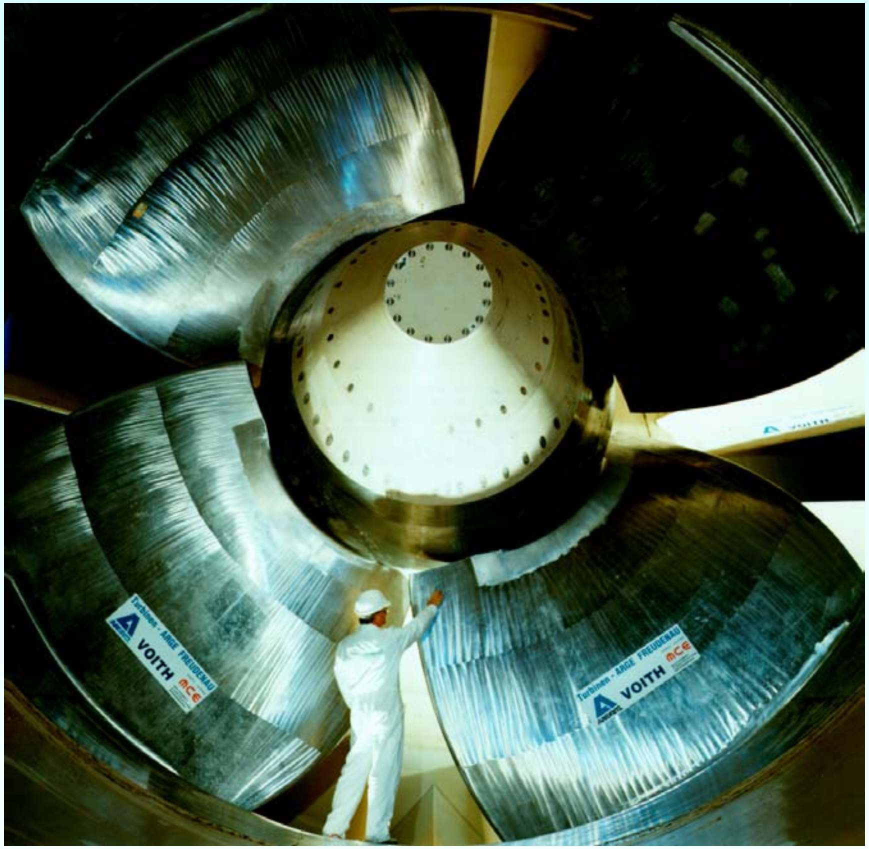
1. Green energy conversion systems

1.2 Hydro energy converters



Source:

VATech Hydro, Austria

Hydro energy conversion

Hydraulic design of hydro power plant

(H: Head, $\rho_{H_2O} = 1000\,\mathrm{kg/m^3}$):

Potential energy of barraged water:

$$W_{pot} = m \cdot g \cdot H = \rho_{H_2O} V \cdot g \cdot H$$

Power:

$$P_{in} = W_{pot} / t = \rho_{H_2O} \cdot (V / t) \cdot g \cdot H = \rho_{H_2O} \cdot \dot{V} \cdot g \cdot H$$

$\dot{V}$: Water flow rate

Efficiency chain:

Hydraulic efficiency: 0.95

Turbine efficiency: 0.9

Generator efficiency: 0.98

Power plant energy consumption: 0.97

Resulting efficiency of power plant: $\eta_{KW} = 0.95 \cdot 0.9 \cdot 0.98 \cdot 0.97 = 0.81$

Electrical power: $P_{out} = P_e = \eta_{KW} \cdot P_{in} = 0.81 \cdot 9.81 \cdot 1000 \cdot \dot{V} \cdot H$

"Rule of thumb": $\boxed{P_e = 8000 \cdot \dot{V} \cdot H}$, $[P_e] = W, [\dot{V}] = m^3 / s, [H] = m$

Classification of hydro power plants

- High head, low flow rate
- Medium head, medium flow rate
- Low head, high flow rate

*) 3 gorges *Xi-Ling*, *Wu*, *Qutang* at *Yangtsekiang* river (barrage: 2 km width, 600 km length)

**) Height of *Grad Dixence* barrage 285 m: bigger than *Eiffel*-tower in *Paris/France*.

Low head	Medium head	High head	High head
High flow rate	Medium flow rate	Low flow rate	Low flow rate
River plant	River barrage plant	Pump storage plant	Pump storage plant
Wallsee/Austria	*3 Gorges*/China*)	*Kaprun*/Austria	*Bieudron*/Switzerland
$H = 9.1$ m	$H = 183$ m	$H = 780$ m	$H = 1883$ m **)
$\dot{V} = 2880\ m^3/s$	$\dot{V} = 12295\ m^3/s$	$\dot{V} = 32\ m^3/s$	$\dot{V} = 86\ m^3/s$
$P_e = 210$ MW	$P_e = 18000$ MW	$P_e = 200$ MW	$P_e = 1295$ MW
Kaplan-Turbines	*Francis*-Turbines	*Pelton*-Turbines	*Pelton*-Turbines
6 Generators, each 35 MW	26 Generators, each 692 MW	4 Generators, each 2x55 MW, 2x45 MW	3 Generators, each 432 MW

Classification of hydro generator operation

- Mainly **fixed speed operation** directly at the grid, usually no inverter !
- "Small hydro" : Cage induction generators with gear, permanent magnet synchronous generators, or electrically excited synchronous generators to allow over-excited power generation

Unit power: several 100 kW ... Several MW

- "Big hydro" : Electrically excited synchronous generators, allowing over-excited power generation, gearless = directly coupled to turbine

