Photo: ELFALAGID SEV

Pumped Storage Hydro: Governing strength for new renewables

Hydroforum 2025, Rytro, Polska, 07.10.2025

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Norconsult Renewable Energy

Norconsult is one of Europe’s largest hydropower engineering consultant companies, working for clients across the globe for more than 90 years

Norconsult has designed and is currently involved in several pumped storage hydropower plant projects (PSH) in various project phases, both as designer and owner’s engineer

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Our key message today

- In markets with increasing penetration from renewable energy sources, pumped storage hydropower plants (PSH) can provide:
  - Energy balance
    - Power supply when no wind and/or no sun
  - Governing strength (in grid stability support)
    - Ability to stabilize disturbances to frequency or voltage in the electrical grid
- The energy balancing and grid support functions are however limited by the plant layout, unit design, waterway design and power electronics technology. Critical decisions in this regard, must be taken already from the early design phases on
- **How much money the PSP can make from the energy balancing and grid support markets, is depending on which services the the plant is designed to supply, and to which markets**

Grid stability requirements

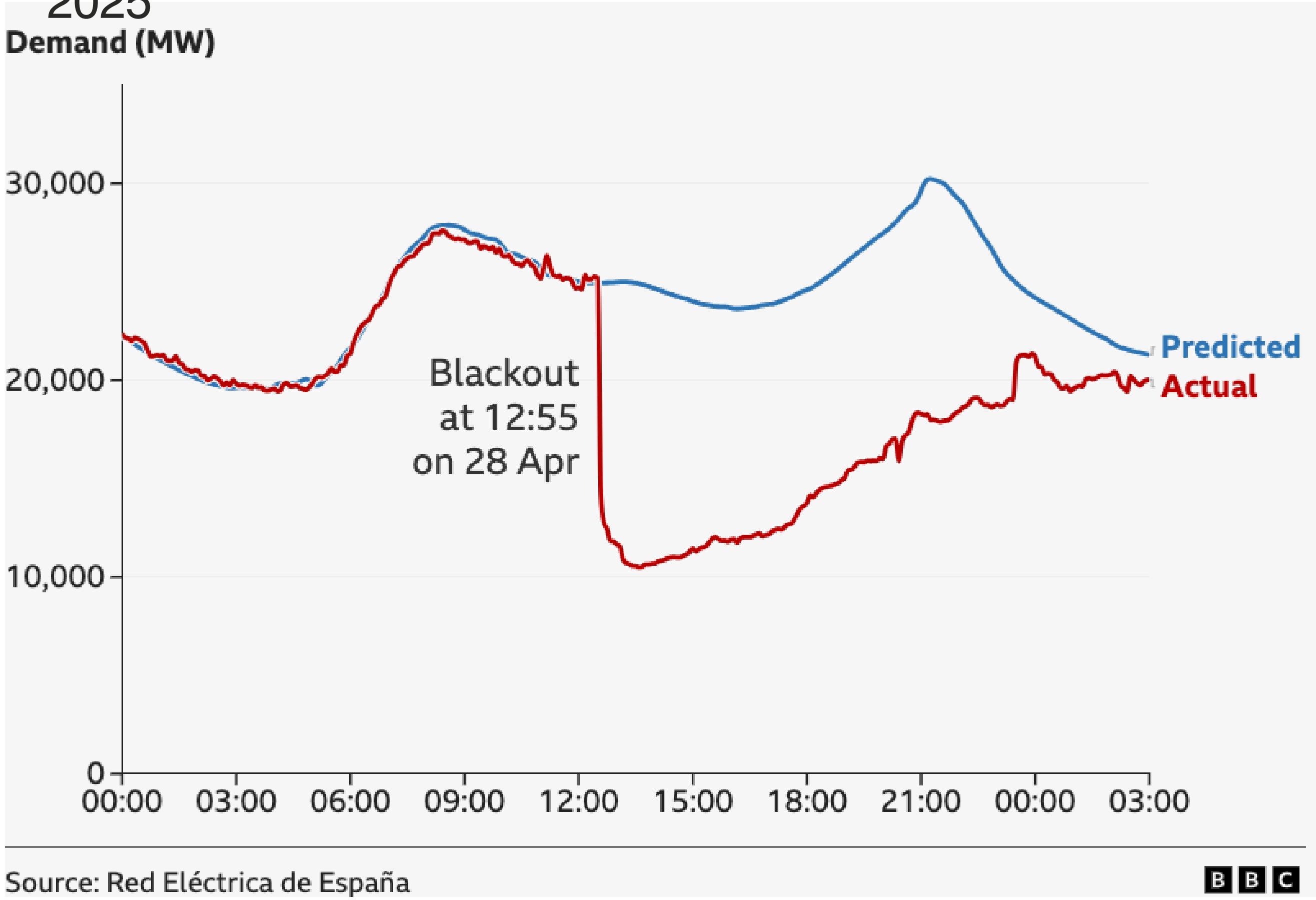
- In brief, the requirements for grid stability in Poland are as follows:
- **Frequency** within **50,0 Hz ±0,2Hz** long term, and **±0,8Hz** in short-term emergency situations.
- **Voltage** within **±10% of the rated voltage**. For 400 kV grids, it is +5% / -10%.
- **Fault ride through - FRT**: Stay connected to the grid when short circuit is cleared within **t =120 ms >220 kV,** t = 150 ms for 110 kV

- Outside these limits the plant gets disconnected

Grid events and consequences of insufficient governing strength

- The strength (=security and reliability) of an electricity grid is its ability to quickly respond and remain stable when unexpected events occur.
- Examples: large power surges, generators breaking down and transmission lines failing
- Maintaining grid strength is a particular challenge as traditional ‘synchronous’ fossil fuel power sources are replaced with ‘asynchronous’ wind and solar power
- Inability to stabilize frequency or voltage disturbances causes shut-downs and blackouts

