STOCKAGE HYDRO

7 decembre 2018

Storage overview

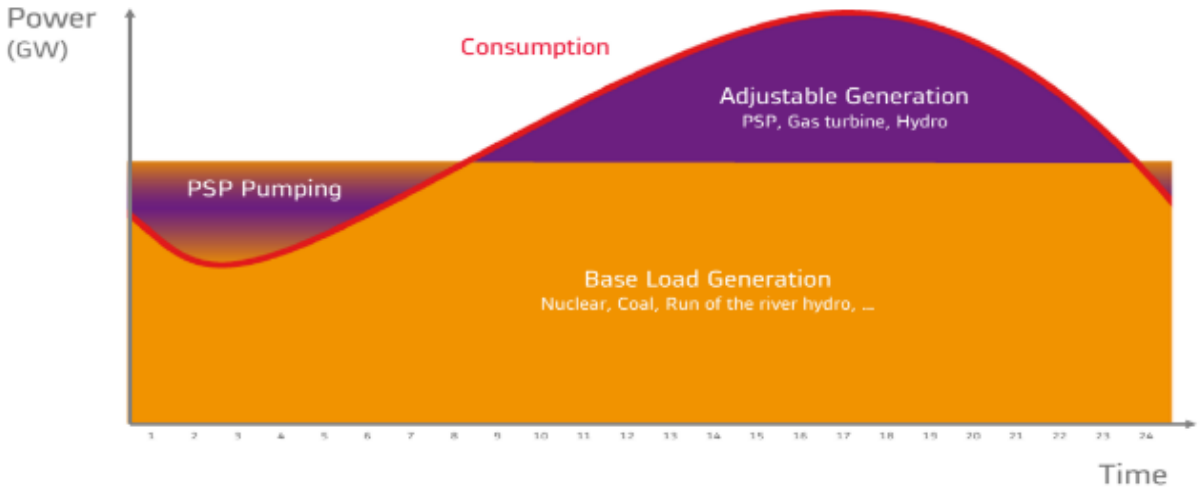
A need of storage

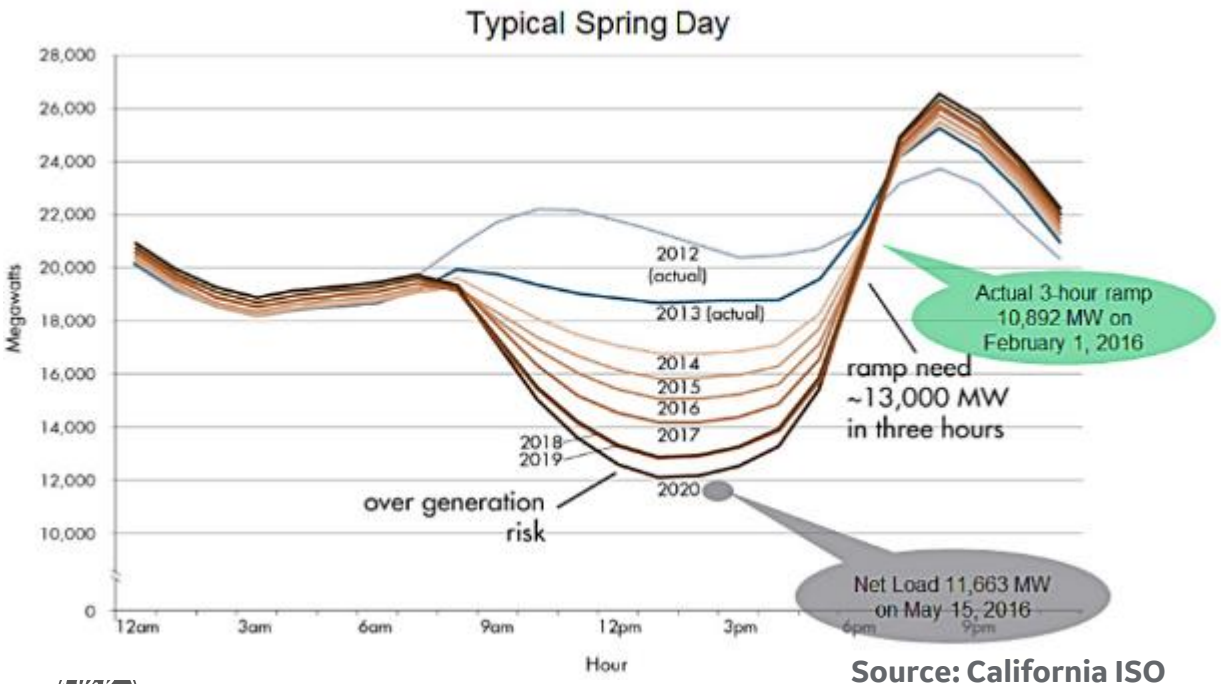
Value of pumped hydro depends on…

- **Electricity price spread for *arbitrage***

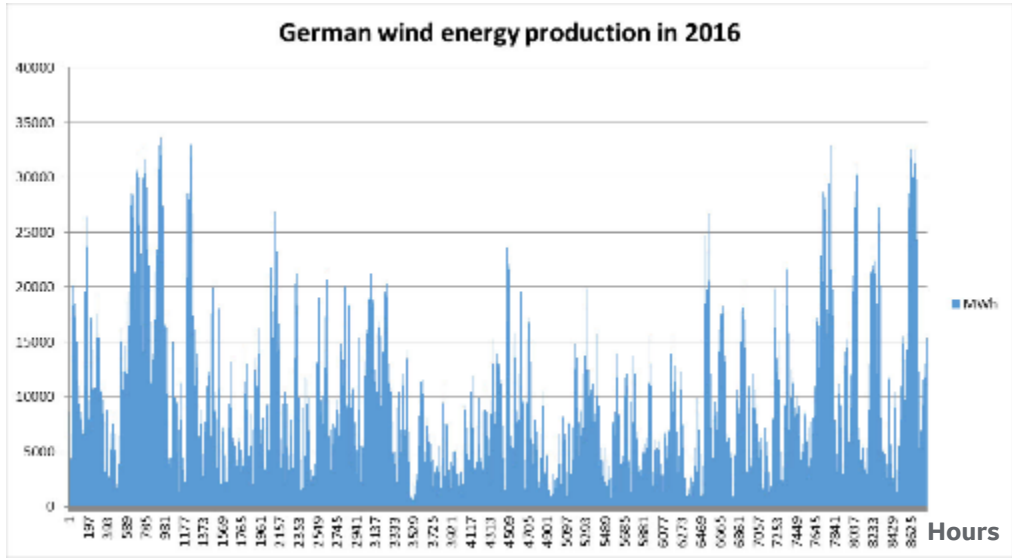
And also

- **Standby capacity payments**
- **Ancillary services payments**



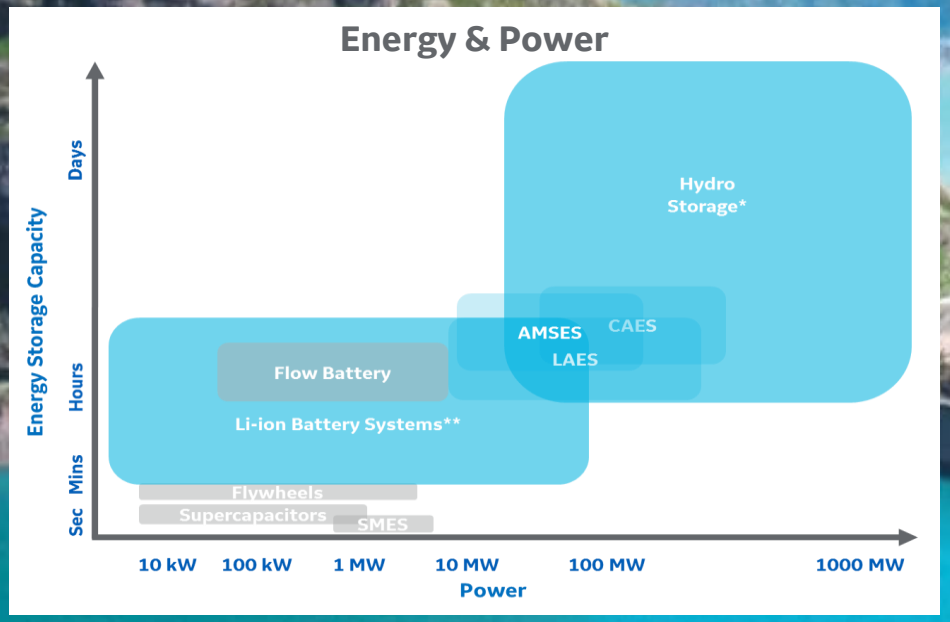


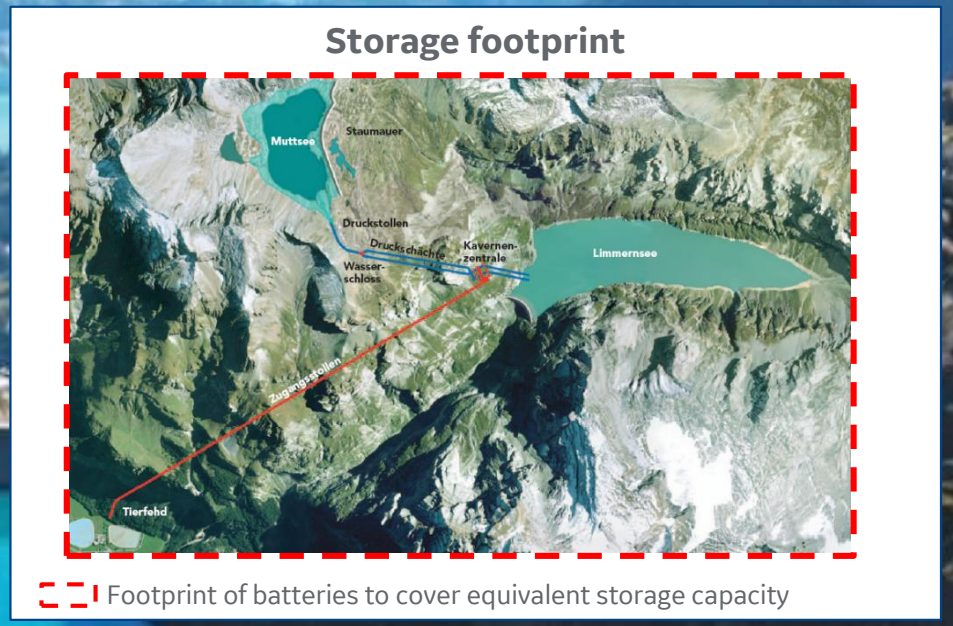
Source: California ISO

