Hydroelectric Power Plants

Hydro Power Generation

- Use of potential (location, pressure) and partly kinetics energy of water flow
- Use of hydroenergetic potential of water flows has some advantages when compared to other power sources:
  - Renewable and clean source of energy
  - Use of own resources (independency on other counties)
  - Low investments and operating costs
  - Low failure rate, long life-time and high number of operating hours

Classification

- With respect to the installed power
  - **smal** with installed power up to 10 MW
  - **medium** with installed power from 10 MW to 200 MW
  - **large** with installed power more than 200 MW
- With respect to the method of needed high creation
  - **run-of-the-river** the water head is created by a weir on river
  - **derivative** artificial channel or pipe
  - **reservoir** head is created by a dam
  - **pump-storage** pump water over upper reservoir
  - **tidal** sea ebb and flow
- According to availability of water head
  - **low head** up to 20 m
  - **medium head** from 20 m to 100 m
  - **high head** more than 100 m

Hydroelectric potential energy

- Can be estimated according to the formula
$$P = Q\rho g H$$

where *P* is power (W), *Q* is water flow (m³/s), *ρ* is the specific weight of water, *H* is hydraulic head (m)

- The real potential energy is smaller and for preliminary estimation can be determined as:
$$P = k_T Q H$$

where k_T is a multiplicative factor, k_T=8 for low pressure turbines of larger dimensions, k_T=7 for low pressure turbines of small dimensions, k_T=6,5 for low pressure unregulated turbines of micro sources

Hydroelectric potential energy
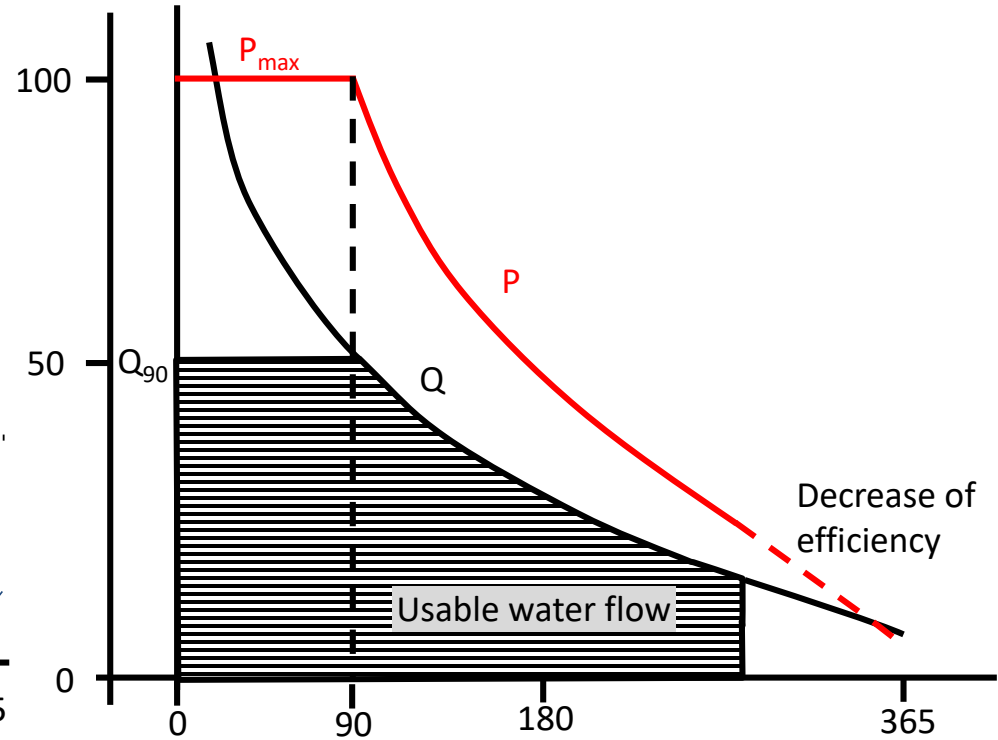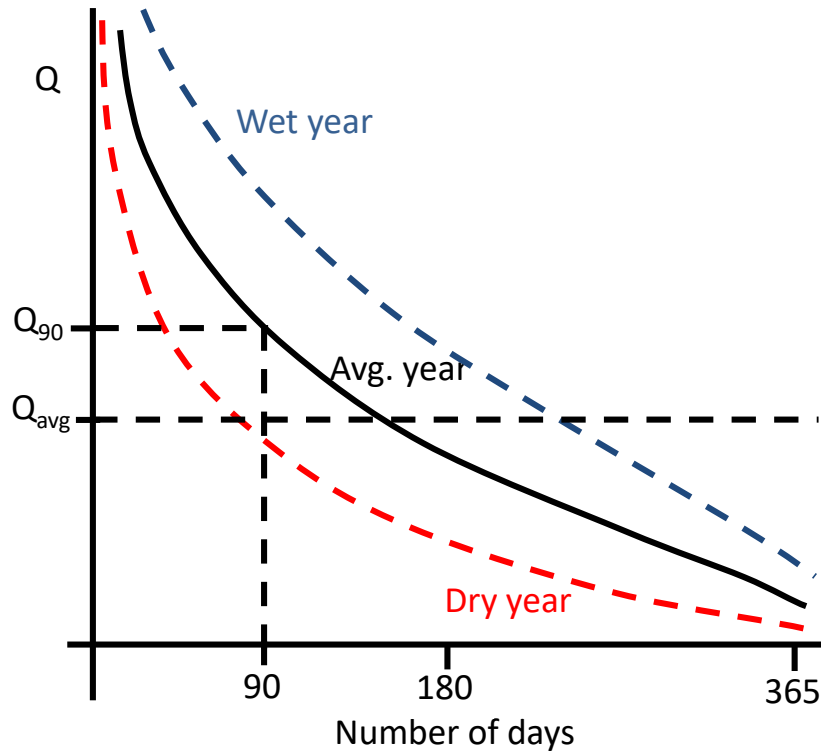
Total hydroelectric potential

