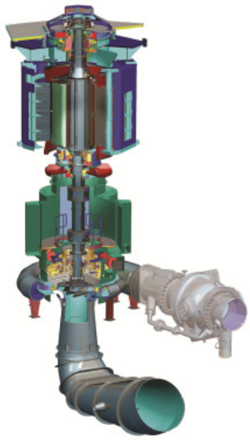

# Pumped Storage: Technology for flexible Operation

Dr.-Ing. Christof Gentner

Golden, CO, USA, November 2012

## Pumped Storage: Technology for flexible Operation

Contents

- The role of pumped storage
- Machine concepts
- Advantages of variable speed
- Application example variable speed
- Standardized pump turbines
- Hydraulic short circuit
- Pump turbine technology


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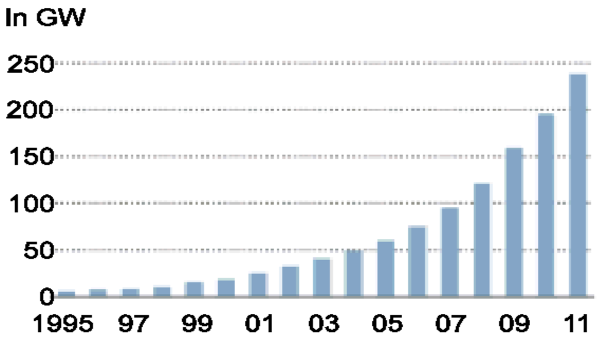
## Pumped Storage: Technology for flexible Operation

### Changing storage requirements



Installed wind power world wide

- Power mix as a major driver
- Share of intermittent production will increase significantly, positive and negative reserve required
- Partly legal requirement to buy power from renewable production (Germany)
- Increasing demands relating to peaking and grid-frequency control
- World wide around 150 GW installed pumped storage capacity (2011)



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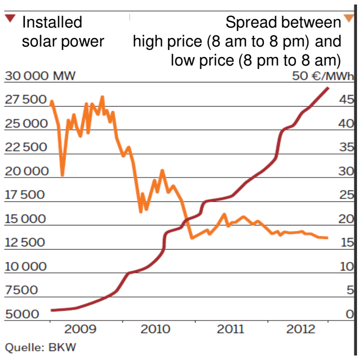
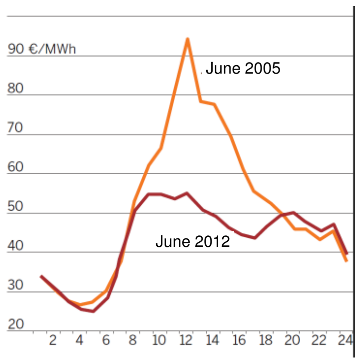
### Influence of non dispatchable power on pricing



Installed solar power and peak price spread in Germany



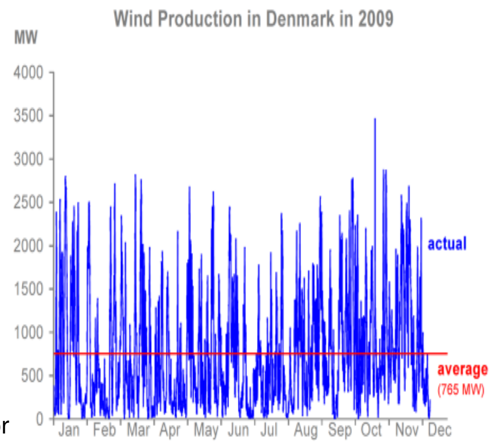
Price for electricity on a sunny day in Germany June 2005 and June 2012

- Non dispatchable power influences price structure
- Storage capacity, both positive and negative is a technical requirement
- Required storage up to 80% of installed wind and solar, depending on grid structure

## Pumped Storage: Technology for flexible Operation

### Required response time becomes shorter

- Renewable energy (wind, solar) is extremely volatile, difficult to predict and non dispatchable
- The stability of the grid is in danger with large percentage of wind and solar power
- The larger the wind and solar power capacity, the larger the problems in the grid
- The amount of renewables in the electricity portfolio is increasing rapidly
- New technologies for electricity storage are needed to compensate for those influences





