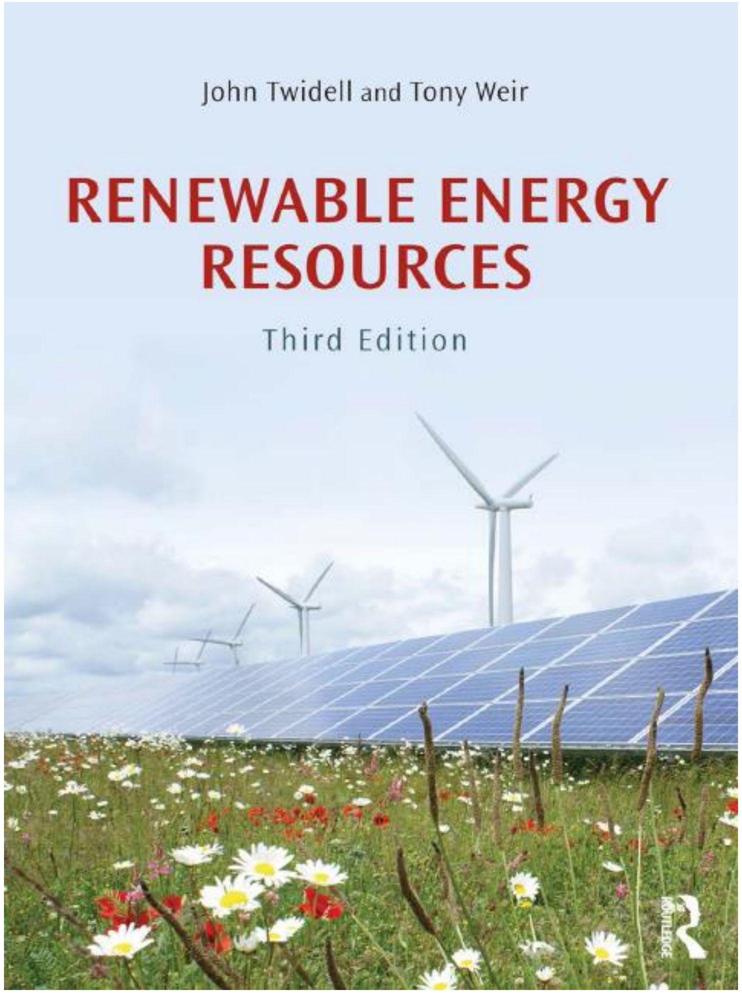
Renewable Electric Energy Systems EE—546

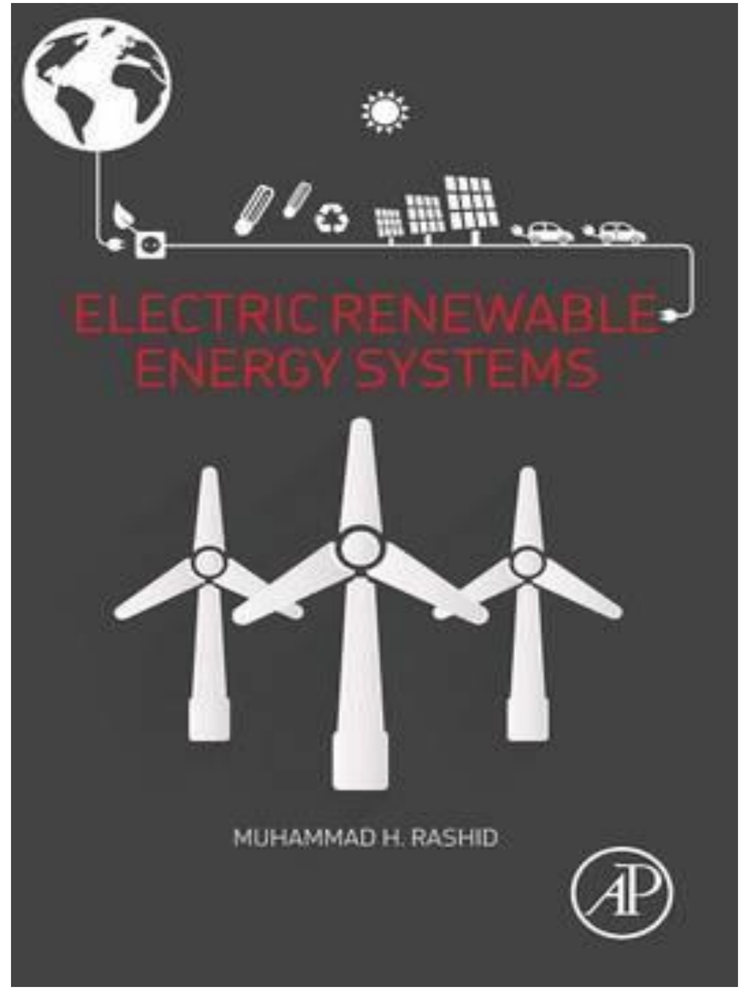
Hydro—Power

Dr. U. T. Shami

Hydro—Power : Slides are prepared from the following books:



John Twidell and Tony Weir—Renewable Energy Resources



Muhammad H. Rashid—Electric Renewable Energy Systems

Typical radial electrical energy system

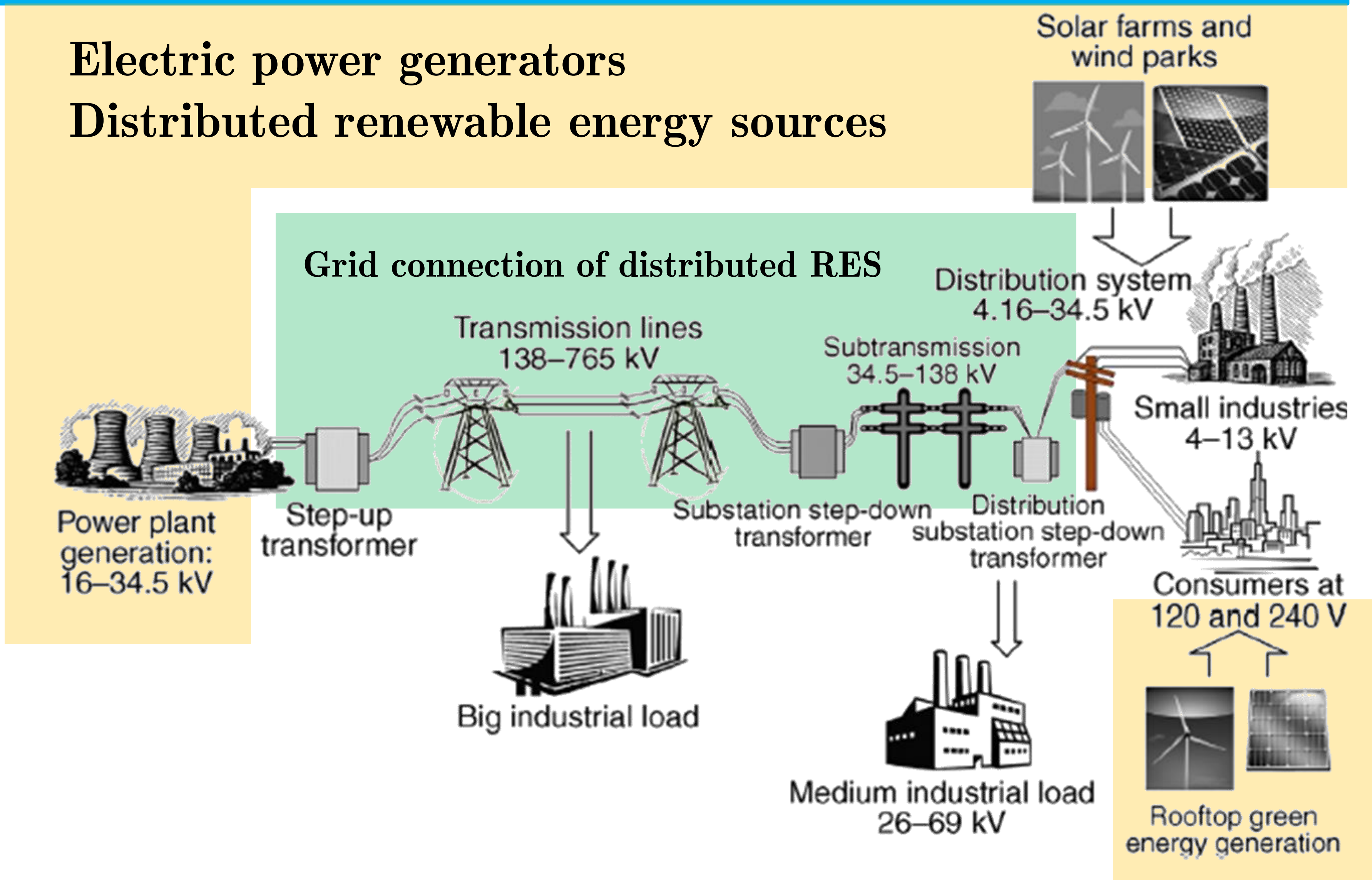


Figure 2.1 Typical radial electrical energy system [1–5].

Typical radial electrical energy system

The most commonly used radial diagram for an electrical energy system is shown in Figure 2.1, where the generation of electricity is typically in a three-phase AC at line-to-line RMS voltages of 16–34.5 kV. Step-up transformers at the remote generation site increase the voltage to the appropriate transmission levels of nominally 138–765 kV, and this power is then transmitted across long distances over AC overhead TLs and underground cables. Substations reduce the voltage levels to 34.5–138 kV for sub-transmission, which is further stepped down to the range of 4.16–34.5 kV for the distribution system. This is eventually reduced to the customer's operating standards of 240 V predominantly in Europe or 120 V mainly in the United States.

Hydro—power plants

- **Hydroelectricity is one** of the oldest generators of electricity and does not include thermal energy in the conversion process.
- **Hydropower plants convert** potential energy into mechanical energy through water turbines, which then generate electricity.
- **Efficiencies of 90%** and higher are achieved through this clean and renewable route. However, its availability is limited to sites with certain geographical and environmental suitability.
- **Electricity production** from hydroelectric sources contributed to 15.9% of the total electricity generation in 2011 [6].

Hydro—power global capacity

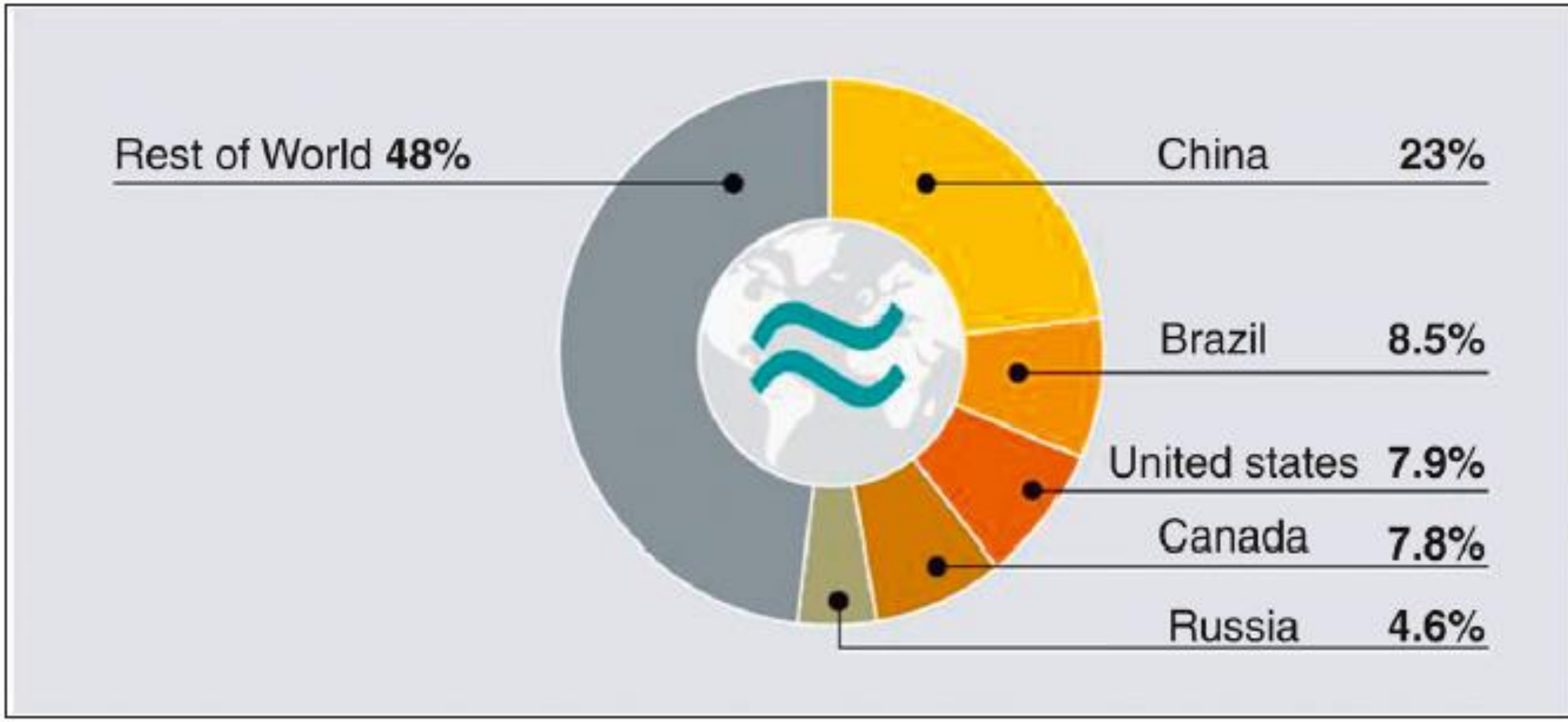


Figure 5.1 Hydropower global capacity – a typical distribution (2008).

Growth Of World Hydroelectricity Generation

- The world's earliest electricity distribution in 1881 was derived from hydroturbines of kW scale capacity.
- By 2008 hydropower capacity had reached about 874 GW, not including ~130 GW of pumped hydro-storage.
- The capacity of total worldwide installations continues to increase at about 2% per year, with hydroelectricity supplying about 16% of worldwide electricity (see Fig. 6.1). This proportion may itself increase.
- However, environmental and social concerns are often the largest challenges.

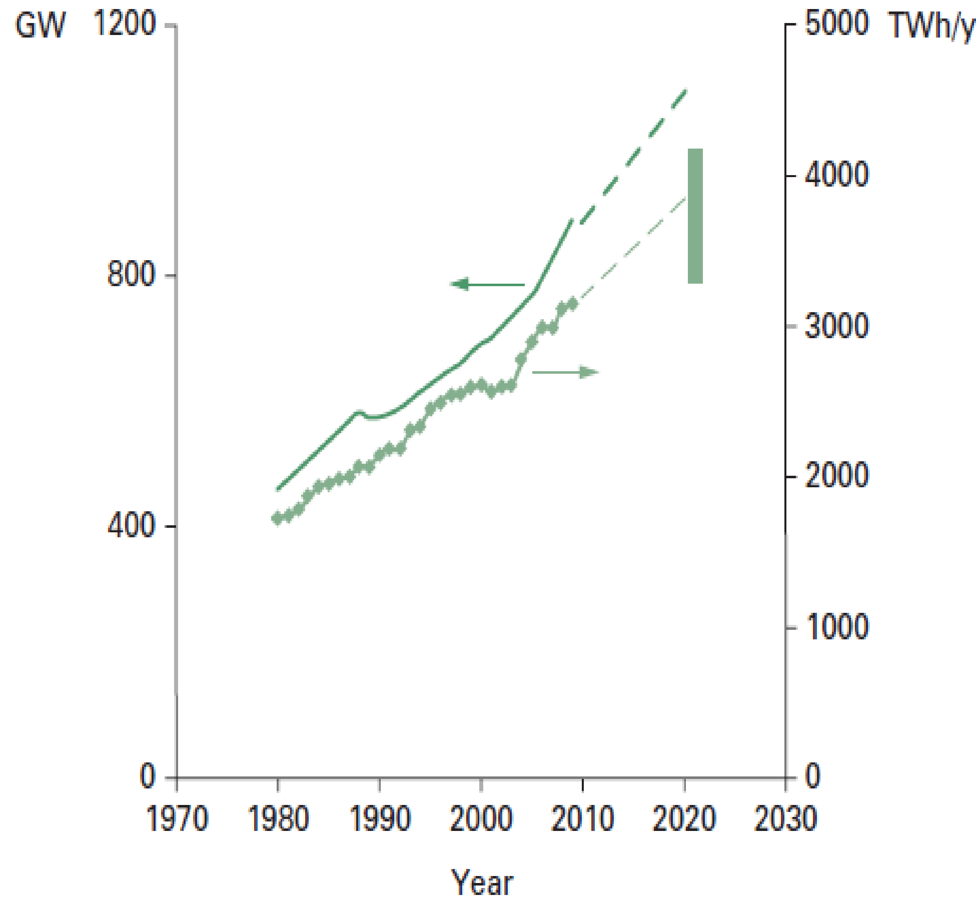


Fig. 6.1 Growth of world hydroelectricity generation (TWh/y) and capacity (GW). Actual data from US Energy Information Agency. (2011).

