Renewable and Alternative Energies

Topic 4. Hydropower

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Topic 3. Ocean energy

- **4.1. Hydropower facilities**.
- **4.2.** Hydropower resources management.
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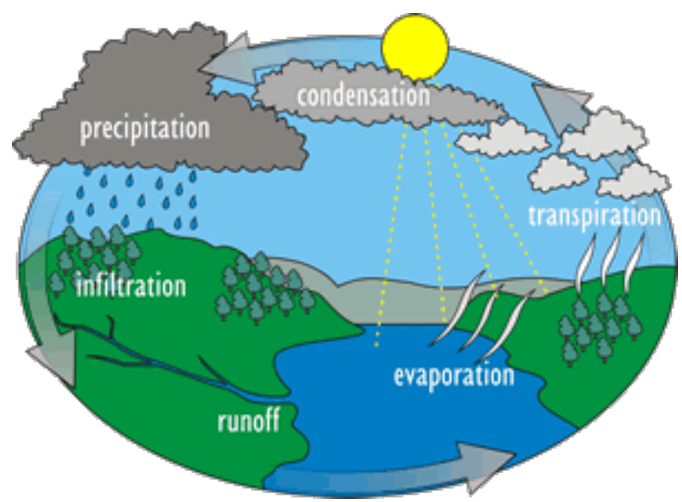
4.1. Hydropower facilities

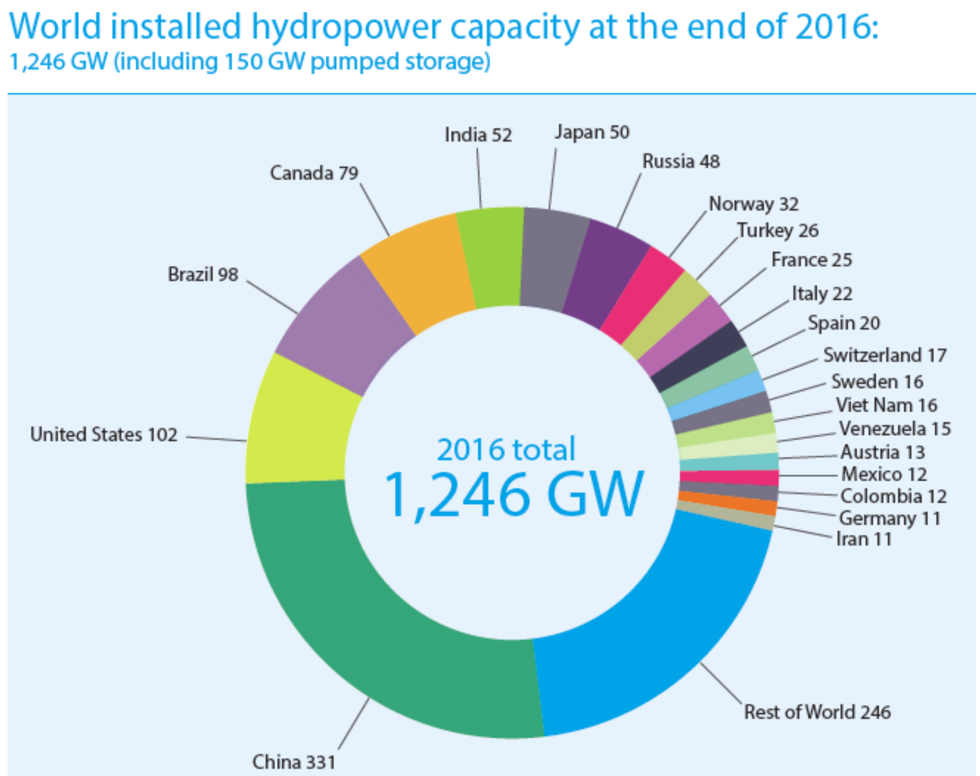
- **Hydropower** generating plants **capture the kinetic energy of falling water**, such as from a river and waterfalls, **to generate electricity**.
- A **turbine and a generator convert** the kinetic energy from water, **first to mechanical energy and then to electrical energy** using a generator.
- **Solar energy heats water** of the river, ocean, and any other water reservoir open to the atmosphere, **causing it to evaporate**. As the water vapor rises to the upper atmosphere, and cools down, **it condenses** into clouds **and falls** back onto the surface **as precipitation** (rain water).
- Hydropower **is** considered **a renewable energy source since** the water cycle **is a continuous cycle**.
- The **water flows through rivers**, back **into oceans**, where it again evaporates **and begins the cycle over again**.



4.1. Hydropower facilities

WORLD (2017 Key Trends in Hydropower, International Hydropower Association)

- It is the **world's most widely-used renewable energy** representing 20% of production.
- The **top countries** for hydro capacity are China, the United States, Brazil, Canada, and India, accounting for 56% of total installed capacity.

