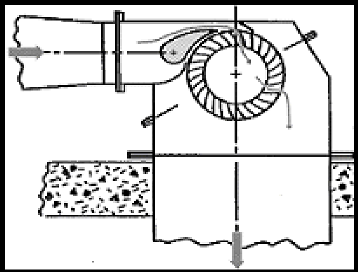
Turbine types



Pelton wheel: jet is split symmetrically by blades on the wheel; wheel can have up to 6 jets if mounted on vertical shaft.

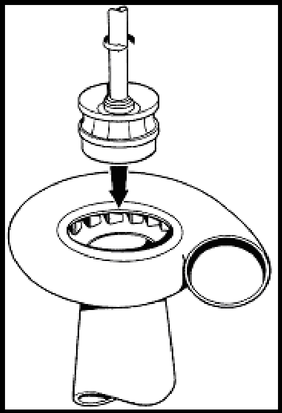


Turgo: jet passes through the wheel from left to right; it may have a larger diameter than the jet for a Pelton wheel of the same size.

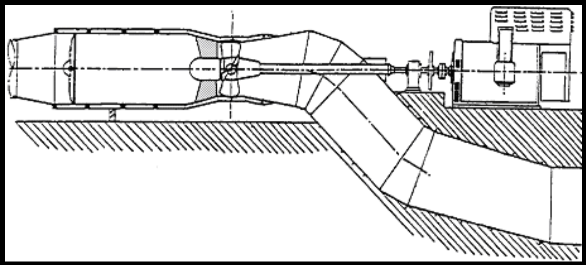


Cross-flow (or Banchi or Ossberger): has a cylindrical runner, and water passes through the blade ring twice. Runner may have several segments on the same axis, to deliver high efficiency for a wide range of flow rates. Runner has simple geometry, may be fabricated from sheet metal.

Turbine types



Francis: fed by water from a spiral casing, fitted with a ring of guide vanes immediately upstream of the runner. These may be adjusted to vary the volume flow rate through the machine. Water exits through a gently expanding draft tube.

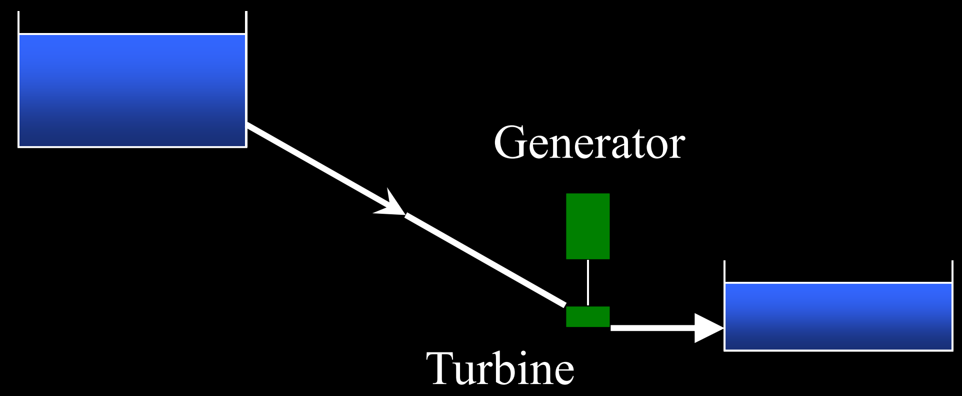


Propeller: an axial-flow machine, normally fitted with guide vanes as shown. If it has adjustable-pitch blades, it is known as a **Kaplan** turbine. It may also be installed with its shaft vertical.

All reaction turbines will operate efficiently as pumps; impulse turbines will not!

