The special challenge in W-Africa

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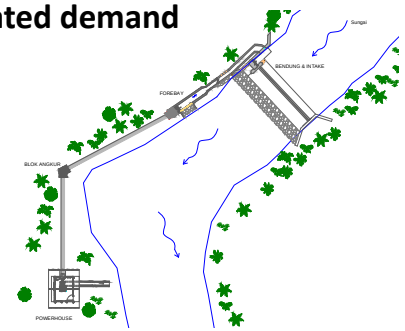
The basic layout of a hydro power plant is decided based primarily on **topography** and on the **designated demand**



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Comparison Low Head vs. High Head

Generic Projects

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Example: Run-of-River with Diversion Channel

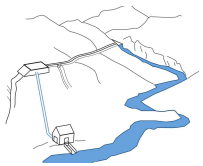
High Head vs. Low Head

Example 1:

H_{net} = 100 m

Q_d = 2.6 m^3/s

P_{el} = 2.0 MW

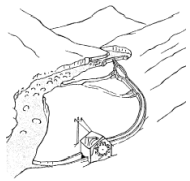


Example 2:

H_{net} = 10 m

Q_d = 27 m^3/s

P_{el} = 2.0 MW



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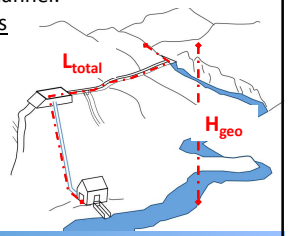
***NB:* plant gradient**
(unit: %)

The quotient of the **difference in altitude** between the water level at the intake and the water level at the turbine outlet **divided by** the total **length of the water conveyance structures** from intake to the end of the tailrace channel.
Common indicator for the attractiveness of a project.
Projects with > 6% are very favourable, < 2% indicates low attractiveness.

$$\text{PlantGradient} = \frac{H_{geo}}{L_{total}} \cdot 100\ [\%]$$



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Examples: Intake

2-3 m^3/s	25-30 m^3/s
Usually smaller rivers with less destructive floods → less complex design and construction	Usually large rivers with high flood levels → complex design and construction
Long term gauging data for smaller streams rarely available. → Own gauging required, analysis to be based on empiric approaches.	Long term gauging data available for many rivers, analyses can be related to similar basins. → Frequently faster and more reliable analysis possible

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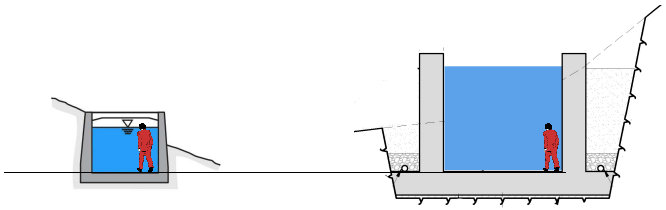
Example: Channel

2-3 m^3/s	25-30 m^3/s
Relatively **small cross section**, but **long channel**	Relatively **large cross section**, but **short length**



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Penstock: Economic diameter

Computation of the most economic penstock diameter usually is a time consuming task. Additionally, many of the required economic and technical parameters may not yet been known at a certain stage of project development.
→ use rule of thumb (empiric formula):

$$D_{opt} = \frac{1}{2} H^{-1/7} \left(\frac{P_{hydr}}{H} \right)^{3/7}$$

where D_{opt} = optimum diameter (in m)
H = gross head of the hydro power plant (m)
P_{hydr} = hydraulic power = $\rho * g * Q * H$ (kW)

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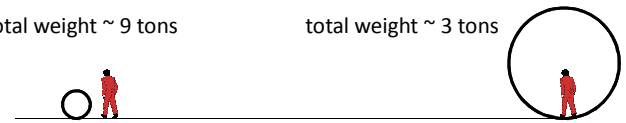
Examples: Penstock Optimum Diameter

2.6 m^3/s	27.0 m^3/s
Usually long pipe, but small diameter.	Usually short pipe, but very large diameter.
D_{opt} ~ 1.0 m	D_{opt} ~ 4.0 m
(v ~ 3.3 m/s)	(v ~ 2.2 m/s)
L ~ 350 m	L ~ 40 m
total weight ~ 9 tons	total weight ~ 3 tons