Example: Blackout in Spain and Portugal in April 2025



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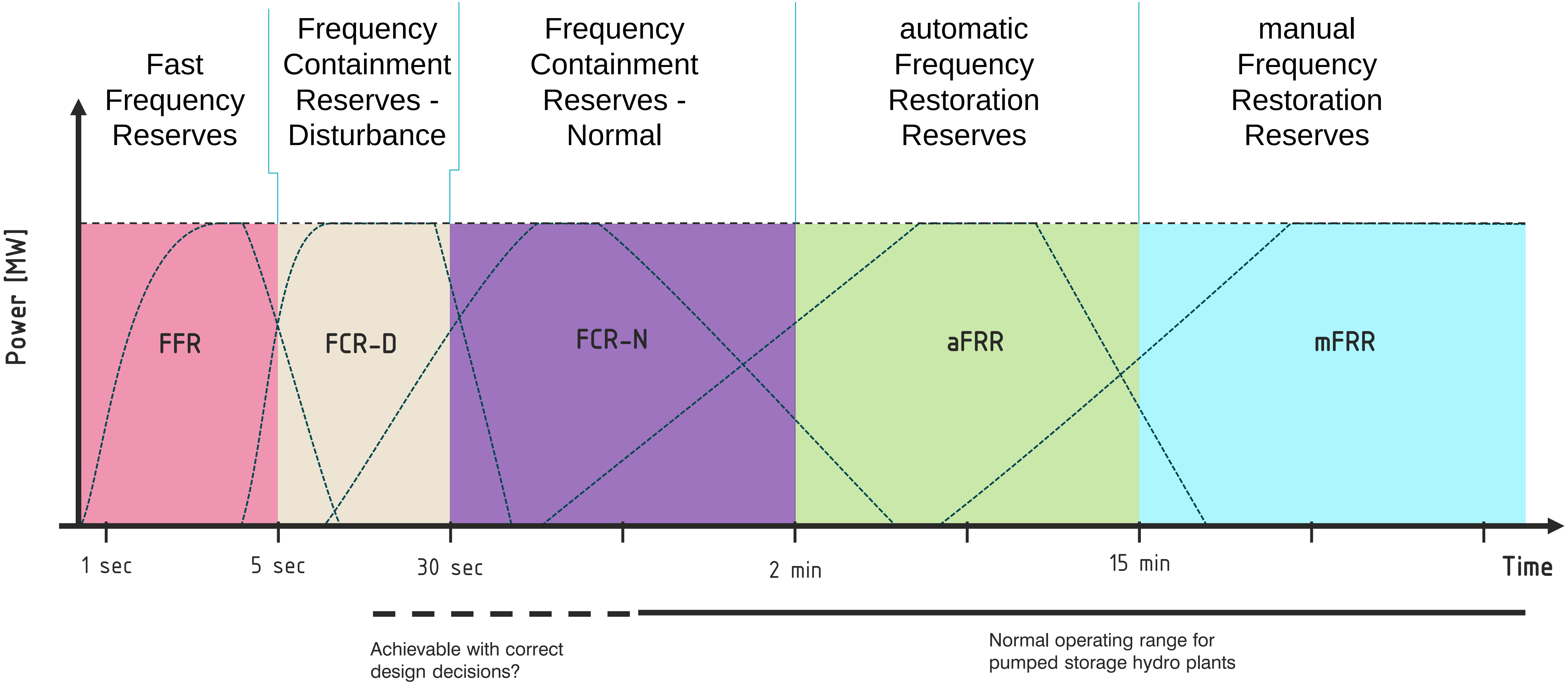
Reserve markets to support grid stability

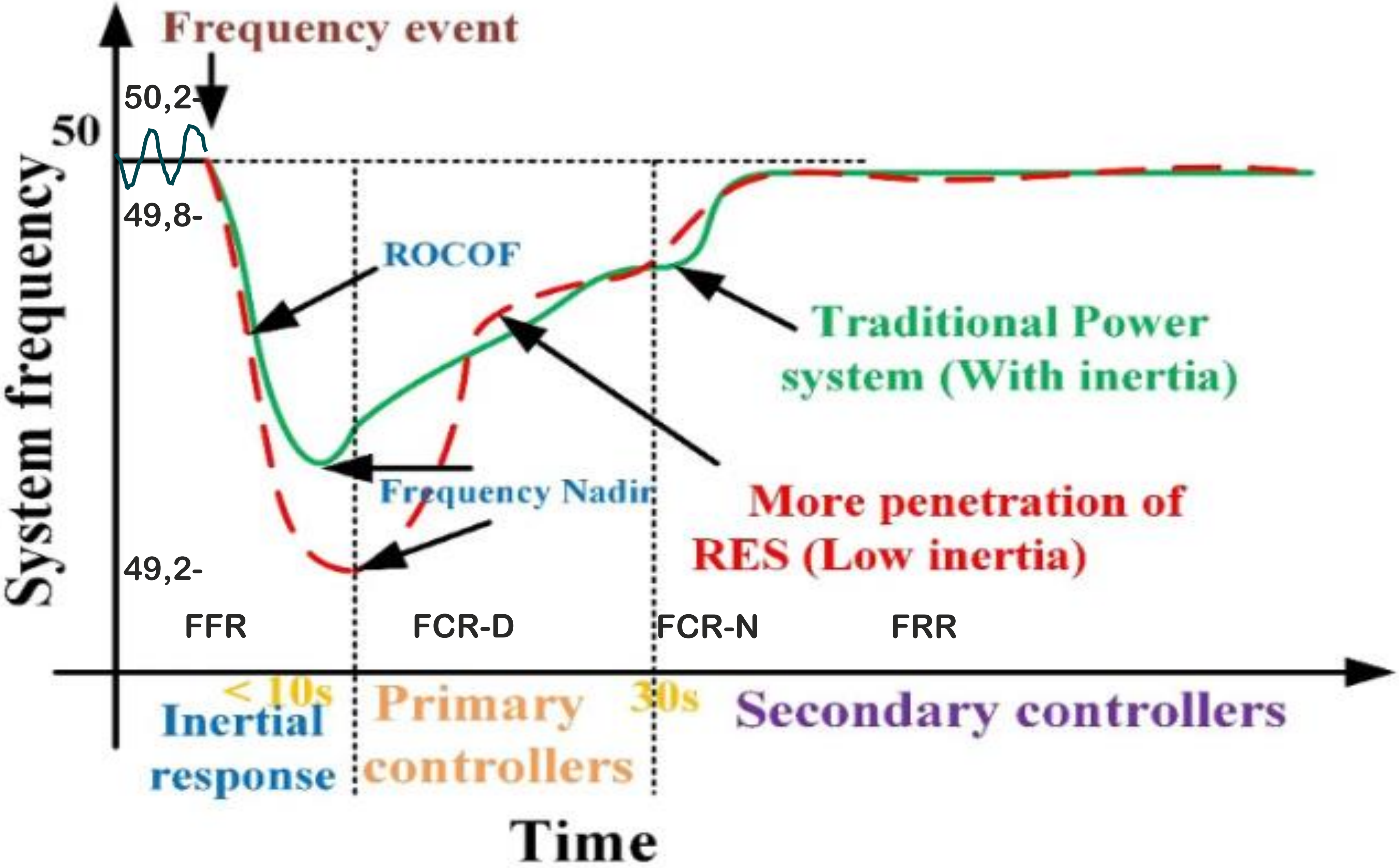
- Reserve markets give power producers incentives to invest in tools to stabilize the grid after disturbances
- Considerable income source, depending on response times and energy volume
- The Polish energy market is now rapidly building its renewable capacity and similar supporting market mechanisms as established in the Nordics