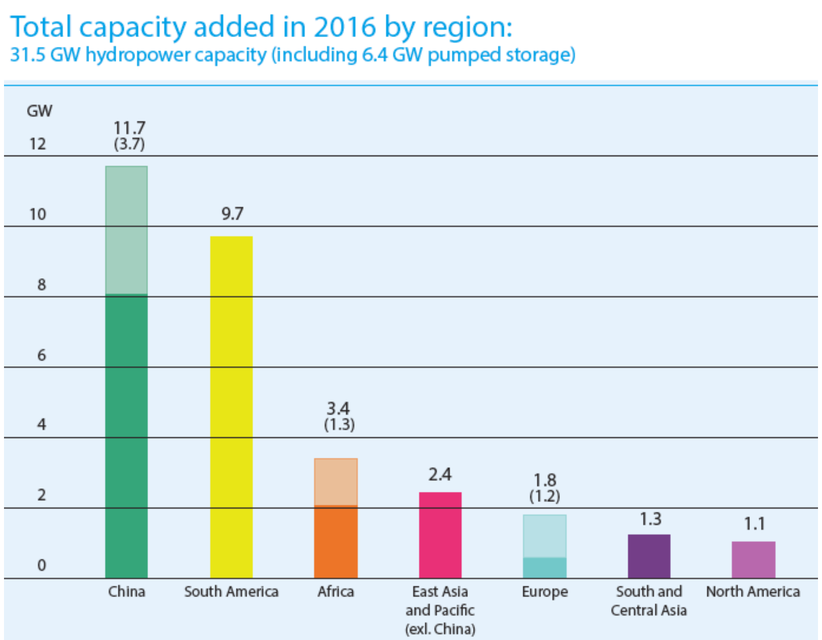


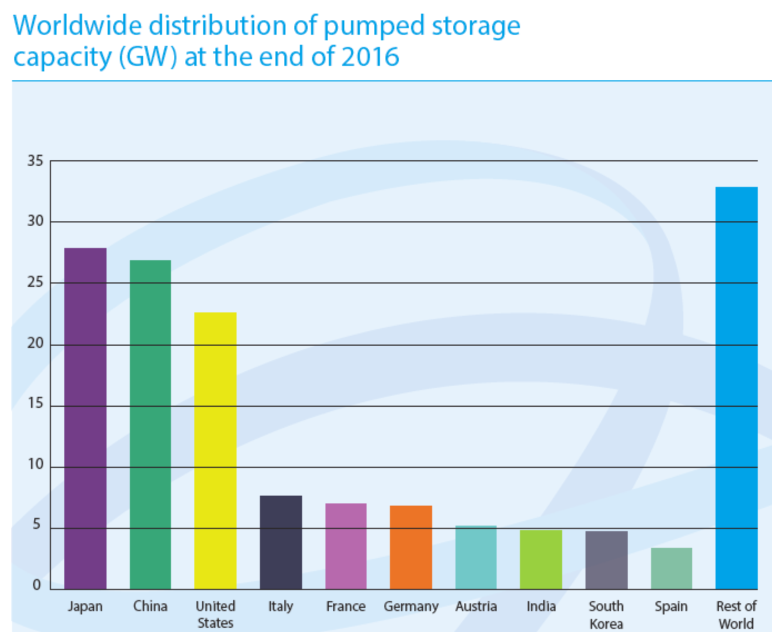
The Chinese Three Gorges (22.5 GW) plant.

4.1. Hydropower facilities

WORLD (2016 Key Trends in Hydropower, International Hydropower Association)

- An estimated 31.5 GW of new hydropower capacity came online in 2016, increasing **global installed capacity** to an estimated **1246 GW**.





4.1. Hydropower facilities

Spain

- Spain is the **fourth country** in installed hydroelectricity **within the EU**, representing 10% of the total installed energy.
- It has an **important** and consolidated **hydroelectricity generating system** due to the **tradition** of this technology in the country and the large amount of dams with a total capacity of **55,000 Hm^3**.
- In **recent years** there has been a **decrease in hydropower contribution** to the electric system in favor of other renewable energies. Nevertheless it is one of the most productive renewable resources along with wind energy.
- In 2016, the hydroelectricity contribution was 1**4.6% of the total energy** production in Spain.

Topic 3. Ocean energy

- **4.1.** Hydropower facilities.
- **4.2. Hydropower resources management**.
- **4.3.** Types of turbines.

4.2. Hydropower facilities

Hydropower systems

Hydropower systems can be divided in the following 2 ways:

a) According to **construction** methods.

b) According to **size**.

There are 3 types of hydropower systems based on construction methods:

1) Impoundment.

2) Diversion or run-of-river.

3) Pumped storage.

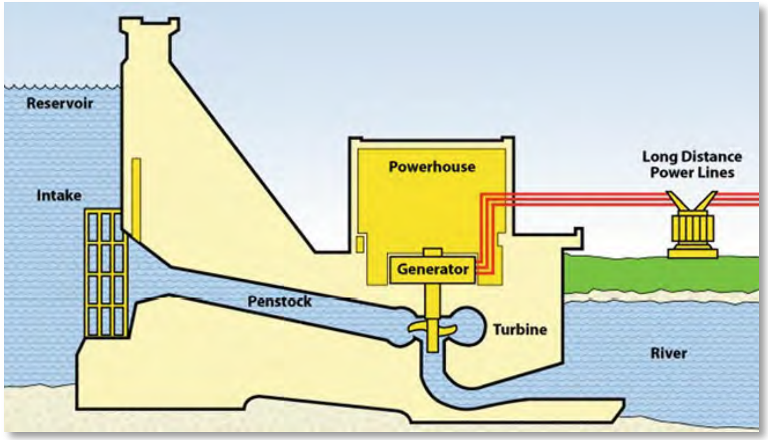
- Large hydropower systems (from 5,000 to 10,000MW) supply electricity to a great number of consumers whereas small or micro hydropower plants meet the energy needs of just a small population. These systems are also divided into three categories based on their size:
  - **Large hydropower** (> 30 MW).
  - **Small hydropower** (100 kW-30 MW).
  - **Micro hydropower** (< 100 kW).