Hydropower potential, capacity and output by sample countries (2008).

A Region/e.g. country	B Gross potential TWh/y	C Technical potential TWh/y	D Actual generation TWh/y (2008)	E = D/C Proportion of technical utilized %	F Installed capacity (2008) GW	G Capacity factor $D/(F \times 8760\ h/y)$ %

Notes

- **Gross potential** from rainfall runoff and mapping, **technical potential** from constructional experience, actual capacity installed and actual generation.

- **Actual generation** in one year

- Capacity and output figures exclude stations that are mainly or purely pumped hydro.

Source: Data from World Energy Council (2010), Survey of Energy Resources.

Hydropower potential, capacity and output by sample countries (2008).

A Region/e.g. country	B Gross potential TWh/y	C Technical potential TWh/y	D Actual generation TWh/y (2008)	E = D/C Proportion of technical utilized %	F Installed capacity (2008) GW	G Capacity factor D/(F × 8760 h/y) %
WORLD, total	39842	15955	3194.0	20	874.0	42
AMERICA North	5511	2416	694.0	29	168.0	47
Canada	2067	820	377.0	46	73.4	59
USA	2040	1339	255.0	19	77.5	38
ASIA	**16618**	**5590**	**985.0**	**18**	**306.8**	**37**
China	6083	2474	580.0	23	171.0	39
India	2638	660	114.8	17	37.8	35
Indonesia	2147	402	11.5	3	4.5	29
Japan	718	136	74.1	54	27.9	30
Pakistan	475	204	27.7	14	6.5	49
EUROPE	4919	2762	714.8	26	220.7	37
France	270	100	59.3	59	21.0	32
Italy	190	65	41.6	64	17.6	27
UK	35	14	5.1	36	1.6	36
MIDDLE EAST	690	277	27.7	10	11.5	27

Hydro—Power Principles

The fundamental equation (6.1) is sufficient for estimating hydropower potential at a particular location; the methods described in article 6.3 give a more accurate assessment.

Water of volume per second $\boldsymbol{Q}$ and density $\boldsymbol{\rho}$ falls down a slope. The mass falling per unit time *is* $\boldsymbol{\rho Q}$, and the rate of potential energy lost by the falling fluid is

$$P_0 = \rho Q g H \tag{6.1}$$

where $\boldsymbol{g}$ is the acceleration due to gravity and $\boldsymbol{H}$ is the vertical component of the water path.

The turbines convert this power to shaft power. There is no fundamental thermodynamic or dynamic reason why the output power of a hydro system should be less than the input power $\boldsymbol{P_0}$, apart from frictional losses that can be proportionately very small.

For a site with a water reservoir, $\boldsymbol{H}$ is fixed and $\boldsymbol{Q}$ is adjustable. Hence the power output is quickly controlled at, or less than, the design output, provided that there is sufficient water supply.

WORKED EXAMPLE 6.1

Water from a moderately sized river flows at a rate of 100 m^3/s down a perfectly smooth pipe, falling 50 m into a turbine.

(a) How much power is available? (b) If in practice 10% of the power is lost by friction, transformation and distribution, how many houses having average electricity use of about 0.5 kW (i.e. 12 kWh/day) could this power supply?

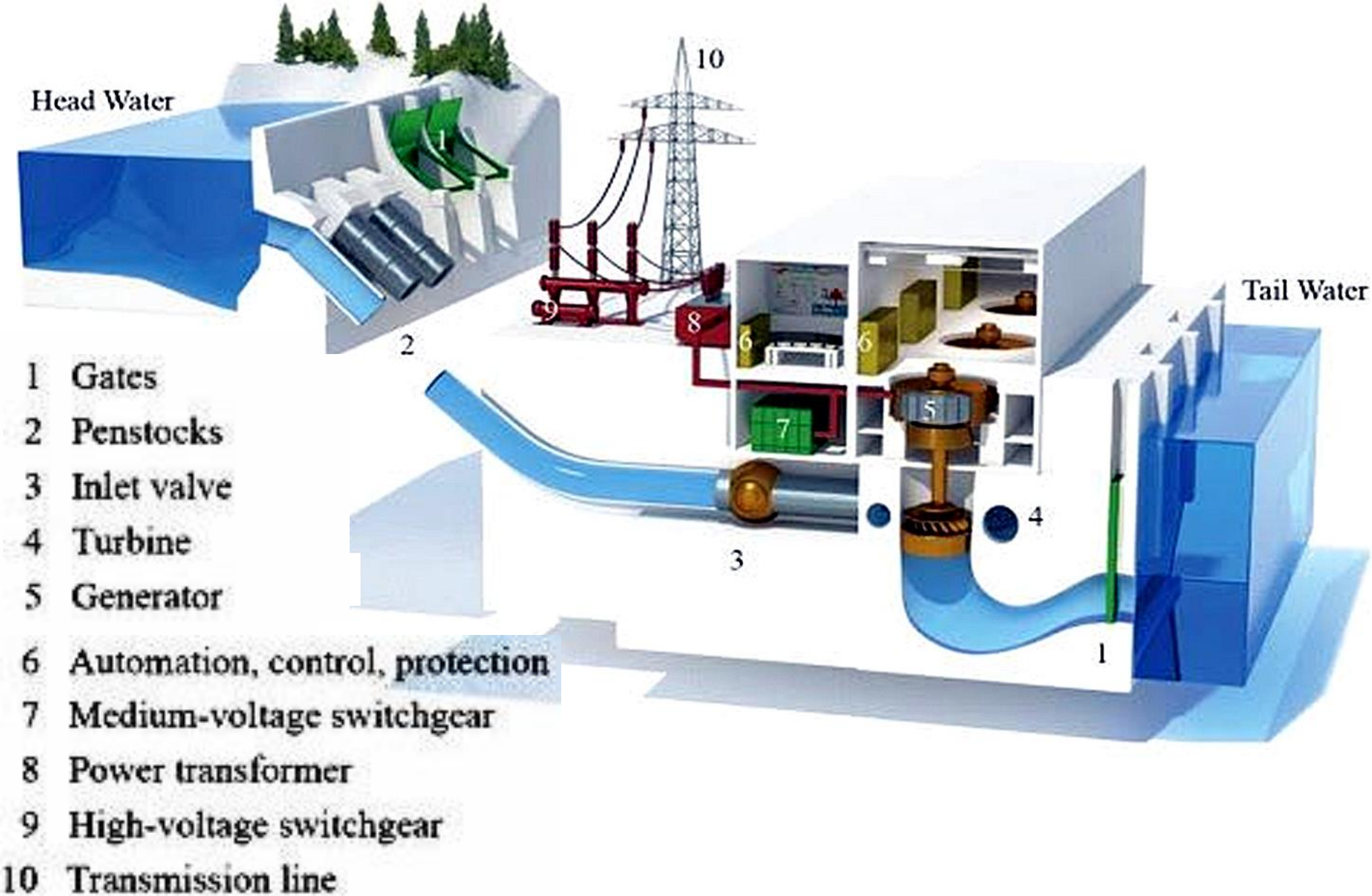
Solution

From (6.1),

$$P_0 = (1000\text{kg/m}^3) \times (100\text{m}^3/\text{s}) \times (9.81\text{m/s}^2) \times 50\text{m}$$
$$= 49 \times 10^6 \text{kg.m/s}^3 = 49\text{MJ/s} = 49\text{MW}$$

The number of houses is (49,000 – 4,900) kW/(0.5 kW per house) ≈ 88,000 houses, i.e. a large town with a population of about 220,000.

Hydro—Power Typical Installation



Hydro—Power: Assessing the Resources

Suppose we have a stream available which may be useful for hydropower. At first, only approximate data, with an accuracy of about ±50%, are needed to estimate the power potential of the site. If this survey proves promising, then a detailed investigation will be necessary involving data, for instance, rainfall taken over several years.

It is clear from (6.1) that to estimate the input power $\boldsymbol{P_0}$ we have to measure the flow rate $\boldsymbol{Q}$ and the available vertical fall $\boldsymbol{H}$ (usually called the head).

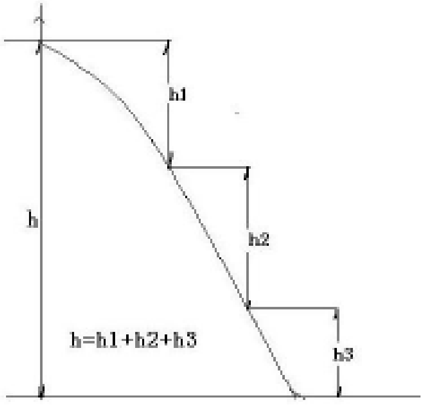
For example, with $\boldsymbol{Q}$**=40liter/s** and $\boldsymbol{H} = \mathbf{20\ m}$, the maximum power available at source is **8 kW**. This might be very suitable for a household supply.

Hydro—Power: Measurement of head H

For nearly vertical falls, trigonometric survey methods or level and pole surveying is used. Note that the power input to the turbine depends not on the geometric (or '*total*') head $\boldsymbol{H_t}$ as surveyed, but on the *available* head $\boldsymbol{H_a}$:

$$H_a = H_t - H_f \qquad (6.2)$$

where the ***head loss*** $\boldsymbol{H_f}$ allows for friction losses in the pipe and channels leading from the source to the turbine. With suitable pipework $\boldsymbol{H_f}$ =<~ $\boldsymbol{H_t}$ /3; however, by $\boldsymbol{H_f}$ increases in proportion to the total length of pipe, so the best sites for hydropower have steep slopes.



Hydro—Power: Measurement of Flow Rate Q

The flow through the turbine produces the power, and this flow will usually be less than the flow in the stream. However, the flow in the stream varies with time, for example, between drought and flood periods.

For power generation, the *minimum* (dry season) flow is required, since a turbine matched to this will produce power all the year round without overcapacity of machinery.

Also, the *maximum* flow and flood levels is required to avoid damage to installations.

The measurement of Q is more difficult than the measurement of H.

For large installations, the 'sophisticated method' is always used.

MEASUREMENT OF FLOW RATE Q: PRINCIPLES AS DESCRIBED FOR SMALL SYSTEMS

As in § R2.2,

$$\text{flow rate } Q = (\text{volume passing in time } \Delta t) / \Delta t \tag{6.3}$$

$$= (\text{mean speed } \bar{u}) \times (\text{cross-sectional area } A) \tag{6.4}$$

$$= \int u \, \mathrm{d}A \tag{6.5}$$

(a) *Basic method* (Fig. 6.3(a)). The whole stream is either stopped by a dam or diverted into a containing volume. In either case it is possible to measure the flow rate from the volume trapped (6.3). This method makes no assumptions about the flow, is accurate and is ideal for small flows, such as those at a very small waterfall.

(b) *Refined method (i)* (Fig. 6.3(b)). Equation (6.4) defines the mean speed $\bar{u}$ of the flow. Since the flow speed is zero on the bottom of the stream (owing to viscous friction), the mean speed will be slightly less than the speed u_s at the top surface. For a rectangular cross-section, for example, it has been found that $\bar{u} \approx 0.8u_s$. u_s can be measured by simply placing a float (e.g. a leaf) on the surface and measuring the time it takes to go a certain distance along the stream. For best results the measurement should be made where the stream is reasonably straight and of uniform cross-section.

The cross-sectional area A can be estimated by measuring the depth at several points across the stream and integrating across the stream in the usual way (Fig 6.3(b)):

$$A \approx \tfrac{1}{2}y_1z_1 + \tfrac{1}{2}(y_2 - y_1)(z_1 + z_2) + \tfrac{1}{2}(y_3 - y_2)(z_2 + z_3) + \tfrac{1}{2}(y_4 - y_3)z_3 \tag{6.6}$$

(c) *Refined method (ii)* (Fig. 6.3(c)). A refinement which avoids the need for accurate timing can be useful on fast-flowing streams. Here a float (e.g. a table tennis ball) is released from a standard depth below the surface. The time for it to rise to the surface is independent of its horizontal motion and can easily be calibrated in the laboratory. Measuring the horizontal distance required for the float to rise gives the speed in the usual way. Moreover, what is measured *is* the mean speed (although averaged over depth rather than over cross-section: the difference is small).

(d) *Sophisticated method* (Fig. 6.3(d)). This is the most accurate method for large streams and is used by professional hydrologists. Essentially the forward speed u is measured with a small flow metre at the points of a two-dimensional grid extending across the stream. The integral (6.5) is then evaluated by summation.

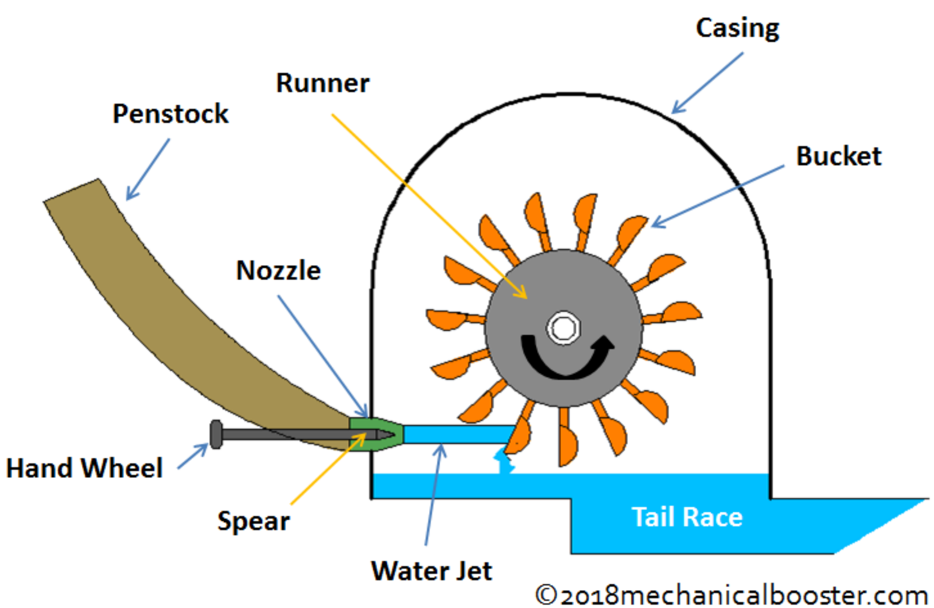
(e) *Using a weir* (Fig. 6.3(e)). If Q is to be measured throughout the year for the same stream, measurement can be made by building a dam with a specially shaped calibration notch. Such a dam is called a weir. The height of flow through the notch gives a measure of the flow. The system is calibrated against a laboratory model having the same form of notch. The actual calibrations are tabulated in standard handbooks. Problem 6.2 shows how they are derived.

Turbines

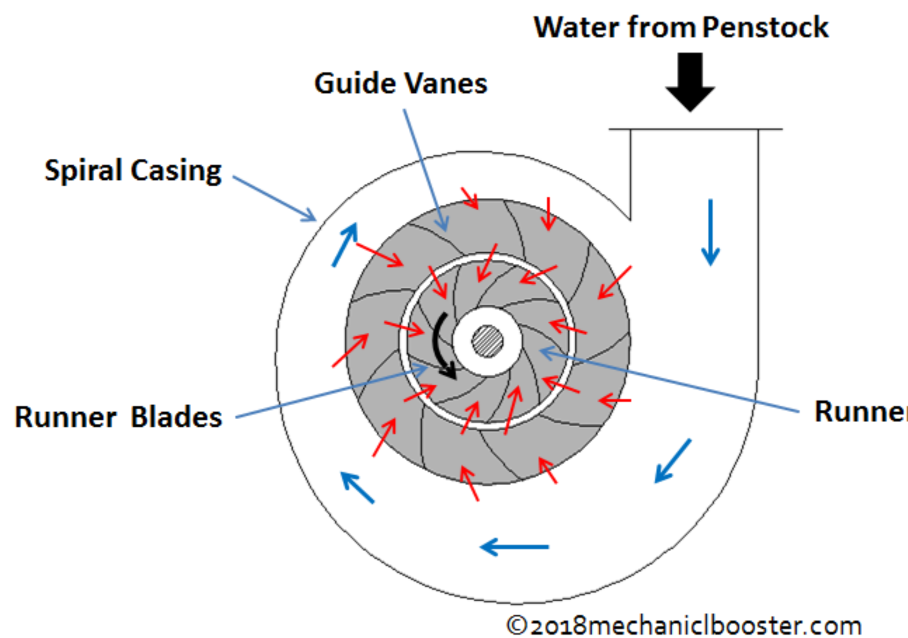
Turbines are of two types:

(a) **Impulse Turbines**, where the flow hits the turbine as a jet in an open environment, with the power deriving from the kinetic energy of the flow (see §6.4); and

(b) **Reaction Turbines**, where the turbine is totally embedded in the fluid and powered from the pressure drop across the device (see §6.5).