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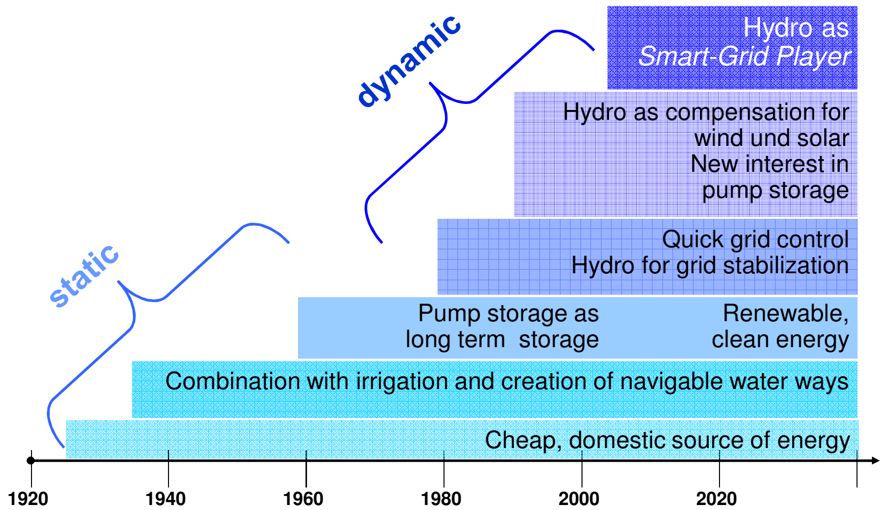
## Pumped Storage: Technology for flexible Operation

### From static to dynamic





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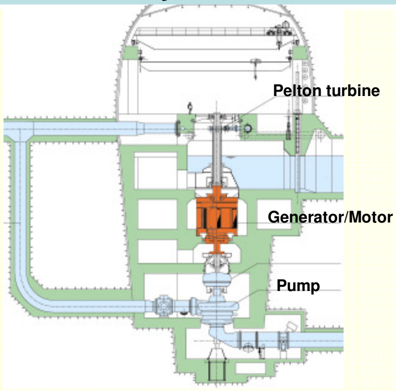
# Pumped Storage: Technology for flexible Operation

## Machine concepts

| Reversible unit | Ternary unit |
|---|---|

**Reversible Pump turbine**

- Smaller cavern required
- Cost attractive solution (investment and maintenance cost)
- Lower complexity
- Longer change-over time (pump ↔ turbine)
- Pump start with drained runner
- Preferred method for pump startup
  - electrical shaft „back to back“
  - static frequency converter (SFC) in air




**Ternary units**

- Both turbine and pump optimized
- Quick change-over time (pump ↔ turbine)
- Higher investment cost
- No start up device necessary
- Direct hydraulic short circuit possible

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# Pumped Storage: Technology for flexible Operation

## Advantages of variable speed

| Variable speed | Fixed speed |
|---|---|
| • Ability for variation of input power in pump operation<br>• Improved efficiency in pump and turbine operation<br>• Increased operation range pump and turbine operation<br>• Improved operation behavior<br>• Reduced pressure pulsation and vibration<br>• Increased life time of the hydraulic machines<br>• Reduced dynamic loads<br>• Additional loss of converter | • No power variation in pump<br>• Non-optimal turbine operation<br>• No additional losses of converter<br>• Lower investment cost |