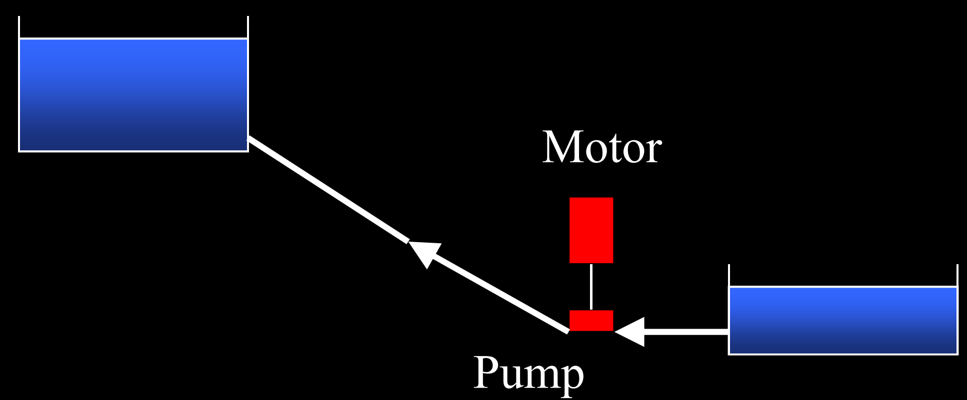
Hydraulic pumped storage

- In generating mode, the plant operates as a conventional hydro power plant.

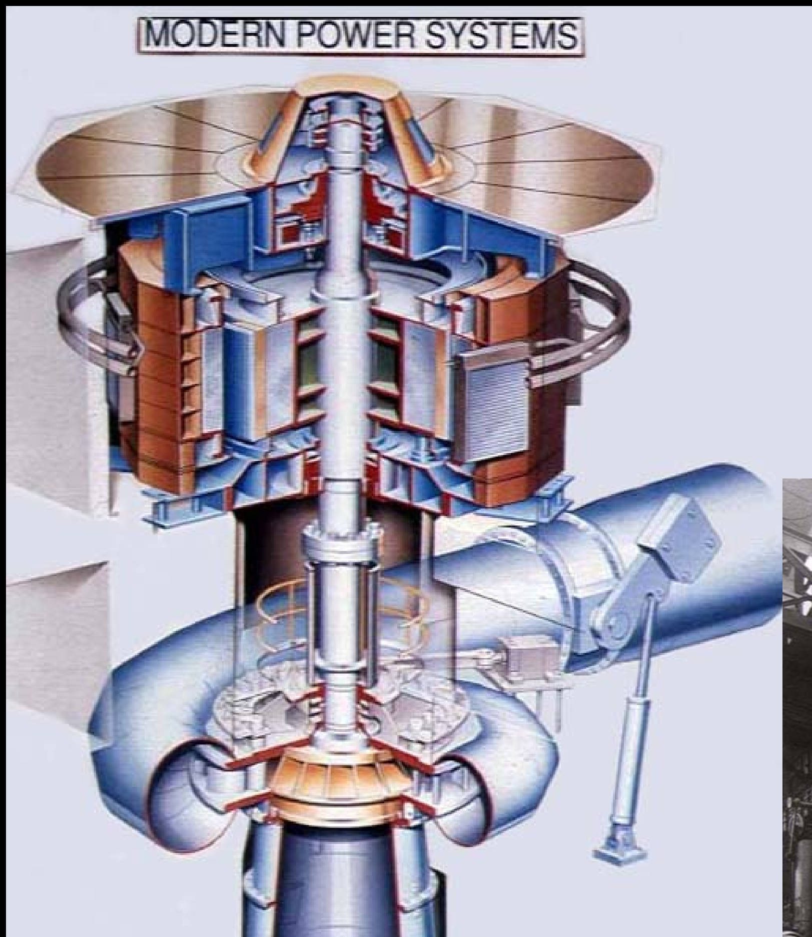


- But the generator can function as a motor, and the turbine as a pump.

- When demand for electricity is low, power may be taken from the grid to pump water into the upper reservoir, to act as an energy store for future use when demand for electricity is high.