Main Parts of Impulse Turbine



Reaction Turbine

Turbines: Classifications

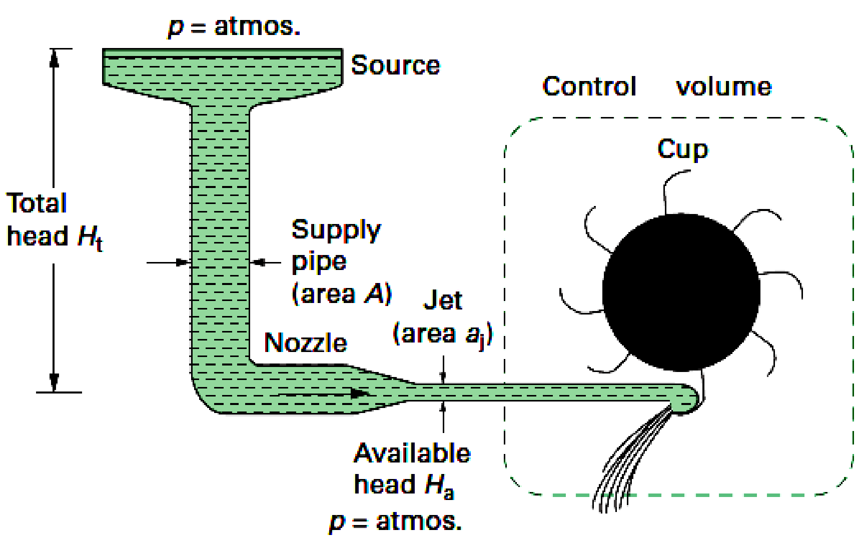
The main classification depends upon the type of action of the water on the turbine. These are:

1. Impulse turbine: The potential energy is converted to kinetic energy in the nozzles. The impulse provided by the jets is used to turn the turbine wheel. The pressure inside the turbine is atmospheric. This type is found suitable when the available potential energy is high and the flow (discharge) available is comparatively low.

2. Reaction turbine: The available potential energy is progressively converted in the turbine rotors (stages) and the reaction of the accelerating water causes the turning of the wheel. These machines are again divided into radial flow, mixed flow, and axial flow depending upon the head available. Radial flow machines are found suitable for moderate levels of head and medium quantities of flow. The axial machines are suitable for low levels of head and large flow rates.

Impulse Turbines

We first consider a particular impulse turbine: the *Pelton wheel turbine*. The potential energy of the water in the reservoir is changed into kinetic energy of one or more jets. Each jet then hits a series of buckets or 'cups' placed on the perimeter of a vertical wheel, as sketched in Fig. 6.4. This tangential force applied to the wheel causes it to rotate. Although the ideal turbine efficiency is 100%, in practice, values range from 50% for small units to 90% for accurately machined large commercial systems.



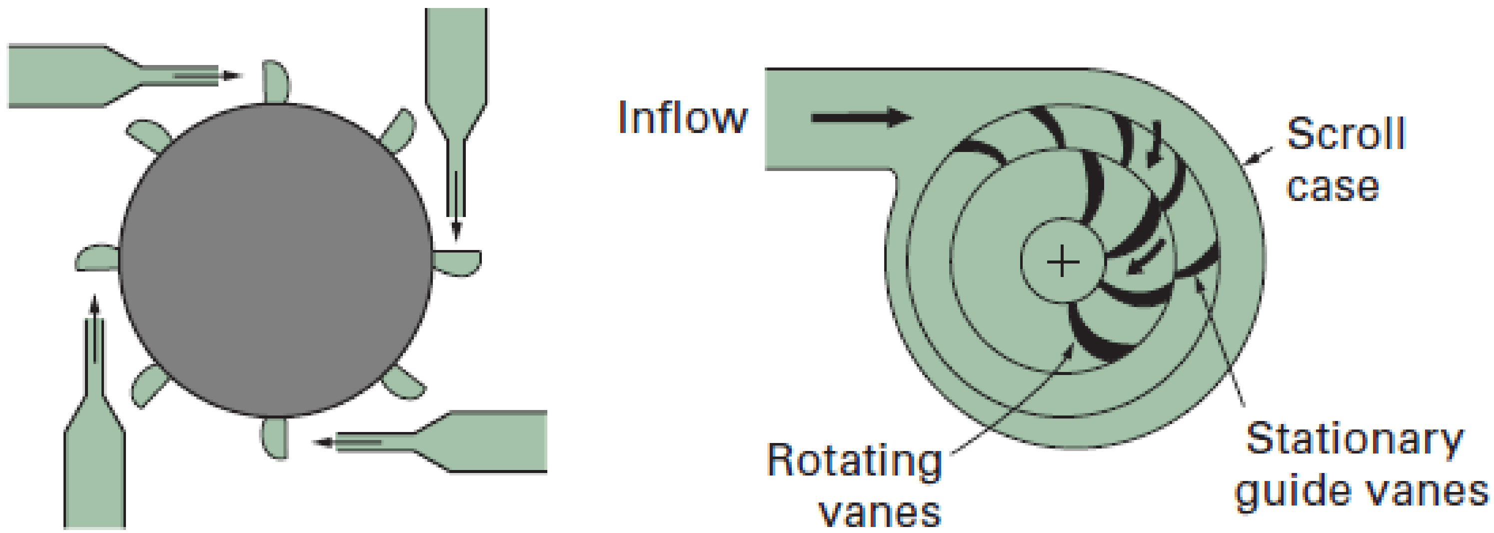
6.4
Schematic diagram of a Pelton wheel impulse turbine.

The nozzles are adjusted so that the water jets hit the moving cups perpendicularly at the optimum relative speed for maximum momentum transfer. The ideal cannot be achieved in practice, because an incoming jet would be disturbed both by the reflected jet and by the next cup revolving into place.

Impulse Turbines

(a) Pelton (impulse)

(b) Francis (impulse)

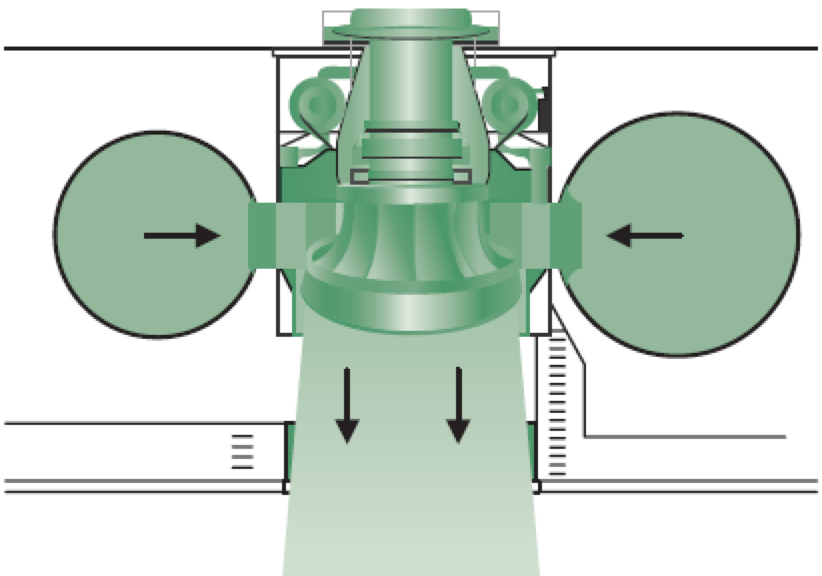


Reaction Turbines

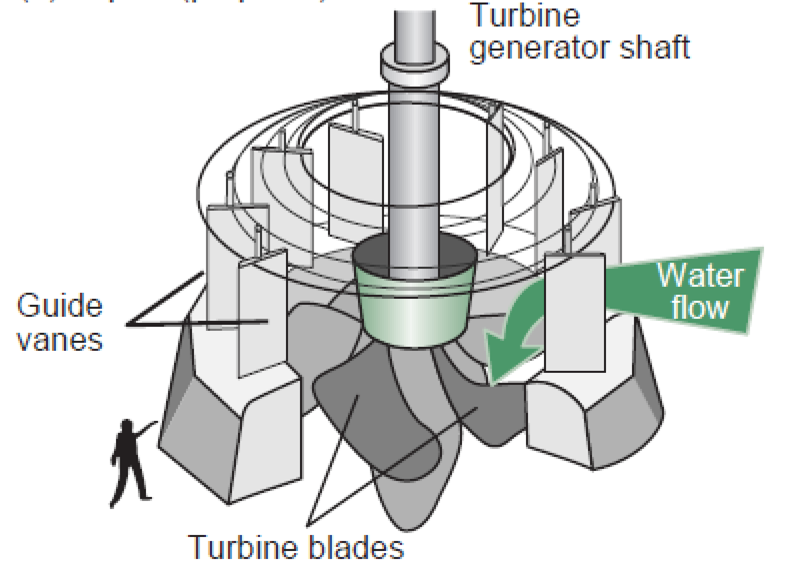
Low-head situations (6.1), require a greater flow Q through the turbine than for high-head. Likewise, considering the shape number S of (6.19), to maintain the same ω and P with lower H, we require a turbine with larger S. For instance, by increasing the number of nozzles on a Pelton wheel: see (6.18) and Fig. 6.7(a). However, the pipework becomes unduly complicated if $n > 4$, and the efficiency decreases because the many jets of water interfere with each other. To maintain a larger flow through a turbine, design changes are needed, as in the Francis reaction turbine of Figs 6.7(b) and 6.7(c). In effect, the entire periphery of the wheel is made into one large 'slot' jet for water to enter and then turn in a vortex to push against the rotor vanes. Such turbines are called *reaction* machines because the fluid

Reaction Turbines: Examples

(c) Francis (side view)



(d) Kaplan (propeller)



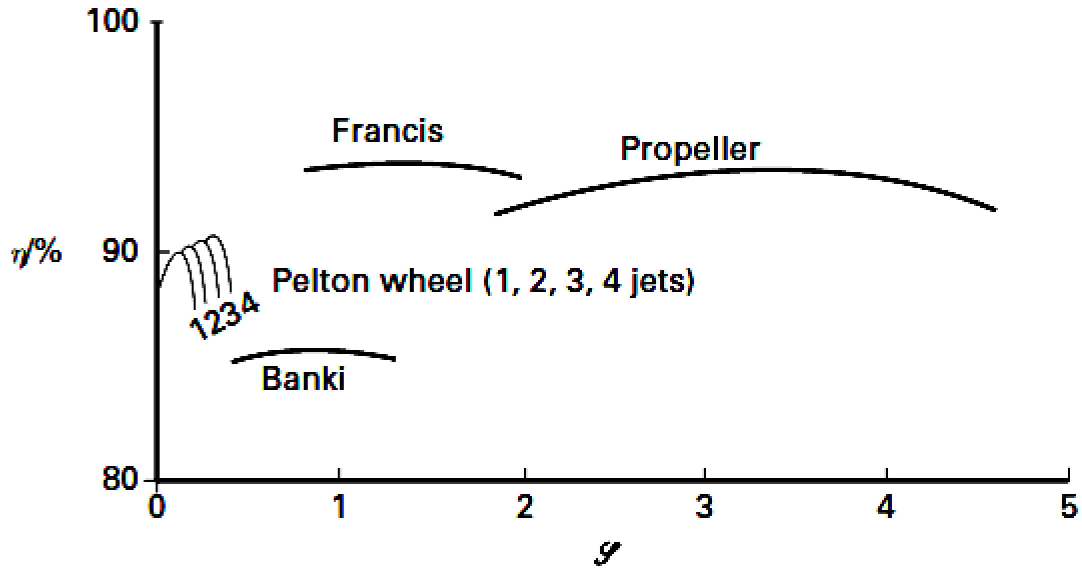


Fig. 6.8

Illustrative peak efficiencies, here ranging between 85% and 95%, of various turbine types in relation to shape number.

Source: Adapted from Çengel and Cimbala (2010).

Kaplan Turbine **(Propeller Hydro Turbine)**

Francis Turbine

Turbine Efficiency versus Specific speed

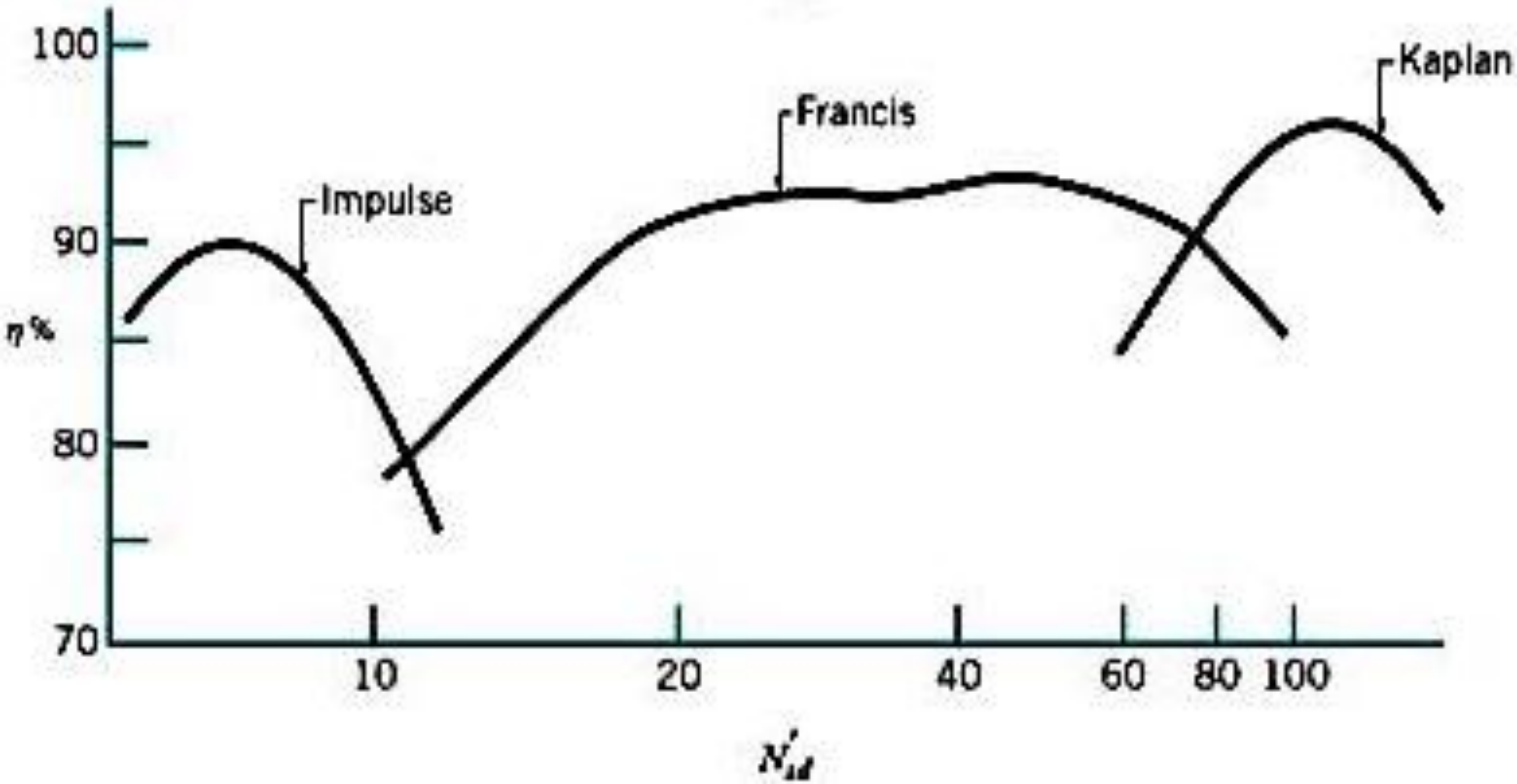


FIGURE 12.32
Typical turbine cross sections and maximum efficiencies as a function of specific speed.

