HYDRO POWER

INTRODUCTION

- The term hydro-power is usually restricted to the generation of shaft power from falling water
- The power is then used for direct mechanical purposes or, more frequently, for generating electricity
- Other sources of water power are waves and tides

SMALL HYDRO POWER

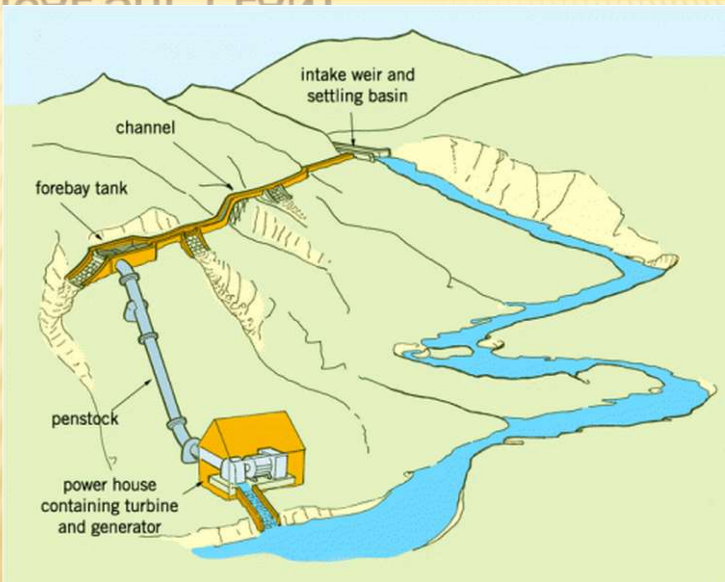
- Up to 25 MW capacity projects

Class	Capacity (kW)
Micro	Up to 100
Mini	101-2000
Small	2001-25000

The estimated potential for power generation in the country from such plants is about 20 GW

Most of the potential is in Himalayan States as river-based projects and in other States on irrigation canals

TYPICAL SHP PLANT



MAIN COMPONENTS

Civil Works

- The cost of civil works for small hydro accounts for about 50-60% of the total cost
- A low dam or simple diversion weir made of concrete, wood or masonry is mostly used in small hydro
- Valves and gates at the entrance and exit of turbines are used to shut off flow during maintenance
- Settling basins for settling and excluding the sediment from entering the turbines
- A forebay is also used upstream of the penstock to balance the fluctuations in the water levels during sudden operation and shutdown of the turbines
- When a tunnel is used for water conveyance, a surge tank is used to avoid the impacts of sudden opening and shutting down of power generation.

ENERGY CONVERSION

- Hydro turbines have a rapid response for power generation, power may be used to supply both base load and peak demand requirements on a grid supply

Reaction turbines: the turbine is totally embedded in the fluid and powered from the pressure drop across the device

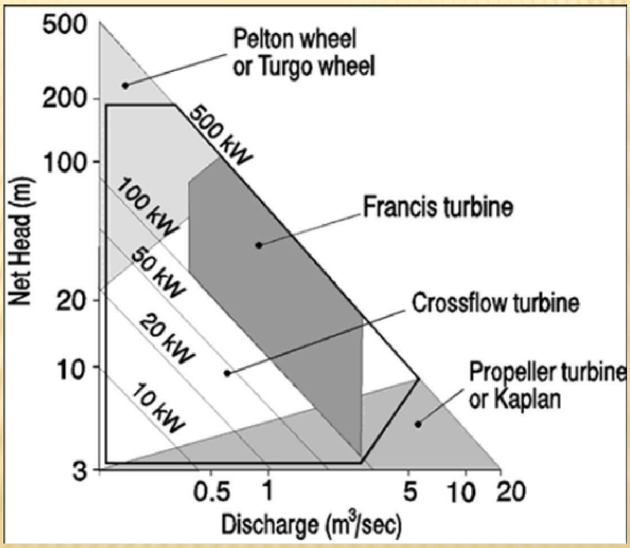
Impulse turbines: flow hits the turbine as a jet in an open environment, with the power deriving from the kinetic energy of the flow

ESTIMATION OF POWER

$$P = \eta \rho g Q H$$

$P = power$ (in Watts or kilo Watts)
$\eta = system\ efficiency$
$\rho = density\ of\ water$ (for water, $\rho = 1000\ kg/m^3$)
$g = acceleration\ due\ to\ gravity$
$Q = flowrate$ (or discharge in m^3/s)
$H = available\ head$ (m of water)

HEAD – FLOW RANGE



ENERGY ANALYSIS OF SHP

- The mechanical energy of a flowing fluid can be expressed on a unit mass basis as