Francis turbine



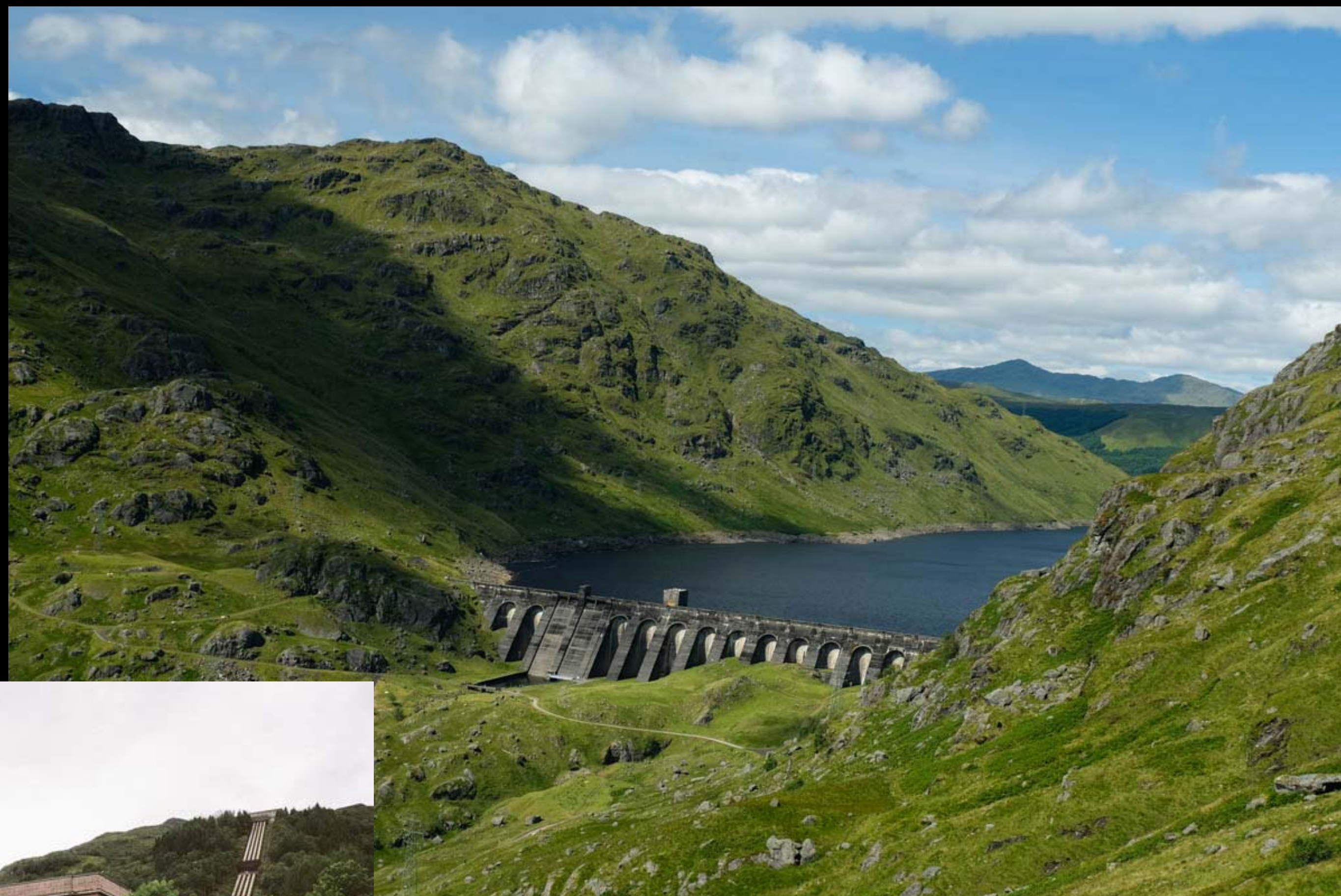
- Section showing the inlet valve and spiral casing, guide vanes, runner and draft tube.
- Direct shaft drive to the generator mounted above.

- Runner: being hand finished prior to delivery.