- Generated electric power

$$P_s = Qg\rho H\eta_T\eta_P\,\eta_G$$

where η_T is turbine efficiency (0,6-0,9), η_P is efficiency of torque transfer to the generator shaft (0,94-0,97) and η_G is generator efficiency (0,95-0,97 for MW powers)

Hydro turbines speed

- Operating speed of different hydro turbines with various parameters are in the range from 53 to 1500 rpm

- Estimation of nominal turbine speed:

$$n = 1{,}166 \ \frac{n_s H \sqrt[4]{H}}{\sqrt{P_T}}$$

where n is the nominal speed of a turbine (rpm), n_s is the specific speed of a turbine, H is head (m), P_T is power on the shaft of turbine (kW).

Specific speed of hydro turbine

- The specific speed of a turbine is the speed of a geometrically similar turbine (model) so that at the head of 1 m a turbine produces the power of 1 kW

- From geometrical similarity the specific speed can be formulated as

$$n_s = \frac{n}{H^{\frac{5}{4}}} \sqrt{P}$$

where n is turbine speed, P is turbine power and H is hydraulic head.

Specific speeds of turbines	
Type of turbine	Usual range of n_s (1/min)
Pelton	4 - 32
Banki	70 - 150
Francis	50 - 450
Kaplan	300 - 1000