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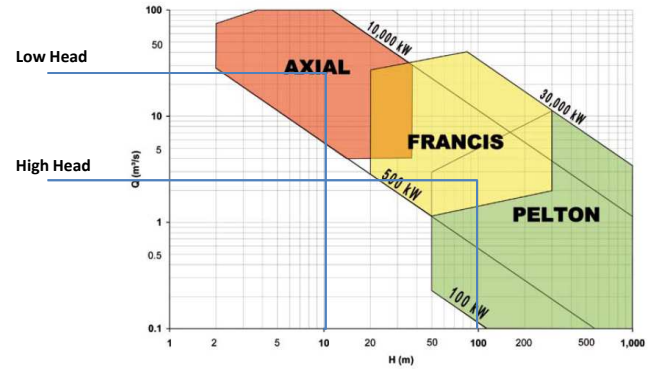
Turbines



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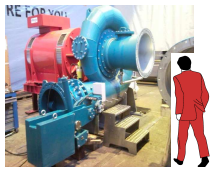
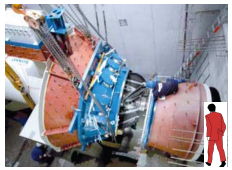
Examples: Powerhouse and Turbine

2-3 m^3/s	25-30 m^3/s
Madland HPP, Norway	**Gstatterboden HPP, Austria**
1 Francis, Dr = 572 mm	1 Axial Bulb, D1 = 1 950 mm
P = 1.9 MW, H = 84 m	P = 2.0 MW, H = 9.4 m
Photo: Gugler	Photo: Andritz Hydro





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Specific Types of HPP

Hydropower Barrage
Hydropower Dam

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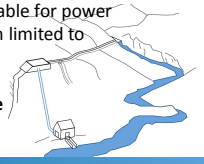
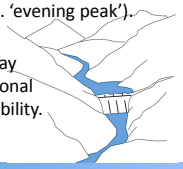
Run-of-River (ROR) and **Reservoir (RES) HPPs** have different electricity supply characteristics

Run-of-River (ROR) HPP	Reservoir (RES) HPP
• These schemes usually supply **base load.** • Seasonal variations in generation may occur (i.e. below design capacity operation in dry season). • Flow available for power generation limited to the actual river flow, **no storage capacity**.	• These schemes can supply **peak load**. • River flow, as energy source, can be stored and released through the turbine during times of high demand (e.g. 'evening peak'). • Very large reservoirs may provide seasonal storage capability.





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River Barrage

- Low head and large flow usually result in **large structures and turbines**, and correspondingly in high costs per installed capacity.
- In large hydro these schemes are often built as **cascades**, frequently with a large 'head reservoir' upstream.
- May have substantial **environmental and social impact** if large upstream areas are converted to reservoir.
- As it usually blocks off large rivers which are required for **navigation.** Adequate measures have to be implemented (expensive in implementation and operation!)
- In some countries (if environmental legislation permits) these schemes are operated to provide **balancing load**, resulting in fluctuating water levels.

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Hydropower Dams

- Common only above 10 MW (**large hydro**)
- Usually **medium to high head**
- Frequently hydropower dams have substantial **strategic value for a utility** as they provide peak / balancing capacity.
- **Seasonal storages** allow increased hydropower generation during dry seasons and impact on the operation of downstream hydropower plants.
- **Multi-purpose projects**: Dam might serve for various purposes with different priorities (drinking water, irrigation, river control, etc.)
- Such projects are generally **expensive**!
- **Power market** does not provide adequate tariffs in most countries for IPPs.

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Comparison On-Grid vs. Off-Grid

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Optimisation criteria for on-grid and off-grid HPPs are very different

On-grid	Off-grid
• Aim is to maximise the economic attractiveness of the project → adjustment of the capacity to maximise the rate of return on the investment (NB: Limited validity non-commercial projects)	• Aim is to ensure provision of peak demand throughout the year. → provision of the 'least cost option' for electricity supply

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Summary and comparison of different types of HPP plants

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There are 3 main types of MHP commonly found

Grid Connected	Captive	Stand Alone
on-grid	off-grid	
usually commercial projects	commercial projects	usually rural electrification
• **Private sector or utility** financed • Mostly implemented on a **fully commercial basis** (Government run utilities might follow other objectives as well) • **Medium / High level technology** adopted • Only **viable from a certain size** (economy of scale) • Operated & Managed by **professionals staff**	• **Private sector** • Always implemented on a **fully commercial basis** • **Medium / High level technology** adopted • Mostly viable **from relatively small size** ranges • **Operated & Managed by the industry** owning the scheme • Often **combined with electrification** for staff	• **Normally grant financed** • Usually **not viable on a fully commercial basis** • **Low to medium level technology** adopted • **Small size ranges** • Usually **official procedures relatively uncomplicated** • **Locally managed** by community