4.2. Hydropower facilities

Hydropower system construction methods

1) Impoundment:

- Most of the **large hydropower systems** are impoundment type.
- A dam is **used to store river water in a reservoir**. Water released from the reservoir flows through a turbine to generate electricity. The water may be released either to meet changing electricity needs or to maintain a constant reservoir level.
- The **main components** that are constructed on site of an impoundment hydropower system are:
  - **1.1.** Dam.
  - **1.2.** Spillway.

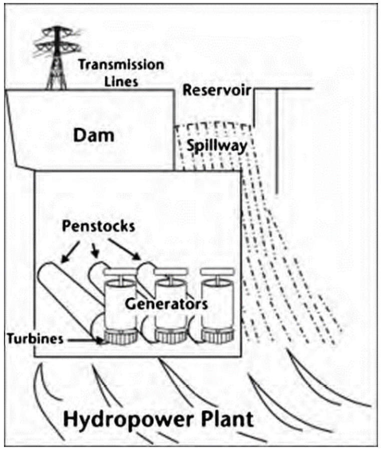


4.2. Hydropower facilities

Impoundment

1.1. Dam:

- A **dam is built to raise the water level of the river** to create a falling water system. This also controls the flow of water.
- The reservoir of a dam basically **stores the energy in the form of potential energy**. When water flows down from the reservoir into a turbine, this potential energy is converted to kinetic energy that rotates the turbine blades.
- The main factor that needs to be considered is the **ability of the dam to withstand the build-up of pressure from the water** behind it.
  This will determine the type and capacity, of a dam to be constructed and construction materials. The construction materials should be impermeable to water.
- Dams can be grouped in **two major categories** on the basis of the **composition** of their construction **materials:**
  - Embankment dams.
  - Concrete dams.

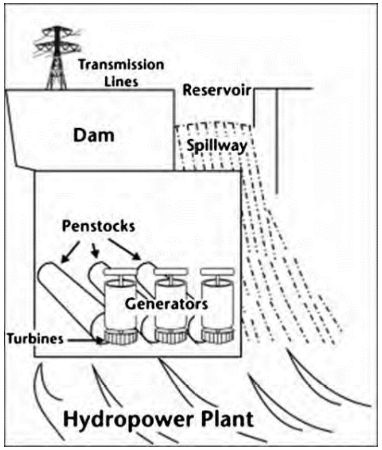


4.2. Hydropower facilities

Impoundment

1.2. Spillways:

- When dams are designed, **provision** must be made **to cope with large floods**.
- Spillways are **pathways for floodwater** to flow over or around the dam so that the dam itself is not breached.
- Spillways on **concrete dams** are usually constructed **to allow water to flow over the top**.
- Spillways in **embankment dams** are built **at the side of the dam** and away from the downstream face.
- If the water is allowed to flow over the dam, serious damage can occur to rocks or the earth that are used to construct it.

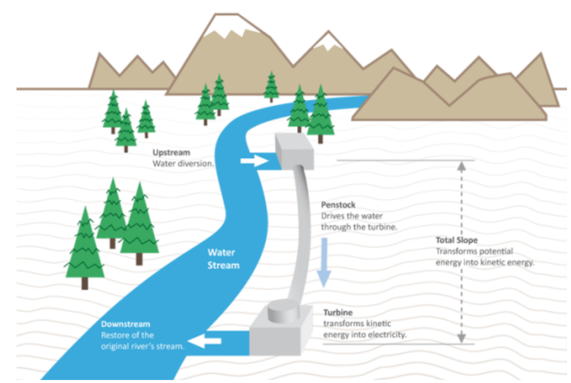


4.2. Hydropower facilities

Hydropower system construction methods

2) Diversion or run-of-river:

- Run-of-river plants **derive energy from a water flow with minimal disruption of the flow or the surroundings**. Also, run-of-river hydroelectric plants use the power in the river water as it passes through the plant without causing an appreciable change in the river flow.
- Normally, such systems are built on small dams that impound little water. They **may not cause changes in the water quality**. The presence of decomposition products that result from lubricants, grease, and sealants of a large plant operation is negligible.
- They **do not normally affect downstream habitat** or terrestrial habitat. Other concerns, such as ladder rejection by fishes, are not problems.
- Although run-of-river plants **are small**, several plants have been designed that exceeded 1,000MW.

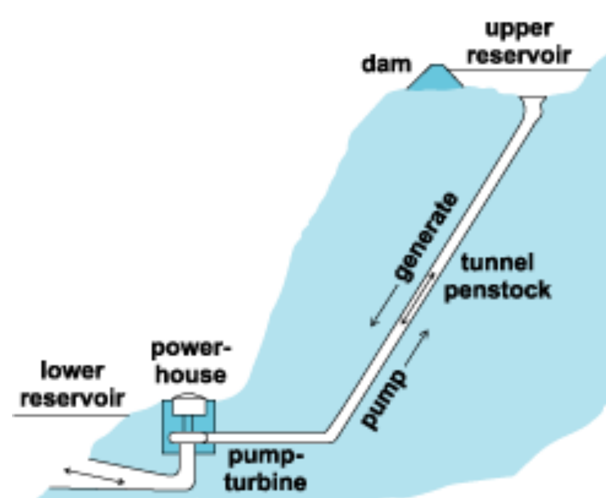


4.2. Hydropower facilities

Hydropower system construction methods

3) Pumped storage:

- Pumped-storage hydropower systems **are operated differently** from conventional hydroelectric systems.
- Although these systems use falling water to generate power in the same manner as a conventional hydroelectric system, **water, after falling** through the turbine, **is collected in a reservoir** (called lower reservoir).
- **A reversible turbine** that works in both directions **is used at the pumped storage facility**. When demand for electricity is low, the turbine is operated in the reversible mode to pump the water back to an upper reservoir.
- Water from the upper reservoir is released **to generate power during periods of peak demand**.