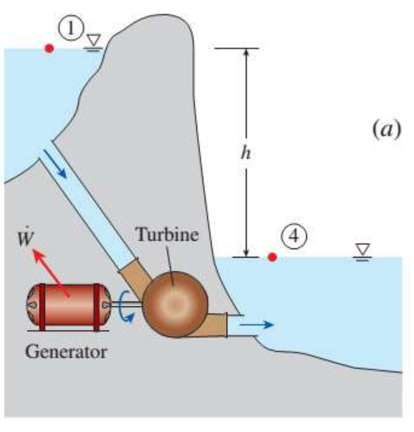
$$e_{\text{mech}} = \frac{P}{\rho} + \frac{V^2}{2} + gz$$

The mechanical energy change of a fluid during incompressible flow:

$$\Delta e_{\text{mech}} = \frac{P_2 - P_1}{\rho} + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)$$

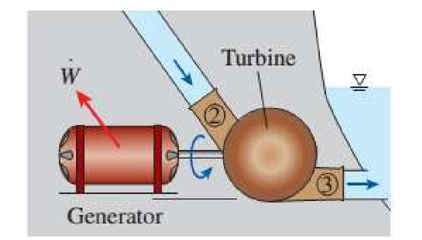
The maximum (ideal) power generated by a turbine

$$\dot{W}_{\max} = \dot{m}\Delta e_{\text{mech}}$$



$$\dot{W}_{\max} = \dot{m}\Delta e_{\text{mech}} = \dot{m}g(z_1 - z_4) = \dot{m}gh$$
since $P_1 \approx P_4 = P_{\text{atm}}$ and $V_1 = V_4 \approx 0$

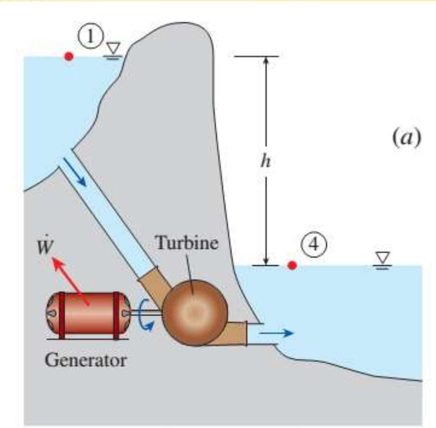
$$\eta_{\text{turbine}} = \frac{\dot{W}_{\text{shaft}}}{\Delta \dot{E}_{\text{mech, fluid}}} = \frac{\dot{W}_{\text{shaft}}}{\dot{m}\Delta e_{\text{mech}}} = \frac{\dot{W}_{\text{shaft}}}{\dot{m}gh} = \frac{\dot{W}_{\text{shaft}}}{\dot{W}_{\max}}$$



$$\eta_{\text{generator}} = \frac{\dot{W}_{\text{electric}}}{\dot{W}_{\text{shaft}}}$$

$$\eta_{\text{turbine-generator}} = \eta_{\text{turbine}}\eta_{\text{generator}} = \frac{\dot{W}_{\text{shaft}}}{\dot{W}_{\text{max}}}\frac{\dot{W}_{\text{electric}}}{\dot{W}_{\text{shaft}}} = \frac{\dot{W}_{\text{electric}}}{\dot{W}_{\text{max}}}$$

$$\frac{P_1}{\rho_1} + \frac{V_1^2}{2} + gz_1 = \frac{P_2}{\rho_2} + \frac{V_2^2}{2} + gz_2 + w_{\text{turbine}} + e_{\text{mech, loss}}$$



$$\dot{W}_{\text{max}} = \dot{m}\Delta e_{\text{mech}} = \dot{m}g(z_1 - z_4) = \dot{m}gh$$
since $P_1 \approx P_4 = P_{\text{atm}}$ and $V_1 = V_4 \approx 0$

$$\eta_{plant} = \frac{\dot{W}_{elec}}{\dot{W}_{max}} = \frac{\dot{W}_{elec}}{\rho Q g H_{gross}}$$

$h = H_{\text{gross}}$

$$\eta_{\text{plant}} = \eta_{\text{generator}}\eta_{\text{turbine}}\eta_{\text{piping}}$$

$$\eta_{\text{turbine}} = \frac{\dot{W}_{\text{shaft}}}{\rho g \dot{V} H_{\text{net}}}$$

$$\eta_{\text{turbine}} = \frac{\dot{W}_{\text{shaft}}}{\dot{W}_{\max} - \dot{E}_{\text{mech,loss,piping}}} = \frac{\dot{W}_{\text{shaft}}}{\rho g \dot{V} H_{\text{gross}} - \rho g \dot{V} h_L} = \frac{\dot{W}_{\text{shaft}}}{\rho g \dot{V}(H_{\text{gross}} - h_L)}$$