What are the names of the new markets?

From Statnett's (the Norwegian TSO) perspective



Penetrating more renewable energy sources (RES) into the grid



Battery Technology versus Pumped Storage Hydro Power

Energy storage with Batteries

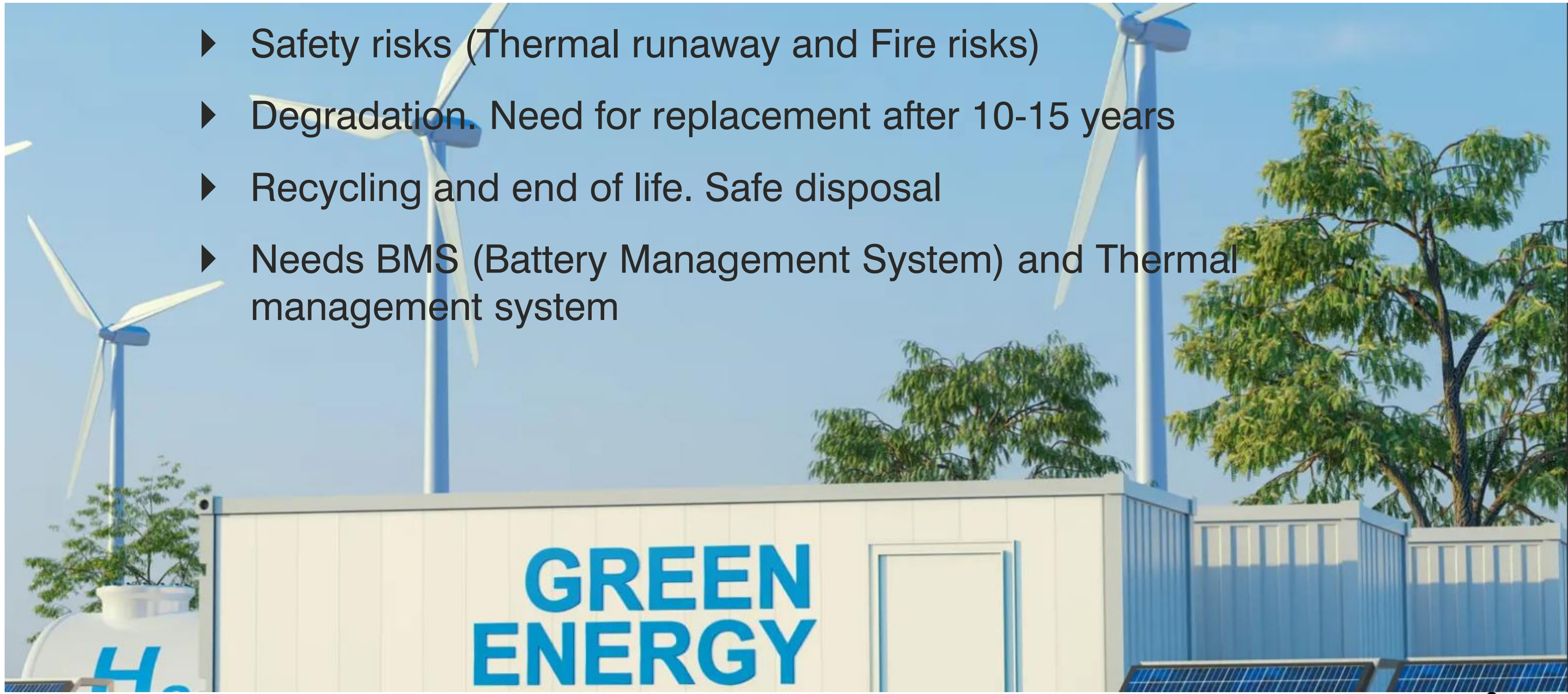
Today, battery storage can exceed 100 MWh of renewable energy, with typical round-trip efficiencies of 80-90%

Advantages

- Fast response in energy balancing
- Grid Services (also fast response)
  - Frequency support (FCR, FFR, aFRR)
  - Peak shaving (power demand peaks)
  - Fault ride through (FRT)
  - Voltage Support

Challenges

- High Capex
- Large battery plants need several acres
- Short discharge time (typically <2 hrs)
- Safety risks (Thermal runaway and Fire risks)
- Degradation. Need for replacement after 10-15 years
- Recycling and end of life. Safe disposal
- Needs BMS (Battery Management System) and Thermal management system