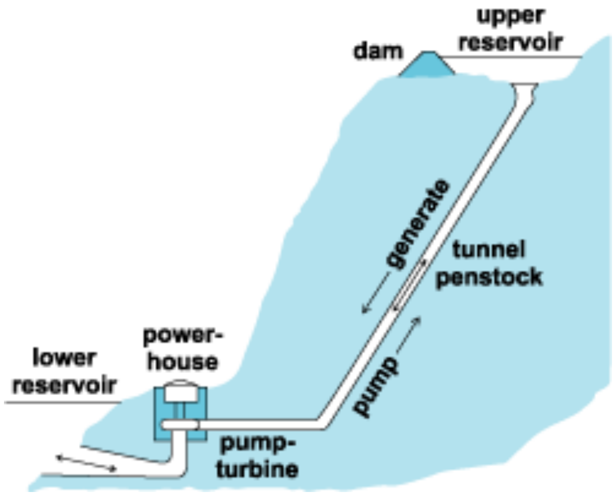


4.2. Hydropower facilities

Hydropower system construction methods

3) Pumped storage:

- Pumped storage systems actually are **net users of electrical energy**. The generation and pumping cycles are usually **90% efficient**. When other losses, such as friction loss, turbine efficiency, etc., are considered, the overall efficiency is generally around 75%.
- There are **several benefits** of a pumped storage system:
  - Improved energy regulation and operation of the supply grid.
  - Creates environmental benefits such as reduced gaseous emissions and has little environmental impact during its operation.
  - Allows flexible and rewarding commercial operations across a variety of electrical power supply scenarios.
- About **140,000 MW of pumped-storage** hydro capacity is already operating **around the world**.



Topic 3. Ocean energy

- **4.1.** Hydropower facilities.
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- **4.3. Types of turbines**.

4.3. Types of turbines

- **Several types** of hydroelectric turbines **are available for power generation**.
- **All** of them operate on the principle **of converting the potential energy stored in water to mechanical energy** by rotating a paddle-wheel which then generates electric power.
- Hydroelectric turbines **can rotate either on their vertical or horizontal axis**. However, most turbines employed for electricity generation have shafts that are vertically oriented.

There are two main types of hydroelectric turbines:

1) Impulse turbines.

2) Reaction turbines.

- The **type** of hydropower turbine **selected** for a plant is **based on the water head** in the reservoir and **the flow** or volume of water at the site. Other factors that are considered in the selection of the turbine include the **depth** at which the turbine must be set, its **efficiency**, and **cost**.

4.3. Types of turbines

1) Impulse turbines:

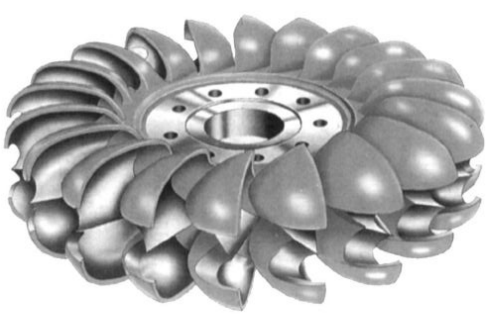
- The **velocity of the water is used to move the runner of impulse turbines**, which generally contain buckets or peddles on a wheel-shaped runner with one or more water jets directed tangentially toward the runner.
- The **water is discharged at atmospheric pressure**, after hitting each bucket on the runner.
- **There is no suction** on the down side of the turbine. Water flows out from the bottom of the turbine housing.
- An impulse turbine is generally **suitable for high head, low flow applications**.
- There are mainly **three types** of impulse turbine:
  - **1.1.** Pelton turbine.
  - **1.2.** Turgo wheel turbine.
  - **1.3.** Cross-Flow or Ossberger turbine.

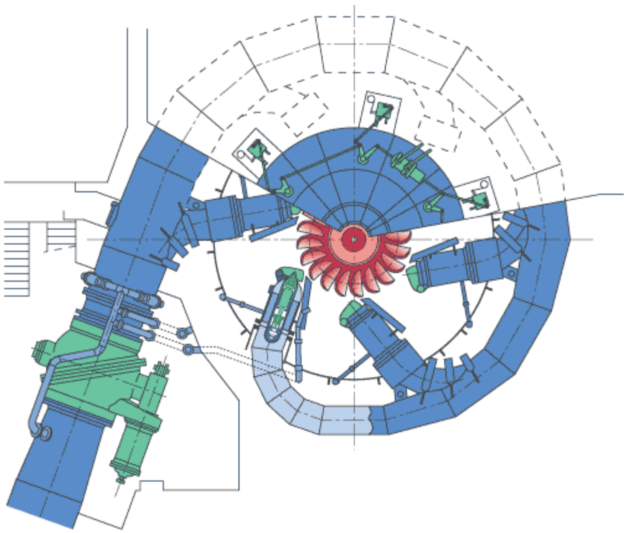
4.3. Types of turbines

Impulse turbines

1.1. Pelton turbine:

- In a Pelton turbine, **water jets** from nozzles **strike cups** or buckets **arranged on the periphery of a wheel**, causing it to rotate. **The wheel is connected to a shaft**, and the rotational motion of the shaft generates electricity via a generator.
- A Pelton wheel **has one or more free jets**, discharging water into buckets of the wheel.
- Pelton turbines are **suitable for high head, low flow applications** and they are **available for** both **large and small hydropower** systems.