Unit power: Several MW ... Several 100 MW

- Typical speed: Synchronous generators: $n = f_s/p$

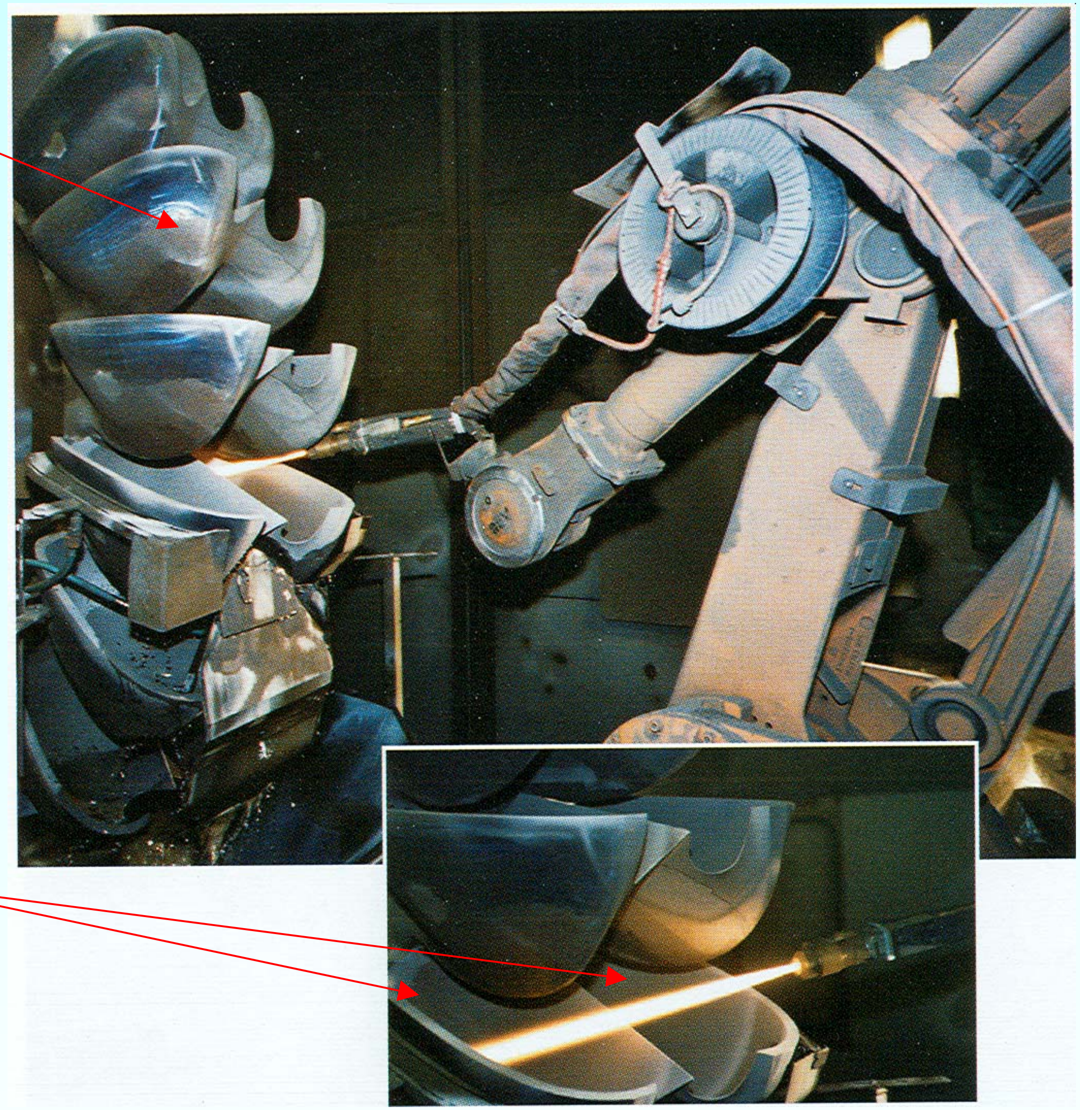
- High head, low flow rate: high speed 750 ... 1000 ... 1500/min

- Medium head, medium flow rate: medium speed 200 ... 500 /min

- Low head, high flow rate: low speed 80 ... 200 /min

Surface finishing of *Pelton* turbine

Fixed blades



Two symmetrical blade shells

Source:

VATech Hydro, Austria

"Small hydro" power plant with *Pelton* turbines

Electrically excited synchronous generator

Housing for flywheel to increase rotor inertia for limiting acceleration at load drop

DC exciter machine

Water inlet

Sleeve bearing

Source:

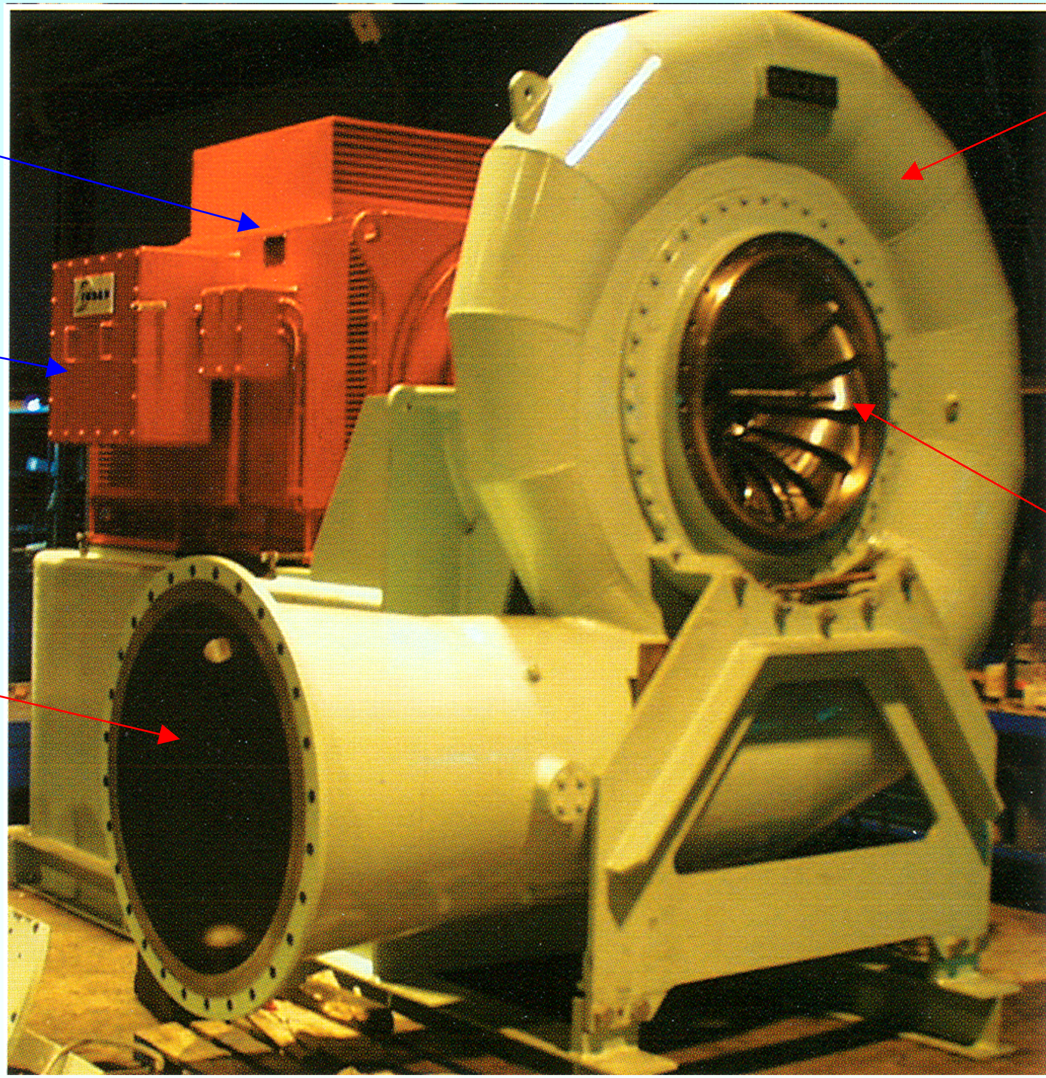
ABB, Switzerland

Small hydro *Francis* turbine in spiral casing

Electrically excited synchronous generator

Terminal box

Water inlet



Spiral housing distributes water flow evenly on turbine

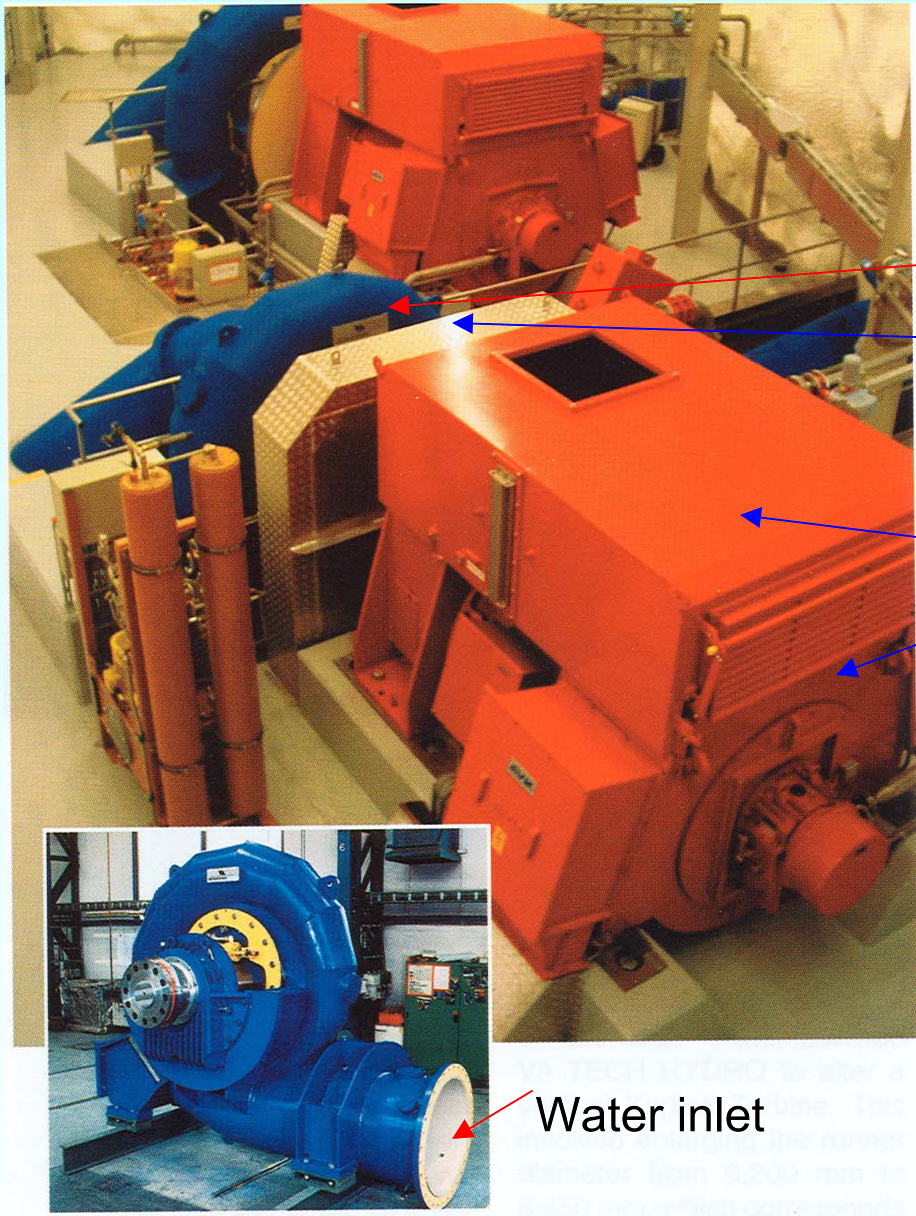
Francis turbine runner,

fixed curved blades

Source:

VATech Hydro, Austria

"Small hydro" power plant with Francis turbines



Francis turbine spiral housing

Flywheel for increase of inertia to reduce acceleration in case of dropping electrical load

Heat exchanger

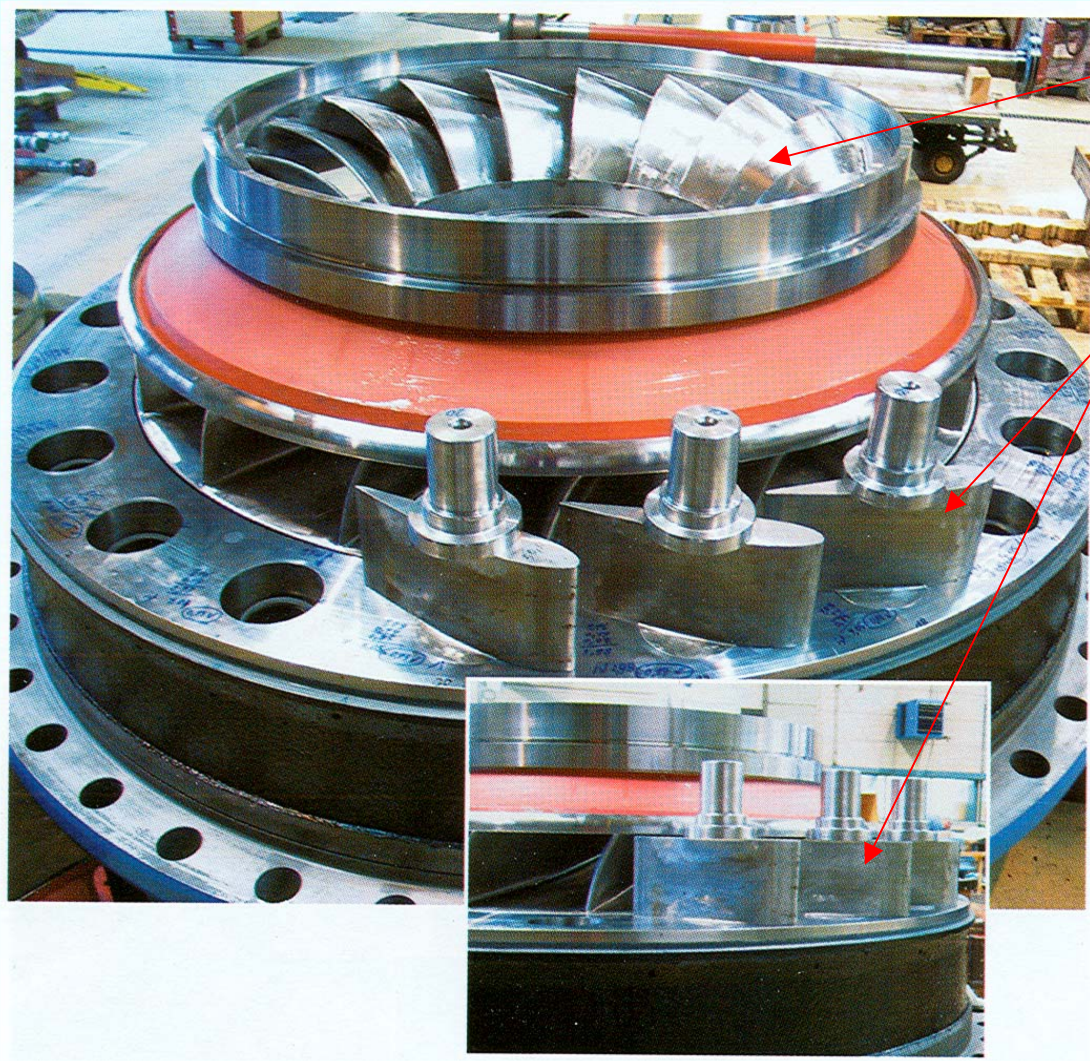
Electrically excited synchronous generator

Water inlet

Source:

VATech Hydro, Austria

"Big hydro" *Francis* turbine with guiding blades visible



Turbine runner with fixed blades

Turning guiding blades for guiding water in-flow to the turbine runner

Source:

VATech Hydro, Austria

Mounting of *Kaplan* turbine runner into turbine housing

Turbine housing

Turbine runner with 5 moveable blades

(propeller turbine)