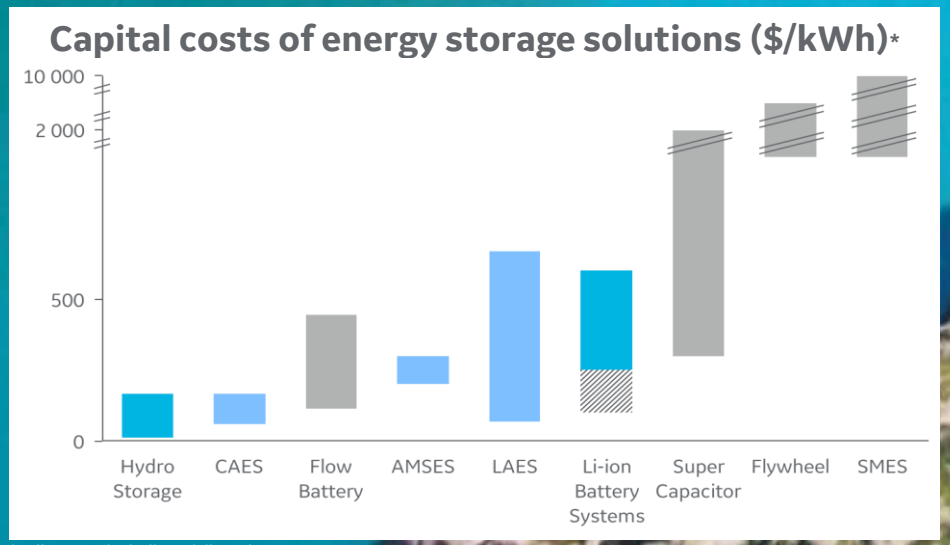


Source: vmisenergy.com

Hydro storage: a key role....

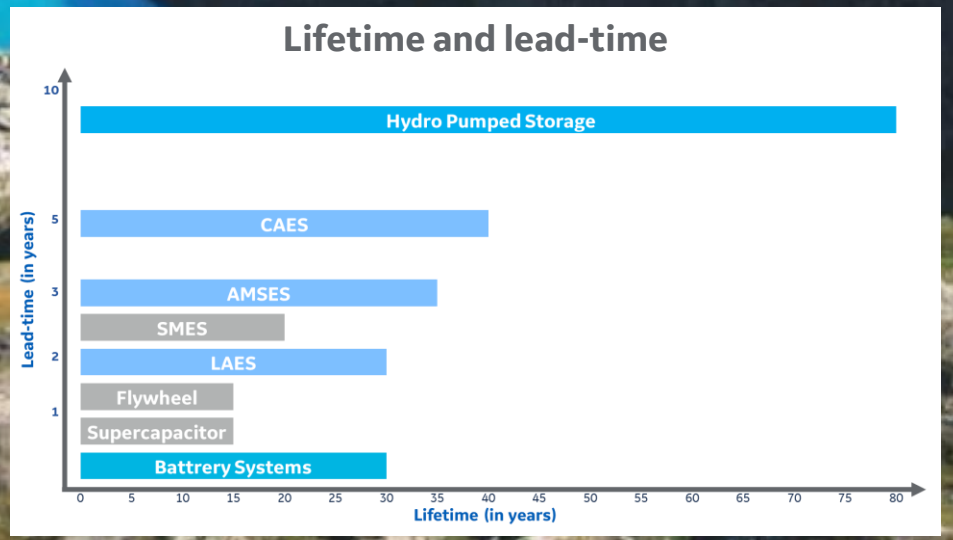






*Full CAPEX including Civil works costs

Source: Range of capital costs for different technologies based on EASE technology reports, IHS studies, GE and Techno-Economic Analysis of Different Energy Storage Technologies report (https://www.intechopen.com/books/energy-storage-technologies-and-applications)