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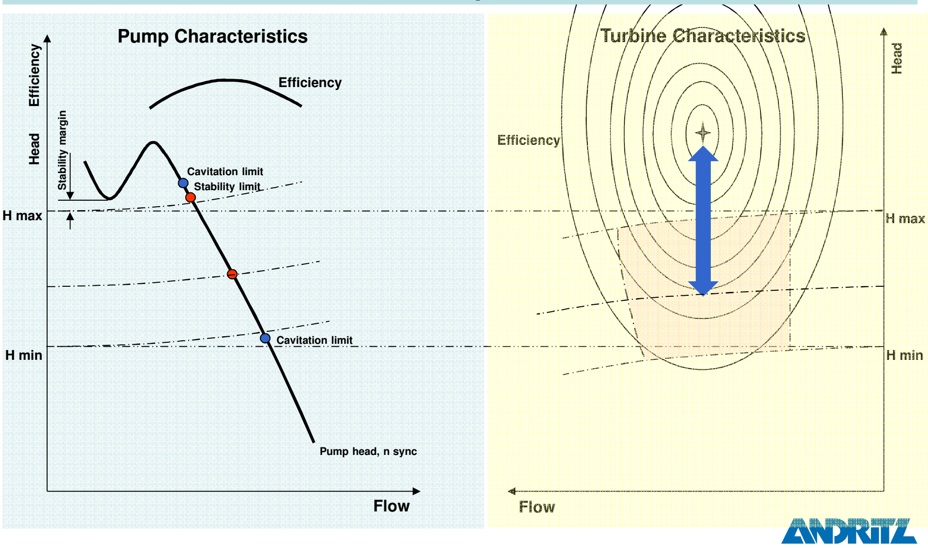
## Pumped Storage: Technology for flexible Operation
### Advantages of variable speed

**Fixed speed**





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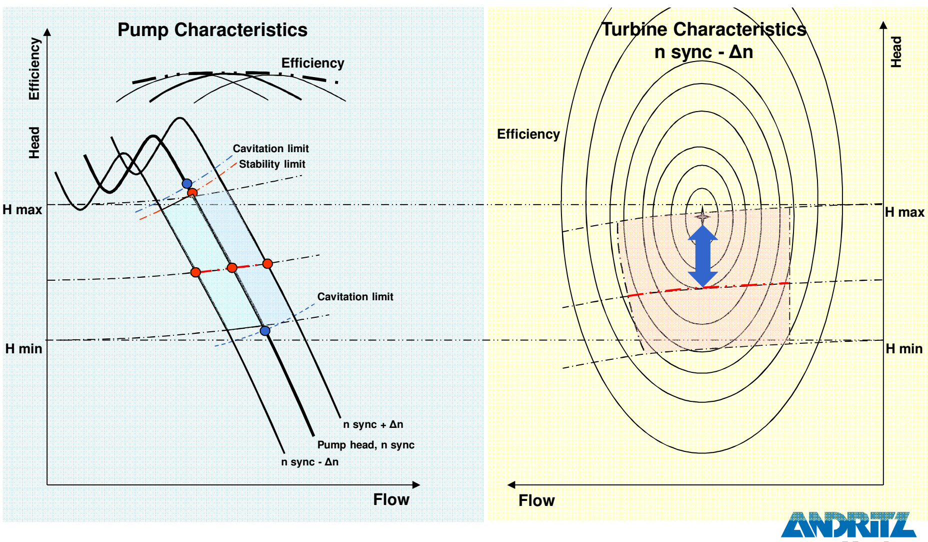
## Pumped Storage: Technology for flexible Operation
### Advantages of variable speed

**Variable speed**





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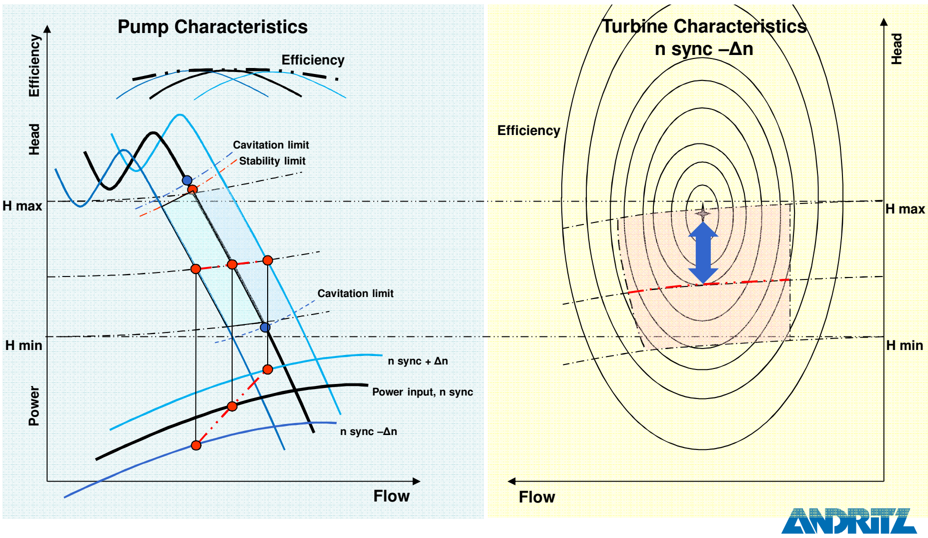
# Pumped Storage: Technology for flexible Operation