Wales, Cwm Dyli power station

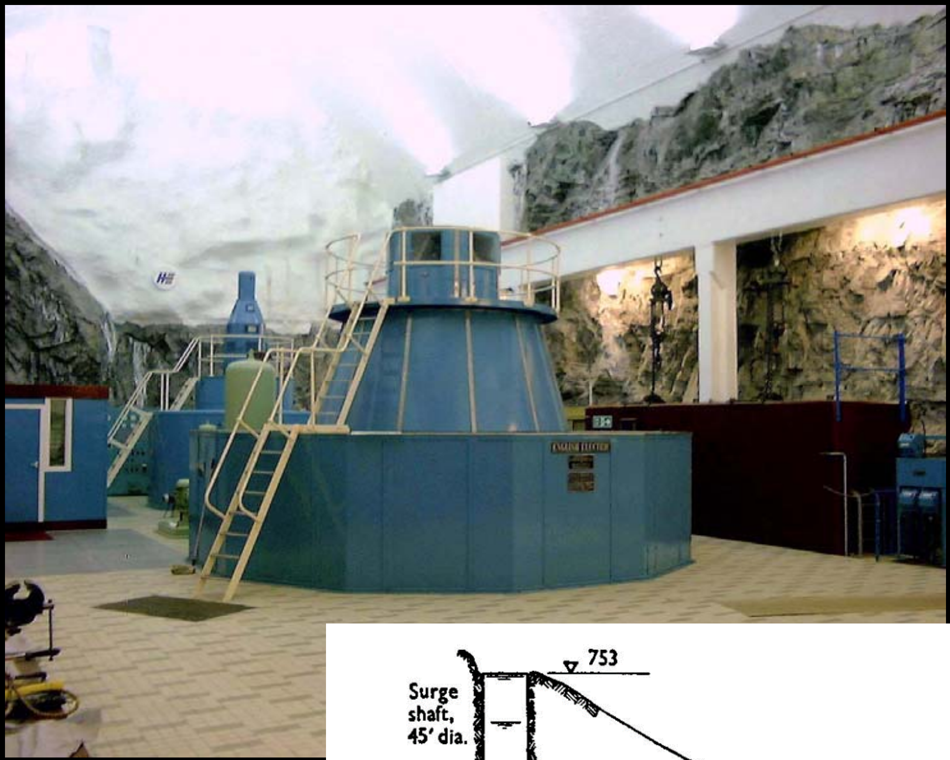
- Built in 1906; single turbine; capacity ~10MW . Still generating!

Scotland, Loch Sloy power station



- 280 m head, 150 MW rated output.

Scotland, Ceannacroc power station



- Underground power station near Fort Augustus.
- 90 m head.
- 20 MW power output from two turbines.