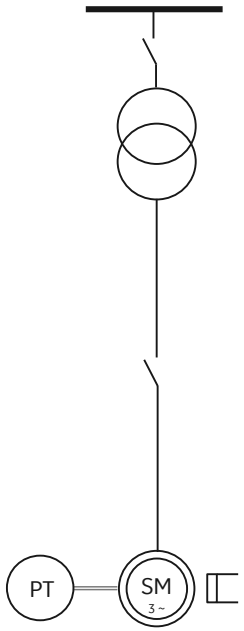


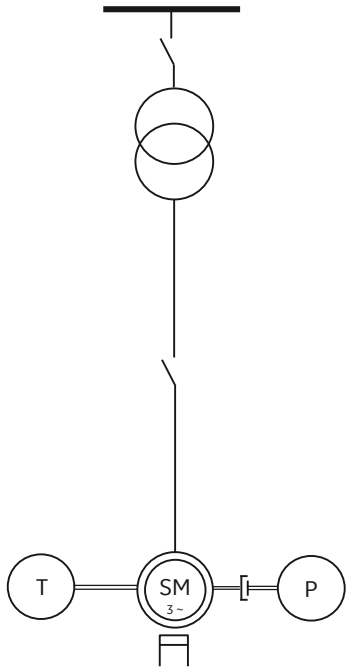
Source: EASE, EPRI, Journal of Energy Storage vol8, Techno-Economic Analysis of Different Energy Storage Technologies, GE Marketing

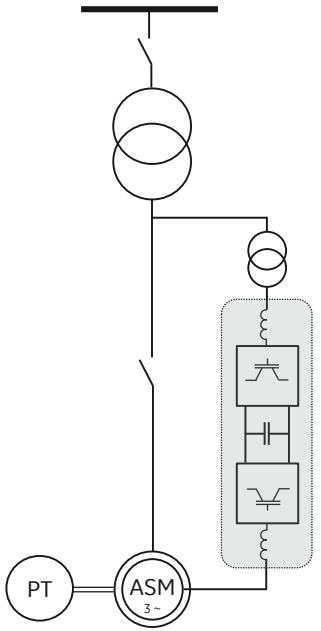
PSP System Technologies

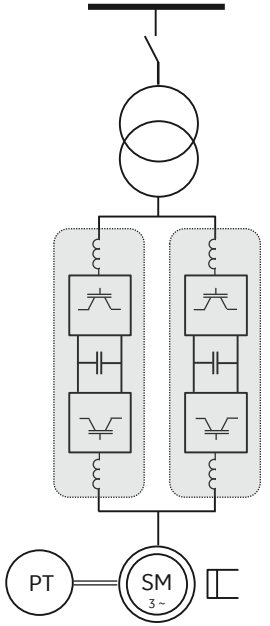
PSP system technologies

Reversible Fixed Speed	Fixed Speed Ternary	Variable Speed Doubly Fed	Variable Speed Fully Fed









Alpine Battery

Integrating Renewables in an Island Grid

A new business model

PSP as a Grid Asset

Integrating Renewables at the Grid periphery

Transformation of existing plant


Integrating Renewables at the Grid Periphery

Alqueva II, Portugal

Higher flexibility thanks to hydraulic design improvement

+37%
Continuous operating range

+50%
Total operating range

Challenge

Integration of intermittent renewables at the grid periphery requires new operation modes, with higher flexibility and wider operating range

GE Solution

Improved low head design thanks to advances in computer modeling and CFD technology
New hydraulic design allowing a shift in the performance hill towards the new needs of operation especially full load in turbine mode

Operator: EDP

Output: 520 MW (Alqueva I & II)

Head: 71 m

Speed : 136 rpm

Turbine technology: Single-stage

Generator technology: fixed speed

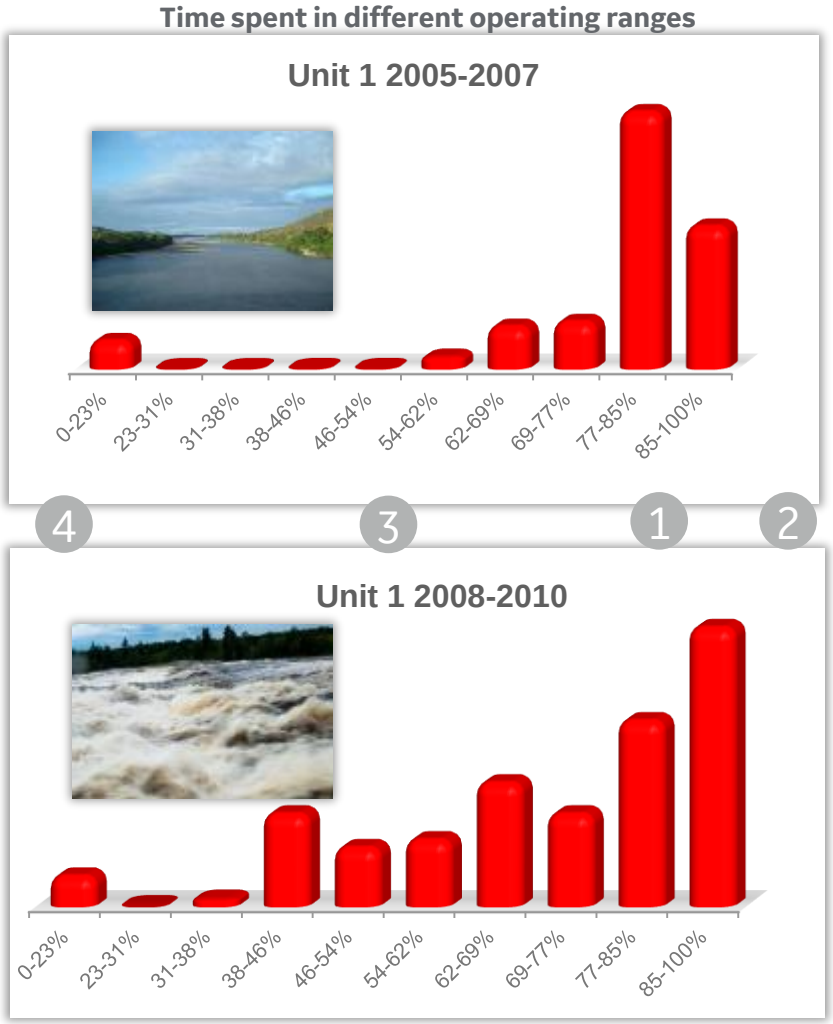
Scope:

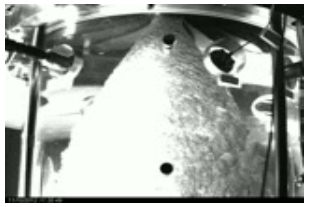
- 4 x 130 MW pump turbines & motor generators
- Control & excitation systems
- Hydro-mechanical equipment
- Erection & commissioning