4.3. Types of turbines

Impulse turbines

1.2. Turgo wheel turbine:

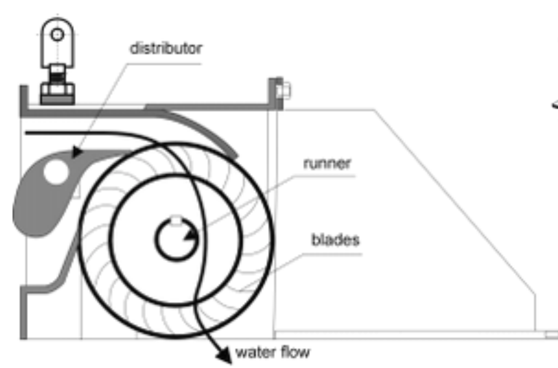
- A Turgo wheel is a **modification of the Pelton turbine**.
- The runner is a wheel whose shape looks like a **Pelton wheel cut in half**.
- The **water stream is applied on one side** usually at an angle of about 20°, goes across the blades and exits on the other side.
- The incoming and outgoing **jets do not cross each other**, and, therefore, can handle a higher flow rate.

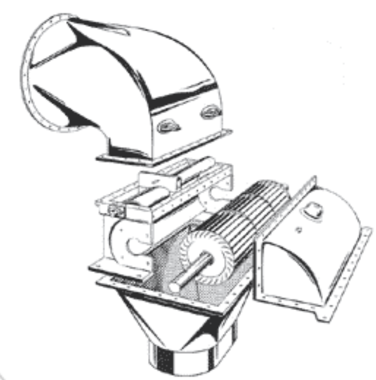
4.3. Types of turbines

Impulse turbines

1.3. Cross-Flow or Ossberger turbine:

- A cross-flow turbine, also known as an Ossberger turbine, is **shaped like a drum** and uses an elongated, rectangular-section nozzle directed against curved vanes on a cylindrically shaped runner.
- The cross-flow turbine allows the **water to flow through the blades twice**. During the first pass, water flows from the outside of the blades to the inside; the second pass is from the inside back out.
- They can be used both in **horizontal and vertical orientations** and can accommodate **higher water flow** and **lower head** than the **Pelton** turbine.
- The mean overall **efficiency** of Ossberger turbines is calculated **at 80%** for small power outputs over the entire operating range.





4.3. Types of turbines

Reaction turbines

- A reaction turbine **generates power from** the combined action of **pressure and moving water**.
- The **runner** is **placed directly in the water stream** flowing over the blades rather than striking each one individually.
- Reaction turbines are generally preferred over impulse turbines **when a lower head but higher flow is available**.

A variety of reaction turbines are available and these are:

1) Propeller turbine:

- **1.1.** Bulb turbine.
- **1.2.** Straflo turbine.
- **1.3.** Tube turbine.
- **1.4.** Kaplan turbine.

2) Francis turbine.

3) Kinetic energy turbine.

4.3. Types of turbines

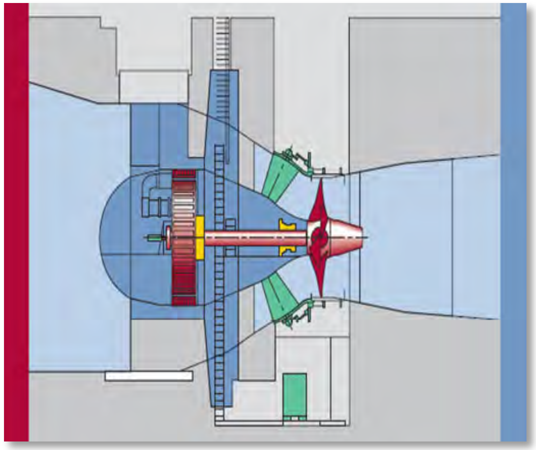
Propeller turbine

1) Propeller turbine:

- **Most of the reaction turbines** are a propeller type turbine. A propeller turbine generally has a **runner with three to six blades** on which water impinges continuously at a constant rate.
- The pitch of the blades **may be fixed or adjustable**. The major **components** besides the runner are a **scroll case, wicket gates, and a draft tube**.

1.1. Bulb turbine:

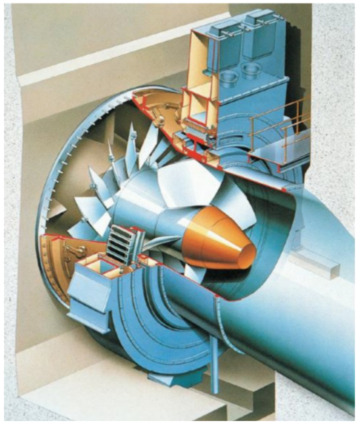
- In this case, the **turbine and generator are sealed** and placed directly **in the water stream**. This type of turbine is suitable for **low heads, below 25 m**. The near-straight design of the water passage **provides** both **size and cost reductions**.
- They **can** also **operate in reverse flow** directions and are available for **power output** in the range of **10-100 MW**.