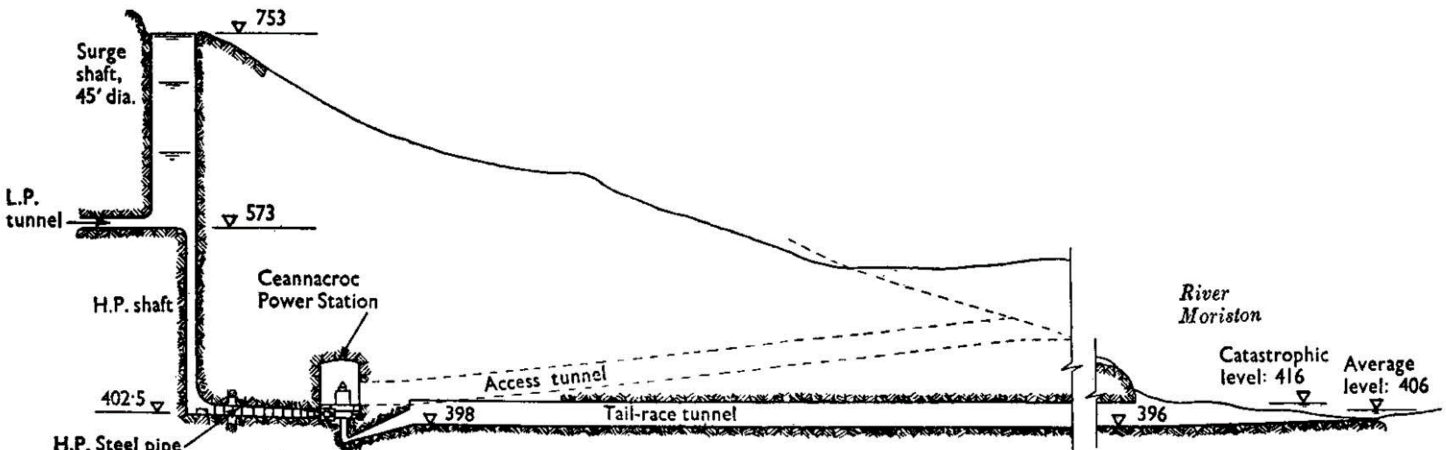


FIG.23.– PROFILE OF UPPER MORISTON (CEANNACROC) STAGE

The Institution of Civil Engineers. Proceedings, September 1958

Scotland, Cruachan power station

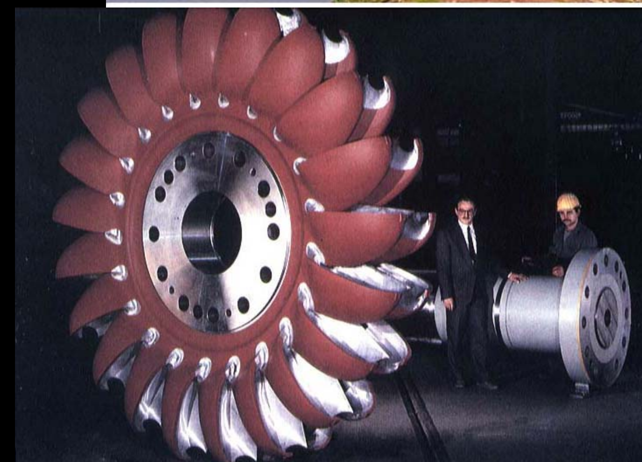
- Pumped storage scheme.
- Power station is underground, 400 m from the loch-side.
- 365 m head, 400 MW rated output.
- 4 Francis pump/turbine units.
- Aerial view shows upper reservoir and dam.
- Administration and visitor centre located on the shore of Loch Awe.

Scotland, Clunie dam (Pitlochry) power station

- 60MW capacity.
- A fish ladder gives access to the upper reservoir.

Scotland, Glendoe power station

- Scotland's latest hydro power scheme located near Fort Augustus, Loch Ness opened June 2009. £160m scheme.
- 600 m head.
- Water flows through a 5 m dia. by 8 km tunnel.
- The head is by far the largest used so far for a major Scottish hydro power scheme.
- An impulse turbine is used, in this case a multi-jet Pelton wheel with rated power of 100 MW.
- Closed August 2009- August 2012 after tunnel collapse. £100m repair cost.



A Pelton wheel rated at 117 MW under a head of 686 m.

A 6-jet Pelton wheel, rated at 122 MW under a head of 650 m; Aoos River, Greece

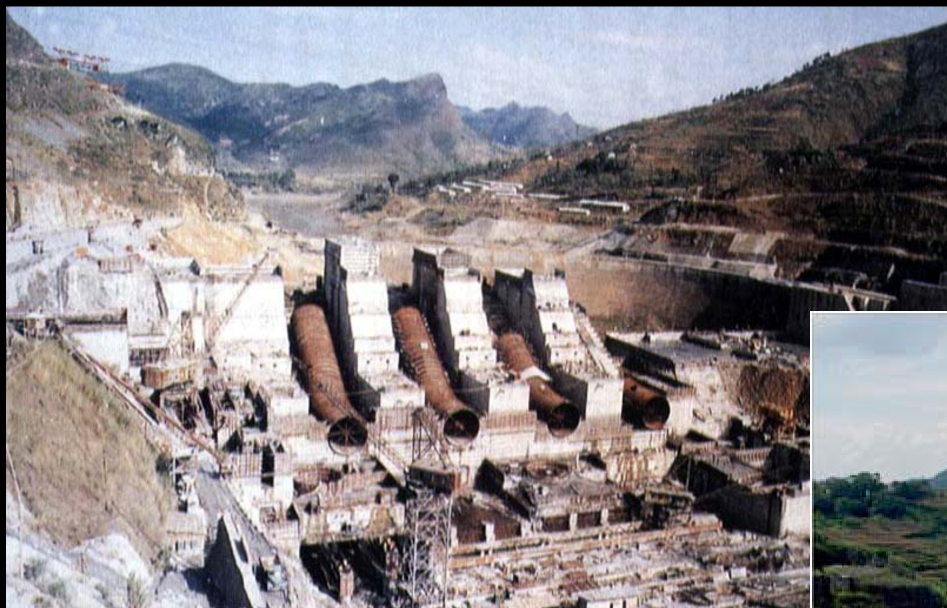
Germany, Augst-Whylen power station

- Large run-of-river scheme (Rhine) comprising 13 Kaplan turbines.
- Central barrier is opened when there is a danger of flooding.
- The flow passes through turbines on both sides of the main channel.
- Kaplan turbine runner is 8.4 m in diameter and has a 20.5 MW rating.