Commercial operation: 2013

Greater Flexibility in Turbine mode

Wider operating range



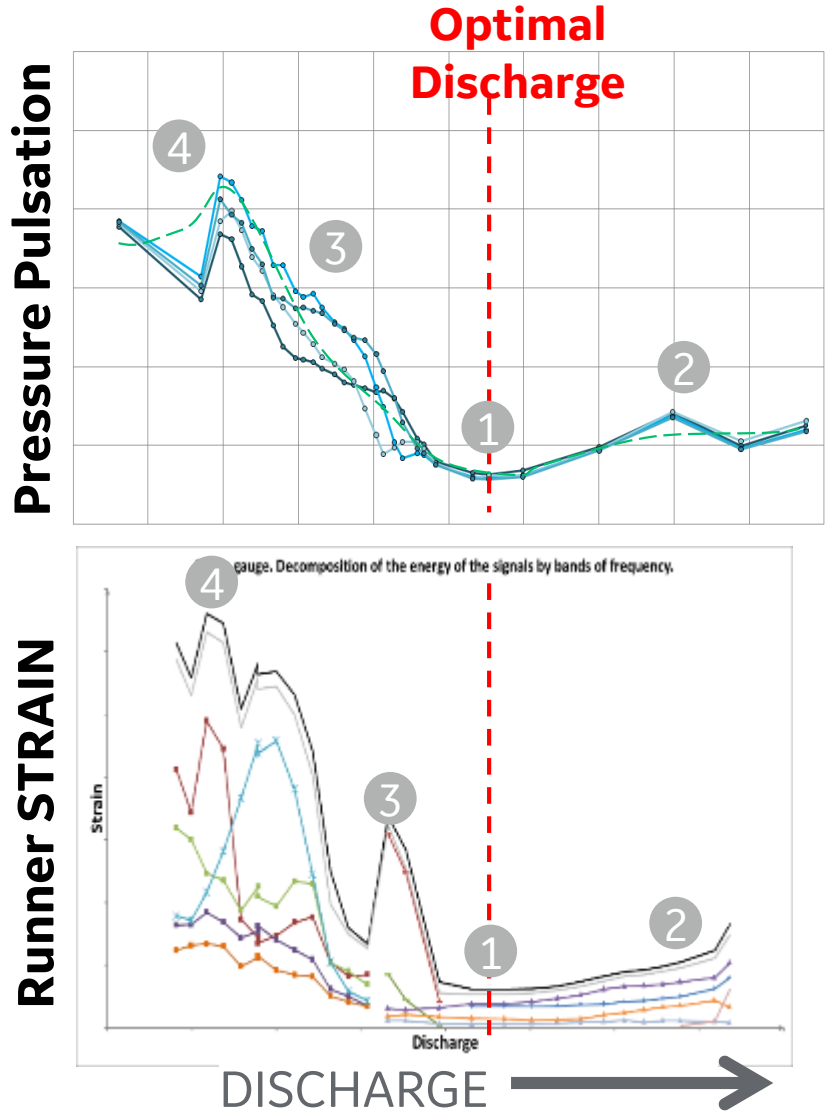


2 Full load

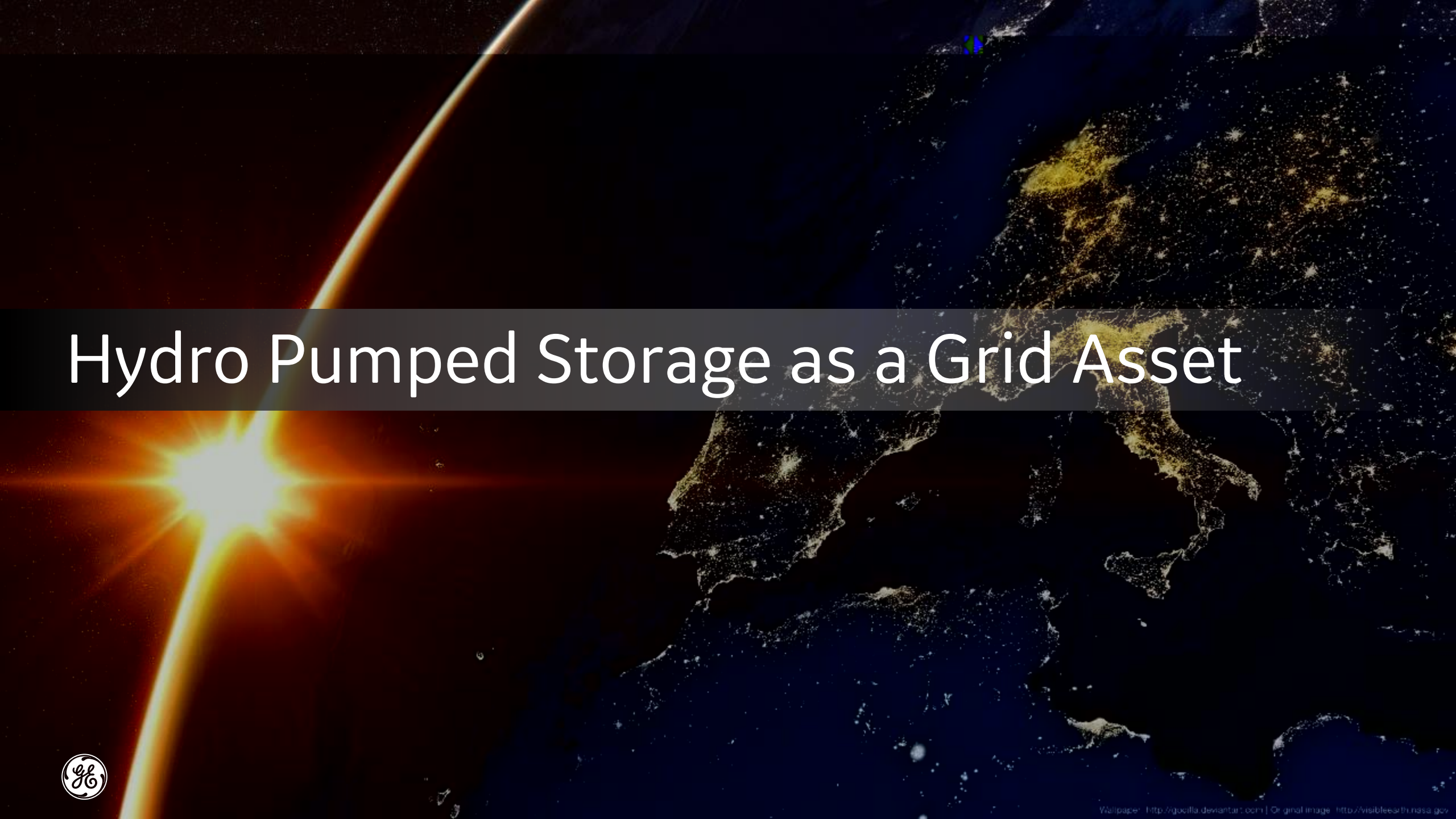
1 Design point

3 Partial load

4 Deep Partial load



Overcoming the intrinsic characteristics of Francis Turbines and better monitoring