Types of hydro turbine

Pelton

Francis

Kaplan

$n_q = 6$

$n_q = 30$

$n_q = 140$

$n_q = 10$

$n_q = 110$

$n_q = 220$
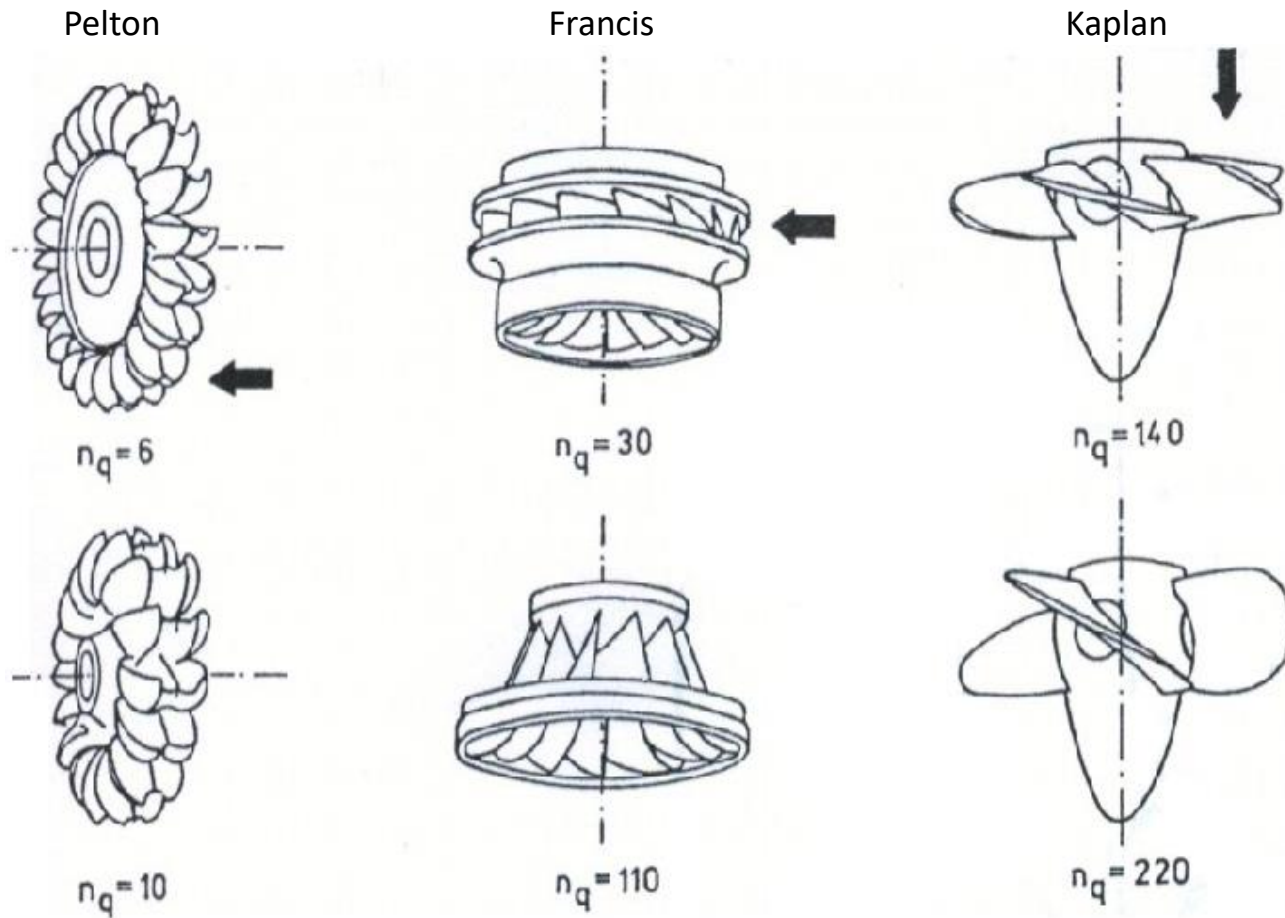
Francis turbine

- Reaction turbine

- Water is directed to blades by guide vanes

- The water outlet is a draft tube with conical shape that creates lower pressure (vacuum)