## Advantages of variable speed

### Variable speed





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# Pumped Storage: Technology for flexible Operation

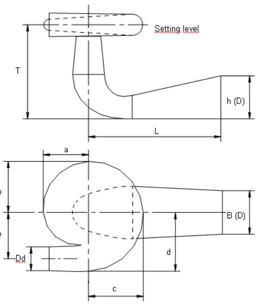
## Application example variable speed

### Main data, size of pump-turbine

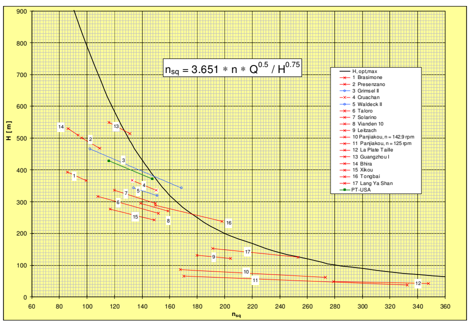
| Specified Values | | Pump Mode | Turbine Mode |
|---|---|---|---|
| HWL max | [m] | 815 | |
| HWL min | [m] | 785 | |
| H gross max | [m] | **425** | |
| H gross min | [m] | **370** | |
| TWL max | [masl] | 415 | |
| TWL min | [masl] | 390 | |
| | | | |
| Pmax | [MW] | **250** | |
| H nominal | [m] | **400** | |
| Qmax | [m³/s] | 63 | 69 |
| | | | |
| n fix | [MW] | **428.6** | |
| n var | [rpm] | **400–440** | |
| Setting level (CLD) | [masl] | 350 | |

Outer diameter of runner:
$D_1$ = 3935 mm

T = 9200 mm
L = 10'500 mm
D = 4'050 mm




$D_d$ = 2320 mm
e = 4090 mm
a = 4090 mm
b = 4600 mm
c = 4980 mm
d = 5340 mm




Trend curve for maximum head, size of pump-turbine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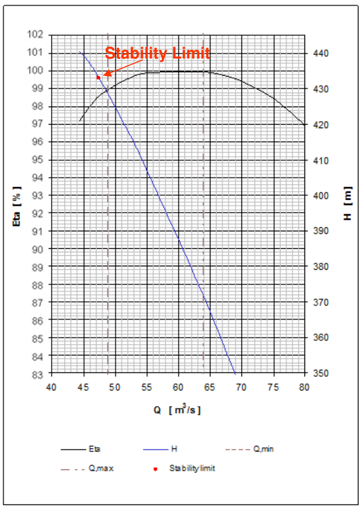
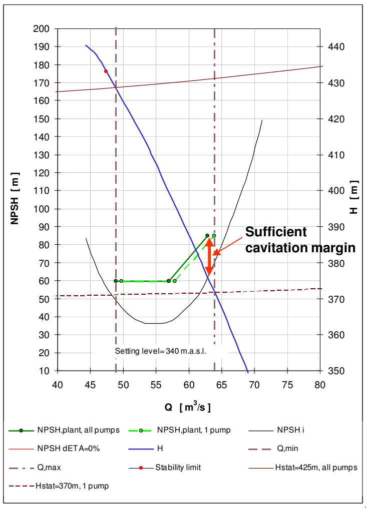
# Pumped Storage: Technology for flexible Operation