4.3. Types of turbines

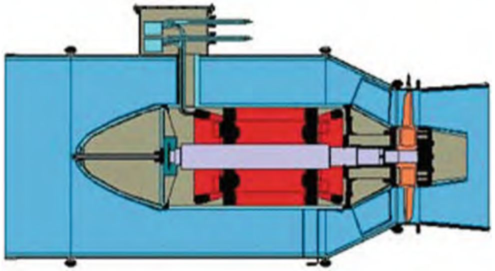
Propeller turbine

1.2. Straflo turbine:



- Straflo is a registered brand name that stands for **straight-flow** (flow straight). A key feature is the **combination of turbine and generator, requiring less space**. The **generator is attached directly to the perimeter of the turbine**.

1.3. Tube turbine:



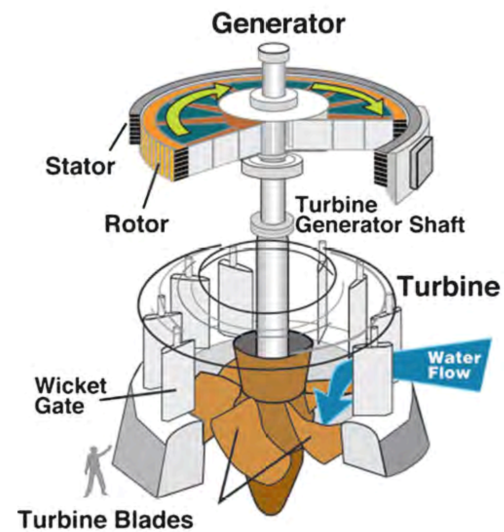
- It allows a **straight line connection** to the generator having a **direct drive** and **compact configuration**. The **power output** ranges from **20 to 700 kW** and **heads from 5 to 30 m** are sufficient for most applications.

4.3. Types of turbines

Propeller turbine

1.4. Kaplan turbine:

- Both the **blades and the wicket gates are adjustable**, allowing for a **wider range of operation**.
- The **rotor** is **attached to the turbine shaft**, and rotates **at a fixed speed**. **When the rotor turns**, it causes the field poles (the electromagnets) to move past the conductors mounted in the stator, which **is a donut-shaped structure surrounding the rotor**.
- This, in turn, **causes electricity to flow and a voltage to develop** at the generator output terminals.
- The **rotational speed of the generator** is usually the **same as the speed of the turbine**, because they are directly connected. The speed of the turbine is determined by the design and hydraulic conditions. **Speeds** for Kaplan generators are typically in the **range of 50-600** revolutions per minute (**rpm**).

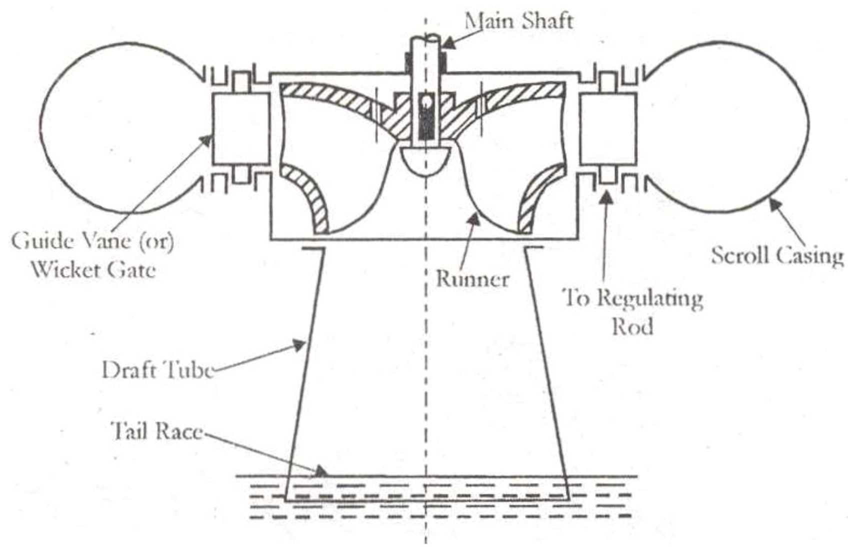


4.3. Types of turbines

Francis turbine

2) Francis turbine:

- A Francis turbine **has a runner with fixed buckets** (vanes), usually nine or more.
- **Water is introduced just above the runner** and all around it **and** then **falls through, causing it to spin**.
- Besides the runner, the other **major components** are a **scroll case, wicket gates, and a draft tube**.