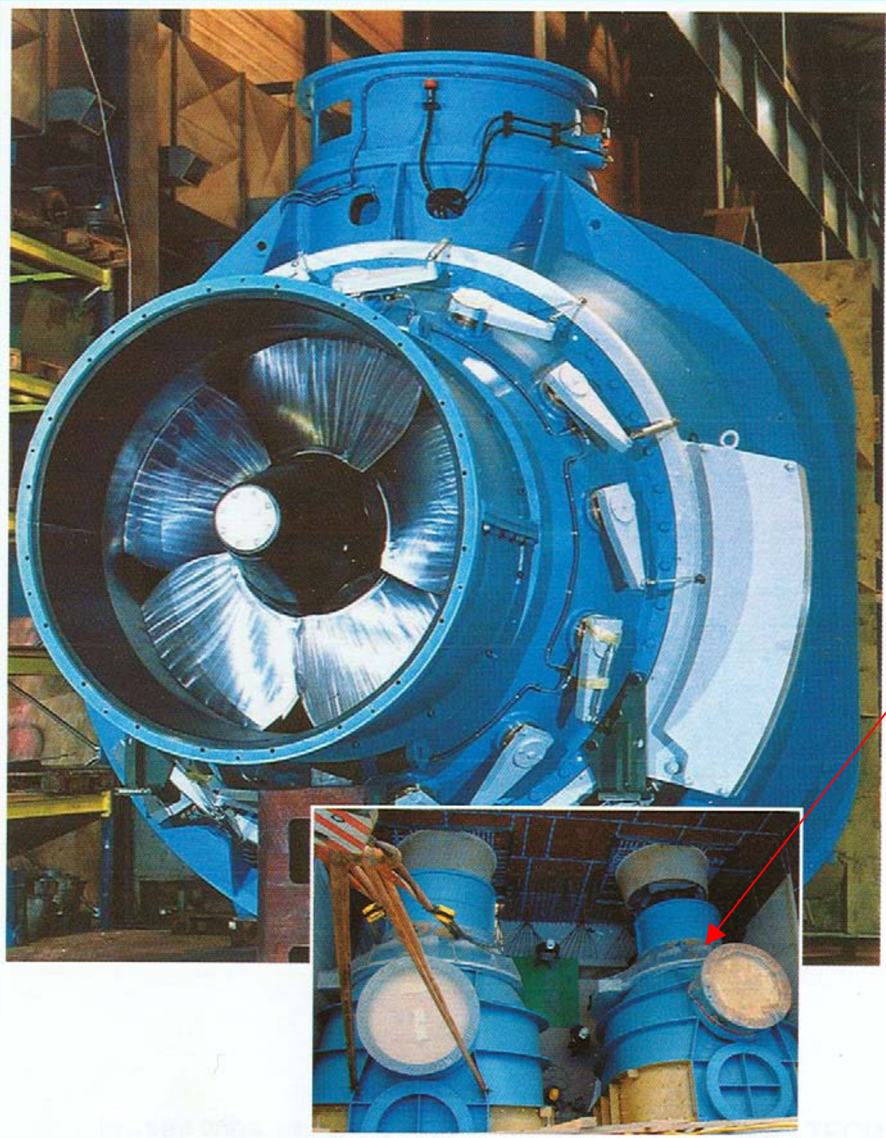
Lever ring to move all guiding blades synchronously

Levers for adjusting the guiding blades, correcting the angle of water inflow at variable flow rate

Source:

VATech Hydro, Austria

Kaplan turbine already mounted

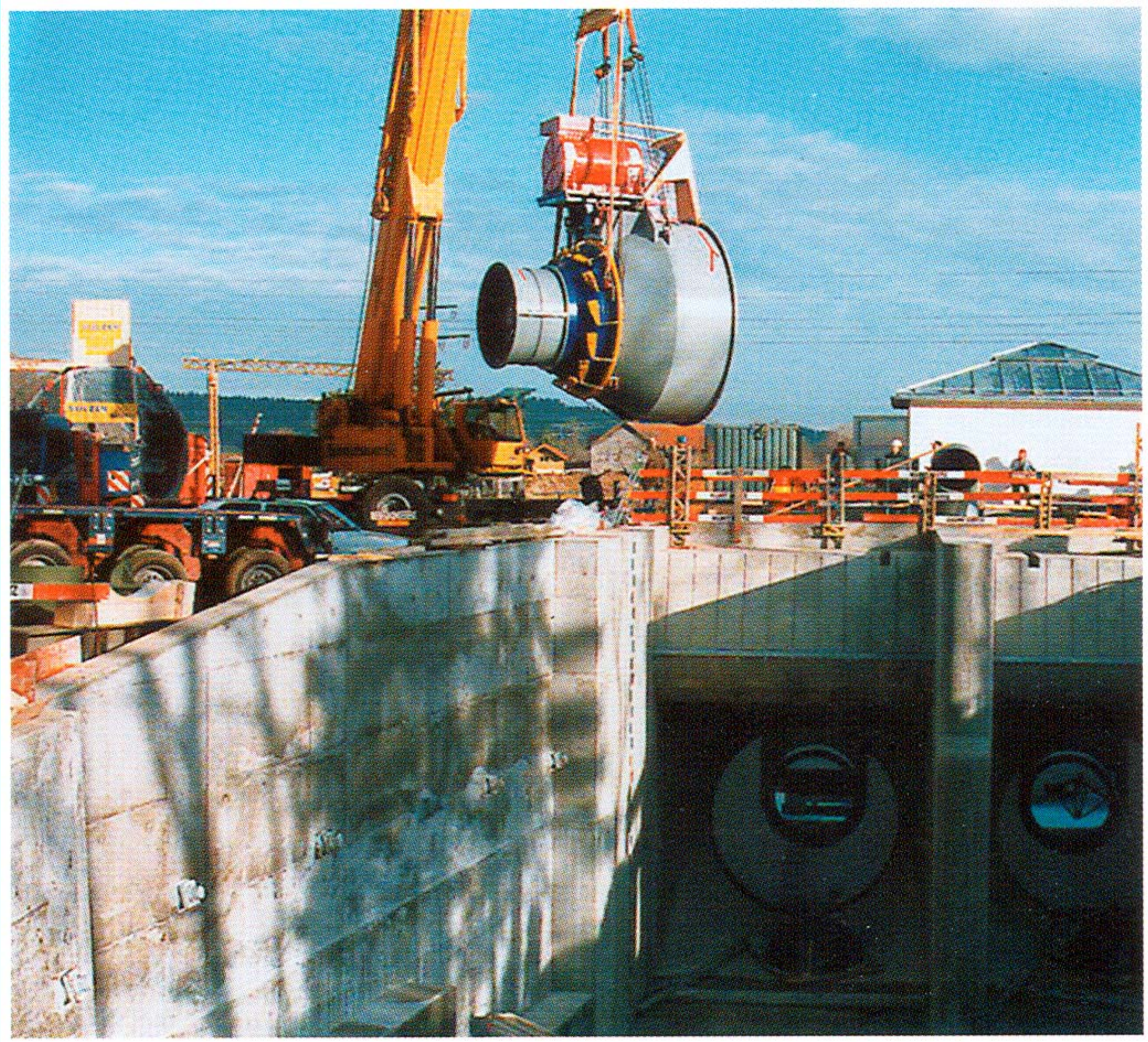


View on two parallel turbine housings, lying horizontally in the plant

Source:

VATech Hydro, Austria

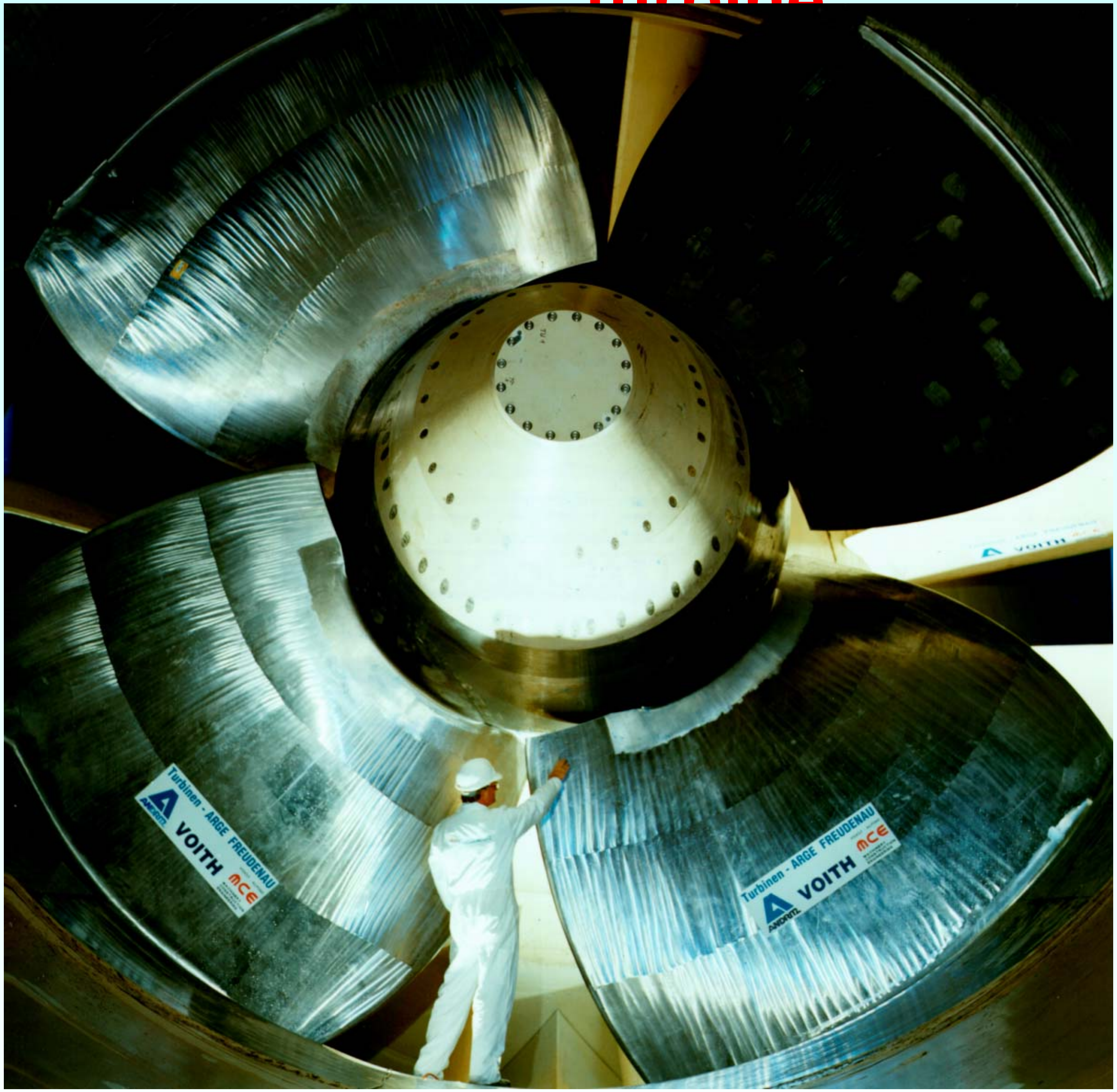
Mounting of *Kaplan* unit into river bed for bulb turbine power plant



Source:

VATech Hydro, Austria

"Big hydro" bulb turbine generators: *Kaplan* turbine

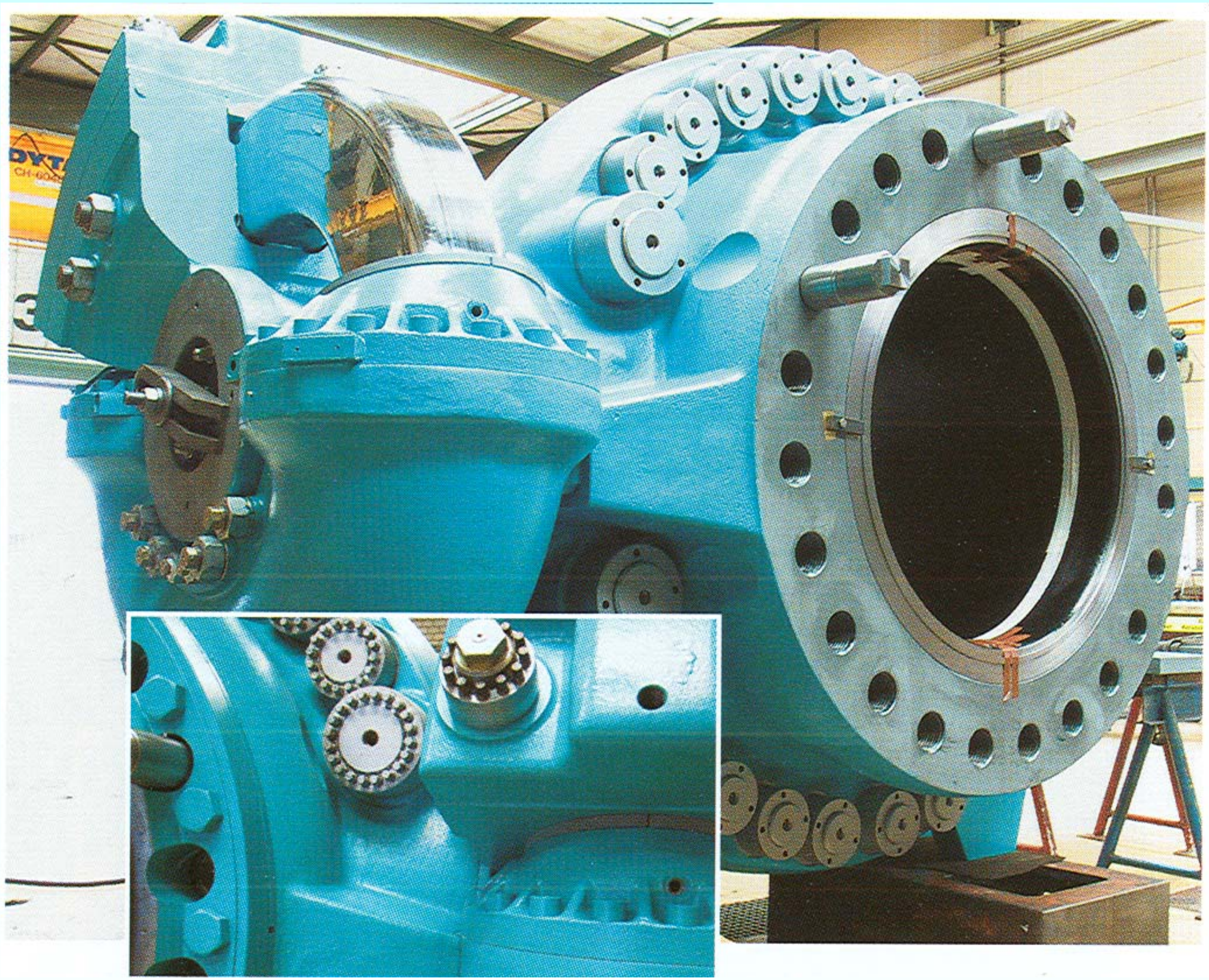


- Four blade runner
- Each blade milled in optimum stream-line profile
- Fixed speed operation
- Pitch control: Blade angle adjusted by hydraulic actuators to ensure optimum torque at variable water flow

Source:

VATech Hydro, Austria

“Big hydro” stop-cock unit ahead of turbine

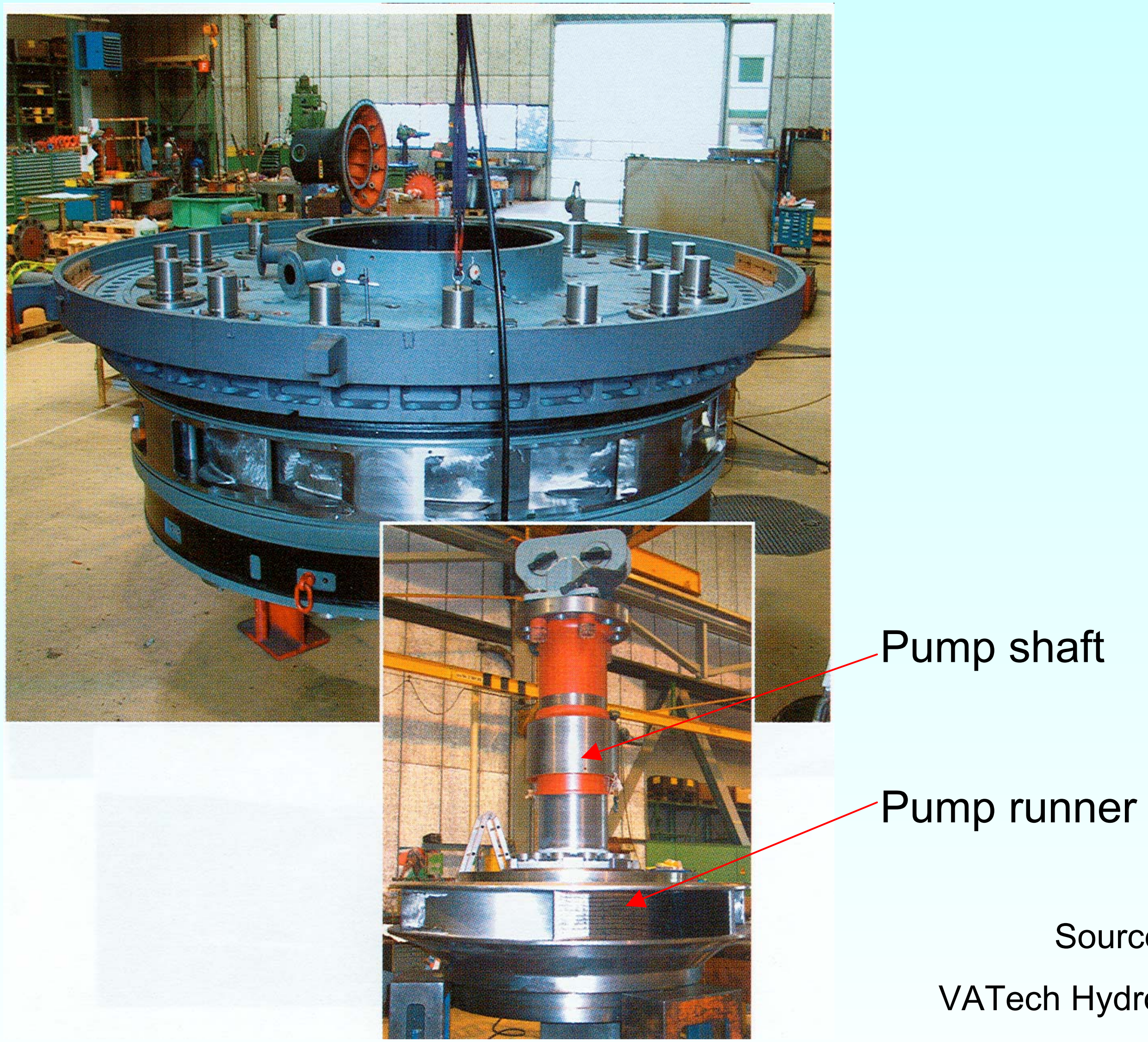


In case of emergency or maintenance the water intake of the turbine is closed by a big “stop-cock”

Source:

VATech Hydro, Austria

Pump unit for pump storage plant



Source:

VATech Hydro, Austria

Three-stage pump for pump storage plant

Electrically excited synchronous motor-generator

Pump housing

Pump runner

Water outlet

Sleeve bearing

Source:

VATech Hydro, Austria

Pelton turbine data - Over speed at load drop

Example: Simple estimation:

- Power plant *Bieudron*/Wallis, Switzerland:
- Speed of water jet: v_1 = 600 km/h = 166.6 m/s.
- Circumference speed of turbine runner:

  theoretically $v_u = v_1/2$ = 83.3 m/s

  in reality due to losses: v_u = 103.5 m/s = $d\pi n$.

- With a runner diameter of d = 4.65 m we get a rated speed of n = 428.6 /min.

- At load dropping: Water jet speed = circumference speed:

  Over speed: 166.6/103.5 = 1.61; in reality: 1.86-fach: n_{max} = 800/min

Generator data:

Salient pole electrically excited synchronous machine:

432 MW, 465 MVA ($\cos\varphi$ = 0.93), Generator mass 800 t

$2p$ = 14, 50 Hz, 428.6 /min, 21 kV, 12.78 kA.

Generators for „Small Hydro Power "

Cage induction generators

Source:

VATech Hydro, Austria

Power plant *Freudenau/Vienna-Austria*

Power plant *Djebel Aulia/Sudan-Nile*

Waste water flow at river barrages: Integration of many small *Kaplan*-Turbines (with fixed blades as propeller turbines) in barrages

Matrix-like arrangement of turbines yields a flat resulting unit: patented MATRIX concept

Cage induction generator for matrix turbine application

Water intake for propeller turbine

Induction generator

Agonitz/Austria

300 kW

Small hydro power plant

Source:

ELIN EBG Motors, Austria

Induction generators are an inductive load: Compensation by capacitor banks necessary , so PM-Synchronous generators preferred: lower losses, no compensation needed, as it operates at unity power factor !

Mounting of prototype matrix generator at *Agonitz*

Source:

ELIN EBG Motors, Austria

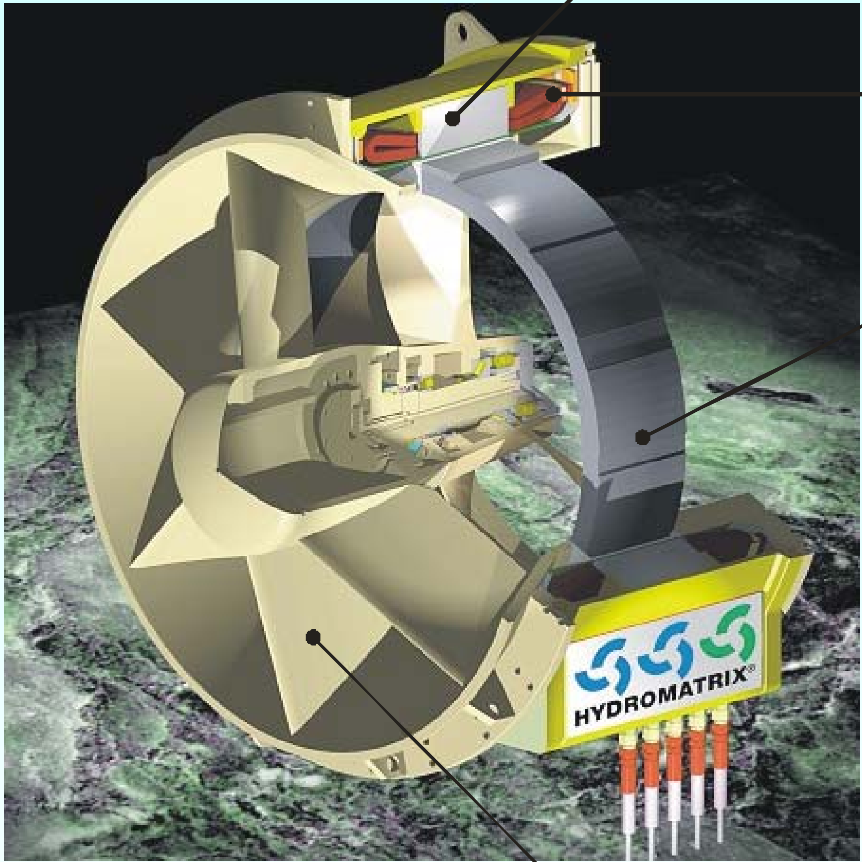
PM-Generators for „Small Hydro Power "

Straight flow Turbines with PM-rotor mounted on turbine runner

Generator stator sealed by non-conducting tube

PM-Rotor is running in water flow

Useful concept for matrix turbine



Source:

VATech Hydro, Austria

Generator operates with copper damper cylinder directly at the grid