Hydro Pumped Storage as a Grid Asset

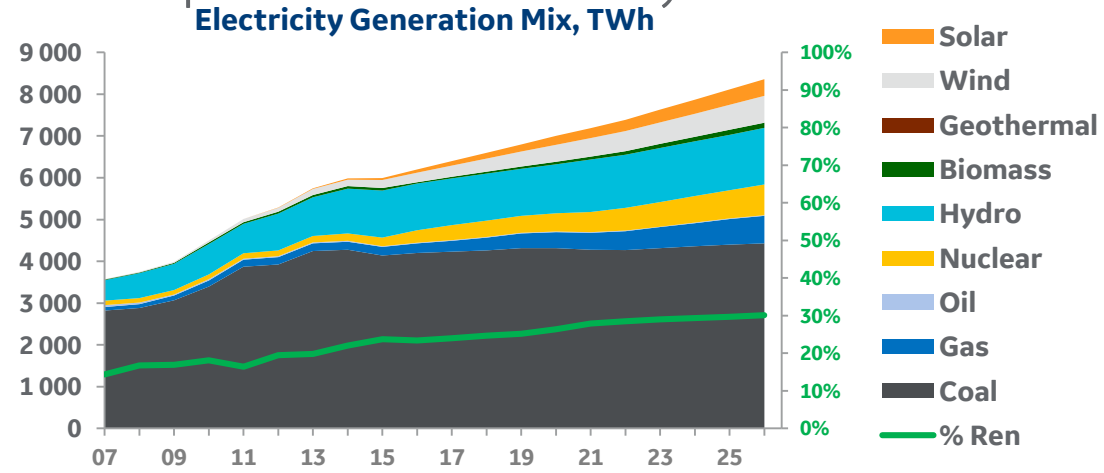
PSP as a Grid Asset

China

Goal to provide at least 15% of primary energy consumption by 2020 from non- fossil energy, and 20% by 2030

Challenges:

- Intermittent renewables integration
- Less start & stops of fossil fueled power plants
- Peak regulation and valley filling
- Optimization of power transmission system



13th five- year plan

PSPs in operation in 2016: **26,690 MW**

Start of construction of a total of **60,000 MW** of pumped storage. In 2016: 26 PSPs under construction (**32,110 MW**)

Total installed capacity of PSP to be built up:

40,000 MW by 2020

90,000 MW by 2025

+60 GW of PSP in 10 years

Huizhou, China

PSP as a grid asset

34 GWh

Challenge

Energy storage is mandatory in Guangdong., the power grid requires emergency reserve capacity of
5,000 MW

GE Solution

- High output level, high efficiency, short starting time
- Increase in peak capacity in an area where thermal and nuclear are the only energy providers
- Outage decrease (overall from 10 to 12 yrs)

Operator: China Southern Power Grid

Output: 2450 MW

Head: 517 m

Speed : 500 rpm

Turbine technology: Single-stage

Generator technology: fixed speed

Scope:

- 8 x 306 MW pump turbines
- 8 x 334 MVA motor generators

Hohhot, China

Flexible energy storage

12 GW

PSP installed or under construction by GE in China

Design for flexibility

Challenge

Complement wind farm production, and provide the grid with power for peak demand, supplemental power for periods of reduced production, energy storage for emergency power stand-by and frequency regulation.

GE Solution

Specific design of pump turbines and motor generators

- Higher stability while operating over a large head range
- Ability to withstand load and thermal cycles due to frequent starts and stops
- Higher availability to cope with demand from the grid

Operator: Hohhot Co., Ltd.

Output: 1224 MW

Head: 521 m

Speed : 500 rpm

Turbine technology: Single-stage

Generator technology: fixed speed

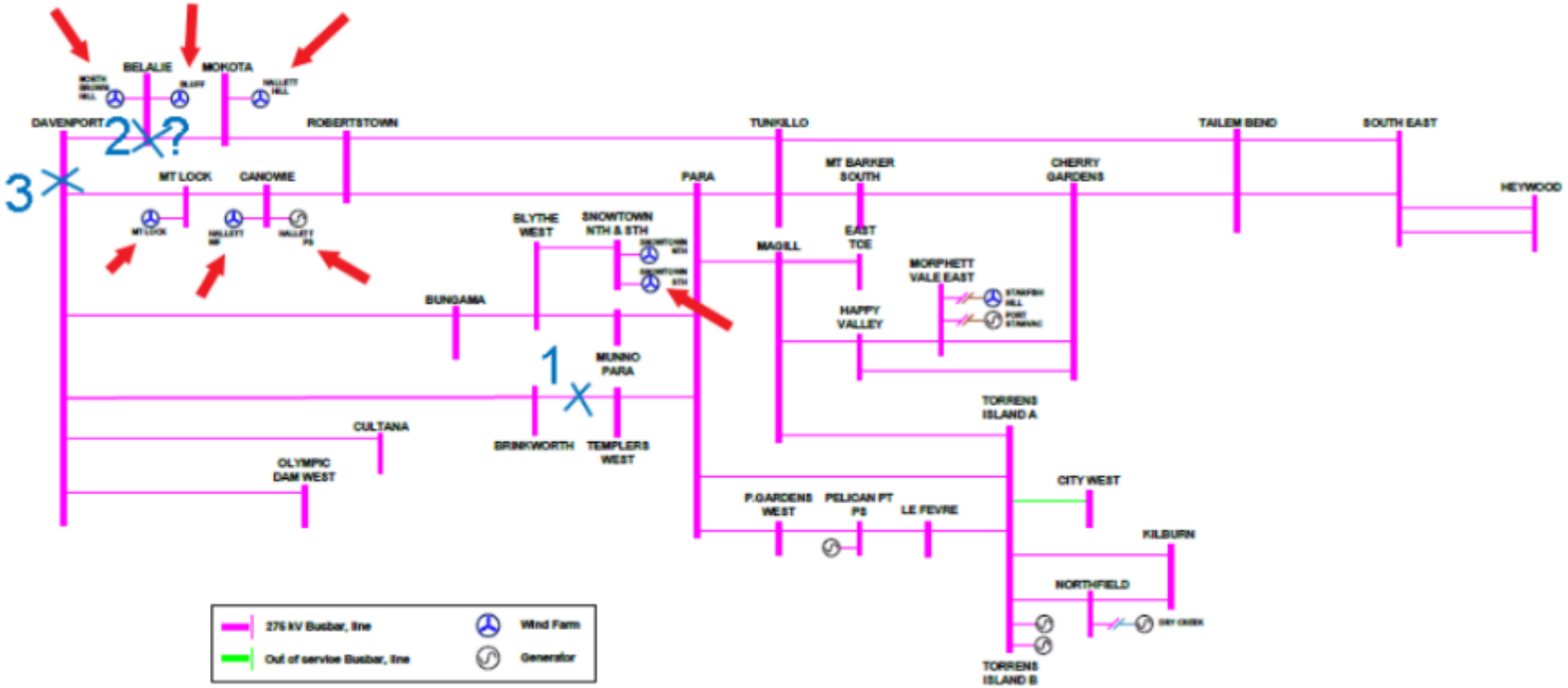
Scope: 4 x 306 MW pump turbines & motor generators, technical and quality support