$$\eta_{\text{piping}} = 1 - \frac{\dot{E}_{\text{mech, loss, piping}}}{\dot{W}_{\max}}$$

$$\begin{aligned}
\eta_{\text{plant}} &= \eta_{\text{generator}}\eta_{\text{turbine}}\eta_{\text{piping}} \\
&= \left(\frac{\dot{W}_{\text{electric}}}{\dot{W}_{\text{shaft}}}\right)\left(\frac{\dot{W}_{\text{shaft}}}{\dot{W}_{\max} - \dot{E}_{\text{mech,loss,piping}}}\right)\left(1 - \frac{\dot{E}_{\text{mech,loss,piping}}}{\dot{W}_{\max}}\right) \\
&= \left(\frac{\dot{W}_{\text{electric}}}{\dot{W}_{\text{shaft}}}\right)\left[\frac{\dot{W}_{\text{shaft}}}{\dot{W}_{\max}(1 - \dot{E}_{\text{mech,loss,piping}} / \dot{W}_{\max})}\right]\left(1 - \frac{\dot{E}_{\text{mech,loss,piping}}}{\dot{W}_{\max}}\right) \\
&= \frac{\dot{W}_{\text{electric}}}{\dot{W}_{\max}}
\end{aligned}$$

- Some engineers are evaluating potential sites for a small hydroelectric power generation . At one such site, the gross head is 650 m, and they estimate that the volume flow rate of water through each turbine would be 1.5 m^3/s. Estimate the ideal power production per turbine in MW. The density of water at T = 20°C is 998.0 kg/m^3

$$\dot{W}_{ideal} = \rho g \dot{V} H_{gross}$$

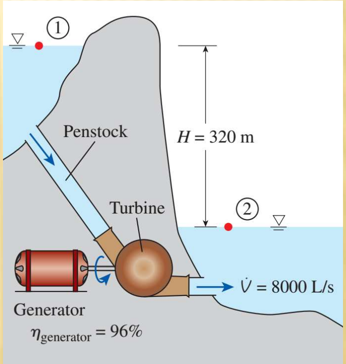
Same as Q (discharge in m^3/s)

$$= \mathbf{9.55\ MW}$$

If a hydroelectric dam were to be built on this site, the actual power output per turbine would be smaller than this, due to inefficiencies.

The water in a reservoir is to be used to generate electricity by the installation of a hydraulic turbine. The elevation difference between the free surfaces upstream and downstream of the reservoir is 320 m. Water is to be supplied to the turbine at a rate of 8000 L/s. The turbine efficiency is 93% based on the net head, and the generator efficiency is 96 %.The total irreversible head loss (major losses + minor losses) in the piping system including the penstock is estimated to be 7.5 m.

Determine the overall efficiency of this hydroelectric plant, the electric power produced, and the turbine shaft power.



$\dot{W}_{max} = \rho Q g H_{gross}$

$$= (1\ \text{kg/L})(8000\ \text{L/s})(9.81\ \text{m/s}^2)(320\ \text{m})\left(\frac{1\ \text{kJ/kg}}{1000\ \text{m}^2/\text{s}^2}\right)$$
$$= 25{,}115\ \text{kW}$$

$\{h_L = \text{head loss}\}$

$\dot{E}_{mech, loss, piping} = \rho Q g h_L$

$$= (1\ \text{kg/L})(8000\ \text{L/s})(9.81\ \text{m/s}^2)(7.5\ \text{m})\left(\frac{1\ \text{kJ/kg}}{1000\ \text{m}^2/\text{s}^2}\right)$$
$$= 589\ \text{kW}$$

$$\eta_{\text{plant}} = \eta_{\text{generator}}\eta_{\text{turbine}}\eta_{\text{piping}} = (0.96)(0.93)(0.977) = 0.872 \text{ or } \mathbf{87.2\ percent}$$

$$\eta_{\text{plant}} = \frac{\dot{W}_{\text{electric}}}{\dot{W}_{\text{max}}} \longrightarrow \dot{W}_{\text{electric}} = \eta_{\text{plant}}\dot{W}_{\text{max}} = (0.872)(25{,}115\ \text{kW}) = \mathbf{21{,}895\ kW}$$

$$\eta_{\text{turbine}} = \frac{\dot{W}_{\text{shaft}}}{\dot{W}_{\text{max}} - \dot{E}_{\text{mech, loss, piping}}}$$

$$\dot{W}_{\text{shaft}} = \eta_{\text{turbine}}(\dot{W}_{\text{max}} - \dot{E}_{\text{mech, loss, piping}})$$
$$= (0.93)(25{,}115\ \text{kW} - 589\ \text{kW})$$
$$= \mathbf{22{,}810\ kW}$$