Guide vanes

Turbine blades

Spiral casing

Draft tube
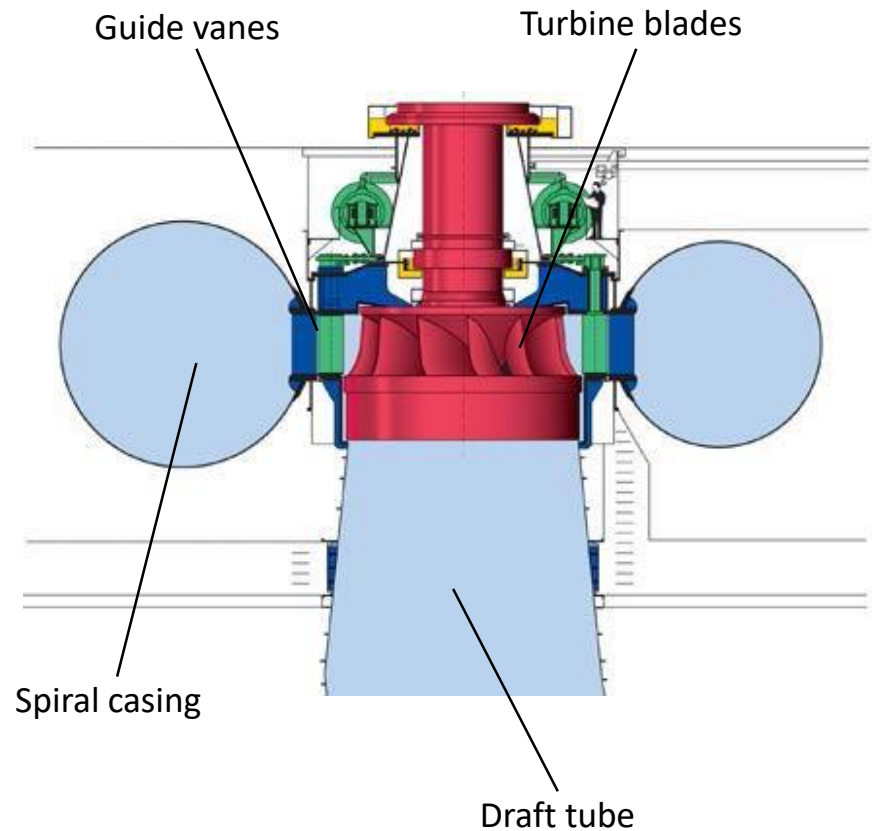
Kaplan turbine

- Axial reaction turbine with lower number of blades