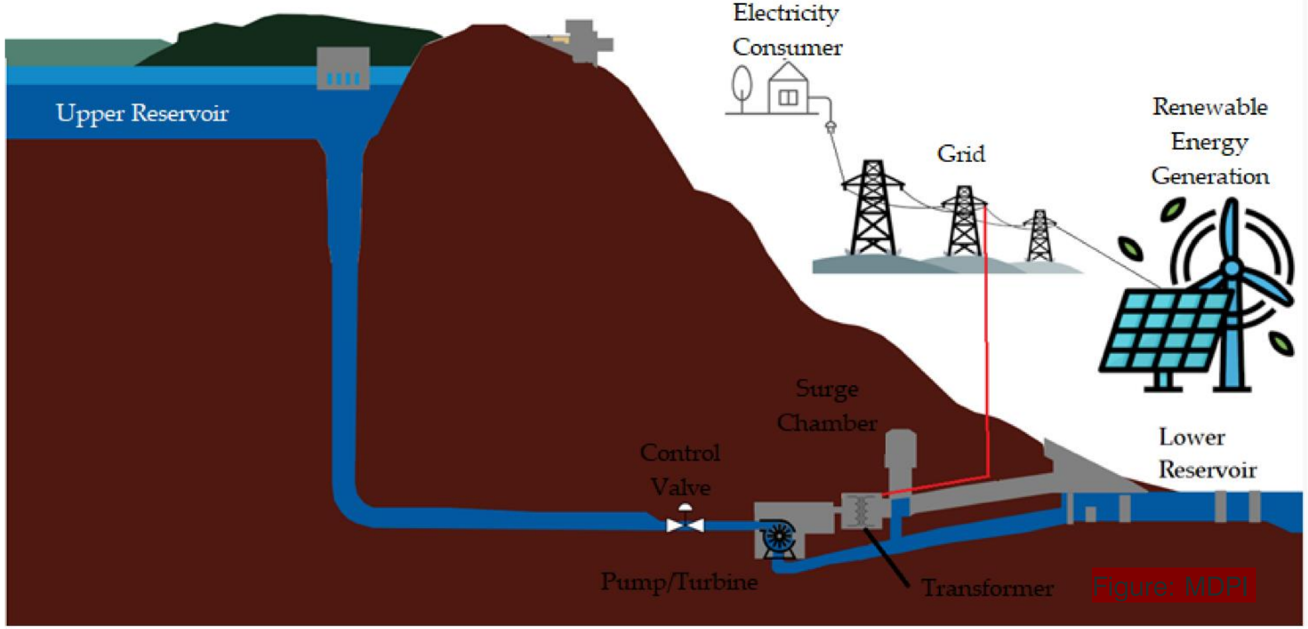
Pumped storage hydropower (PSH)

Advantages

- Can store large amounts of surplus energy
- Great flexibility in terms of production and consumption
- Long lifetime, low OPEX
- Contributes with rotary inertia (grid stabilizer)
- Plants equipped with full-frequency converters:
  - Contribute with synthetic inertia, which contributes even more to grid stability than rotary inertia
  - Short changeover time both ways but in particular from power generating to pumping

Challenges

- High CAPEX
- The efficiency losses are 10-15% in pumping and in production
- Income dependent on future energy and reserve markets



Peculiarities in the design of pumped storage hydropower plants

Relevant turbine types

Pelton turbines

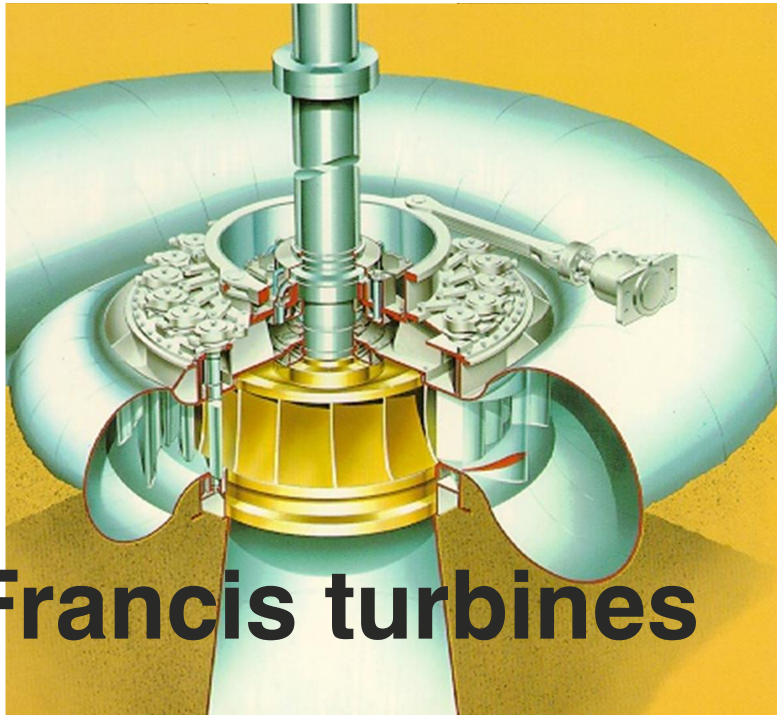
+ Rotating in air, fast start and fast up- and downramping of power

+ Wide operating range (~5%-100% load) high efficiency over the entire range

- High head only

- Lower peak efficiency than Francis turbines

- Capex higher than Francis



Francis turbines

+ Medium head range

+ High efficiency at best point (~70-90% load)

- Rough zone and low efficiency below ~50% load

+ Fast start-up requires a blow-down system for rotating in air (condenser mode)