Hydro Pumped Storage with new driver

Regional Grid Blackout in South Australia

Sudden loss of around 850–900 MW

Diagram illustrating the status of the South Australian 275 kV transmission network before the event - for clarity lower voltage networks such as 132 kV are not illustrated



Source: http://joannenova.com.au/2016/10/sa-blackout-three-towers-six-windfarms-and-12-seconds/

Source: https://www.warwidows.org.au/

Wind farm locations

➢ A stable grid needs “synchronous inertia”

Australia

Reduce lead time

Lead time < 35 months

Two contractual phases:
Optimization
EPC

Challenge
Coal end of life, Gaz price increase
Rapid development of renewable (wind and solar)
Strong need of storage

GE Solution
New contract basis
Available portfolio of hydraulic profile
Reduce lead time
Fix or variable speed

Operator: IPP

Revenues based on

- Arbitrage (pricing every 5 min)
- System Restart Ancillary Service
- Energy Transformation (Regulatory Investment Test- Transmission) :

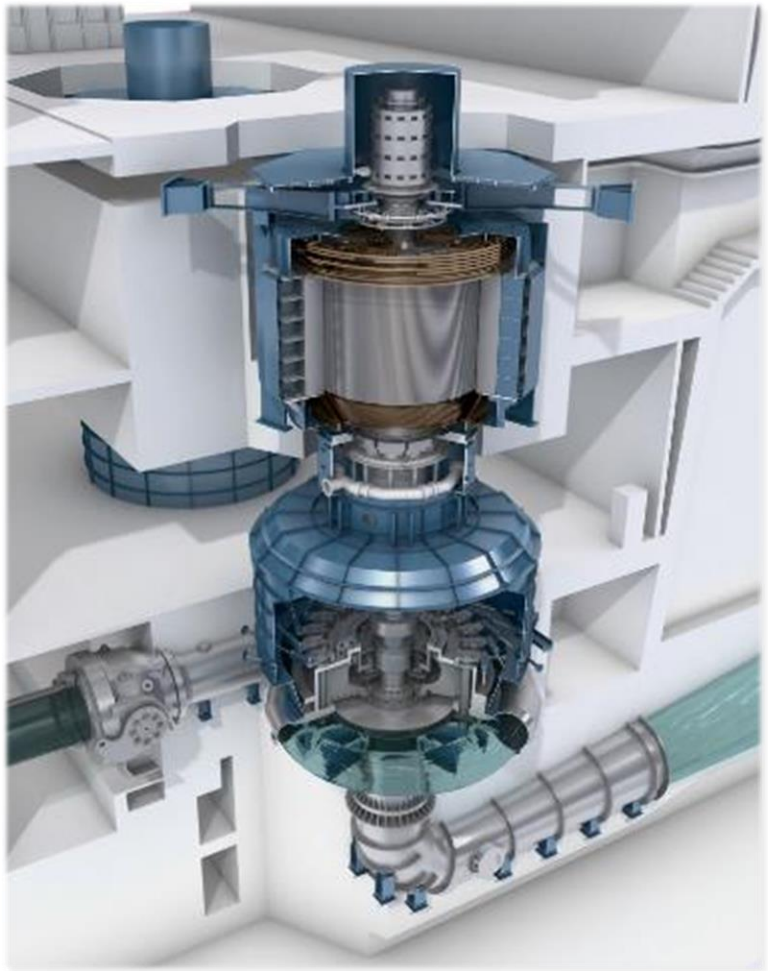
  Inertia Voltage support Frequency control

Alpine Battery

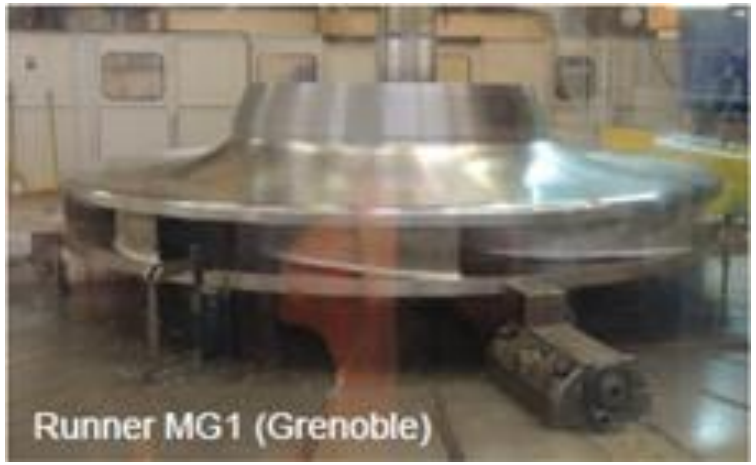
Linthal PSP - Axpo Switzerland

Variable Speed Units (Machine Data)

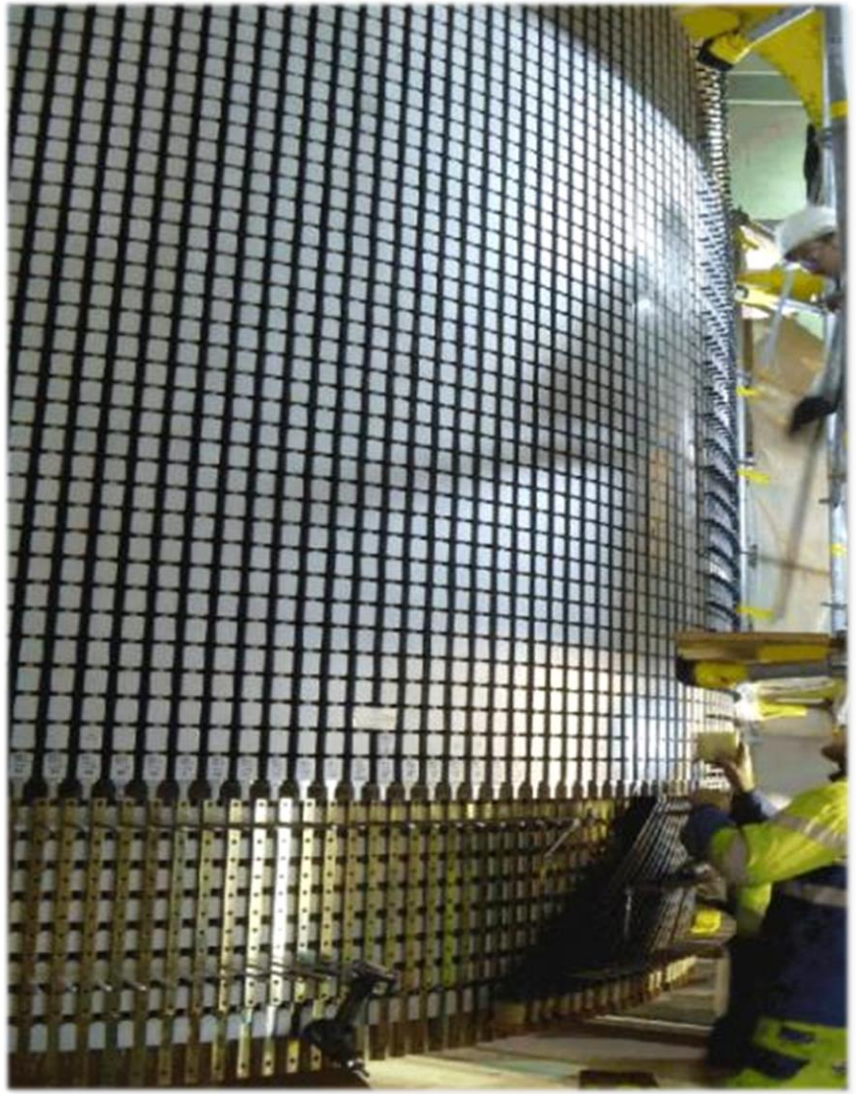
Number of units	4
Apparent power	280 MVA
speed	470–530 min^{-1}
Rated head	700 m
Starting time in turbine mode	120 s
Starting time in pump mode	240 s
Rated voltage	18 kV
Rotor diameter	4672 mm
Weight of complete shaft arrangement	410 t+60 t
Converter power (AC excitation)	34 MW