- Power can be controlled by rotation of blades and guide vanes
- Most often used for large water flows and small hydraulic heads
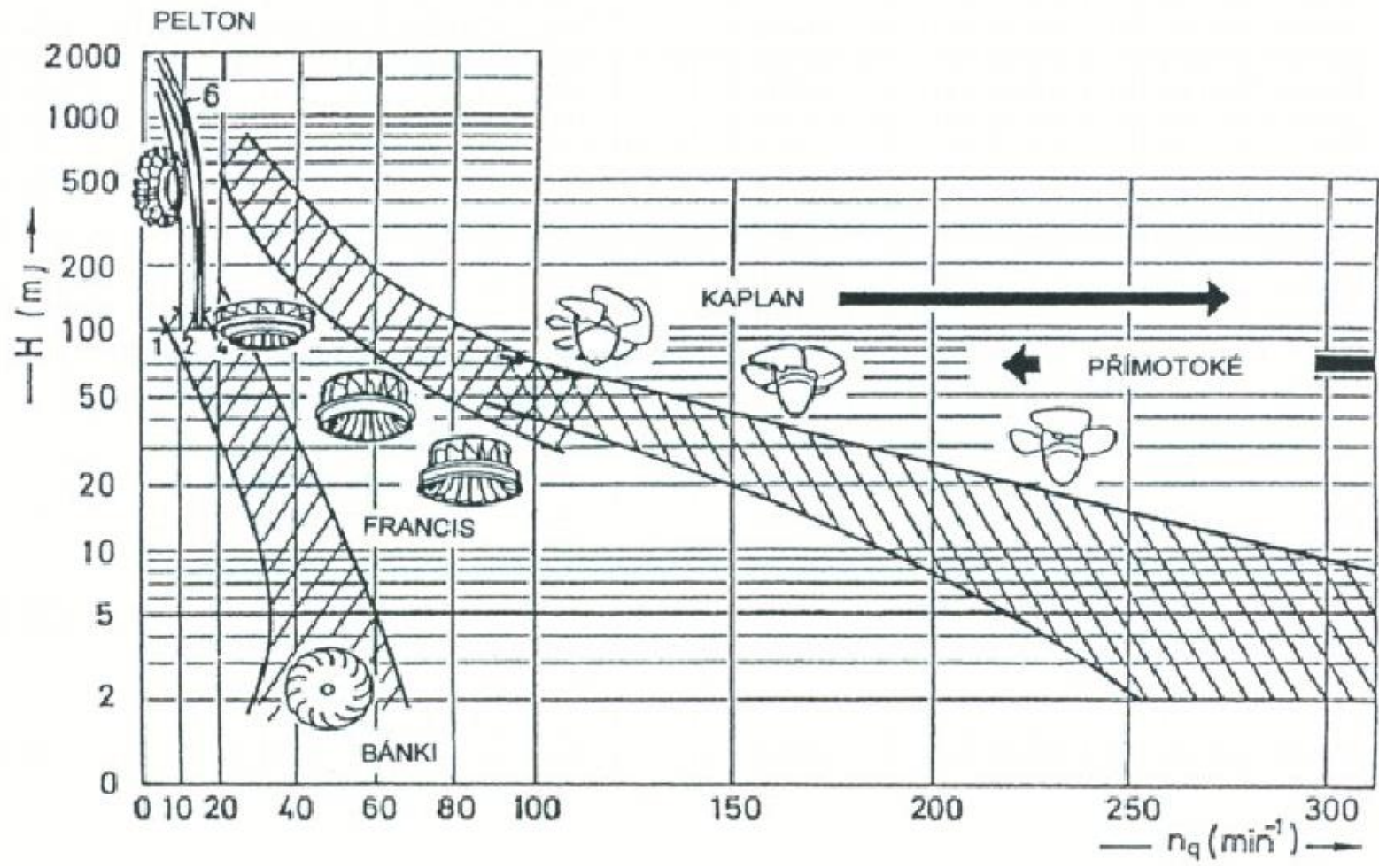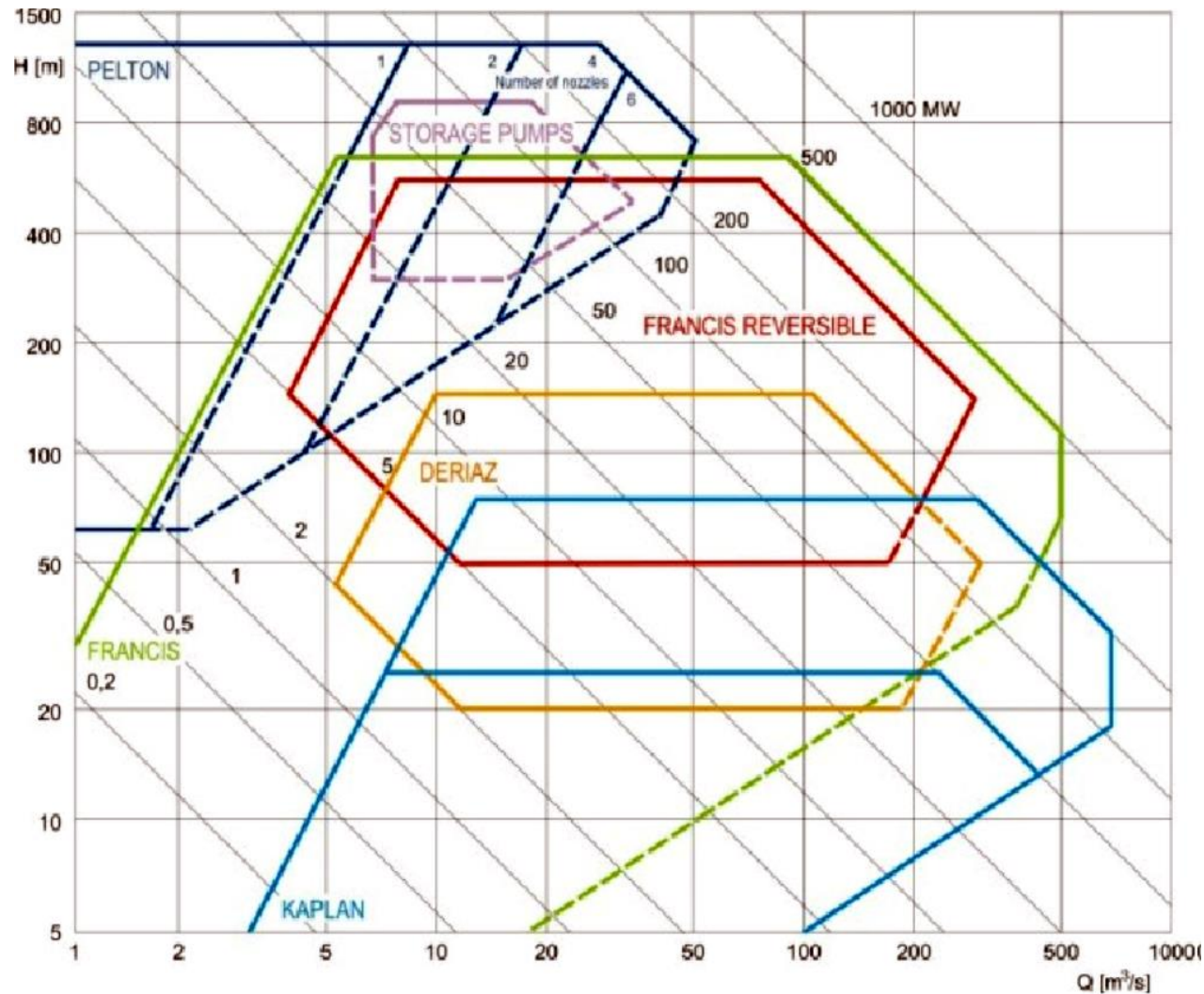
Guide vanes   Turbine blades
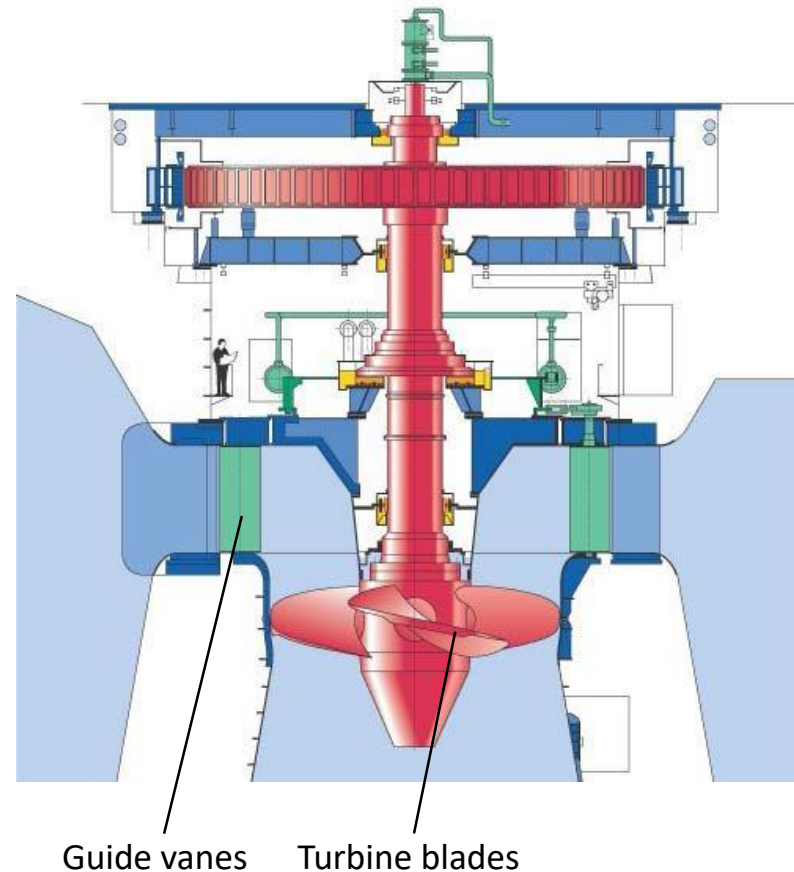
Pelton turbine