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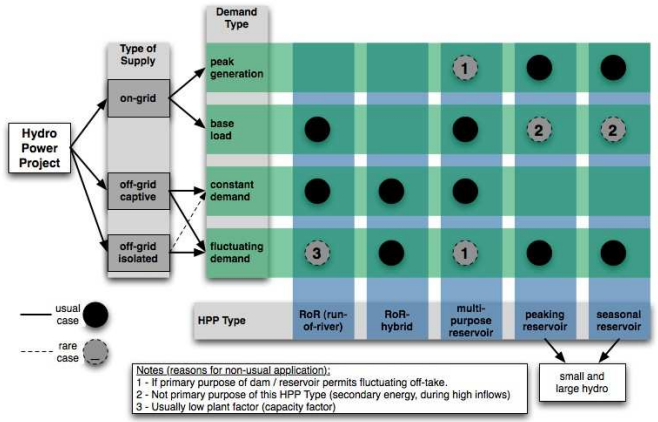

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Most potential issues and challenges are primarily attributed to commercial schemes

Mainly related to grid connected commercial schemes but also applicable to some extent to off grid and captive schemes

	on-grid	captive	isolated
Regulatory and Promotional Issues	++	-	-
Project Identification and Definition	+	+	+
Project Risks	+	+	+
Power Purchase Agreement	++	-	-
Financing Constraints	+	+	+
Project Implementation Structuring	++	+	+

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Most potential issues (risks) and challenges are primarily attributed to commercial schemes

Mainly related to grid connected commercial schemes but also applicable to some extent to off grid and captive schemes

Item	on-grid	captive	isolated
Regulatory and Promotional Issues	**high**	low	low
Project Identification and Definition	medium	medium	medium
Project Risks	medium	medium	medium
Power Purchase Agreement	**high**	low	n/a
Financing Constraints	medium	medium	medium
Project Implementation Structuring	**high**	medium	medium

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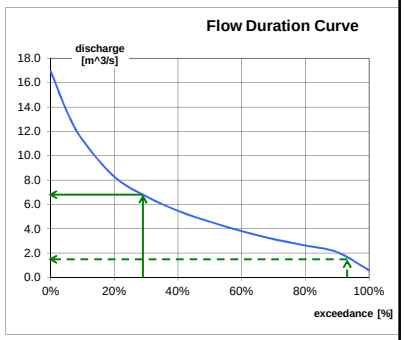
Example on-grid vs. off-grid: indicative design flow for a run-of-river HPP

- The on-grid HPP (⟵) uses a much larger design flow than the off-grid HPP (⇠ –).
- The installed capacity (directly related to the flow), would be much bigger for the on-grid scheme.
- The on-grid scheme can run on full capacity only during 30% of the time, the off-grid HPP can generate the full capacity during 95% of the time.



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Thank you for your attention!

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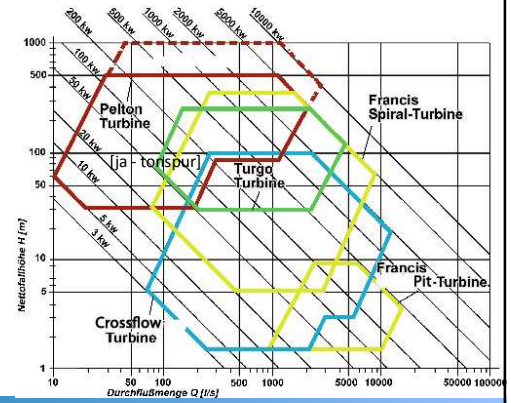
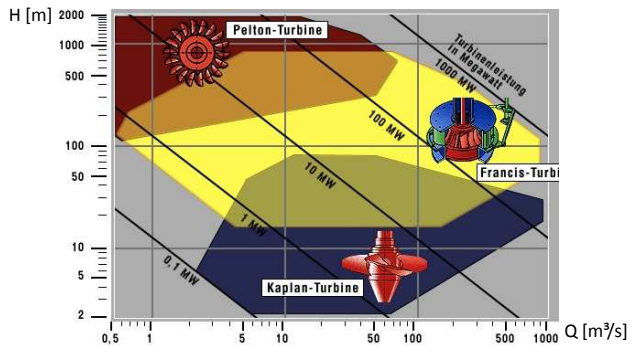
_Turbines (backup)

6-8 Slides

Turbine Application Ranges

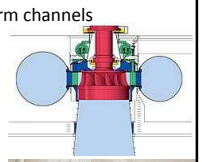


Turbine Application Ranges



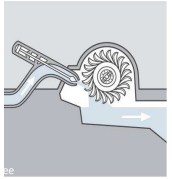
The Francis Turbine
Medium head ROR with moderate flow fluctuation

- The Francis turbine is the oldest and probably the best-known reaction turbine.
- The runner consists of a row of curved blades which form channels through which the water is accelerated and redirected.
- Regulation of flow is accomplished by a row of adjustable blades, the so-called wicket-gates or guide vanes, which are arranged concentrically around the runner.
- For very low head applications (< 10 m), Francis turbines come in the form of open flume or pit-type machines. For higher heads up to 200 m, spiral casings are used.