Linthal Variable Speed PSP

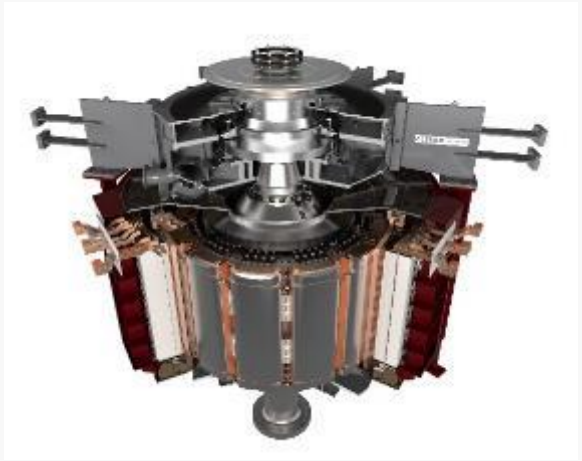


Installation of spiral case



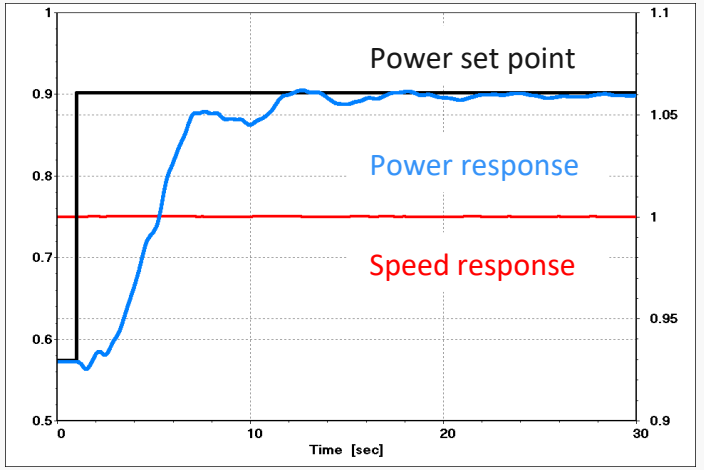
Stacked rotor rim

Fast dynamic power response



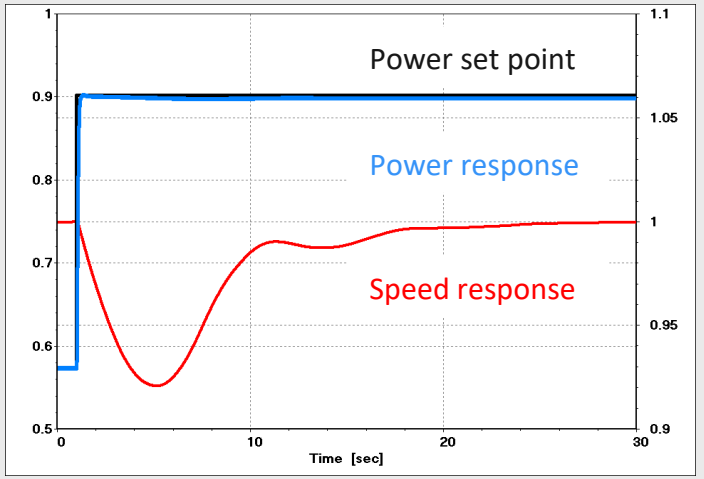
Conventional PSP

- Reaction time depends on hydraulic time constant



Variable speed PSP

- Same reaction time as batteries
- Same pressure in the hydraulic system

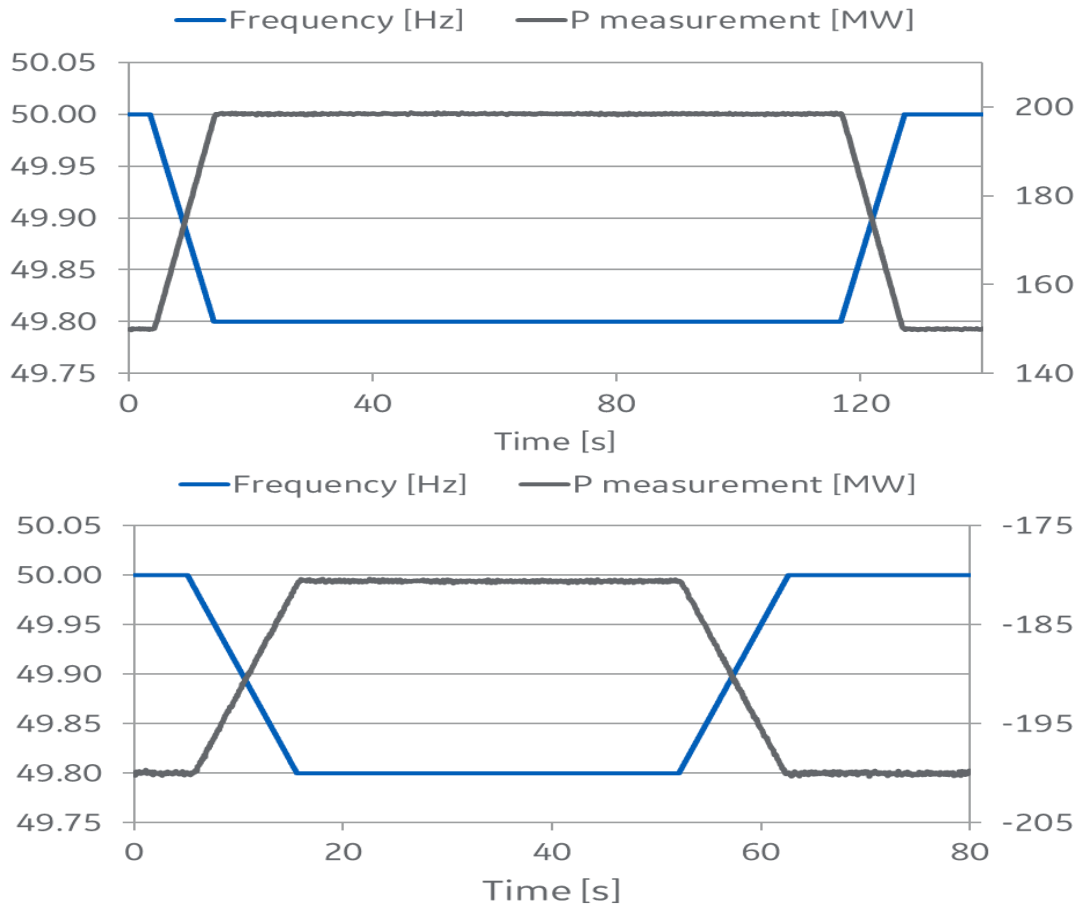


Linthal PSP - Axpo Switzerland – Dynamic II

Primary frequency test

- Dedicated tests done with Swiss TSO (swissgrid)
- Machine is reacting much faster to the frequency changes then required
- Primary frequency control could be confirmed in both turbine **and** pump mode