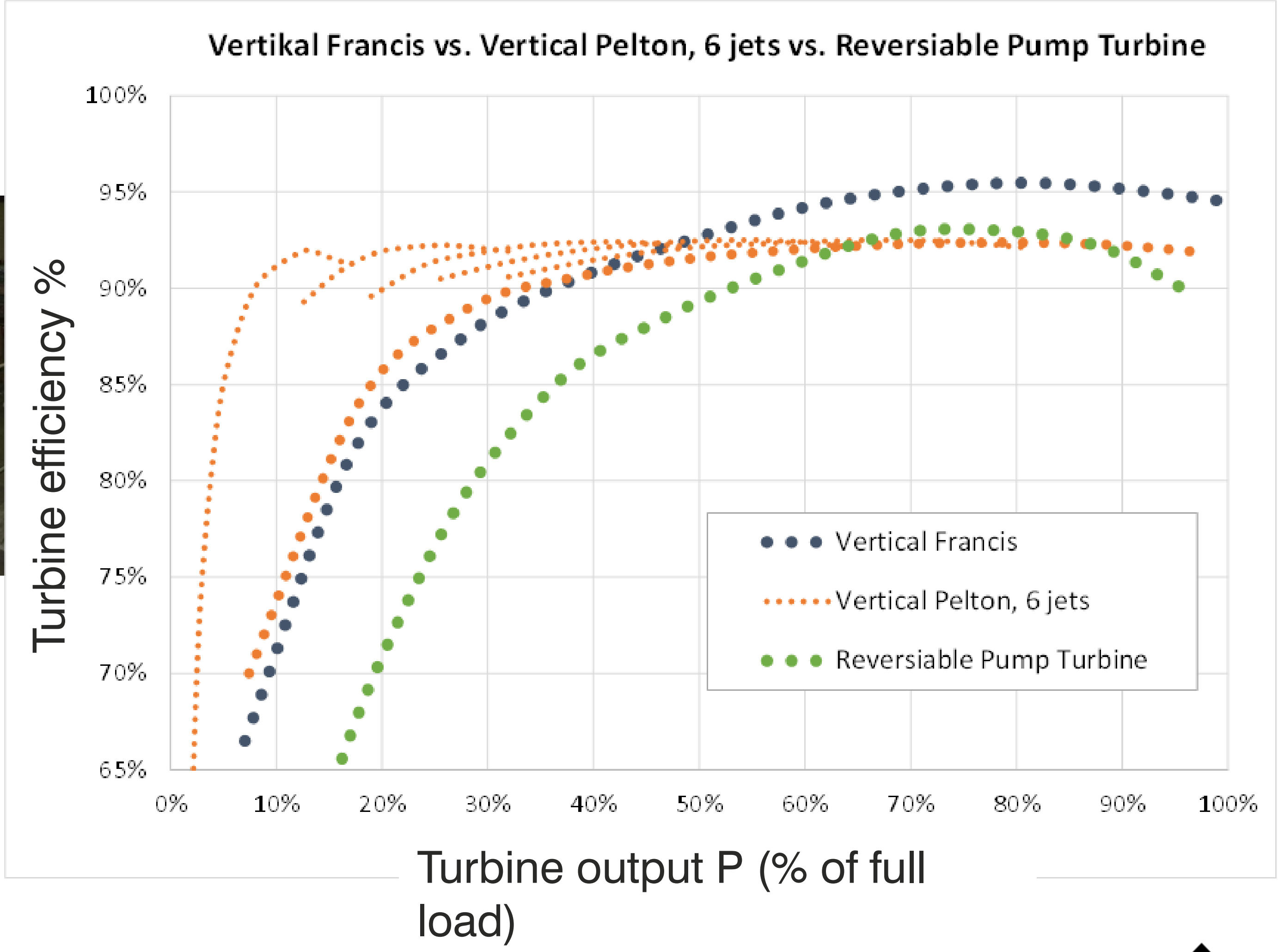
+ Fast upramping, downramping is often limited by pressure surges in the waterway (this can be reduced by installing a pressure relief valve)

Pump turbine technology considerations

Reversible pump turbines (RPT)

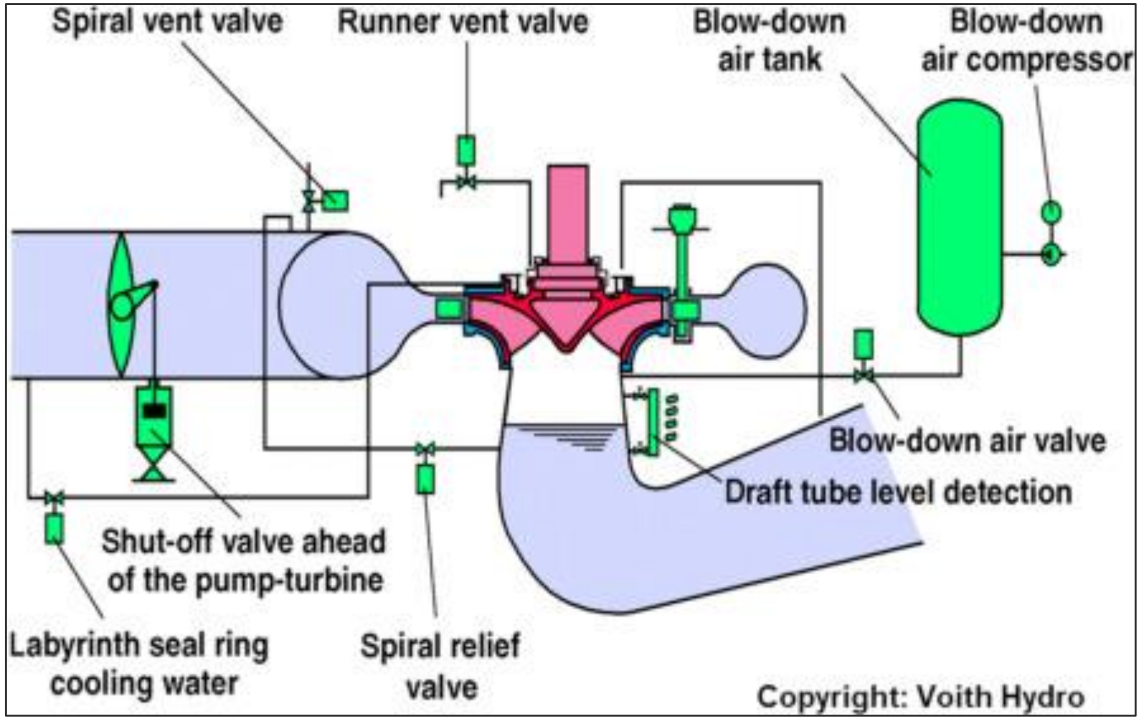
- **Francis type turbine**
- **The impeller has a larger diameter and fewer vanes compared to a Francis turbine runner**