## Application example variable speed

- **Fix speed n =428.6 rpm layout: Main characteristic**



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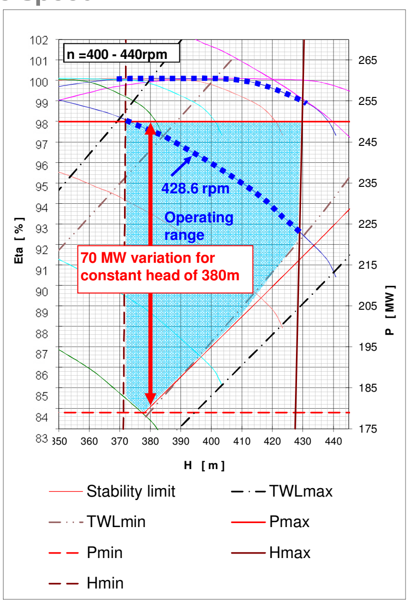
# Pumped Storage: Technology for flexible Operation

## Application example variable speed

- Variable speed, pump mode: Main characteristic
- n: 400 rpm – 440 rpm
- $P_{max}$ = 250 MW
- Power variation possible between 30–70 MW
- Operation of pump at best efficiency possible over wide head range



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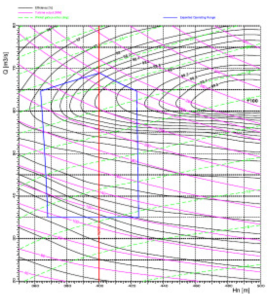
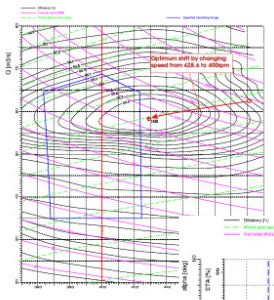
## Pumped Storage: Technology for flexible Operation

### Application example variable speed

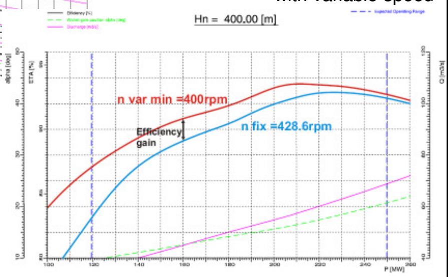
- **Comparison: Turbine mode, operating area , fix - and variable speed**
  - **Hill chart, fix speed =428.6rpm**



  - **Hill chart, var speed min =400 rpm for best efficiency**



Turbine mode, at head 400m
fixed and variable speed
Improved efficiency over wide range
with variable speed



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## Pumped Storage: Technology for flexible Operation

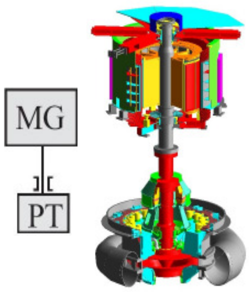
### Current solution

- To stabilize the grid a large amount of reserve capacity is needed
- The classical storage technology is

  HYDRAULIC PUMPED STORAGE (HPS),

However:

- Large HPS plants are in mountain regions, often far away from wind farms
- Large distance between HPS plants and wind farms: additional loading for already stressed grid, additional transmission losses
- To compensate the very volatile wind and solar energy, the pump input power should be varied continuously. This was so far only possible with variable speed units (double-fed asynchronous motor-generators) which are rather expensive. Only few references in Europe and Japan are available.



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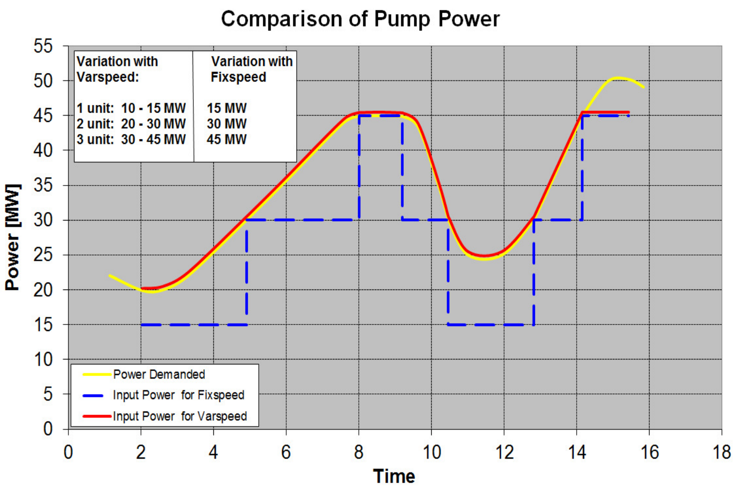
## Pumped Storage: Technology for flexible Operation