Results in Turbine and Pump mode




Integrating Renewables in an Island Grid

Gilboa, Israel

Higher flexibility to integrate renewables in an island grid

90 sec
transition from standstill to full generation

18 year
O&M contract

Challenge

Isolated grid needing power independence and strong reliability for the installation of the 1st PSP in the country, managed by private investor

GE Solution

Full turnkey solution

Electromechanical equipment contract incl. Engineering, Procurement and Construction

Full Operation and Maintenance for :

- Improved performance
- Reduced operational risks

Operator: PSP Investment Ltd

Output: 300 MW

Head: 500 m

Speed : 750 rpm

Turbine technology: Single-stage

Generator technology: fixed speed

Scope

- 2 x 150 MW pump turbines & motor generators
- Main Inlet Valves
- Hydromechanical Gates
- Mechanical BOP
- Electrical BOP
- Control System with cybersecurity

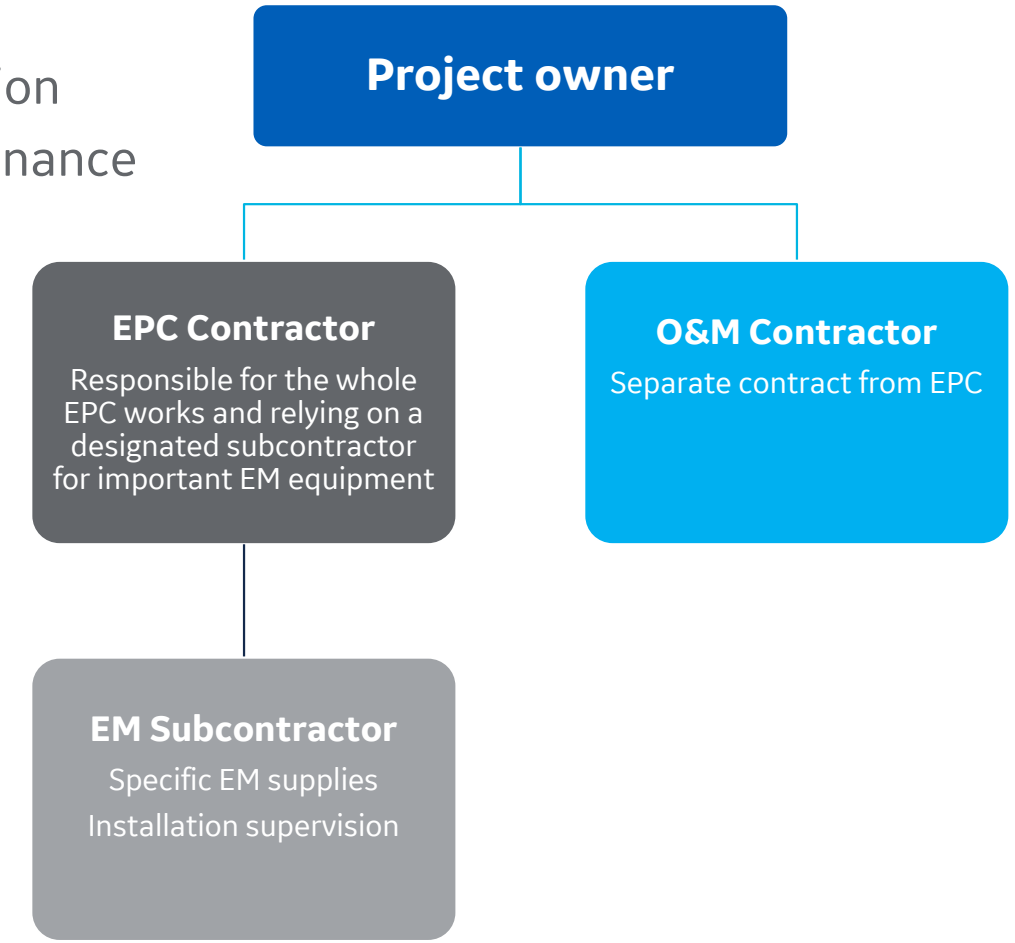
Integrating Renewables in an Island Grid

2 Contracts

- EM1 Contract: New Build contract incl. Engineering, Procurement and Construction
- O&M contract: Full Operation and Maintenance over 18 years

Scope:

- Turbines and Main Inlet Valves
- Generators
- Hydromechanical Gates
- Mechanical BOP
- Electrical BOP
- Control System with cybersecurity



Hydro Pumped Storage upgrade

Cabin Creek, USA

Extending flexibility and output

High head : + 2m

+38% maximum input

+10% power output


Source Xcel Energy

Challenge

Cabin Creek hydropower plant was commissioned in 1967 and is classified as a facility required for reliable operation of the grid. Upgrade needed due to increased penetration of intermittent wind and solar.

GE Solution

Upgrading for higher overall efficiency

- Increase operating head (high head) and maximum output
- Increase operating range in Turbine mode
- Improve cavitation

Operator: Public Service Company of Colorado (a regulated public utility 100% subsidiary of Xcel Energy Inc.

Output: 324 MW

Head: 363 m

Speed : 360 rpm

Turbine technology: Single-stage

Generator technology: fixed speed

Scope: refurbishment of 2X162 MW units – pump turbines, motor generators, wicket gates, head covers, excitation system

Alpine Battery

- Grid regulation in Pumping mode
  - High Power Variable speed
- High Head
- Voltage support
- GE Converters
- Tough site conditions

PSP as a Grid Asset

- High capacity
- Close to consumption
- Avoid Wind curtailment
- Massive development

Integrating Renewables in an Island Grid

- Reactivity : sequence times
- Private customer needs :
  - Long-term (18 years) O&M
  - Full integrated Electro-mechanical package
- Control Systems with high-level Cybersecurity

Integrating Renewables at the Grid periphery

- Need for balancing
- Weaker grid requiring flexibility and reactivity
- Improved existing units
- Application of Digital

A new business model

- Shortened lead time
- Early stage involvement

Transformation of existing plant

- Extending flexibility and output of existing PSP
- Upgrading fixed speed PSP to Variable Speed for higher efficiency and flexibility