- **Opposite rotational direction between turbine and pumping**
- Requires extra switchgear to change direction – takes up a lot of space
- Cooling of seal clearances to avoid overheating when rotating in air

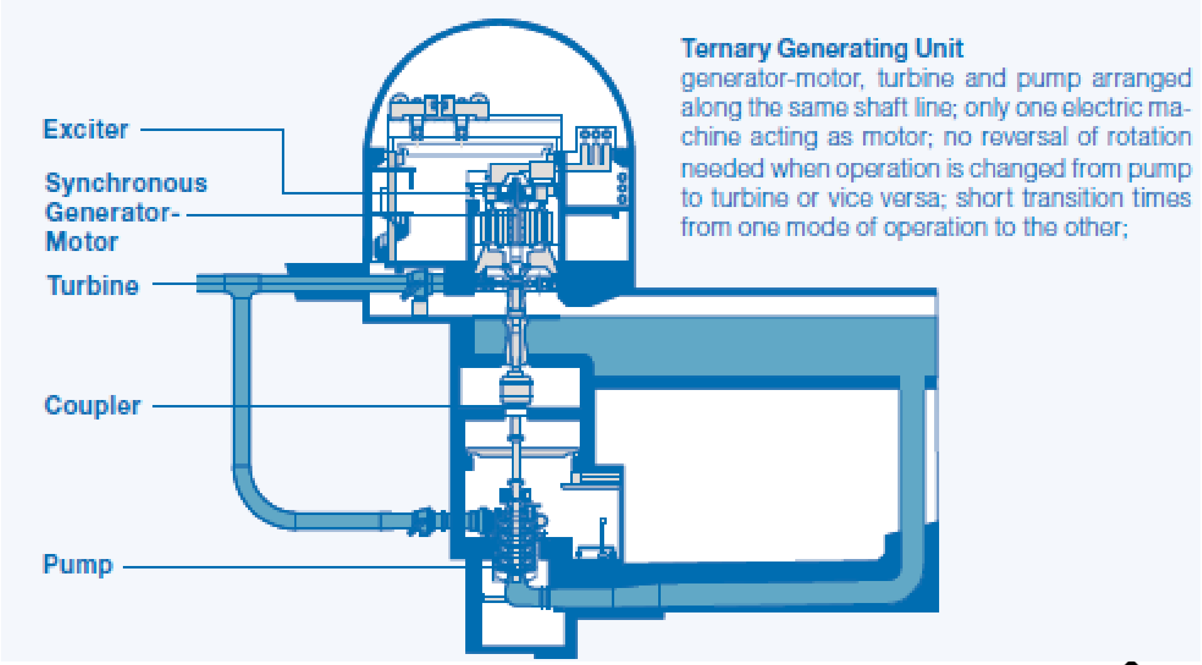


Pump turbine technology considerations cont'd

- Pump turbines, or pumps + turbines?
  - A pump turbine has significantly lower CAPEX than separate pumps and turbines, and less space consuming, but has lower pump and turbine efficiency, and deeper submergence
- Blowdown system?
  - Enables faster changeover times between operating modes
  - More complex system gives higher CAPEX



- Separate pump and turbine with common shaft and motor/generator
  - Always rotates in the same direction
  - The pump unit is started with the turbine – no starting equipment needed
  - Common at high heads where multistage pumps, and pelton turbines are used
  - Hydraulic short circuit allows for an operating range from 100% pumping to 100% turbinating



Hongrin Léman, CH - H_n = 880 mVs – Source: Andritz

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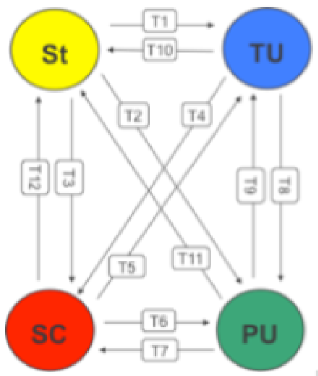
Operating modes and changeover times (for pump turbines)

- Possible operating modes
  - Turbinating
  - Pumping
  - Condenser operation in air (both directions of rotation)
- Rapid change of operating mode is possible from the following conditions
  - From standstill to turbinating
  - From condenser operation to pumping/turbinating
  - From pumping to turbinating
    - Using the water as a "brake" (load rejection in pump operation and opening of the guide vanes)
- Transition from turbinating to pump operation is more time-consuming
- Requires time to stop, blow down and accelerate
- Needs a lot of thinking through in the design phase!

Ternary Pumped Storage Units



T	Pump Turbine Mode change			time [seconds] A	B	C	D	E
1	Standstill	→	TU-Mode	90	75	90	90	65
2	Standstill	→	PU-Mode	340	160	230	85	80
5	SC-Mode	→	TU-Mode	70	20	60	40	20
6	SC-Mode	→	PU-Mode	70	50	70	30	25
8	TU-Mode	→	PU-Mode	420	240	470	45	25
9	PU-Mode	→	TU-Mode	190	90	280	60	25

Reversible PT
A – advanced conventional (2012)
B – extra fast response conventional
C – VarSpeed, DFIM
Ternary set
D – with hydraulic torque converter + hydr. short circuit, horiz, with Francis Turbine
E – same as E but vertical with Pelton Turbine

TU = Turbine, PU = Pump, SC = Synchronous Condenser

Source: Reference 6, Fisher et al. (2012)