### Comparison of fix and variable speed

Benefit of variable speed: ability to follow a variable demand for input power
Fixed speed: variation only by ON-OFF for complete units





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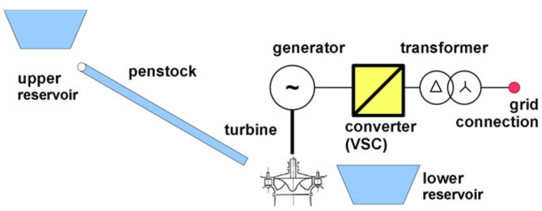
## Pumped Storage: Technology for flexible Operation

### Standardized pump turbines

Solution for grid stabilization based on
- Projects of smaller size for better chance of realization
- Flexibility in operation
- Progress in Full size converter technology

ANDRITZ HYDRO has developed a new innovative concept:
- Small **decentralized** pump storage plants with
- **Standardized** pump turbines with **variable speed**
- Synchronous motor-generator and
- **Full size converter**





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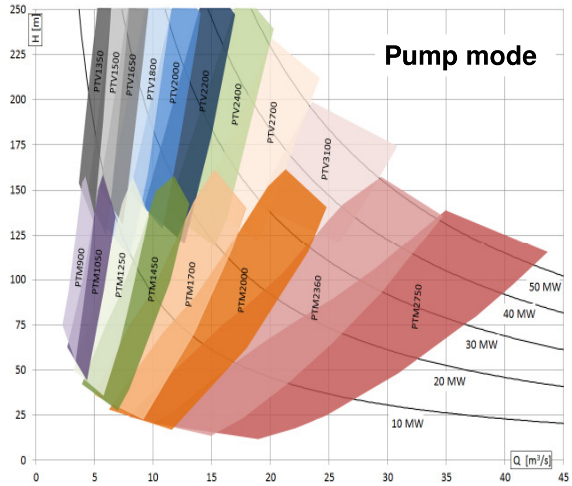
## Pumped Storage: Technology for flexible Operation

### Standardized pump turbines

**Concept**

- Two different hydraulic designs
- 17 machine sizes
- Full size converter, with speed variation from 0–100%
- Application range H=20–250 m and P=5–50 MW





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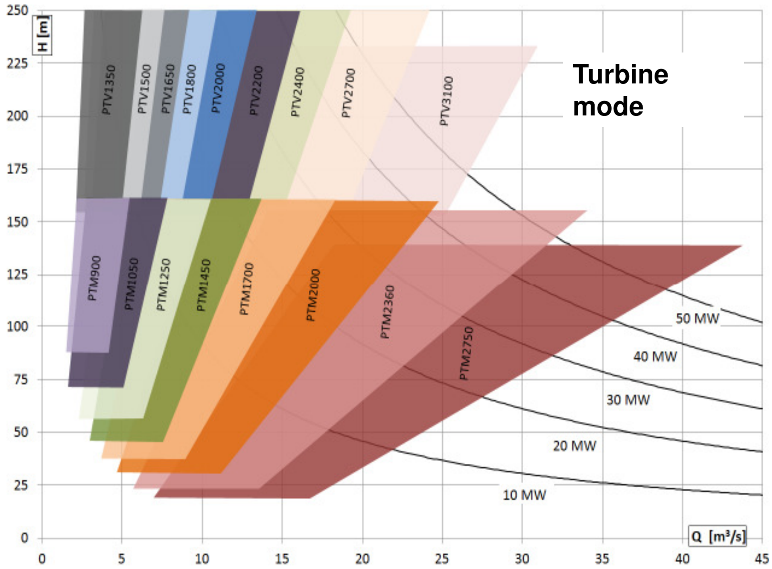
## Pumped Storage: Technology for flexible Operation