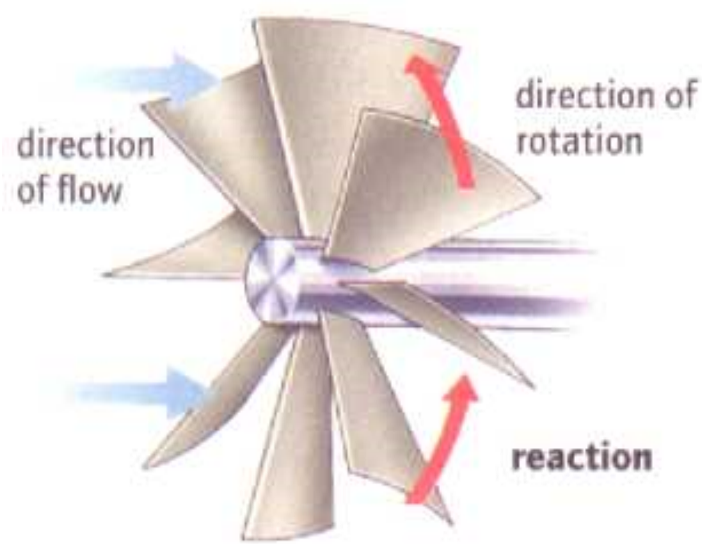


4.3. Types of turbines

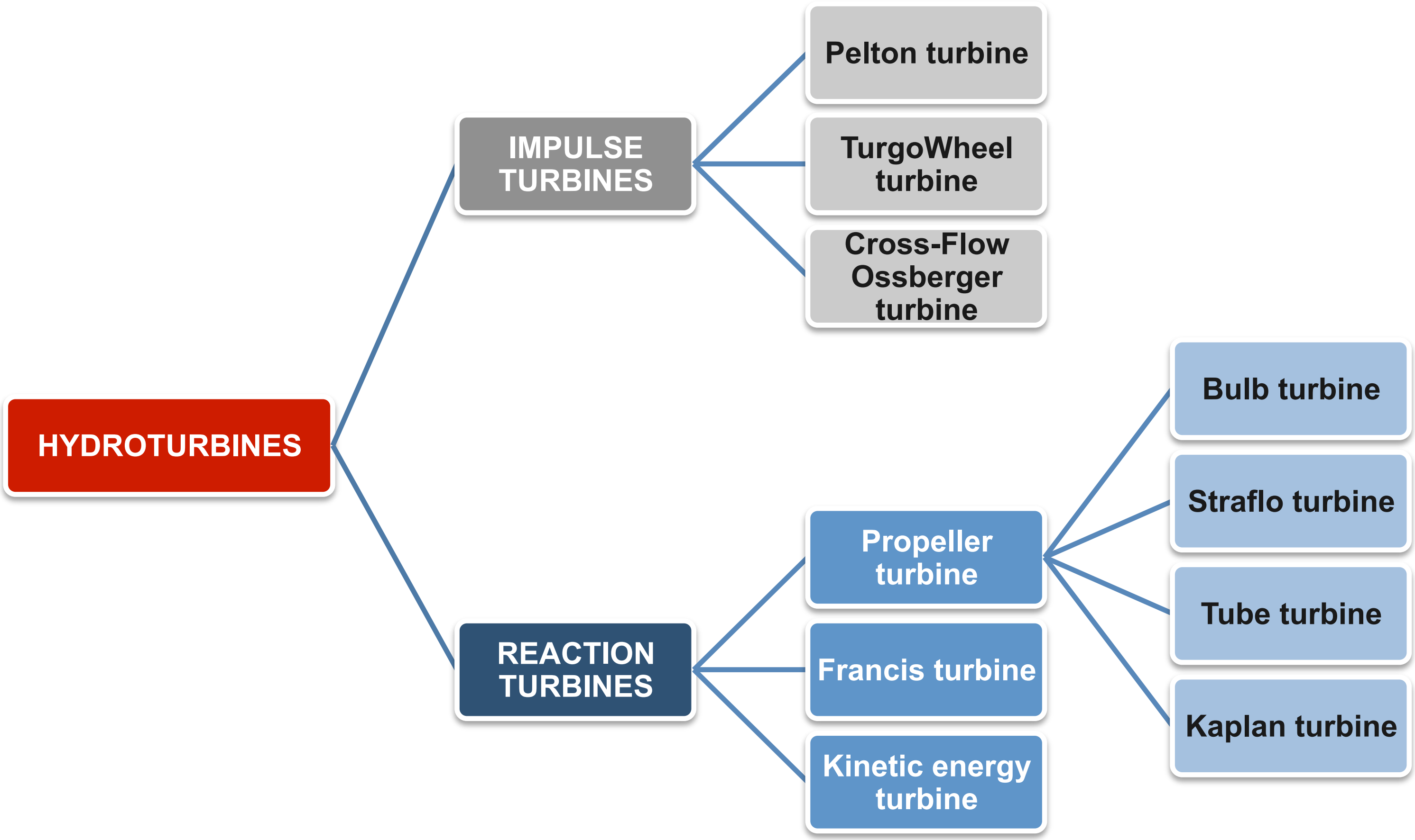
Kinetic energy turbine

3) Kinetic energy turbine:

- Kinetic energy turbines, **also called free-flow turbines, generate electricity from the kinetic energy present in flowing water** rather than the potential energy from the head. They **utilize the water stream's natural pathway**.
- The systems may **operate in rivers, man-made channels, tidal waters, or ocean currents**.
- The **diversion of water** through man-made channels, riverbeds, or pipes **is not required**.
- These systems **do not require large civil works**; rather, existing structures such as bridges, tailraces and channels are sufficient for these turbines.



4.3. Types of turbines



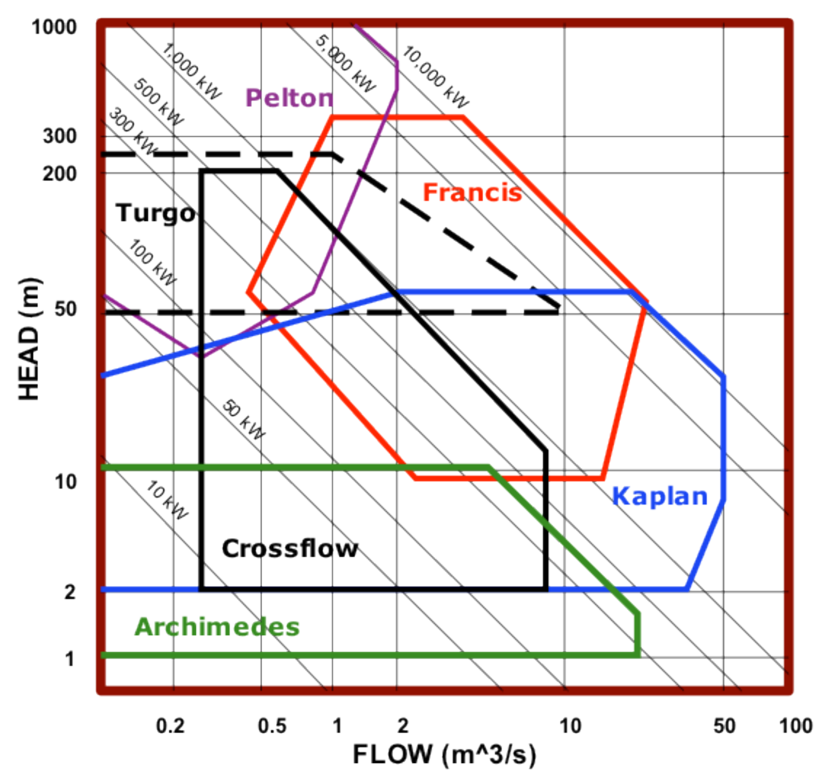
- **Video:** [Virtual turbines].