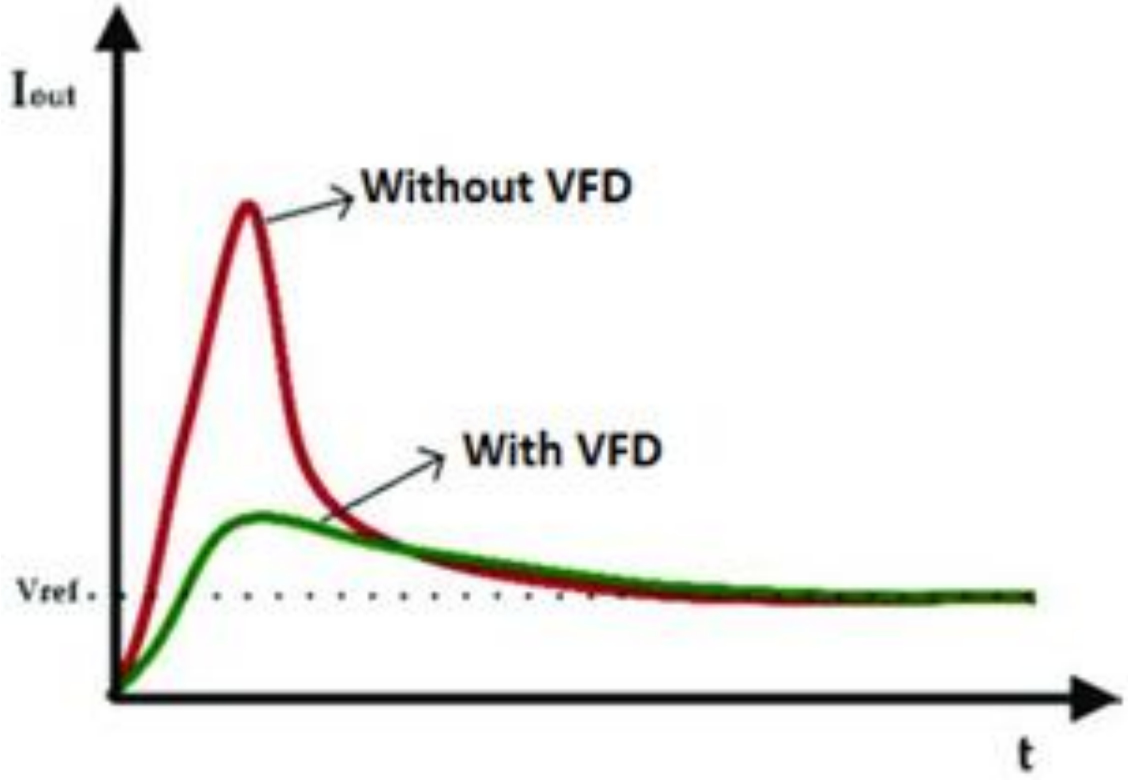
Figure 2-5 Mode Change Times for Various Advanced Pumped Storage Technologies

Source: "ANL/DIS-13/07 Modeling Ternary Pumped Storage Units", Argonne National Laboratory,

Pump turbine; Pump start and operation – Fixed speed and variable speed (frequency converter or DFIG)

Pump start

- Starting a large motor from a standstill requires overcoming the inertia of heavy rotating components plus the water in the system. Direct start will overload the grid.
- Methods to reduce high Start-Up Currents:
  - Start from spinning in air
  - **Pony motors:** Some systems use a small auxiliary "pony motor" to bring the motor-generator unit up to a partial speed before the main motor starts. This reduces the initial current needed from the grid.
  - **Frequency converters (VFD, VSD, etc):** Modern pumped storage plants often employ frequency converters (AC-DC-AC converters) to gradually bring the motor-generator up to speed
    - Various configurations are available, from simple "soft starters" to full frequency converters