### Application range of concept





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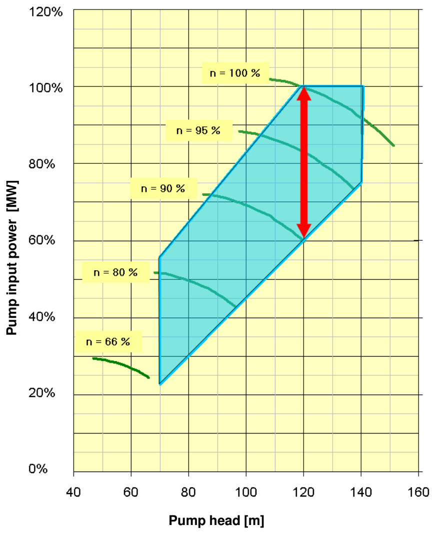
## Pumped Storage: Technology for flexible Operation

### Standardized pump turbines

**Advantages of the new concept**

- The pump input power can be varied continuously due to full size converter
- Large power variations in pump mode
- Operation over very wide head ranges possible
- Flat efficiency characteristics
- Large speed variation (DFAM: only max. +/– 5–10%)
- Standardization due to variable speed (cost advantage compared to tailor-made small HPS units)
- Investment costs not significantly higher than fix speed solution





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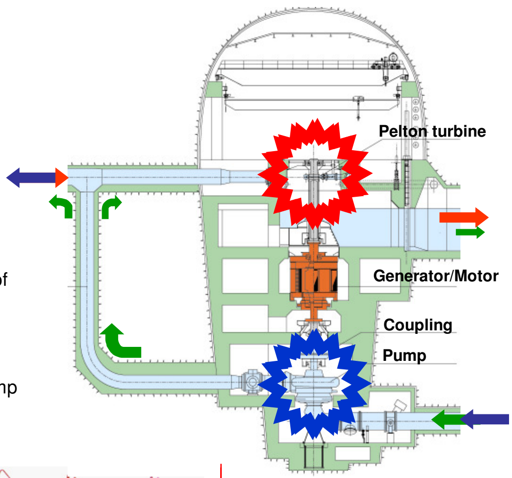
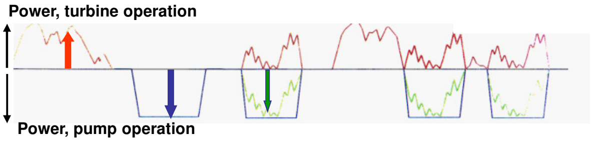
## Pumped Storage: Technology for flexible Operation

### Hydraulic short circuit

**KOPS 2, Ternary units**

- **Customer: Vorarlberger Illwerke, Austria**
- 3 x 180 MW Pelton turbines,
- 3 stage Pumps
- 3 x 200 MVA Generator/Motor
- Head range 696 – 826 m
- n = 500 rpm
- Highlights:
  - Hydraulic short circuit enables variation of input power by ± 100 %
  - Pelton turbines pressurized
  - Designed up to 60 load changes per day
  - Ramp-up time to full load < 20 sec in pump and turbine




Turbine operation
Pump operation
Hydraulic short circuit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## Pumped Storage: Technology for flexible Operation

### Summary

Hydro power, pumped storage in particular, is becoming increasingly dynamic
- Price spread is reduced
- Flexibility and grid stability become important

Consequences for manufactures and operating utilities
Peak efficiency alone not a sufficient measure to evaluate quality
Focus on operating life and availability

Technical solutions for flexible operation
Variable speed
Ternary sets with short switch-over times
Full size converters
Small scale, standardized pump storage plants

Benefit for operation
Optimized hydraulic performance and cavitation safety
Smooth and stable operation in wide operation range
Maximum reliability though dynamic operation
Extended service life

Pumped storage will very likely be the most beneficial storage solution to integrate a high percentage of non dispatchable renewables in the grid


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