4.3. Types of turbines

Selection of turbines

- The **selection** of a turbine **depends on several factors**. Each turbine operates **most efficiently** at a certain **pressure and flow range**. However, often, the **working head** determines the turbine types for a specific application.

- The **operating range** of various turbines for a given head and flow rate is **shown in the Figure**. The same figure can also be used for selection of a turbine type if a certain power output is required.



4.3. Types of turbines

Energy and power balance in turbines

- The **potential energy** stored in a body of moving water is **converted to kinetic energy**, which is then used to turn the turbine and **generate power**.
- The potential energy is given by the following expression:

$$E = m * g * H \qquad [J]$$

Where, m is the mass of water, g is the acceleration due to gravity, and H is called head.

- The **theoretical maximum power (P)** content of the water may be calculated using the following expression:

$$P = \frac{E}{t} = \frac{m*g*H}{t} = \frac{\rho*V*g*H}{t} = \rho * Q * g * H = \dot{m} * g * H \qquad [W]$$

Where, t is the time, ρ is the water density, $\dot{m}$ is the mass flow rate (kg/s) and Q is the volumetric water flow rate (m^3/s).

4.3. Types of turbines

Energy and power balance in turbines

- If the energy balance between two reference points –up and downstream of a hydroelectric power station– is set, the **Bernoulli equation** can be written according to:

$$\underbrace{p_1}_{\text{Static pressure term}} + \underbrace{\rho * \frac{{v_1}^2}{2}}_{\text{Kinetic energy term}} + \underbrace{\rho * g * H_1}_{\text{Potential energy term}} = p_2 + \rho * \frac{{v_2}^2}{2} + \rho * g * H_2 = cte \qquad \text{[Pa]}$$

- And the energy captured by the turbine blades is given by:

$$\underbrace{\left(\frac{p_1}{\rho} + g * H_1\right) - \left(\frac{p_2}{\rho} + g * H_2\right)}_{\substack{W_p \\ \text{Potential energy term}}} + \underbrace{\frac{{v_1}^2 - {v_2}^2}{2}}_{\substack{W_c \\ \text{Kinetic energy term}}} = W_{12} \qquad [m^2/s^2]$$

1. Inlet gate of the wheel.
2. Outlet gate of the wheel.

$$Degree\,of\,reaction = \tau_r = \frac{W_p}{W_{12}}$$

4.3. Types of turbines

Energy and power balance in turbines

- The essential characteristics of a water turbine can be summarized by a single parameter, the **specific speed** $\boldsymbol{n_s}$:

$$n = Wheel\ speed\ [rpm]$$

$$P = Power\ [kW]$$

$$H = Water\ head\ [m]$$

$$\boxed{n_s = \frac{n * \sqrt{P}}{(H)^{5/4}}}$$

- This parameter is of great importance for tests with scale models: two turbines with the same specific speed are geometrically similar.

4.3. Types of turbines

Energy and power balance in turbines

- For the calculation of **net power, various energy losses must be taken into account**.

The most important losses are:

1) Head loss.

2) Leakage loss around the runner.

3) Mechanical loss in the turbine due to mechanical friction.

1) Head loss:

- When water is travelling if **loses** energy as it flows through a pipe, mainly **due to friction** against the pipe wall **and viscous dissipation** as a consequence of the internal friction of flow. The losses due to the **friction** can be determined in terms of **"head", *h_f*:**

$$h_f = f * \left(\frac{L}{D}\right) * \frac{V^2}{2*g} \qquad H_{net} = H_{gross} - h_f$$

Where, ***f*** is the friction factor, a dimensionless number, ***L*** the length of the pipe, ***D*** the piper diameter, ***V*** the average velocity and ***g****,* the gravity.

4.3. Types of turbines

Energy and power balance in turbines

- Various energy losses in a hydropower system affect the net power production. **These losses are taken into account** by multiplying the theoretical power **by efficiences**.

- The **hydraulic efficiency** *(η_h)* addresses the head loss. The leakage around the runner is taken into account by the **volumetric efficiency** *(η_v)*. The **mechanical efficiency** *(η_m)* takes into account various losses involving the hydroturbine and is often called the turbine efficiency. The overall efficiency is, therefore, given by:

$$\eta = \eta_h \cdot \eta_v \cdot \eta_m$$

- The overall efficiency is in the range of 75-90%. The net power, therefore, is given by:

$$P = \eta * \rho * Q * g * H = \eta * \dot{m} * g * H$$

Sources

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