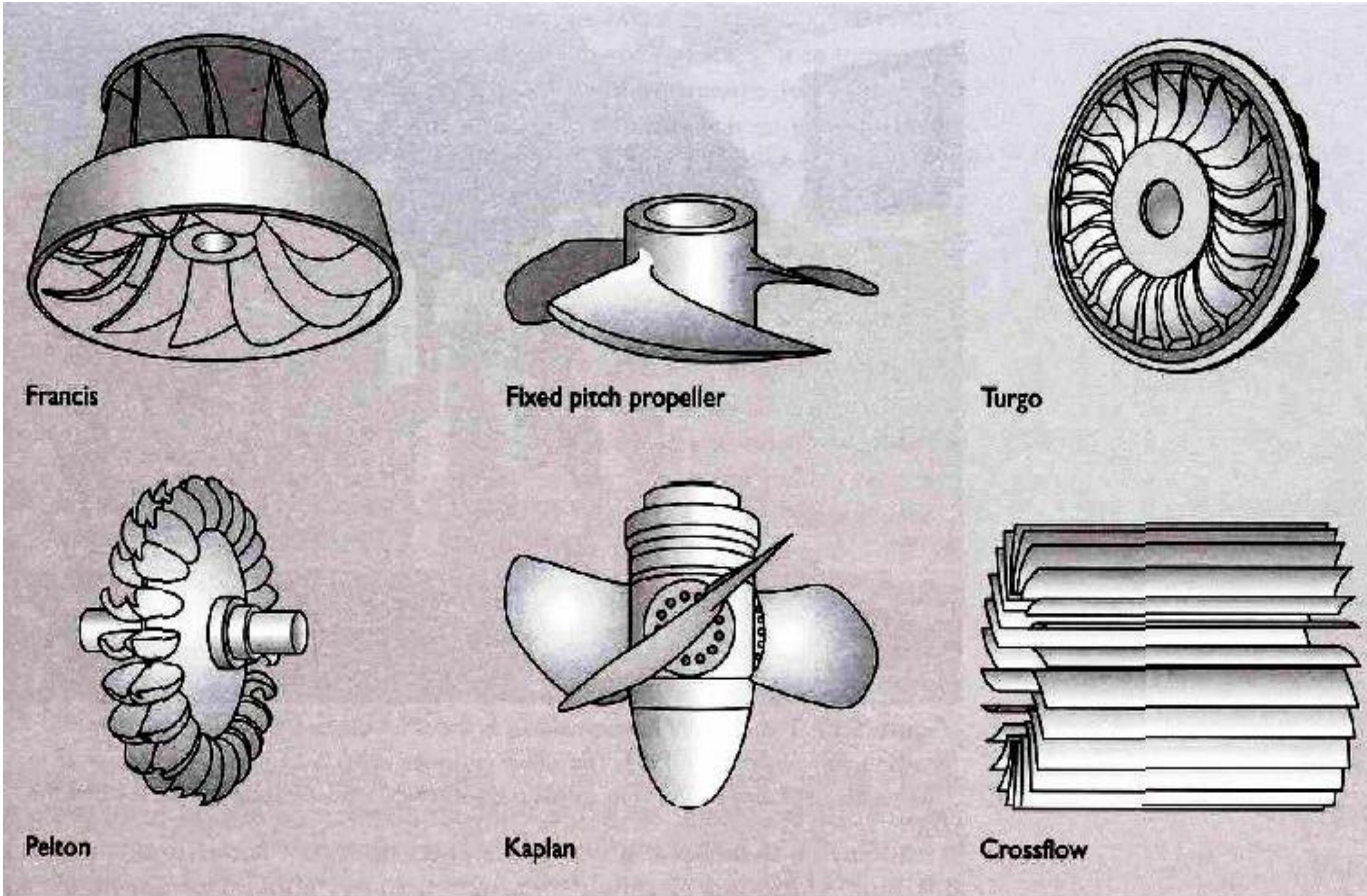
Specific speed

The specific speed is used to select a particular type of pump. The performance curves of the pumps supplied by the manufacturers make use of this quantity for preparing such documents. The expression for the dimensionless specific speed is given by:

$$N_s = \frac{N\sqrt{Q}}{(gH)^{3/4}}, \text{ for pump} \tag{5.1}$$

$$N_s = \frac{N\sqrt{(P/Q)}}{(gH)^{5/4}}, \text{ for turbine} \tag{5.2}$$

where N is rotational speed in rpm, Q is discharge in m^3/s, P is power in W, H is head in m, and g is gravitational acceleration in m/s^2.


Francis
Fixed pitch propeller
Turgo
Pelton
Kaplan
Crossflow

Turbines convert the energy of rushing water, steam or wind into mechanical energy to drive a generator.

Francis turbine : Water strikes the edge of the runner, pushes the blades and then flows toward the axis of the turbine. It escapes through the draft tube located under the turbine. It was named after James Bicheno Francis (1815-1892), the engineer who invented the apparatus in 1849.

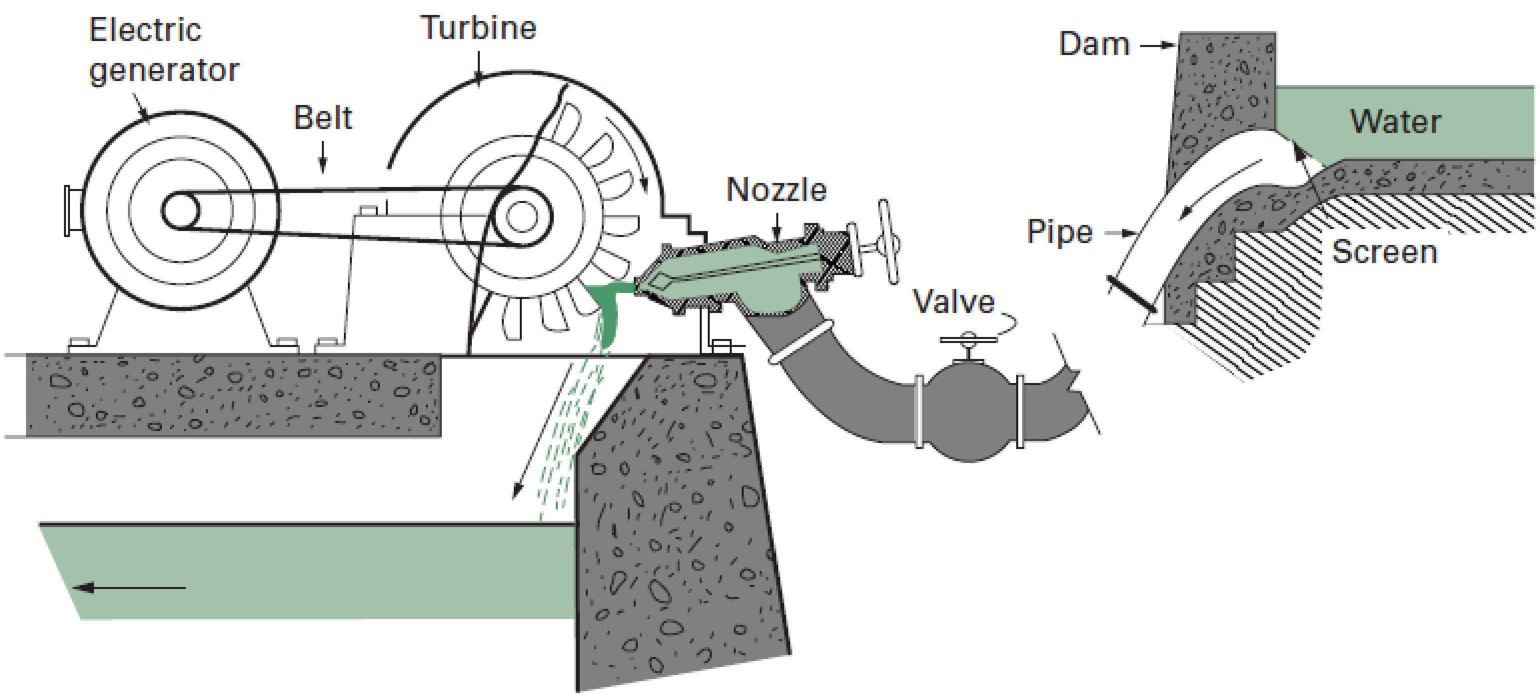
Kaplan turbine : Engineer Viktor Kaplan (1876-1934) invented this turbine. It's similar to the propeller turbine, except that its blades are adjustable; their position can be set according to the available flow. This turbine is therefore suitable for certain run-of-river generating stations where the river flow varies considerably.

Propeller turbine : Since they can reach very high rotation speeds, propeller turbines are effective for low heads. Consequently, this type of turbine is suitable for run-of-river power stations.

Pelton turbine : Named after its inventor, Lester Pelton (1829-1908), this turbine uses spoon-shaped buckets to harness the energy of falling water.

Hydroelectric Systems

The *dam* insures a steady supply of water without fluctuations, and, most importantly, enables *energy storage* in the reservoir. It may also provide benefits other than generating electricity (e.g. flood control, water supply, a road crossing).



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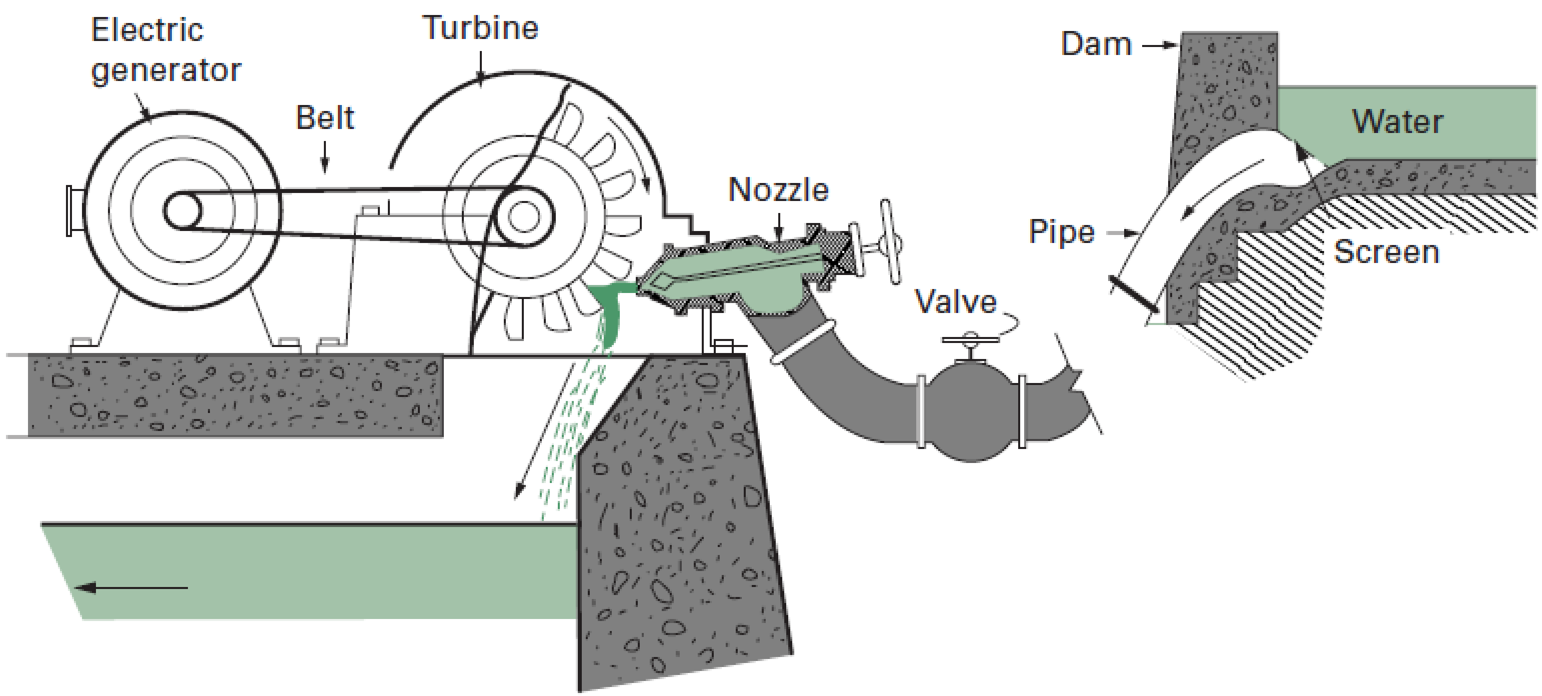
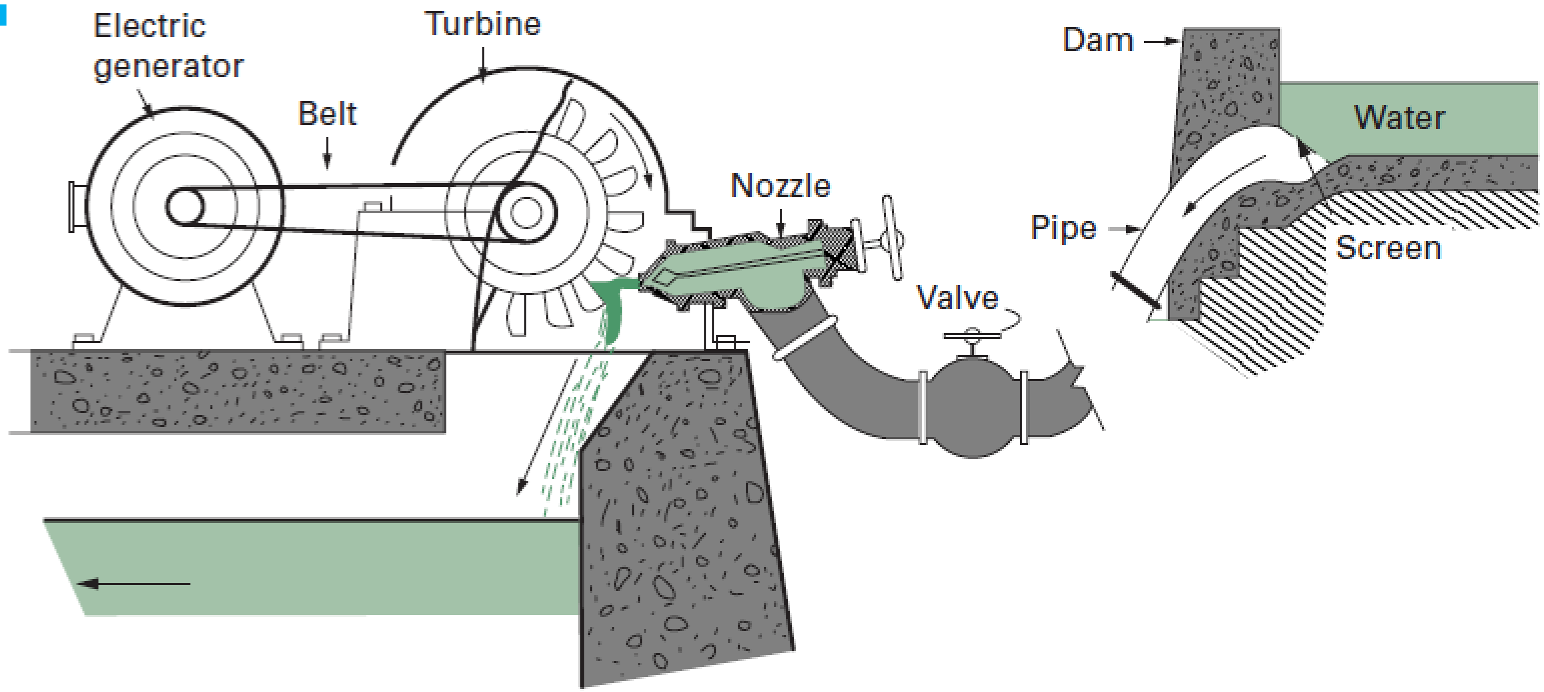
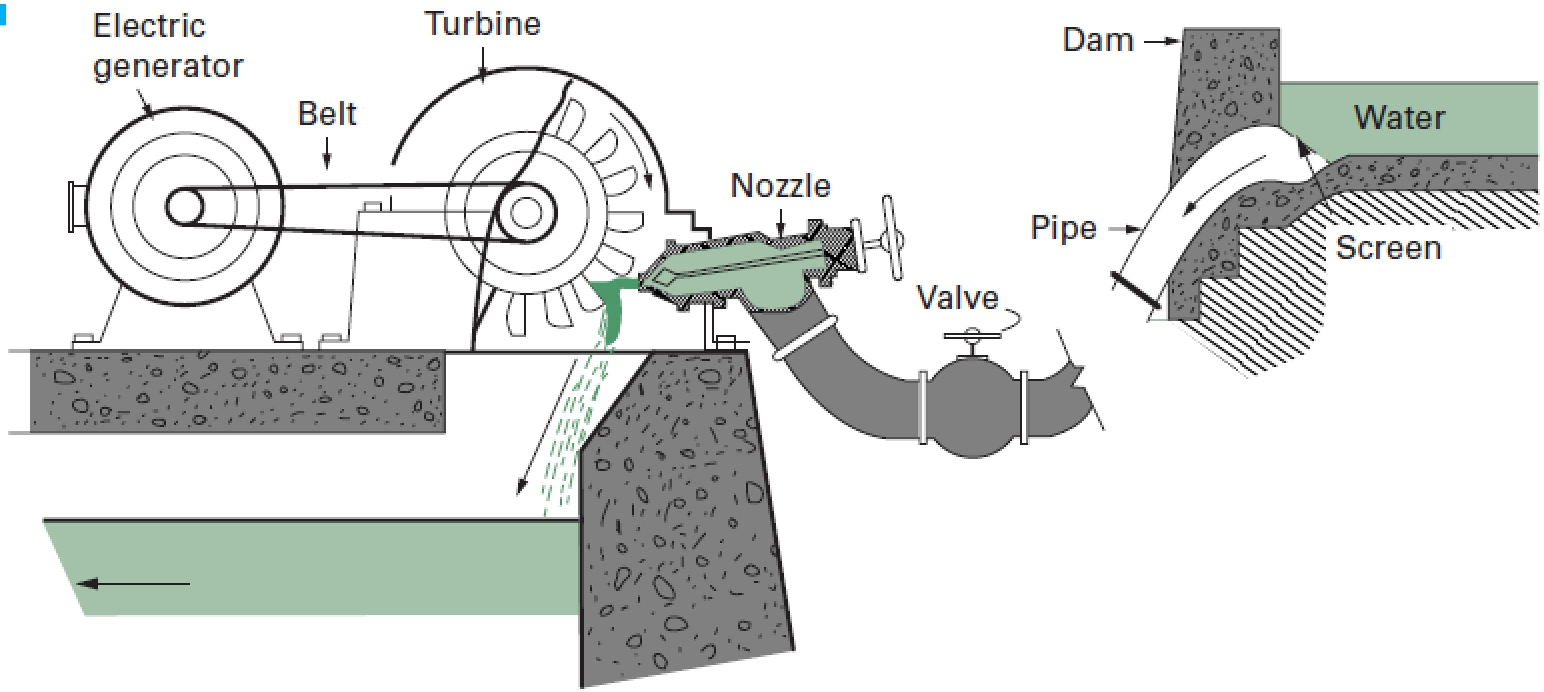


Hydroelectric Systems



The supply pipe (penstock) is usually a relatively major construction cost. It is cheaper if thin walled, short and of small diameter; but these conditions are seldom possible. In particular the diameter $\boldsymbol{D}$ cannot be small due to excessive head loss $\boldsymbol{H_f \propto D^{-5}}$. The greater cost of a larger pipe has to be compared with the continued loss of power by using a small pipe. A common compromise is to make $\boldsymbol{H_f \leq 0.1\ H_t}$.