China, Longyang dam power station

- 178 m head.
- Incorporates 3 turbines each rated at 320 MW.

ChinaYantan power station



- 1200 MW pumped storage scheme.

China, Guangzhou power station

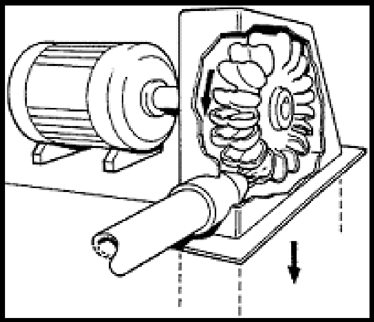
- 1200 MW pumped storage scheme.

Three Gorges Dam

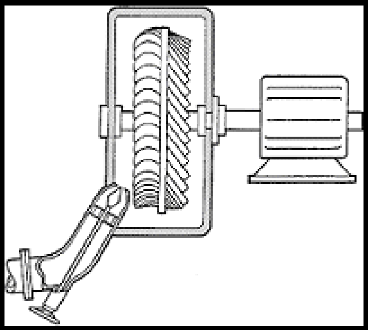
- world's largest power generation capacity of 22.5 GW (highest energy output Itaipu hydroelectric scheme)
- main generation from 26 x 700MW Francis turbines (75 rpm with 86m head)
- 600km long reservoir
- cost £38 bn
- 1.3 million people displaced

Mini and micro-hydro

- Systems with rated output from a few kW upwards.
- Flow rates generally small (moderate head), so an impulse turbine may be used because of its simplicity and ease of control.

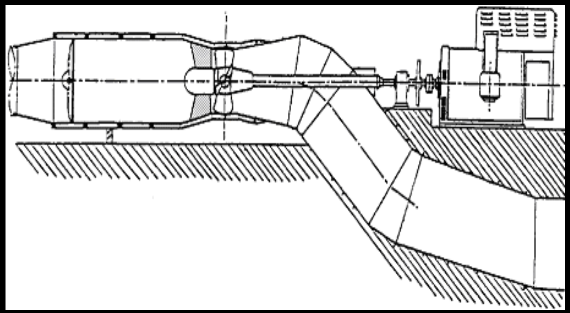


Pelton wheel

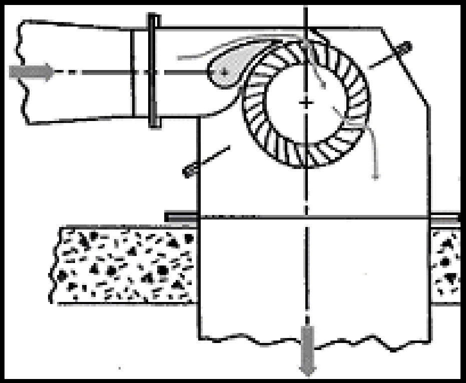


Asymmetric turbine

- Where the flow rate is larger, a different approach must be adopted:



Conventional REACTION turbine (propeller type shown)



CROSSFLOW design, with a cylindrical rotor which can be fabricated from sheet metal (a cheaper alternative).

Environmental/social issues

- ❑ Flooding of useful land.
- ❑ Population displacement.
- ❑ Risk of catastrophe.
- ❑ Interference with water supplies.
- ❑ Interference with fishing.
- ❑ Local eco-system damage during construction.
- ❑ Visual impact of dams and power stations.
- ❑ Visual impact of pipelines.
- ❑ Visual impact of transmission lines.
- ❑ Increased seismic activity

- ❑ Capital cost: $8k-$16k/kW capacity (~90% site, 10% equipment)