- Impulse turbine, the water from nozzle tangentially enters turbine blades

- Turbine power can be controlled by change of nozzles cross section

- A fast drop of power can be realized by deflection of water beam.
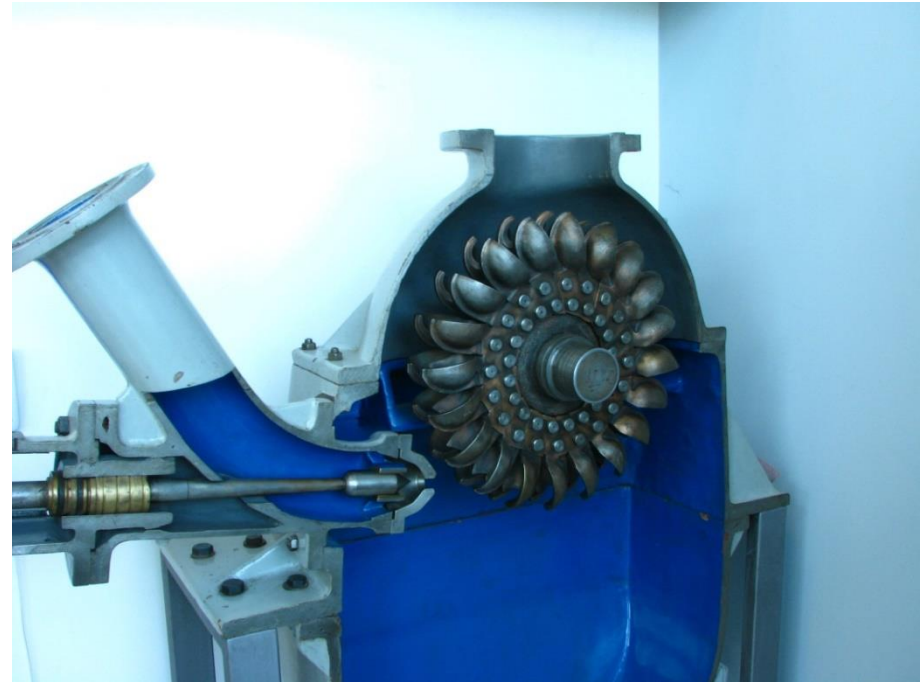
# Regions of operation of hydro turbines

# Regions of operation of hydro turbines – Q/H diagram

Run-of-the-river hydro power plants

- Small or no water storage is provided
- Energy generation mainly for the base load
- For low heads, the head depends on water flow, for large amounts of water (high flows) the low level of water can be equalized with higher level
- Power increases with water flow at first, then after the maximum is reached, it declines to zero value
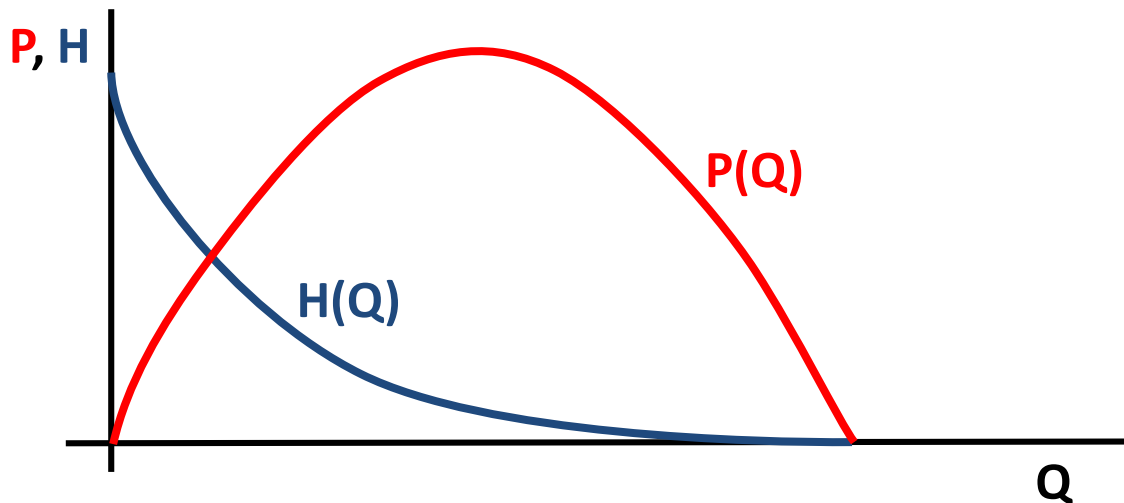
Reservoir (Dam) hydro power plants