Hydroelectric Systems



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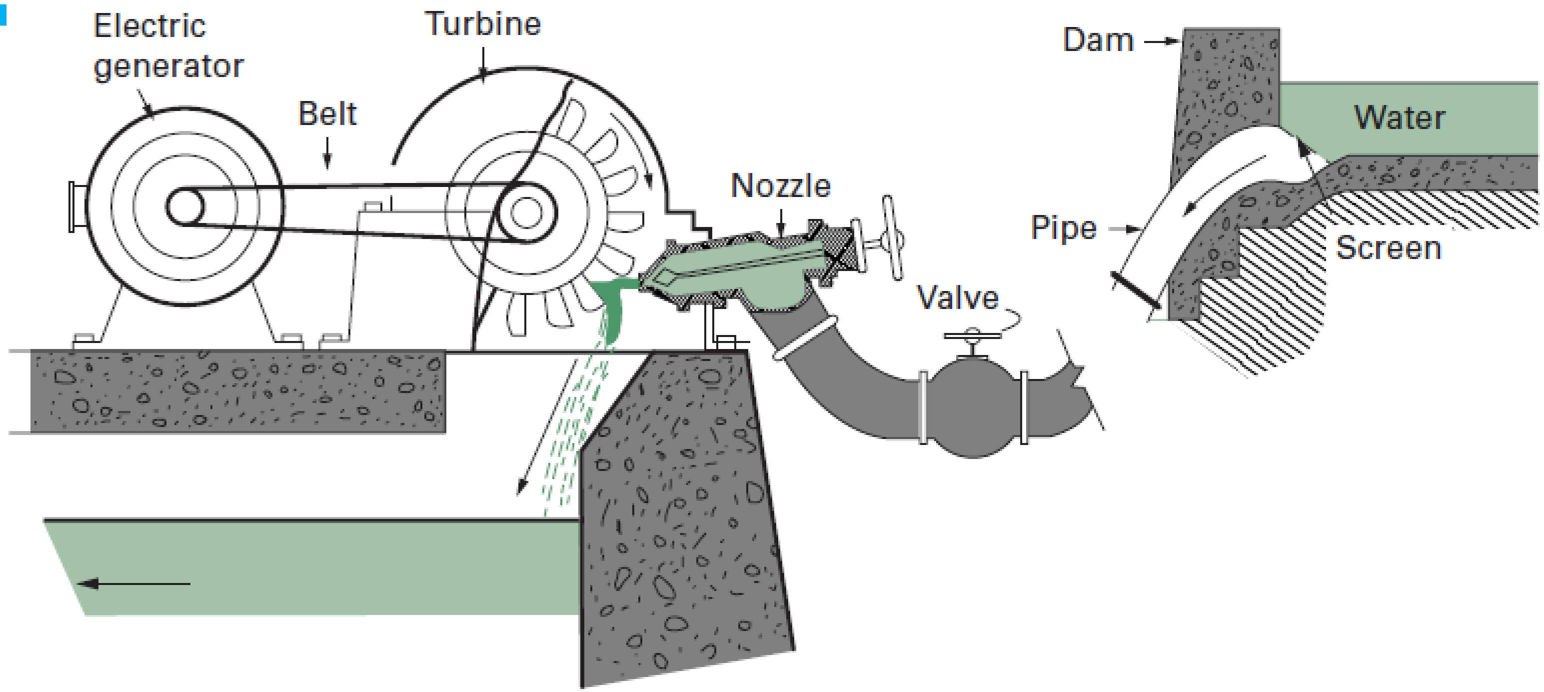

The material of the penstock needs to be both smooth (to reduce friction) and strong (to withstand the static pressures)

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The material of the penstock needs to be both smooth (to reduce friction) and strong (to withstand the static pressures, and the considerably larger dynamic 'water hammer' pressures from sudden changes in flow).

Energy Conversion Schemes For Hydroelectricity-1

The following types of generators are normally employed for grid fed mode:

1. Three-phase synchronous generators (wound field) – both brushed and brushless
2. Three-phase induction generators (squirrel cage)

The following types of generators are normally employed for off-grid mode:

1. Three-phase synchronous generators (wound field) – both brushed and brushless
2. Three -phase capacitor self-excited induction generators (SEIG) with squirrel cage rotor
3. Three -phase SEIG operating in single-phase mode
4. Single-phase SEIG.

The following sections describe both grid fed and off-grid small hydro systems.

Grid Fed Systems

Here, **typical unit sizes** may vary from a few hundred kW to a few MW feeding hydropower to the local grid. Both wound field synchronous generator (WFSG) and squirrel cage induction generator (SCIG) can be used. In this scheme, the hydro turbine operated by water power drives the generator either directly or through some speed enhancing mechanism. A step-up transformer is interfaced to match the grid voltage with the generator voltage. Power P_0 in W in a hydro-turbine is given by:

$$P_0 = \rho Q g H \tag{6.1}$$

where $\boldsymbol{g}$ is the acceleration due to gravity and $\boldsymbol{H}$ is the vertical component of the water path.

Small uncontrolled turbines operate at near constant head and discharge and hence produce near constant power in a given season. Thus, the power fed to the grid from a generator is almost constant. **In large hydro schemes** turbine blades are controlled to vary power input.

Synchronous Generator

The WFSG driven by a hydroturbine is shown in Figure 5.5. As explained, power (P) fed to the grid is nearly constant dependent on hydropower input unless there is turbine control.

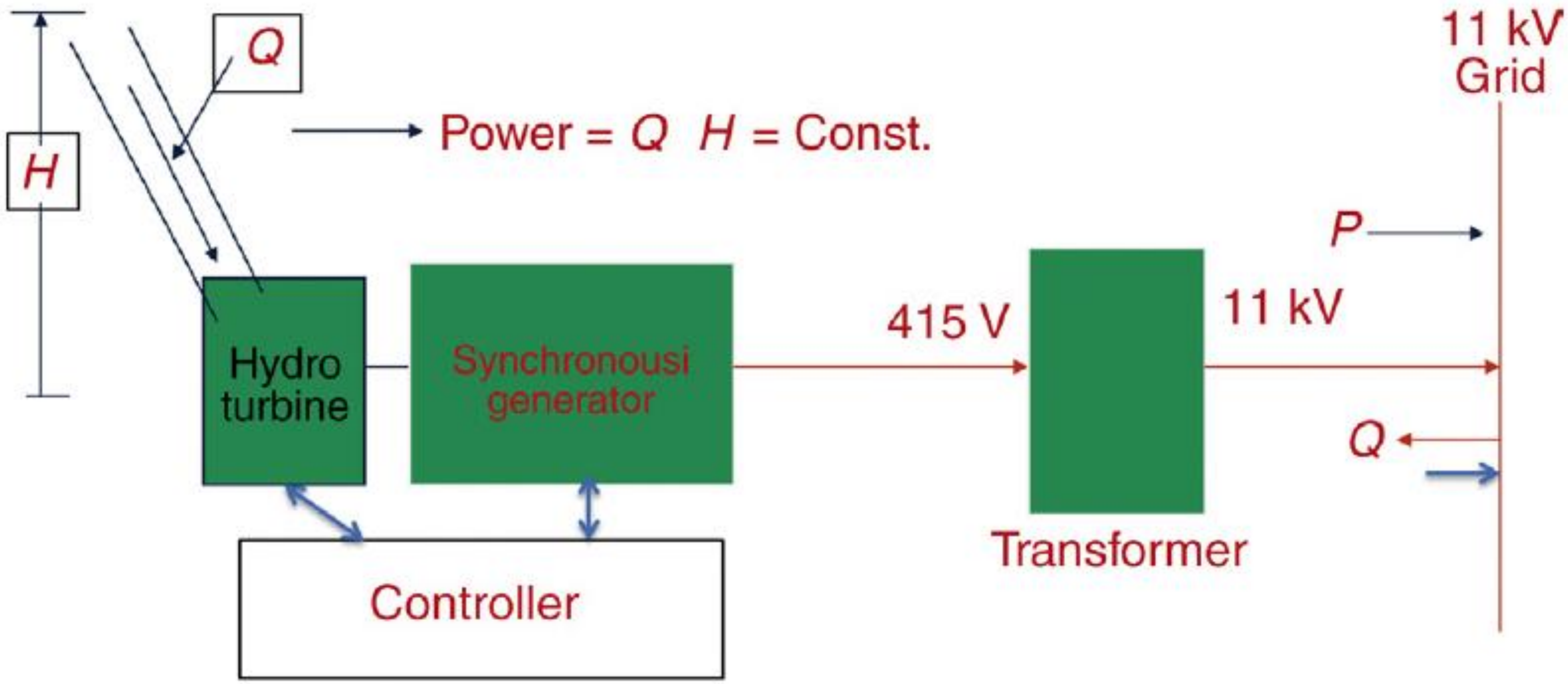


Figure 5.5 Hydroturbine-driven WFSG feeding power to grid.

Synchronous Generator

The lagging reactive power or VAR(Q) drawn by the grid can be controlled by field current ($\boldsymbol{I}_{\mathbf{f}}$). With low $\boldsymbol{I}_{\mathbf{f}}$ or an underexcited condition, Q drawn by the grid is positive and PF is lagging at the grid. With high $\boldsymbol{I}_{\mathbf{f}}$ or overexcited condition, Q drawn by the grid is negative and PF is leading at the grid. Thus, there is one value of $\boldsymbol{I}_{\mathbf{f}}$ at which the PF is unity when $Q = 0$. VAR control is an important feature of hydro generator performance and WFSG provides
considerable flexibility. A major drawback is the need for synchronization with the grid every time the synchronous generator is connected to grid through adjusting voltage, frequency, and phase positions. WFSG needs a slip ring and brush arrangement, which needs regular maintenance unless a brushless arrangement with rotating diodes is used. An automatic voltage regulator (AVR) for stabilizing grid voltage and Q control is an integral part of this system that adds to complexity. The controller shown in Figure 5.5 involves AVR to control generated voltage. In large hydro it may contain turbine control to orient the blades. A controller operates by receiving feedback signals from generator/turbine.

Induction generator

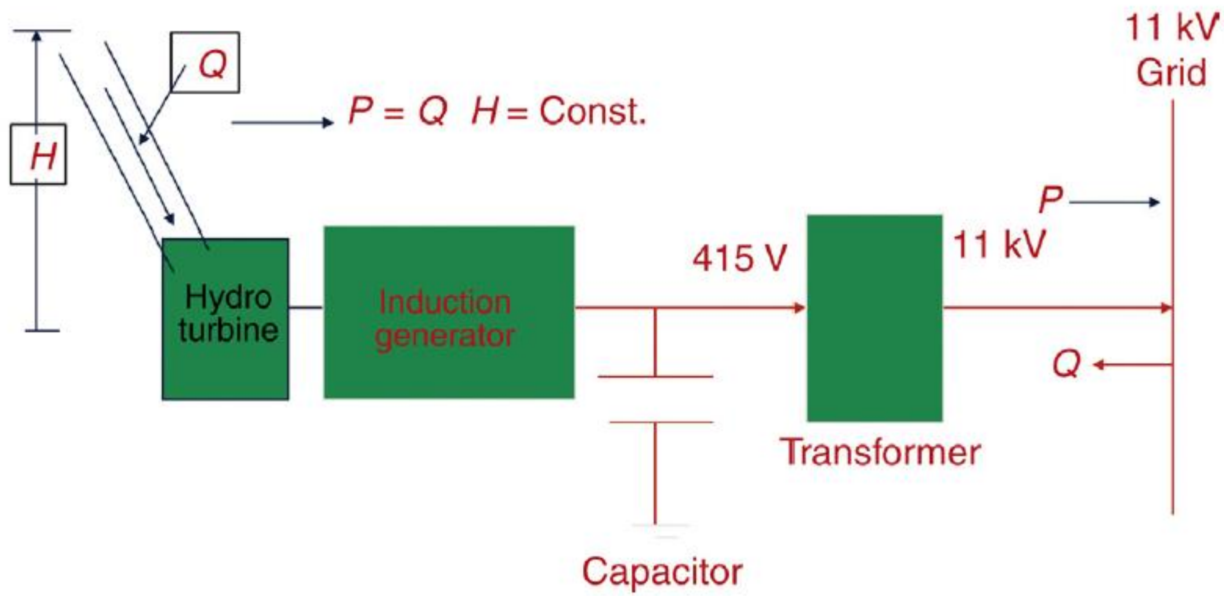


Figure 5.6 SCIG in a minihydro system.

SCIG is also suited for grid connected small hydro systems whose schematic is shown in Figure 5.6. To reduce reactive power (VAR) drain from the grid terminal capacitors are used. Since power fed to the grid is constant, slip too is constant. Q control is made through capacitors whose value can be fixed based on desired PF at the grid.

Induction generator

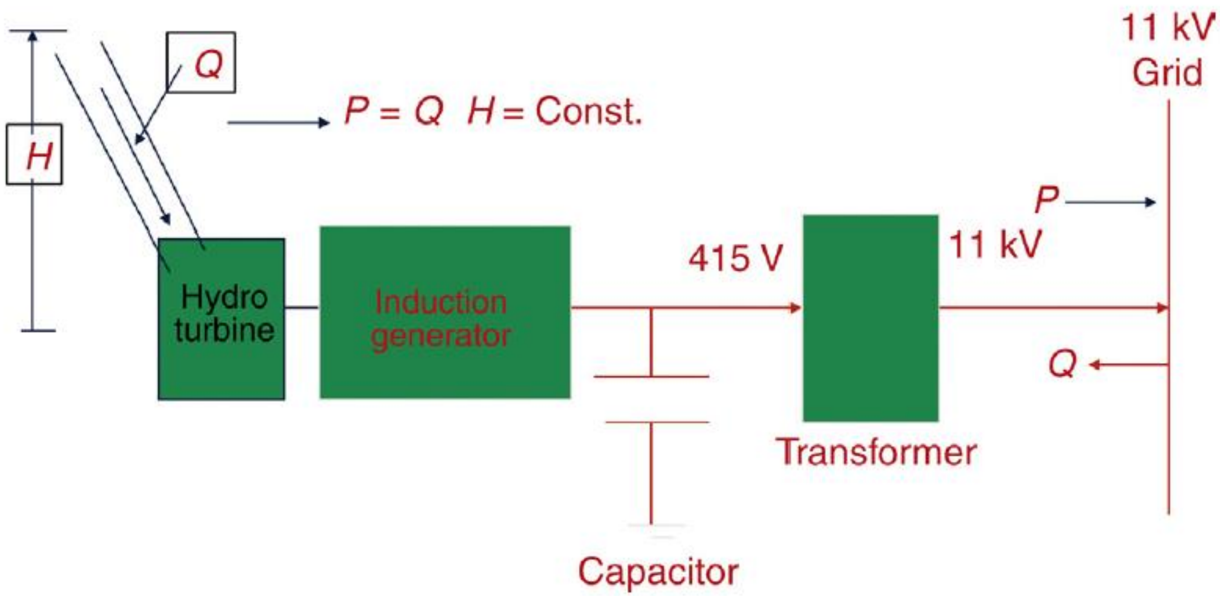


Figure 5.6 SCIG in a minihydro system.