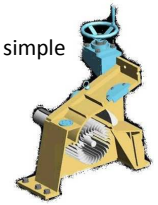
The Pelton Turbine
High head schemes with relatively small discharges

- Turbine consists of a runner with a number of buckets on which one or more water jets impinge.
- Flow and hence power output is typically adjusted by a spear valve which can increase or decrease the nozzle opening.
- For higher flows the number of jets can be increased.
- Highly efficient turbine also for part-flow operation down to 10 % of design flow.
- By installing a jet deflector the pressure surge in the penstock can be avoided.



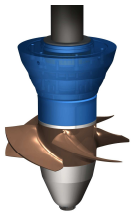
The Crossflow Turbine
'Robust working horse' in MHP for low to medium head

- Cross-flow turbines are very robust and relatively simple machines and are therefore highly recommended for **small scale rural electrification** where operators might be limited in availability of skills and maintenance support.
- The efficiency of cross-flow turbines (up to 80%) is lower compared to other turbine types.



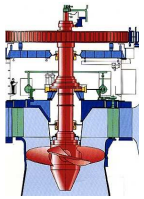
Propeller-Type Turbines

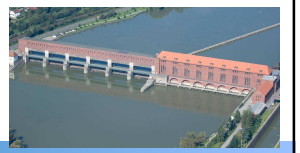
- Propeller turbines are reaction turbines. Flow passes through the runner in axial direction with little to no inward deflection.
- The oldest propeller type turbine is the Kaplan turbine (see next slide) with a scroll or spiral casing and radial wicket gate configuration for flow regulation similar to the Francis.
- Propeller turbines are also available in the form of tube, bulb and S-turbines.
- Propeller turbines with non-adjustable runner blades (different from the Kaplan-principle) have a less good part-flow efficiency.



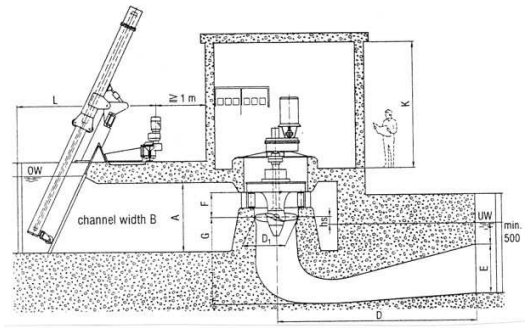
The Kaplan Turbine
Low Head Run-of-River Plants with High Discharge

- The classic Kaplan turbine has both adjustable blades and adjustable wicket gates which gives best efficiencies over a wide range of flow rates.
- The axial-flow Kaplan turbine was invented by Viktor Kaplan in 1912.
- This type of turbine is perfectly suited for HPPs with high discharges and relatively low heads (run-of-river).

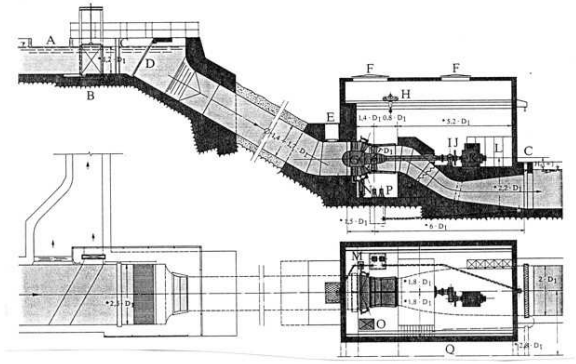




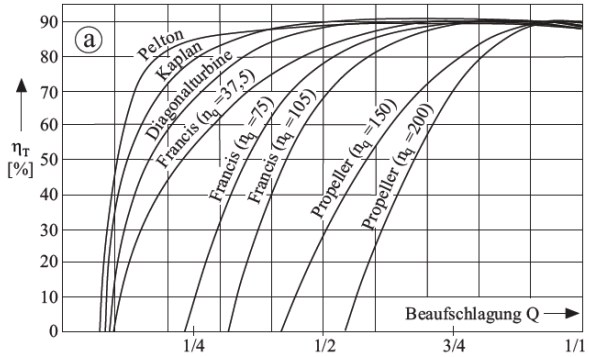
Example: SHP Kaplan Turbine



Example: S-Type Propeller Turbine



Part-Flow Efficiencies for Different Turbines



Examples: Intake

2-3 m^3/s	25-30 m^3/s