- Typically a large hydropower system, uses a dam to store river water in a reservoir (artificial or natural)
- Energy generation mainly for peak or intermediate load (ability of wide power control)
- The reservoir has to provide energy accumulation for some time
- The volume of reservoir is split into three parts: V_∞ volume of permanent retention, V_u useable volume and V_r protective volume
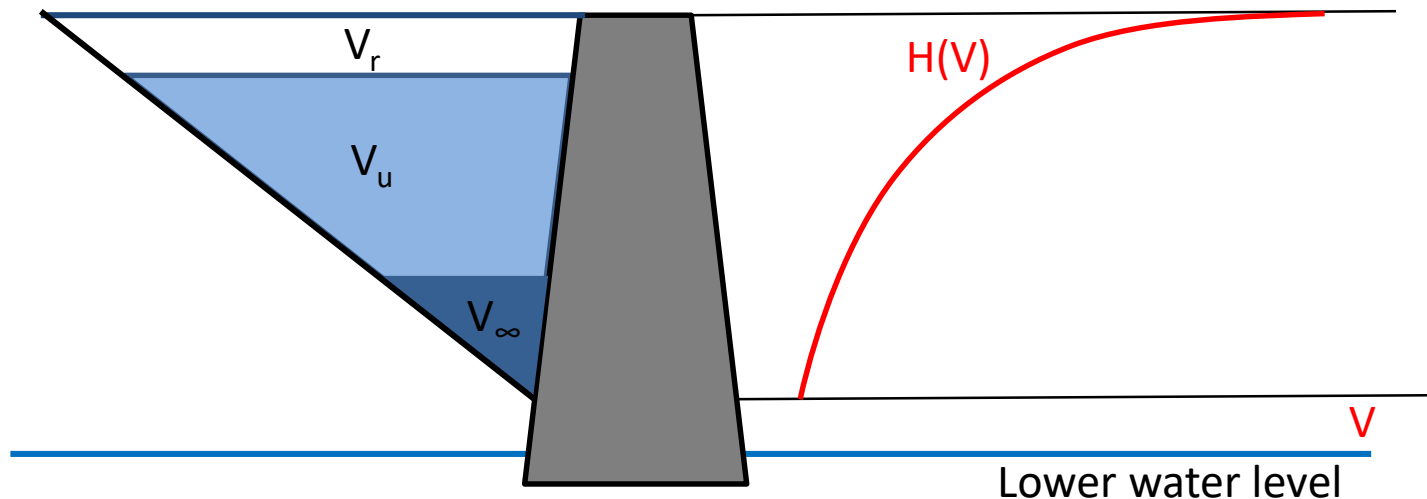
Pump-storage hydro power plants

- Three vertically arranged machines: turbine-motor-pump or two vertically arranged machines with reversal turbine (turbine/pump) – nowadays more frequent configuration
- Mainly for the load diagram balancing, fast synchronization to grid and increase in power, efficiency 60-70%