SCIG is simpler compared to a synchronous generator due to brushless cage construction with reduced unit cost and ease of maintenance. There is no synchronizing need. Performance under short circuit is better compared to that with a synchronous generator. An induction generator can operate with variable speed controlled by input power. It can start as a motor and run as a generator with input water flow.

Energy Conversion Schemes For Hydroelectricity-2

For utility supply companies, hydroelectricity provides an extremely flexible and reliable method of generating electricity, only constrained by lack of rainfall. The key feature is that power can be increased or decreased rapidly within seconds to fine-tune the power balance on a grid. If hydropower is offline, it can be brought fully online within a few minutes from a 'standing start'. If it is offline, no resource is being wasted.
A further benefit of hydropower is that a system powered from water in a reservoir and feeding water into a river or lake *can be reversed*.

Excess power on the grid (e.g. from wind farms and at night from nuclear power stations) may be used to pump water uphill to the reservoir. Later, when peak electricity is needed, the water can be returned downhill to generate the necessary 'extra' power.

Pumped Storage Scheme

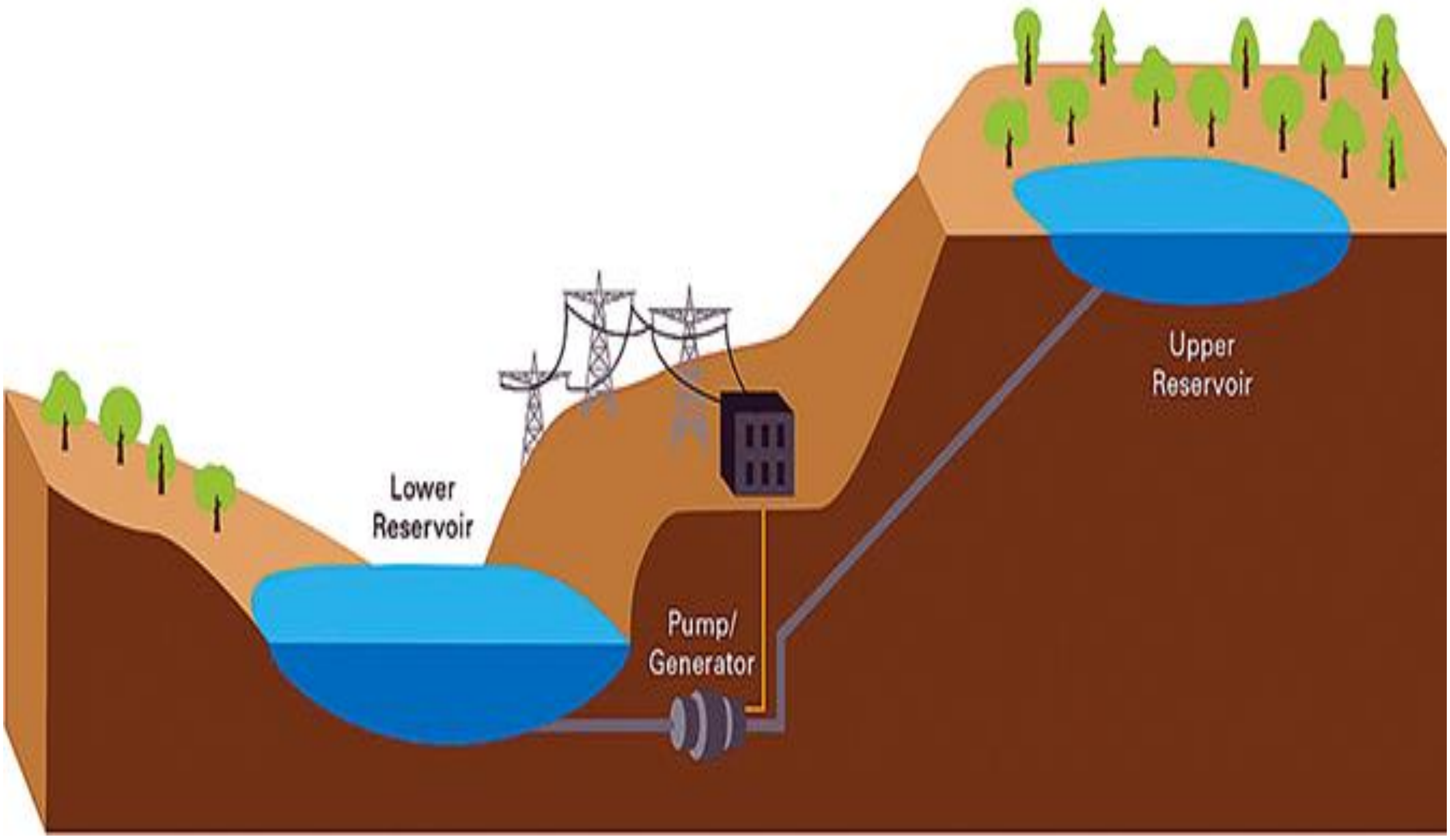
The top reservoir of a pumped storage scheme may (a) accept rainfall within a catchment (as with conventional hydropower), and (b) receive water pumped from the lower 'reservoir'.

You must have heard in TV and read in news-papers that a certain dam's water level is now only such and such Low level. Worst case is if the natural dam is empty then no electric power will be generated until the dam is refilled. So we have to wait for natural rain or snow to melt and transfer water from mountains to the dam.

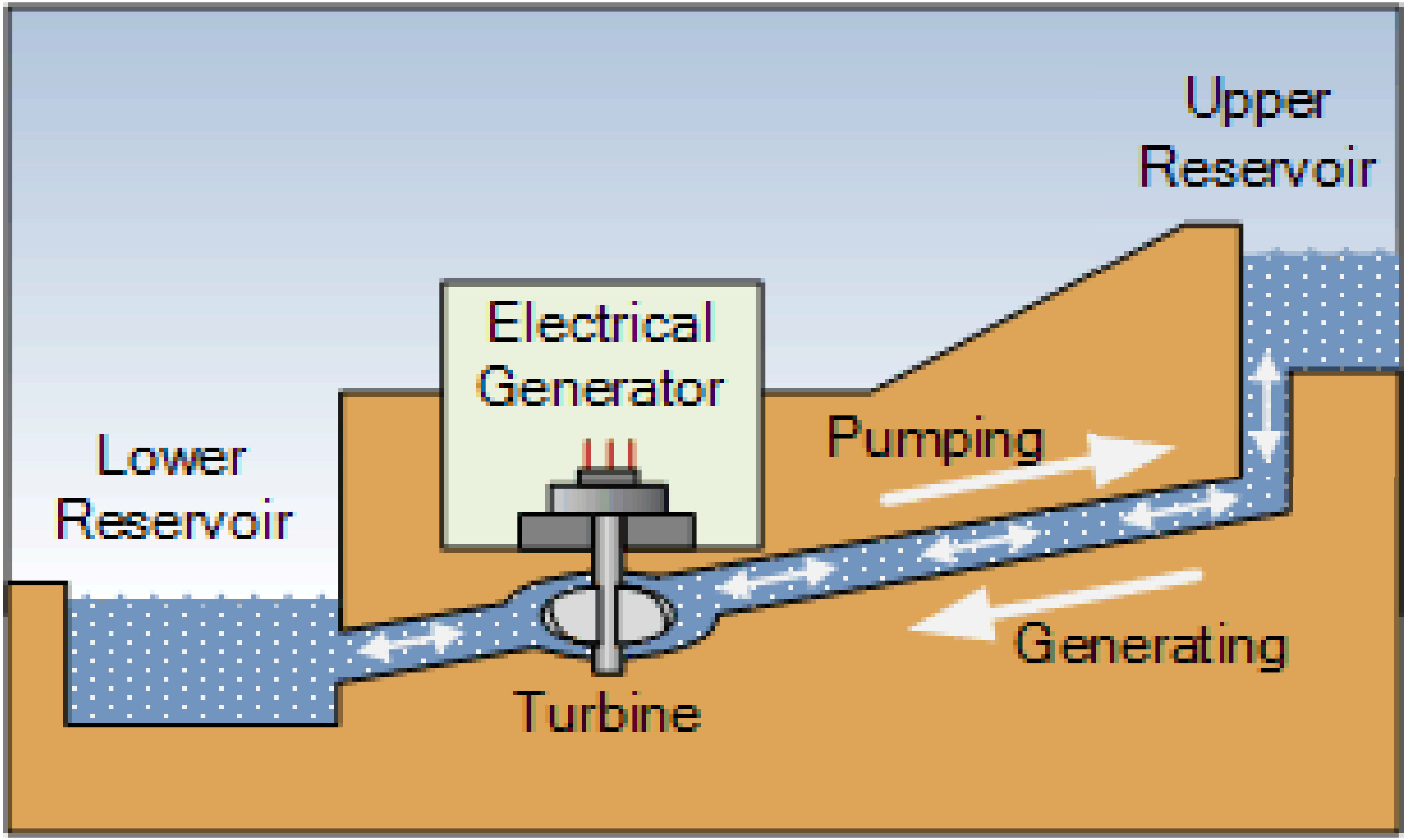
Engineers have proposed a solution for such situation. The solution is called **Pumped storage scheme**. The concept is to refill the dam with the same water by installing a ***pump*** to push the water back.

The ratio of energy out to energy in (i.e. the efficiency of storage) is about 70%.