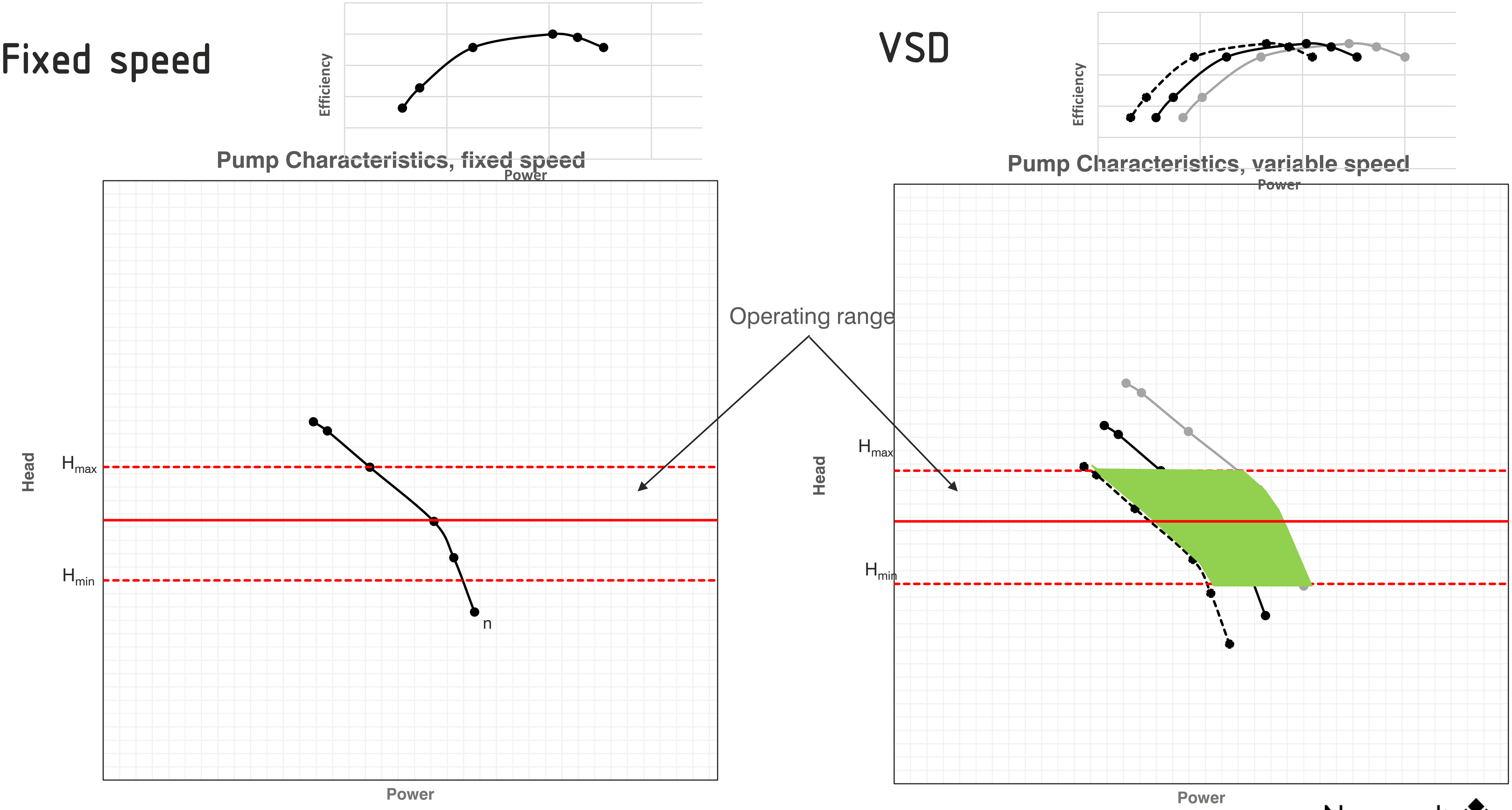
Frequency converter

- Key component in a PSH. Selected configuration requires a lot of thinking through
- Variable speed using alternating current on rotor ("Doubly feed Induction generator" = DFIG)
  - Requires a frequency converter to feed rotor at capacity of approximately 20% of motor-generator nominal MVA
  - Optimizes the operating range between pumping/turbinating and at varying head by varying the speed +/- 10%
  - **High capex, space-consuming and complex, but less so than a full-frequency converter**
  - **Proven technology on large generators**

- Full frequency converter (Variable speed drive – VSD)
  - **The unit can be operated at optimal speed in turbine and pump operation over even larger and load variations than DFIG**
  - Enables control of motor power in pump operation, at +/- 20-25% of motor nominal MVA
  - **Enables quick pump start and qualification for FCR services**
  - **Can eliminate need for a blow-down system**
  - **Capacities >100 MW are at the prototype/development stage**
  - High CAPEX, space consuming, complex

Fixed speed

VSD



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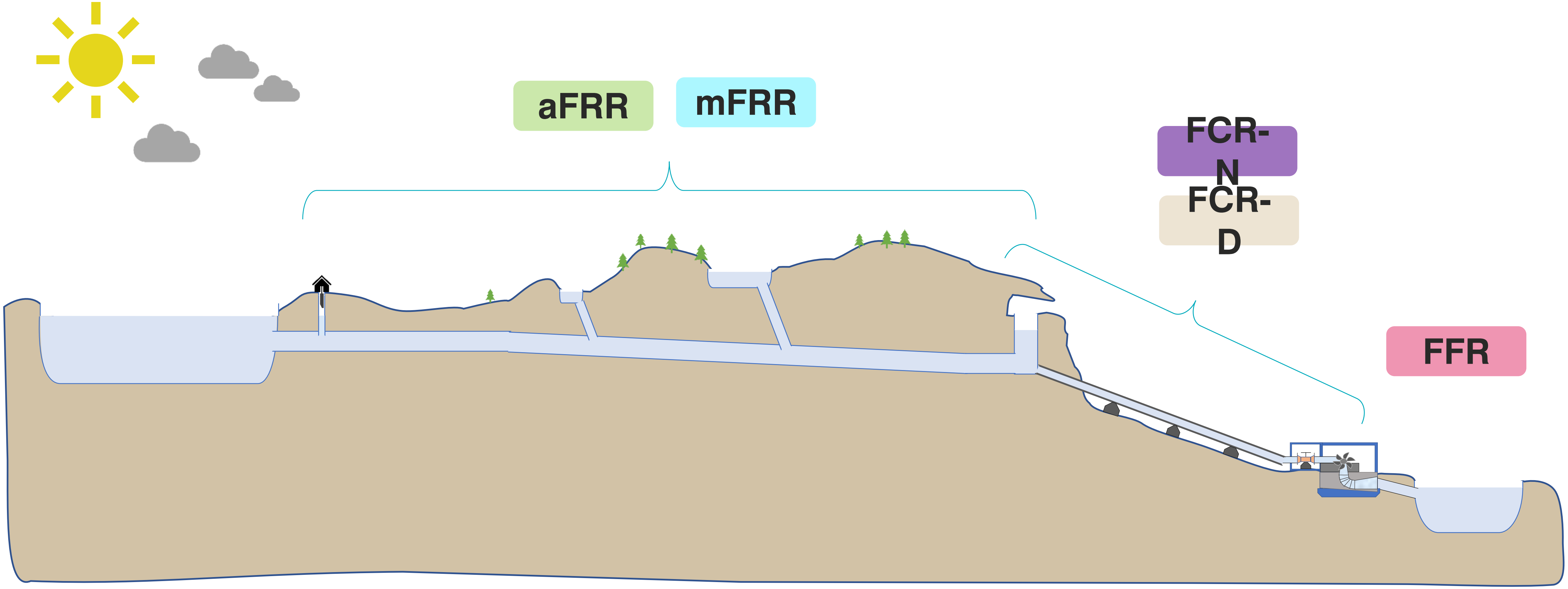
Waterway design

- Fast loading is what requires most of the waterway design
- The **waterway is often the main limiting factor** in how quick and how much power increase the plant can deliver!
  - FCR-N, FCR-D and aFRR are the services that place the highest demands on waterway design

- Repeated load changes can lead to oscillations between the surge chamber and reservoir and make it impossible to obtain stable grid frequency
  - Can take time to dampen, and limit the size of load changes that the plant can offer
  - The need for a surge chamber can be partly compensated by increased waterway cross-section and rotating inertia, but is critical to safeguard frequency governing stability in long waterways

Which parts of the waterway gets affected



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Thank you for your attention!

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Every day we improve everyday life

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