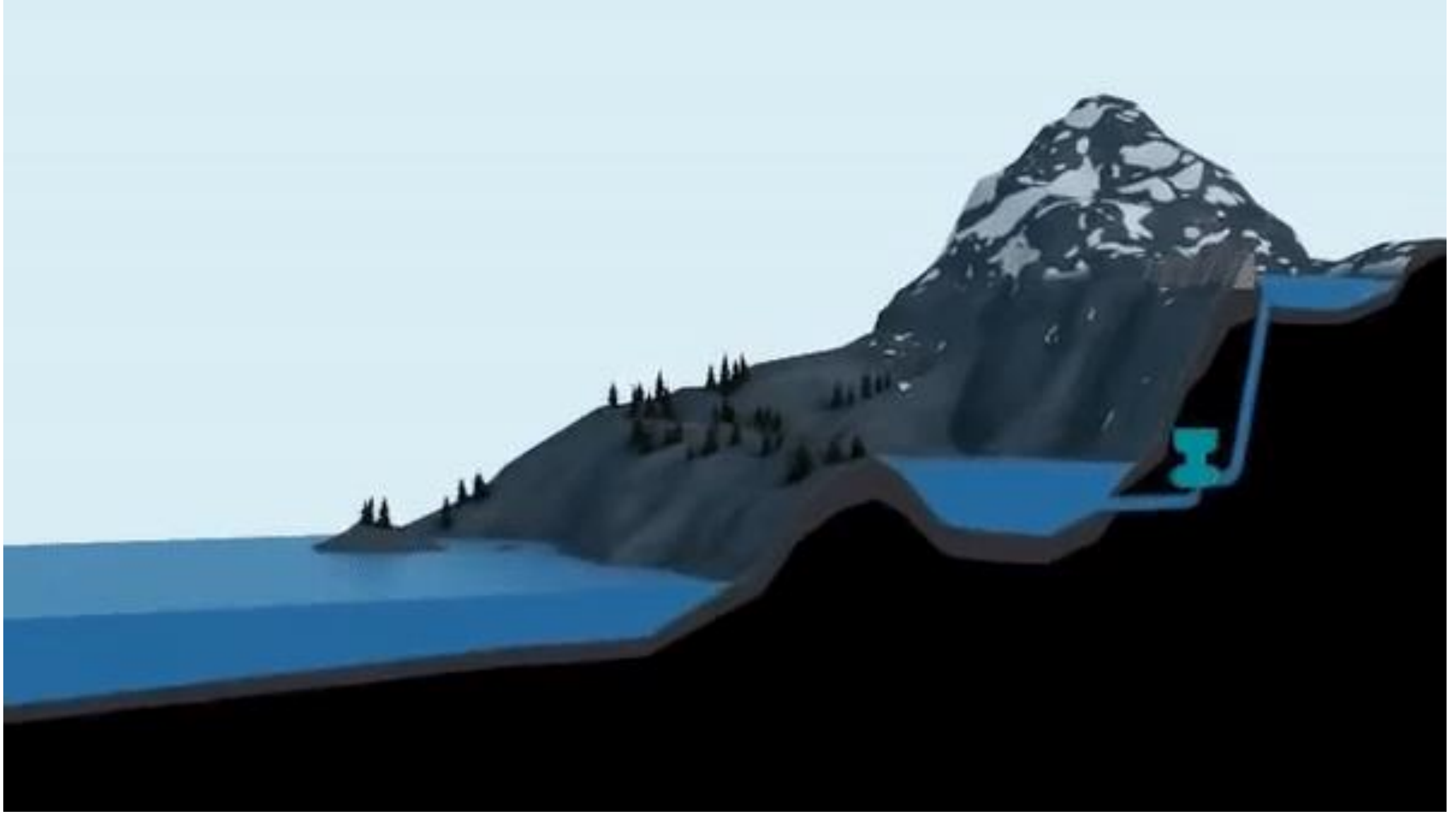
Pumped Storage Scheme



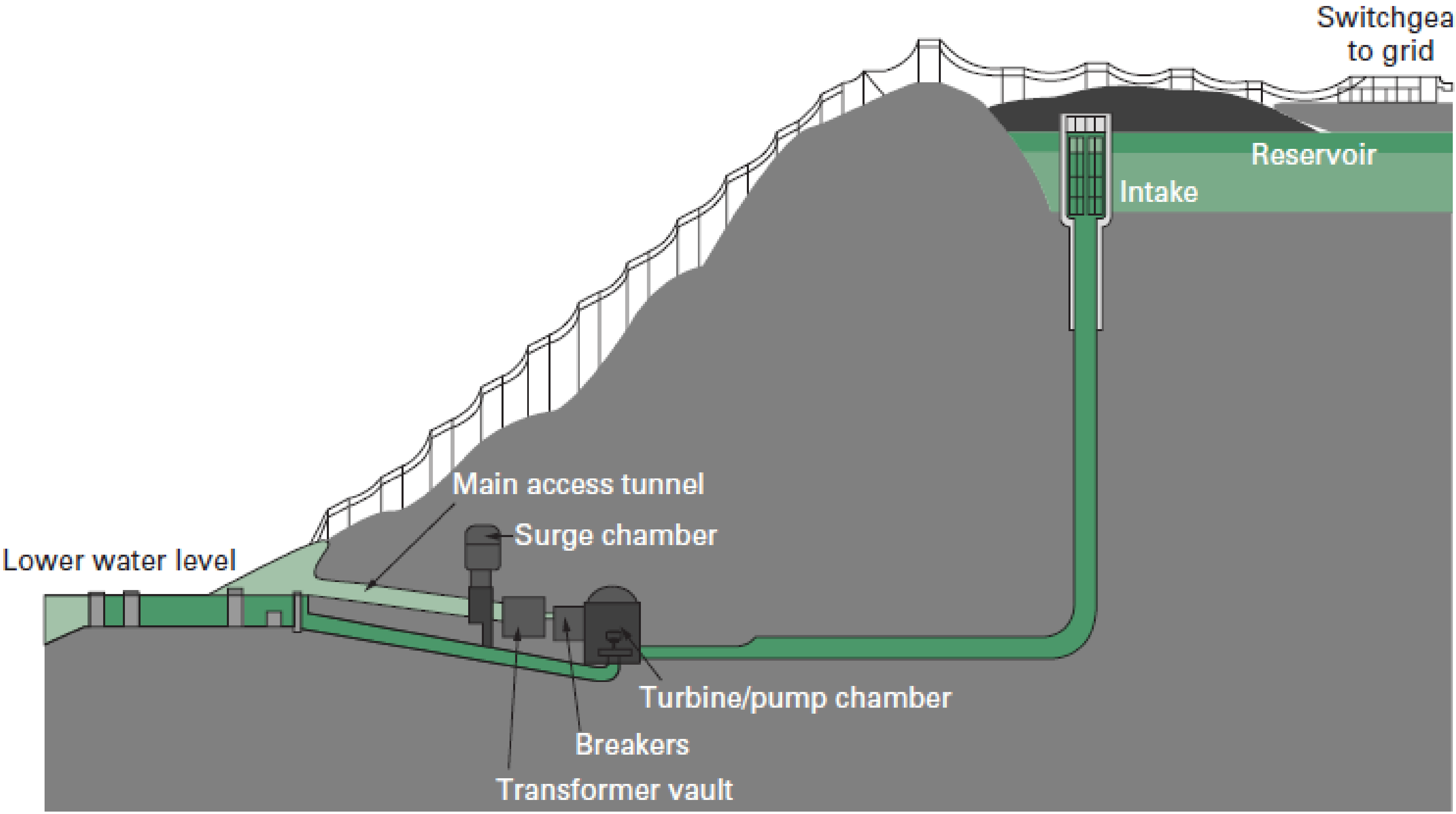
Pumped Storage Scheme



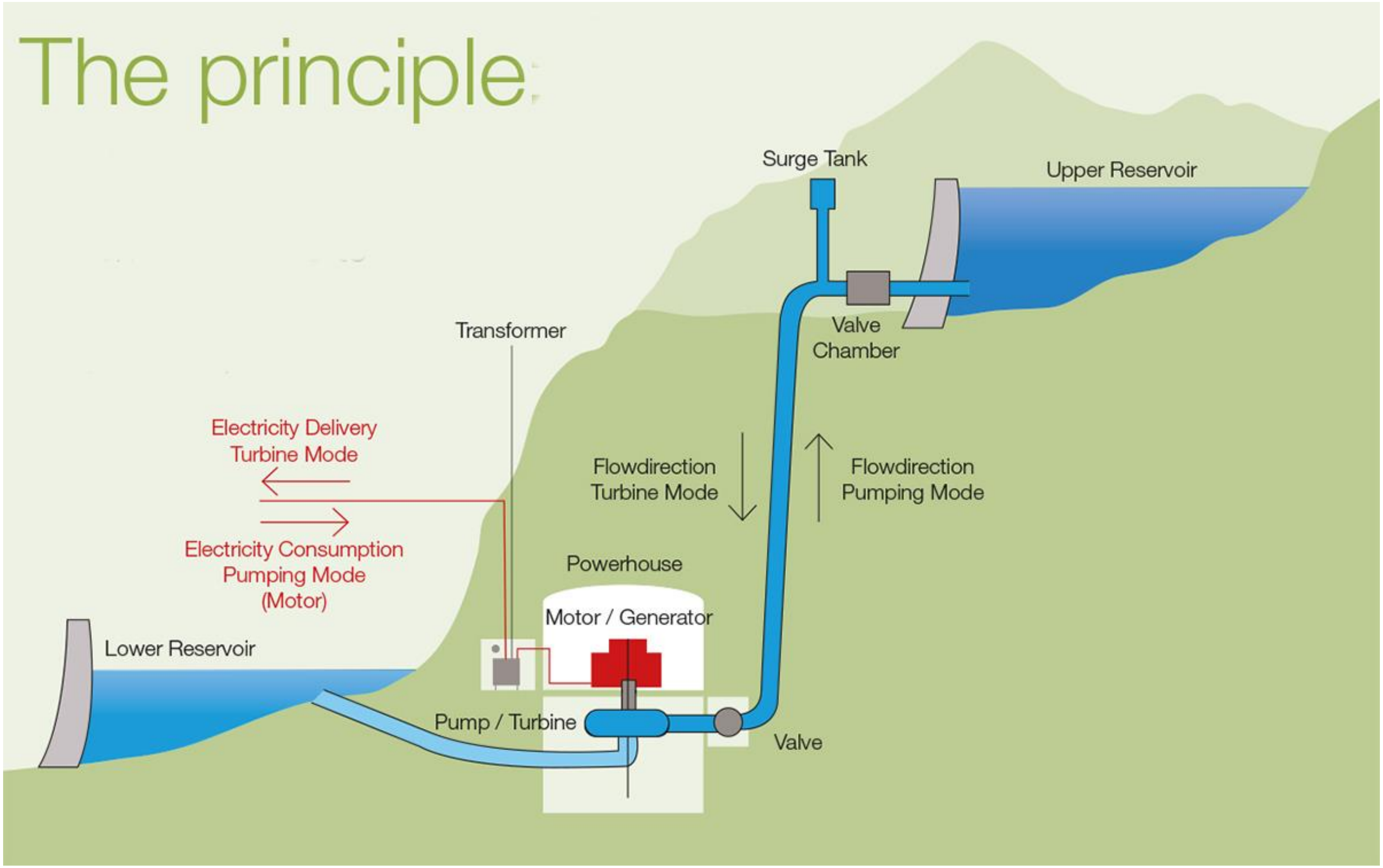
Pumped Storage Scheme...*Animation*



Pumped Storage Scheme



Pumped Storage Scheme



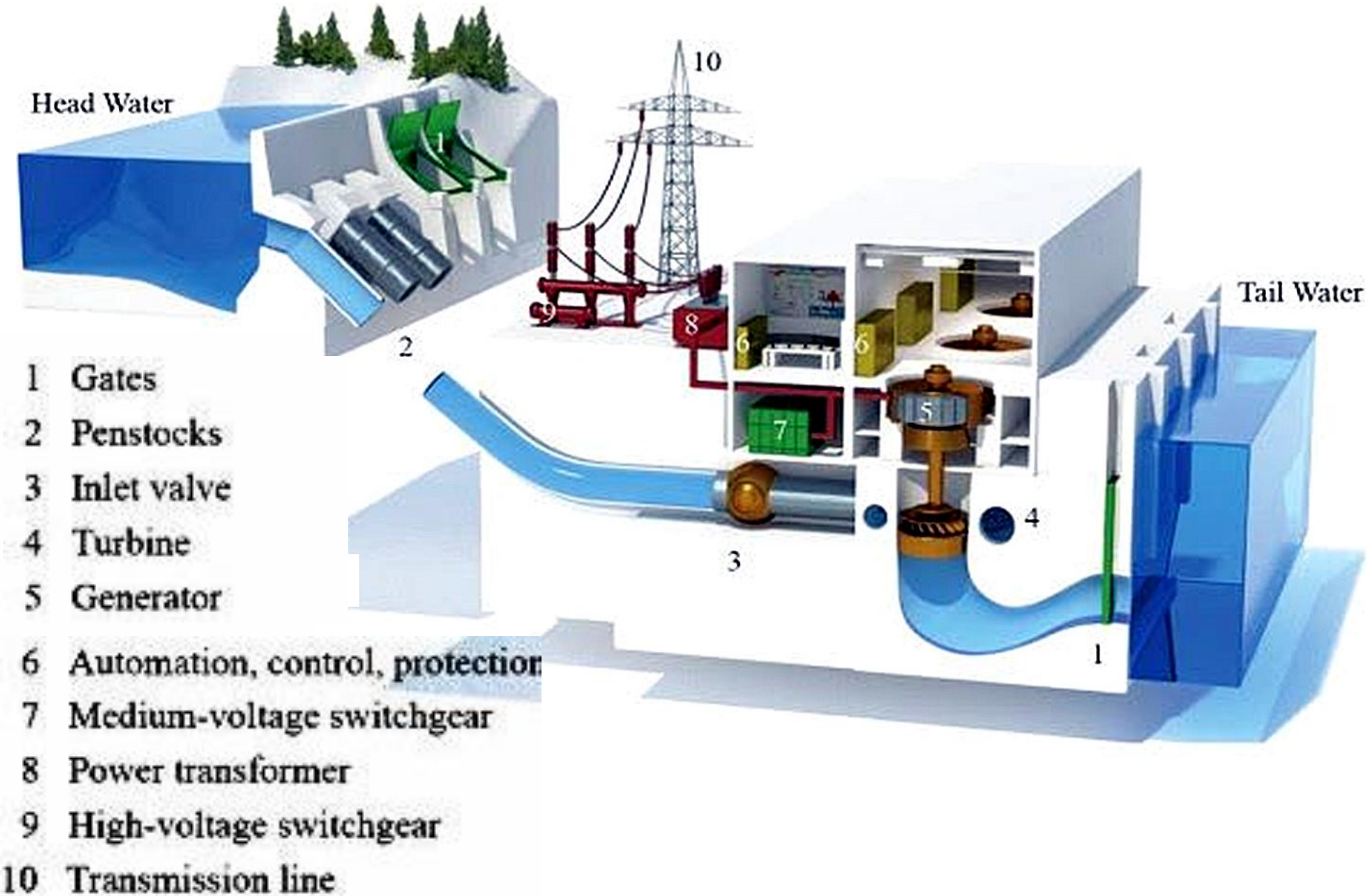
Pumped Storage Scheme

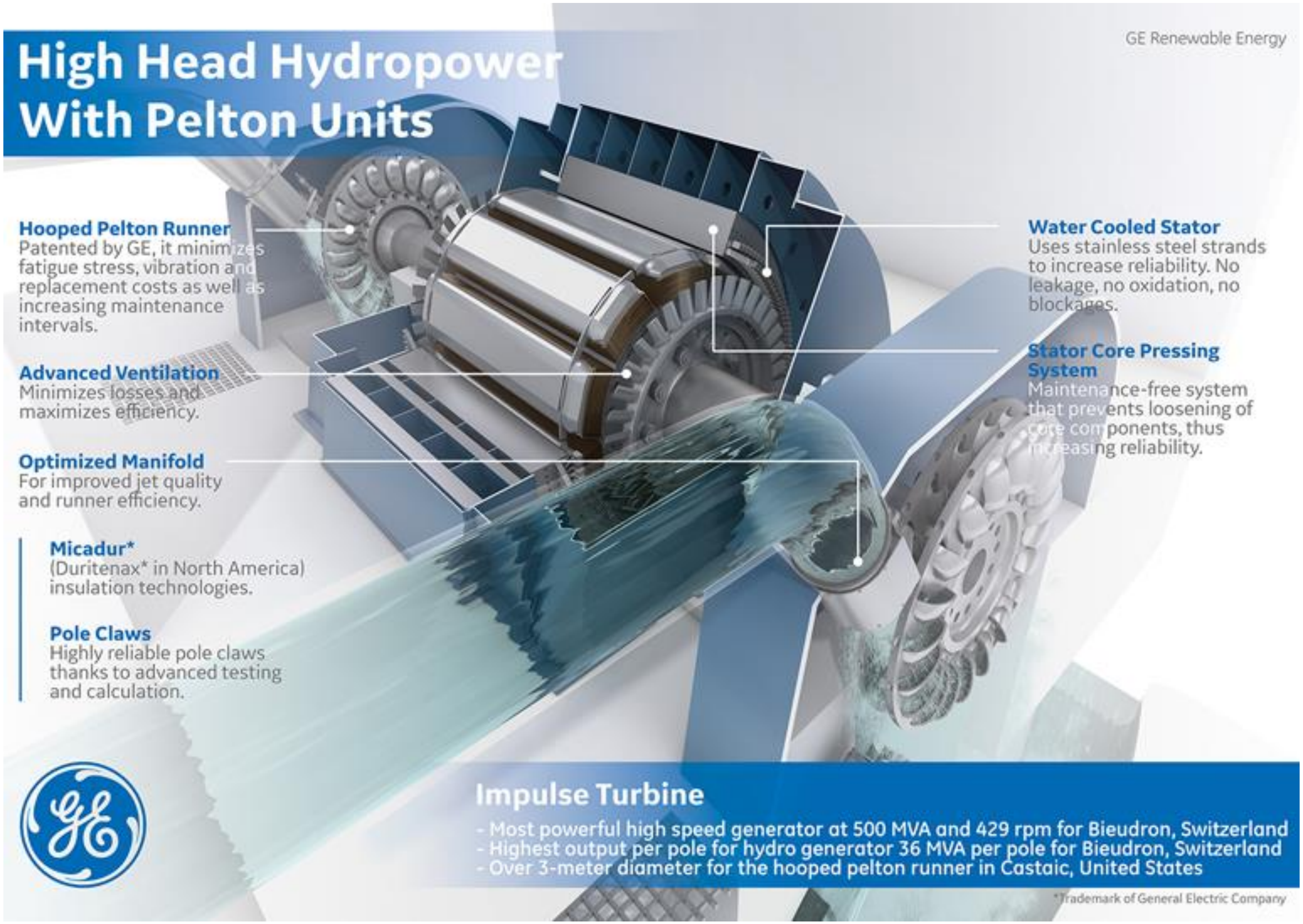
The top reservoir of a pumped storage scheme may (a) accept rainfall within a catchment (as with conventional hydropower), and (b) receive water pumped from the lower 'reservoir'. Usually (b) dominates.

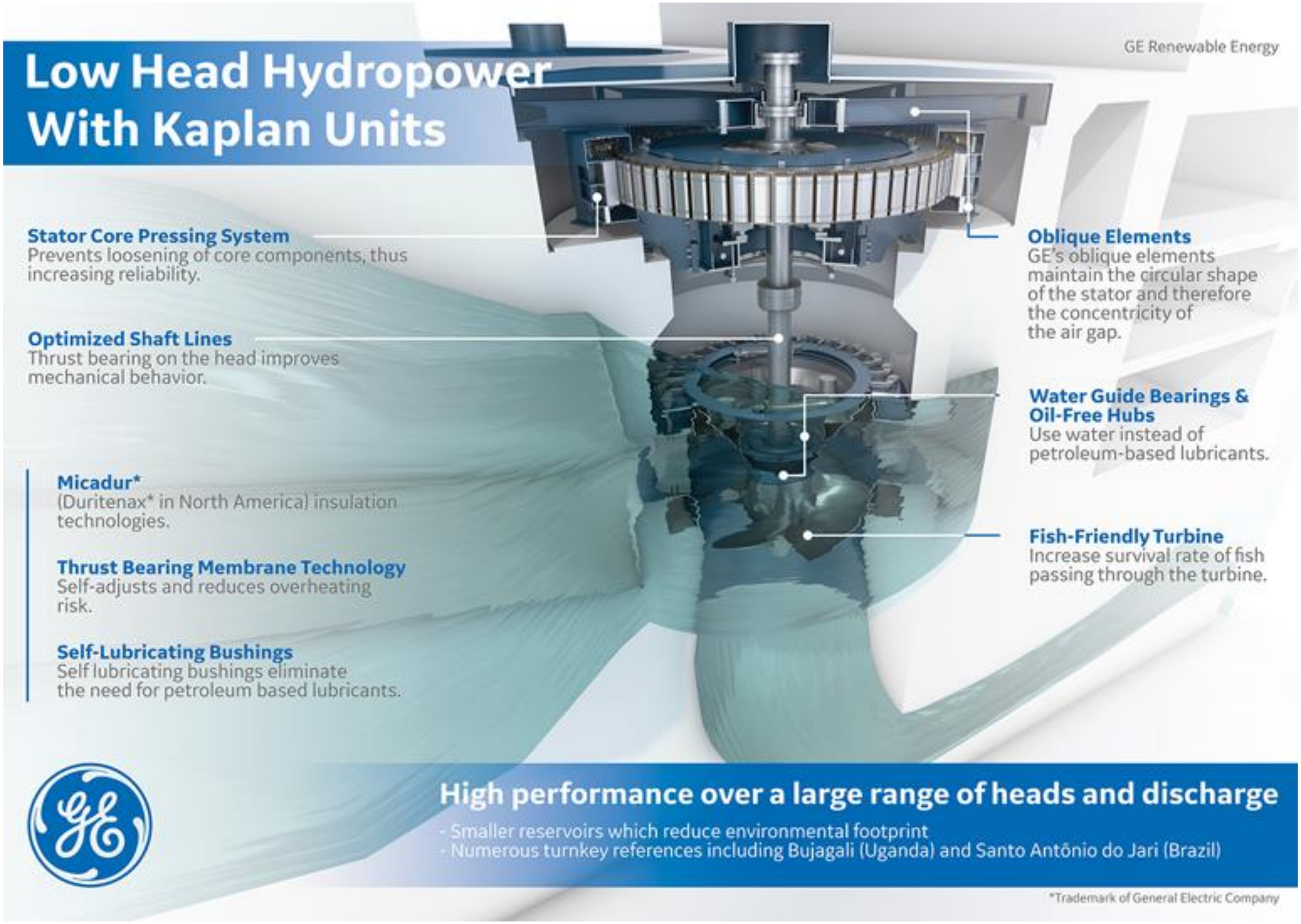
Thus the electricity from the pumped storage component should not be treated as renewable energy such as; the primary generation labels the classification (e.g. if from wind farms then renewable, if from nuclear and/or fossil fuels then non-renewable). Thus the carbon abatement of pumped storage is not obvious, and since the efficiency of storage is about 70 to 80% at most, about 20 to 30% of the input energy is wasted.

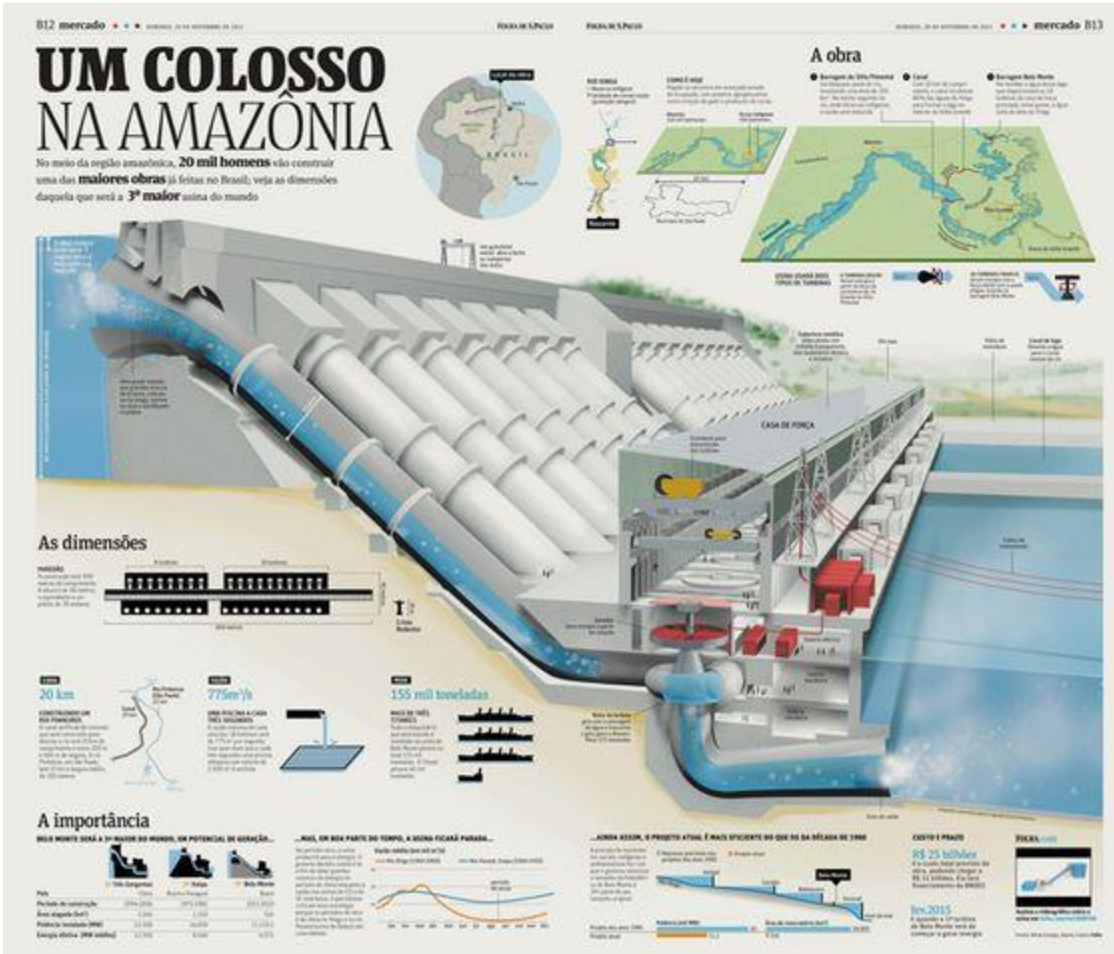
Since pumped storage is a net user of electricity (it requires electricity to pump the water to the higher storage reservoir), it depends on strong differentials in the market price of electricity, between low and peak demand, for its financial viability.

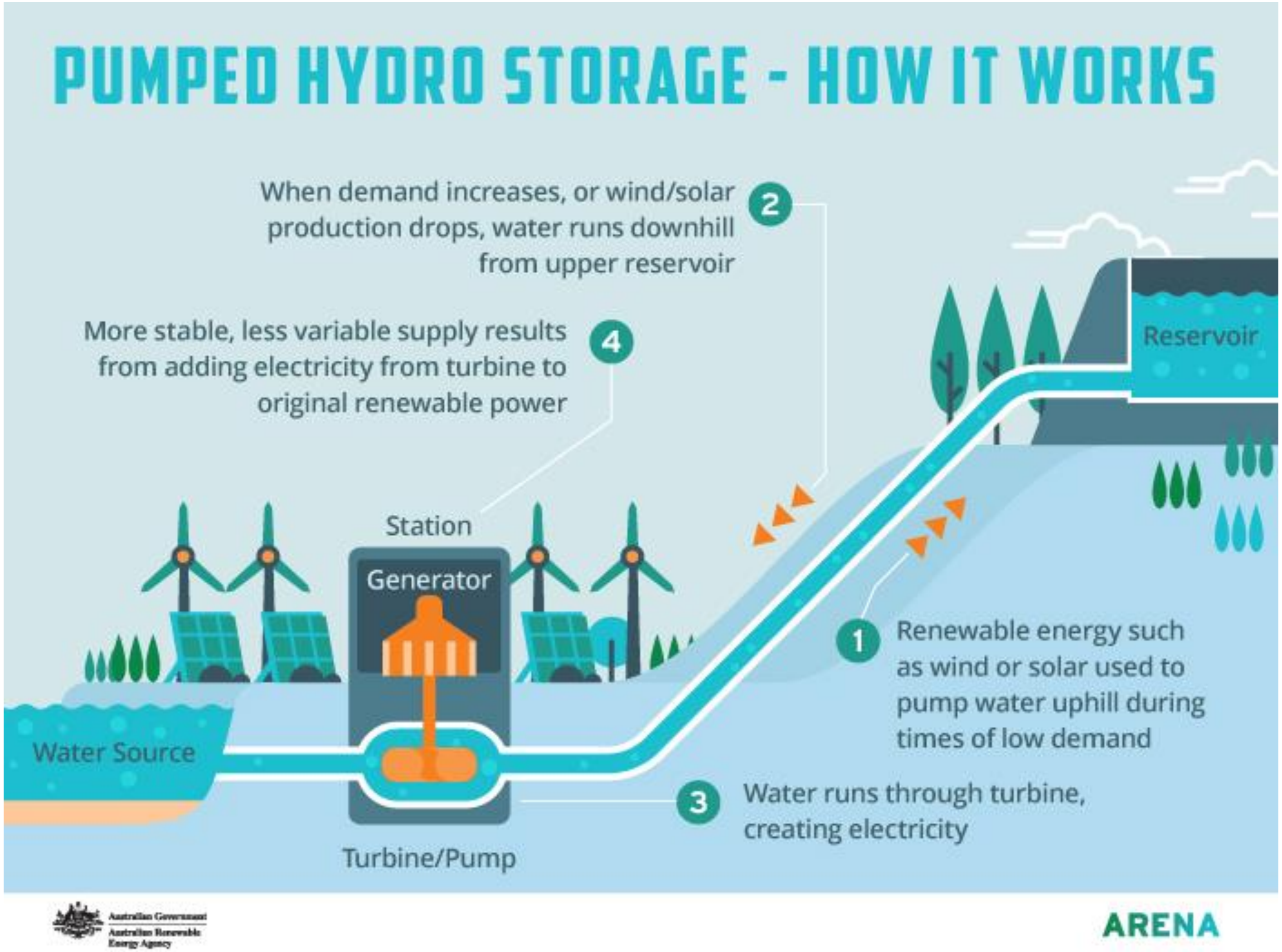
Hydro—Power Typical Installation




High Head Hydropower
With Pelton Units
GE Renewable Energy
Hooped Pelton Runner
Patented by GE, it minimizes fatigue stress, vibration and replacement costs as well as increasing maintenance intervals.
Advanced Ventilation
Minimizes losses and maximizes efficiency.
Optimized Manifold
For improved jet quality and runner efficiency.
Micadur*
(Duritenax* in North America) insulation technologies.
Pole Claws
Highly reliable pole claws thanks to advanced testing and calculation.
Water Cooled Stator
Uses stainless steel strands to increase reliability. No leakage, no oxidation, no blockages.
Stator Core Pressing System
Maintenance-free system that prevents loosening of core components, thus increasing reliability.
Impulse Turbine
- Most powerful high speed generator at 500 MVA and 429 rpm for Bieudron, Switzerland
- Highest output per pole for hydro generator 36 MVA per pole for Bieudron, Switzerland
- Over 3-meter diameter for the hooped pelton runner in Castaic, United States
*Trademark of General Electric Company


GE Renewable Energy
Low Head Hydropower With Kaplan Units
Stator Core Pressing System
Prevents loosening of core components, thus increasing reliability.
Optimized Shaft Lines
Thrust bearing on the head improves mechanical behavior.
Micadur*
(Duritenax* in North America) insulation technologies.
Thrust Bearing Membrane Technology
Self-adjusts and reduces overheating risk.
Self-Lubricating Bushings
Self lubricating bushings eliminate the need for petroleum based lubricants.
Oblique Elements
GE's oblique elements maintain the circular shape of the stator and therefore the concentricity of the air gap.
Water Guide Bearings & Oil-Free Hubs
Use water instead of petroleum-based lubricants.
Fish-Friendly Turbine
Increase survival rate of fish passing through the turbine.
High performance over a large range of heads and discharge
- Smaller reservoirs which reduce environmental footprint
- Numerous turnkey references including Bujagali (Uganda) and Santo Antônio do Jari (Brazil)
*Trademark of General Electric Company


B12 mercado
UM COLOSSO
NA AMAZÔNIA
No meio da região amazônica, 20 mil homens vão construir uma das maiores obras já feitas no Brasil; veja as dimensões daquela que será a 3ª maior usina do mundo
mercado B13
A obra
CASA DE FORÇA
As dimensões
20 km
775m³/s
155 mil toneladas
A importância
R$ 25 bilhões
fev.2015

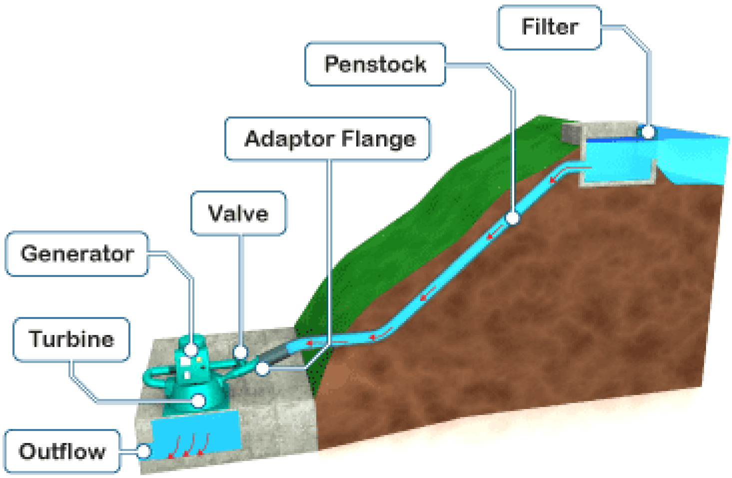

PUMPED HYDRO STORAGE - HOW IT WORKS
2 When demand increases, or wind/solar production drops, water runs downhill from upper reservoir
4 More stable, less variable supply results from adding electricity from turbine to original renewable power
Reservoir
Station
Generator
1 Renewable energy such as wind or solar used to pump water uphill during times of low demand
Water Source
3 Water runs through turbine, creating electricity
Turbine/Pump
Australian Government
Australian Renewable Energy Agency
ARENA

Power Equations Summary

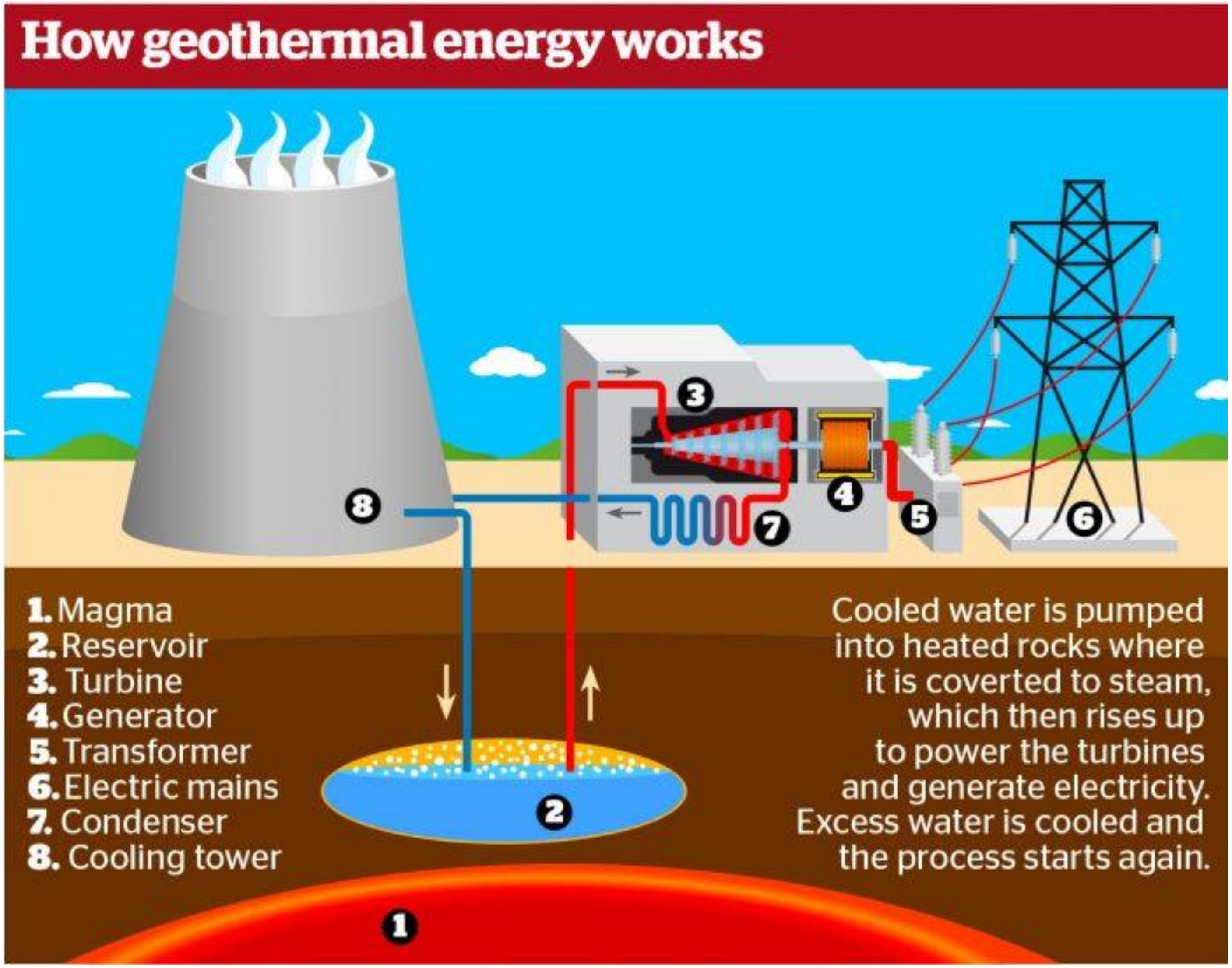
- Hydroelectric: $P = \rho Q g h$
- Wind: $P = C_p A(\frac{1}{2} \rho v^3)$
- Wave front: $P = \frac{1}{2} \rho L v g A^2$

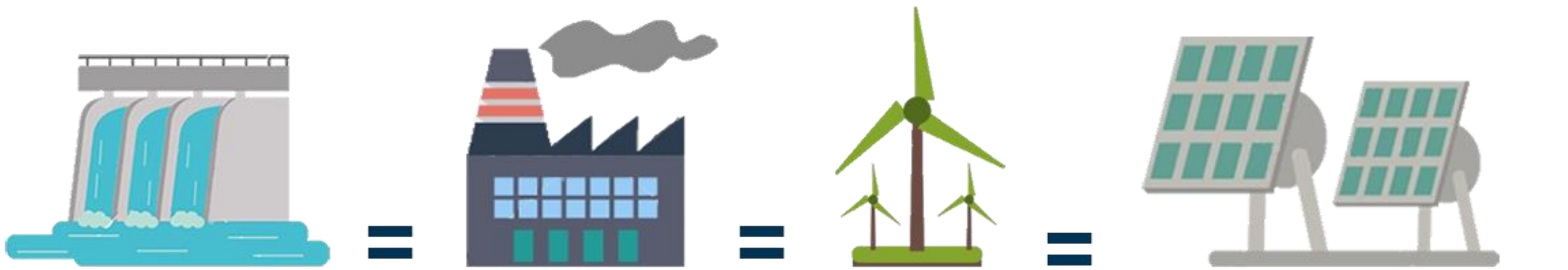
- NOVA Program: Energy Surge

  http://www.pbs.org/wgbh/nova/tech/power-surge.html


Filter
Penstock
Adaptor Flange
Valve
Generator
Turbine
Outflow

Energy Resources





1
Hydroelectric Dam
Site C
1,100 MW

12
Natural Gas Plants
McMahon Co-Generation
120MW

990
Wind Turbines
Leitwind LTW77-1500
1.5 MW

30,000,000
m^2 of Solar Panels
Canadian Solar
500 W

EnergyBC